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## **NICER observations of the 2018 outburst of the black hole candidate MAXI J1727-203**

Alabarta, Kevin; Altamirano, Diego; Remillard, Ronald; Mendez, Mariano

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**233rd AAS**  
**Seattle, WA – January, 2019**  
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## **001 - HAD I: The Spitzer Observatory Space Mission**

### **001.01 - Making the invisible visible: A history of the Spitzer Infrared Telescope Facility (1971-2003)(Renee Rottner)**

This talk describes the development of NASA's Spitzer Space Telescope until its launch in 2003. As a project requiring cooperation between the public and private sectors, Spitzer ultimately involved more than 1,000 people from 24 organizations including government, universities, and for-profit firms. In the early 1970s, there was but a small group of advocates for an infrared space telescope. They faced a set of daunting challenges: infrared astronomy was a new field, cooled electronic sensors were a new technology, and placing a complex observatory in space was many years off. Under development for nearly three decades, the project encountered many technological, scientific, economic, and political hurdles. Spitzer also had to remain nimble as the key stakeholders changed over time—in their composition, goals, and influence. By presenting Spitzer in its historical context, I discuss the some of the strategies the project team used to overcome the challenges in building a one-of-a-kind telescope facility while working across diverse institutions.---This work was supported under NASA Contract NNH08CC97C for the development of NASA History Series Monograph SP-2017-4547.

**Author(s):** Renee Rottner

**Institution(s):** University of California - Santa Barbara

### **001.02 - “Minefields of Opportunity: Getting Spitzer into Space” (David Gallagher)**

The Spitzer Space Telescope has dramatically exceeded scientific expectations and been an enormous success for NASA and the world. Having just completed 15 years of discovery and providing answers to some of the most challenging scientific questions, it is appropriate to pause and consider some of the lessons learned in getting this fabulous mission into space. These lessons are divided into the following categories and the talk will address each area: o Sponsor relationships o Creating and organizing the project team o Take advantage of the Science Team and community o Reviews o It's the people! o Selecting and managing contractors While there are numerous technical and scientific details that can and are addressed in other presentations, it is important to examine the leadership and management approach that helped create the environment for success. This paper is based in part on work carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

**Author(s):** David Gallagher

**Institution(s):** Jet Propulsion Laboratory

### **001.03 - Though She Be But Little, She is Fierce; Spitzer's Scientific Success”(Michael Werner)**

The Spitzer Space Telescope has just completed its 15th year of on-orbit operations, and its scientific success has far outstripped even the wildest dreams of those of us who brought the facility to fruition. One measure of that success is that our tally of peer-reviewed papers has just passed 8,000, which amounts to 1.5 papers published each day of the 15 years of operation. The scientific targets observed span the Universe from Near Earth Objects to galaxies at  $z > 11$ , and Spitzer has addressed the three fundamental questions of modern astrophysics: Where did we come from? How did the Universe evolve? Are we Alone? In addition to presenting key scientific results from Spitzer which bear on each of these questions, this talk will discuss the reasons for Spitzer's scientific success, which are many and varied. These include: 1. The intrinsic sensitivity of a cooled space telescope for infrared observations; 2. The imaging and spectroscopic power of Spitzer's arrays; 3. The use of radiative cooling in a heliocentric orbit; 4. The simplicity and robustness of Spitzer's three instruments and the Spitzer spacecraft; the cooperation of the Universe, which has continually presented Spitzer with new phenomena to study; and 5. The flexibility and dependability of Spitzer operations, which have allowed Spitzer to respond to these new challenges. In addition, the timing of Spitzer with respect to other missions, past and present, has benefitted Spitzer science. With that said, however, the single most significant reason for Spitzer's success is people - both those who worked on the design and development of the facility and the many scientists from around the world who have implemented their own scientific vision using Spitzer.-----This paper is based in part on research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

**Author(s):** Michael Werner

**Institution(s):** Jet Propulsion Laboratory/Caltech

## **100 - Welcome Address by AAS President Megan Donahue (Michigan State University) Welcome Address by AAS President**

### **101 - Plenary Prize Lecture: Kavli Foundation Plenary Lectureship: A Color Out of Space: “‘Oumuamua’s Brief and Mysterious Visit to the Solar System, Gregory Laughlin (Yale University) with Ka’iu Kimura (‘Imiloa Center)**

#### **101.01 - A Color Out of Space: “ ‘Oumuamua’s Brief and Mysterious Visit to the Solar System(Gregory Laughlin)**

‘Oumuamua -- the first macroscopic body observed to pass through the inner Solar System -- provided one of the most exciting recent discoveries in Astronomy. In this talk, I will summarize what is known and what is postulated about this mysterious object. I will outline the consequences that this first detection of an interstellar object (an ISO) implies for the

planet-forming process, and I will assess the near-term prospects for detecting and observing (both remotely and in situ) future Solar System visitors of this type. Using “Oumuamua as a proof-of-concept, I will provide an overview of prospects for missions that intercept ISOs using conventional chemical propulsion.

**Author(s):** Gregory Laughlin

**Institution(s):** Yale University

## **102 - The Landscape of Next-Generation Gravitational Wave Observatories**

### **102.01 - Next-generation ground based gravitational-wave detectors(Evan Hall)**

The current generation of gravitational-wave detectors has provided a wealth of information from coalescences of binary black holes and binary neutron stars. However, even at design sensitivity these detectors are only able to observe coalescences from the local universe, out to redshifts of a few. In contrast, the next generation of longer and more sensitive gravitational-wave detectors, such as Einstein Telescope and Cosmic Explorer, will detect binary coalescences throughout the entire universe, out to redshifts well beyond 10. Additionally, these next-generation detectors will detect nearby coalescences with exquisite signal-to-noise ratios, enabling precision tests of general relativity and nuclear physics. I will discuss some of the science goals and technological challenges for this next generation of detectors.

**Author(s):** Evan Hall

**Institution(s):** Massachusetts Institute of Technology

### **102.02 - Next-generation observatory network, infrastructure and governance(Sheila Rowan)**

The future of gravitational wave astronomy will be of a detector network embedded within a global framework. This talk will discuss the work of the community in preparing the path towards such a network of future detectors, particularly in an international context.

**Author(s):** Sheila Rowan

**Institution(s):** University of Glasgow

### **102.03 - Low-frequency gravitational wave astronomy with the Laser Interferometer Space Antenna(James Ira Thorpe)**

The early results from ground-based gravitational wave observatories have powerfully demonstrated the impact that a new measurement technique can have on the field of astronomy. The Laser Interferometer Space Antenna (LISA) will expand our window into the gravitational wave universe into the milliHertz frequency band - a band rich in both number and variety of astrophysical sources. LISA has recently been selected by the European Space Agency (ESA) and is under active development with contributions from European National

Agencies and NASA. In this talk I will present an overview of the science case for LISA, describe the mission and its key technological components, and discuss plans and progress towards implementation.

**Author(s):** James Ira Thorpe

**Institution(s):** NASA/GSFC Contributing Team(s): The LISA Team

### **102.04 - The science enabled by measuring gravitational waves(Jocelyn Read)**

The gravitational-wave spectrum ranges across many orders of magnitude in frequency, carrying signature patterns from mass in motion across the universe. The potential sources range from fluctuations in the early universe, through distant binaries, to nearby pulsars. Observations offer unique insights into the formation and composition of the universe, and of compact objects in particular. I will give an overview of gravitational-wave sources targeted by different observational facilities and discuss the implications of their measurement on understanding those sources. Finally, I will elaborate on some of the science goals for the next generation of detectors and discuss how the knowledge gained from gravitational-wave observations can contribute to open questions in astronomy and physics.

**Author(s):** Jocelyn Read

**Institution(s):** CSU Fullerton

### **102.05 - Next-generation science with gravitational waves and other messengers(Peter Shawhan)**

The detection of the binary neutron star merger GW170817 by the LIGO-Virgo network, Fermi and INTEGRAL, and across the whole electromagnetic spectrum was a spectacular introduction to multi-messenger astronomy with gravitational-wave sources. Complementary observations can yield insights into progenitor properties such as object compactness, masses and spins, formation history, system orientation, and energy outflows, and can also anchor tests of fundamental physics and cosmology. As ground-based gravitational wave detectors reach farther into the universe, the growing sample of sources will provide numerous opportunities for individual and statistical study, but also challenges for efficient observing. In space, LISA will reveal new low-frequency gravitational-wave sources which may be correlated with electromagnetic variability. These investigations will complement the science which can be done with gravitational waves alone.

**Author(s):** Peter Shawhan,

**Institution(s):** University of Maryland, Joint Space-Science Institute Contributing Team(s): LIGO Scientific Collaboration, Virgo Collaboration

## **103 - Extrasolar Planets: Characterization & Theory Track 2: III. Small Stars and their Planets**

### **103.01 - M dwarfs as exoplanet hosts: characterizing our nearest and smallest stellar neighbors(Elisabeth Newton)**

M dwarf stars, which comprise about 70% of stars in the Solar Neighborhood, are among the most exciting targets for exoplanet surveys. Due to their small sizes, they provide the opportunity for the discovery of small, rocky planets whose masses can be measured and whose atmospheres can be studied in detail. Ground-based surveys, such as those conducted with Keck, HARPS, MEarth, and TRAPPIST, have surveyed many of these nearby M dwarfs in the hunt for new worlds. They have recently been joined by TESS, which began science operations in July 2018. These surveys have yielded a number of exoplanet discoveries that have been subject to intense follow-up efforts, including Gl 436, GJ 1214, TRAPPIST-1, and LHS 1140. Constraining the parameters of the host stars is key to the detailed characterization of these planets. We can infer stellar radii and metallicities from near-infrared spectra and magnetic activity from optical spectra. From photometry, we can determine the stellar rotation period and flare rate. The MEarth Project has dedicated substantial effort to studying nearby M dwarfs using these techniques. I will discuss our observations of nearby M dwarfs, focusing on stellar rotation and metallicity measurements that we have made for low mass stars in the southern hemisphere using MEarth-South and FIRE on Magellan. Our survey is comprised primarily of targets of the MEarth transiting planet survey, and many will soon also be observed by TESS. The MEarth team is grateful for support from the David and Lucile Packard Fellowship for Science and Engineering, the John Templeton Foundation, and the National Science Foundation (awarded to D.C.). E.R.N. acknowledges support from the NSF AAPF under award AST-1602597 and the GRFP. N.M. acknowledges support from the NSF through the GRFP, and the LSSTC Data Science Fellowship program.

**Author(s):** Jennifer Winters, Ian Crossfield, Nicholas Mondrik, Zachory Berta-Thompson, Alana R Sanchez, Elisabeth Newton, Jason Dittmann, Jonathan Irwin, Carissa S Skye, David Charbonneau

**Institution(s):** Massachusetts Institute of Technology, Harvard University, Dartmouth College, University of Colorado at Boulder, Harvard-Smithsonian Center for Astrophysics

### **103.03 - Simulating the Detectability and Characterization of the TRAPPIST-1 Exoplanet Atmospheres with JWST(Jacob Lustig-Yaeger)**

The James Webb Space Telescope (JWST) will offer the first opportunity to characterize terrestrial exoplanets transiting nearby M dwarf stars with sufficient precision to identify high mean molecular weight atmospheres. TRAPPIST-1's seven known transiting Earth-sized exoplanets are particularly amenable to atmospheric characterization due to the star's

small radius and cool effective temperature, both of which increase the detectability of atmospheric spectral features. To help the community prepare for JWST observations, we use self-consistent climate and photochemical models of plausible post-ocean-loss and habitable environments for the TRAPPIST-1 exoplanets to directly compare transmission and emission spectroscopy with various JWST instruments and observing modes. We find that transmission spectroscopy with NIRSpec Prism could lead to a modest detection of atmospheric spectral features (predominantly due to CO<sub>2</sub>) in fewer than 10 transits for all seven TRAPPIST-1 planets, if they lack high altitude aerosols. If the TRAPPIST-1 planets possess self-consistent Venus-like H<sub>2</sub>SO<sub>4</sub> aerosols, atmospheres may require 3-4 times the number of transits to detect, thus mirroring the current high-altitude aerosol paradigm seen for hot Jupiters and super-Earths. Water may be prohibitively difficult to detect in both Venus-like and habitable atmospheres due to its presence lower in the atmosphere where transmission spectra are insensitive. Although the presence of biogenic O<sub>2</sub> will likely be extremely challenging to detect for the TRAPPIST-1 habitable zone planets, abiotically produced O<sub>2</sub> may be detectable for all seven TRAPPIST-1 planets via large O<sub>2</sub>-O<sub>2</sub> collisionally-induced absorption features at 1.06 and 1.27  $\mu\text{m}$ , which would implicate a post-runaway environment. Our results constitute a suite of hypotheses on the nature and detectability of highly-evolved terrestrial exoplanet atmospheres that may be readily tested with JWST.

**Author(s):** Jacob Lustig-Yaeger, Victoria Meadows, Andrew Linowski

**Institution(s):** University of Washington

### **103.04 - Limits on Clouds and Hazes in the TRAPPIST-1 Planets: insights from the laboratory and models(Sarah E Moran)**

As the first known multi-planet system of Earth-sized worlds, the TRAPPIST-1 system has been the subject of intense study since its discovery. With at least three of its planets in the traditional habitable zone, the TRAPPIST-1 system offers an exceptional opportunity to study the evolution, potential habitability, and possible aerosol formation of planetary atmospheres around M-dwarf stars. Using a combination of laboratory results for temperate exoplanet atmospheres and a 1-D atmospheric model, we explored the feasibility of aerosols in hydrogen-rich atmospheres to explain the featureless Hubble Space Telescope (HST) transmission spectra of TRAPPIST-1 d, e, f, and g. From the laboratory, we have constraints on haze particle size and production rate. Using these constraints as a guideline, we found that based on physically realistic haze formation scenarios, TRAPPIST-1 d and e likely do not have hydrogen-rich atmospheres with hazes muting spectroscopic features. We also investigated the effect of an opaque cloud layer in hydrogen-rich atmospheres: high altitude clouds are needed in these models to explain the HST transmission spectra for TRAPPIST-1 d and e. At the required altitudes, it is unlikely that an optically thick cloud could form due to the lack of material available. Finally, I will present lower limits for the



mean molecular weights of the TRAPPIST-1 atmospheres, both with and without an opaque cloud deck. Current observational precision is not yet strong enough to rule out extended hydrogen-rich atmospheres for TRAPPIST-1 f and g, and these worlds will require follow-up with more powerful observatories, such as the James Webb Space Telescope. Our findings support secondary rather than primordial atmospheres for the TRAPPIST-1 planets and allow for substantial evolution of these atmospheres over their lifetimes, as found in previous studies. Beyond the TRAPPIST-1 system, this study has broader implications for other M-dwarf hosted terrestrial planets, which should also be expected to have secondary rather than primordial, hydrogen-rich atmospheres.

**Author(s):** Nikole K Lewis, Sarah M Horst, Hannah R Wakeford, Sarah E Moran, Natasha E Batalha

**Institution(s):** Johns Hopkins University, Cornell University, University of California, Santa Cruz, Space Telescope Science Institute

### **103.05 - Disentangling the planet from the star in late type M dwarfs: A case study of TRAPPIST-1g(Hannah R Wakeford)**

TRAPPIST-1 hosts seven transiting Earth-sized exoplanets readily amenable for atmospheric characterization. However, the star is an ultra-cool dwarf and contains its own molecular signatures which can potentially be imprinted on planetary transit lightcurves due to inhomogeneities in the occulted stellar photosphere. We use a new observation of TRAPPIST-1g, the largest planet in the system, together with previous data to disentangle the atmospheric transmission of the planet from that of the star. We use the out-of-transit stellar spectra to reconstruct the stellar flux based on one, two, and three temperature components. We present the results of the stellar reconstructions, along with the geometry of the planetary transit, using physically motivated stellar and planetary spectra to disentangle the signature of the planet and stellar atmospheres. The method presented in the case study of TRAPPIST-1g is widely applicable to all late type M dwarfs with transiting planets and will be important for future characterization studies.

**Author(s):** Jeff Valenti, Julia Fowler, Sarah E Moran, Hannah R Wakeford, Natasha E Batalha, Nikole K Lewis, Julien deWit, Tom J Wilson, Giovanni Bruno,

**Institution(s):** Space Telescope Science Institute, INAF Osservatorio Astrofisico di Catania, Cornell University, University of California: Santa Cruz, Johns Hopkins University, MIT

### **103.07 - Hydrohalite Salt-albedo Feedback Could Cool M-dwarf Planets(Aomawa Shields)**

A possible surface type that may form in the environments of M-dwarf planets is sodium chloride dihydrate, or “hydrohalite” ( $\text{NaCl} \cdot 2\text{H}_2\text{O}$ ), which can precipitate in bare sea ice at low

temperatures. Unlike salt-free water ice, hydrohalite is highly reflective in the near-infrared, where M-dwarf stars emit strongly. We carried out the first exploration of the climatic effect of hydrohalite-induced salt-albedo feedback on extrasolar planets, using a three-dimensional global climate model. Under fixed  $\text{CO}_2$  conditions, rapidly-rotating habitable-zone M-dwarf planets receiving 65% or less of the modern solar constant from their host stars exhibit cooler temperatures when an albedo parameterization for hydrohalite formation is included in climate simulations, compared to simulations without such a parameterization. Differences in global mean surface temperature with and without this parameterization increase as the instellation is lowered, which may increase  $\text{CO}_2$  build-up requirements for habitable conditions on planets with active carbon cycles. Synchronously-rotating habitable-zone M-dwarf planets appear susceptible to salt-albedo feedback at higher levels of instellation (90% or less of the modern solar constant) than planets with Earth-like rotation periods, due to their cooler minimum day-side temperatures. These instellation levels where hydrohalite seems most relevant correspond to several recently-discovered potentially habitable M-dwarf planets, including Proxima Centauri b, TRAPPIST-1e, and LHS 1140b, making an albedo parameterization for hydrohalite of immediate importance in future climate simulations.

**Author(s):** Aomawa Shields, Regina Carns

**Institution(s):** University of California, Irvine, University of Washington

### **103.02D - The Transit Light Source Effect in F to M Dwarf Systems(Benjamin Vern Rackham)**

Transmission spectra are powerful probes of exoplanet atmospheres, but they are also subject to spectral features introduced by the transit light source (TLS) effect. This phenomenon imprints on transit depths the contrast between the emergent spectrum of the transit chord-the true light source for the transmission measurement-and the out-of-transit disk-averaged stellar spectrum-the necessarily assumed light source. Here we summarize a series of studies exploring the TLS effect in F to M dwarfs. We use a suite of model rotating photospheres to determine spot and faculae covering fractions for typical stellar activity levels, with which we calculate the corresponding TLS signals in transmission spectra. We find that transit depth changes due to the TLS effect can be comparable to or even an order of magnitude larger than those expected for transiting exoplanets. TLS signals are more pronounced in smaller and cooler main sequence stars-the same stars that have been the focus of many transit studies, given their favorable planet-to-star radius ratios. The TLS effect can mimic or mute  $\text{H}_2\text{O}$  features from planetary atmospheres in M-dwarf systems and  $\text{TiO}/\text{VO}$  features in active late-G- and K-dwarf systems. We will discuss the spectral characteristics and scales of TLS signals for F to M spectral types and present transmission spectra from two M-dwarf systems that show evidence for TLS contamination: the GJ 1214 system (M4.5V) and the TRAPPIST-1 system (M8V). Robust methods of disentangling stellar and planetary features in transits will be crucial to

interpretations of high-precision transmission spectra from JWST and future missions.

**Author(s):** Mark S Giampapa, Yifan Zhou, Zhanbo Zhang, Dáiniel Apai, Benjamin Vern Rackham

**Institution(s):** University of Arizona, Peking University, National Solar Observatory Contributing Team(s): ACCESS

### **103.06D - Characterization of transiting exoplanets and their host stars by K2(Teo Mocnik)**

The WASP project has discovered many transiting gas giant exoplanets. Some of these exoplanet systems have been observed by the K2 space-based telescope. The much higher photometric precision, shorter cadence and extended continuous follow-up observations provided by the K2 mission enabled the most detailed photometric characterization yet of the WASP and other planetary systems presented in this talk, which contributes to our understanding of how planets form and evolve. In this dissertation talk I will present the highlights from analysing the majority of transiting exoplanet systems observed by the K2 in the 1-min short-cadence mode within the first 14 regular observing campaigns. I detected starspot occultation events in two aligned and one misaligned planetary system and proved that detecting starspot occultation events is possible in the K2 data. I also detected optical phase-curve modulations in two systems, rotational modulations in four and  $\dot{\Gamma}^3$  Doradus pulsations in one planetary system. I refined the system parameters for all 10 short-cadence targets and used non-detections to provide tight upper limits. In addition, during my PhD I discovered a hot Jupiter using the long-cadence K2 data and refined the ephemeris with the WASP data of another K2-discovered planet.

**Author(s):** Teo Mocnik

**Institution(s):** UC Riverside

## **104 - Extrasolar Planets: Detection - Ground-Based Direct Imaging**

### **104.01 - The Gemini Planet Imager Exoplanet Survey: Status and Results(Bruce Macintosh)**

The Gemini Planet Imager (GPI) is a high-contrast instrument designed for exoplanet imaging, combining an adaptive optics system, coronagraphic masks, and an integral field spectrograph. Its primary science project since first light in 2013 has been the Gemini Planet Imager Exoplanet Survey (GPIS), a systematic survey of young nearby stars to detect and characterize self-luminous giant exoplanets and circumstellar debris disks. The GPIS program is nearing completion with more than 500 stars surveyed. The survey is primarily sensitive to planets above 2 Jupiter masses from 5 to 100 AU and has detected six giant planets and four brown dwarfs. We will present preliminary statistical results from the survey, highlighting the occurrence rate of giant planets in wide orbits around solar-type and high-mass stars. We will also present key science cases for potential upgrades to the GPI instrument. This work benefited from NSF AST-1518332, NSF

AST-1413744, NASA NNX15AC89G & NNX15AD95G/NEXSS

**Author(s):** Robert De Rosa, Bruce Macintosh, Eric Nielsen

**Institution(s):** Stanford University Contributing Team(s): The Gemini Planet Imager Exoplanet Survey

### **104.02 - SPHERE SHINE Exoplanet Imaging Survey: Preliminary Statistical Results(Michael R. Meyer)**

The SPHERE SHINE Exoplanet Imaging Survey survey is a large near-infrared survey of 400-600 young, nearby stars and represents a large fraction of the SPHERE consortium Guaranteed Time Observations (~ 200 nights). One of the central scientific goals is to determine the frequency of gas giant planets (> 1 Mjupiter) at large orbital separations (> 10 AU) and place constraints on the planet mass function and orbital surface density distributions of gas giants. Here we summarize the sample, provide an overview of our approach, and present preliminary results to date, including recent detections such as HIP 65426 b (Chauvin et al. 2017).

**Author(s):** Michael R. Meyer

**Institution(s):** The University of Michigan Contributing Team(s): The SPHERE SHINE Consortium

### **104.03 - The SCExAO High Contrast Imaging Platform: Current and Upcoming Capabilities(Olivier Guyon)**

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system, currently in science operation on the Subaru Telescope, combines high performance wavefront control and starlight suppression to image exoplanets and disks. In addition to its flagship science cameras, CHARIS (near-IR spectro-imaging) and VAMPIRES (visible polarimetric imaging), new capabilities are being deployed, including advanced small inner working angle coronagraphy, high frame rate low noise imaging, near-IR polarimetric imaging, interferometric imaging/nulling and high resolution diffraction-limited spectroscopy. A significant part of SCExAO's development and performance improvements is realized through wavefront control algorithms (focal plane wavefront control, sensor fusion, predictive control, multi-star WFC) implemented through the cacao software package and enabled by advances in detector technologies (photon counting with MKIDs camera) and modern computer hardware. Further improvements are also expected from the use of real-time WFS telemetry to enhance removal of residual starlight in post-processing. Much of SCExAO's development activities are aimed at direct imaging of giant planets in reflected light with current large telescopes, and imaging/spectroscopy of habitable planets with future giant segmented mirror telescopes.

**Author(s):** Frantz Martinache, Steven Bos, Frans Snik, Christophe Clergeon, Ruslan Belikov, Jared Males, Barnaby Norris, Jeff Chilcote, David Doelman, Yoshito Ono, Arnaud Sevin, Garima Singh, Etsuko Mieda, Justin Knight, Hatem Ltaief, Damien Gratadour, Tiphaine Lagad

**Institution(s):** NASA GSFC, oMacquarie University, University of Hawaii, University of Notre Dame, University of

Tokyo, University of Leiden, NASA Ames, Astrobiology Center, Hokkaido University, KAUST, oPrinceton University, Subaru Telescope, Caltech, University

#### **104.04 - Direct Imaging and Spectral Characterization of Extrasolar Planets with the SCExAO/CHARIS(Thayne Currie)**

We present the first science results focused on direct imaging/spectroscopy of young extrasolar planets from Subaru's extreme adaptive optics system, SCExAO, coupled with the CHARIS integral field spectrograph. SCExAO/CHARIS now delivers H band Strehl ratios up to  $\sim 0.92$  and planet-to-star contrasts rivaling that of GPI and SPHERE. SCExAO/CHARIS yields high signal-to-noise detections and 1.1-2.4 micron spectra of benchmark directly-imaged companions like HR 8799 cde and kappa And b that clarify their atmospheric properties. We show how spectra and astrometry for kappa And b lead to a reevaluation of this object's nature. Finally, we briefly describe plans for a SCExAO-focused direct imaging campaign to directly image and characterize young exoplanets, planet-forming disks, and (later) mature planets in reflected light

**Author(s):** Timothy Brandt, Sarah Blunt, Thayne Currie, N. Jeremy Kasdin, Julien Lozi, Masayuki Kuzuhara, Nemanja Jovanovic, Taichi Uyama, Motohide Tamura, Eric Nielsen, Tyler Groff, Christian Marois, Jeffrey Chilcote, Olivier Guyon

**Institution(s):** NAOJ, oNRC-Herzberg, University of Tokyo, NAOJ/Subaru, Princeton University, NASA Ames Research Center, NASA Goddard, University of California-Santa Barbara, Stanford, Notre Dame, Caltech, Harvard

#### **104.05 - The MagAO Giant Accreting Protoplanet Survey (GAPlanetS): Recent Results(Katherine Follette)**

I will summarize recent results of the MagAO Giant Accreting Protoplanet Survey (GAPlanetS), a search for accreting protoplanets at H-alpha inside of transitional disk gaps. These young, centrally-cleared circumstellar disks are often hosted by stars that are still actively accreting, making it likely that any planets that lie in their central cavities will also be actively accreting. Through differential imaging at Hydrogen-alpha using Magellan's visible light adaptive optics system, we have completed the first systematic search for H-alpha emission from accreting protoplanets in fifteen bright Southern hemisphere transitional disks. I will present results from this survey, including a second epoch on the LkCa 15 system.

**Author(s):** Jared Males, Katherine Follette, Laird Close, Katie Morzinski

**Institution(s):** Amherst College, University of Arizona  
Contributing Team(s): MagAO Team

#### **104.06 - Deep exploration of Epsilon Eridani with Keck**

#### **Ms-band vortex coronagraphy and radial velocities: mass and orbital parameters of the giant exoplanet(Dimitri Mawet)**

We present the most sensitive direct imaging and radial velocity (RV) exploration of Epsilon Eridani to date. Epsilon Eridani is an adolescent planetary system, reminiscent of the early Solar system. It is surrounded by a prominent and complex debris disk which is likely stirred by one or several gas giant exoplanets. The discovery of the RV signature of a giant exoplanet was announced 15 years ago, but has met with scrutiny due to possible confusion with stellar noise. We confirm the planet with a new compilation and analysis of precise RV data spanning 30 years, and combine it with upper limits from our direct imaging search, the most sensitive ever performed. The deep images were taken in the Ms band (4.7 micron) with the vortex coronagraph recently installed in W.M. Keck Observatory's infrared camera NIRC2, which opens a sensitive window for planet searches around nearby adolescent systems. The RV data and direct imaging upper limit maps were combined in an innovative joint Bayesian analysis, providing new constraints on the mass and orbital parameters of the elusive planet. Epsilon Eridani b has a mass of  $\sim 0.78$  MJup and is orbiting Epsilon Eridani at about 3.48 AU with a period of  $\sim 7.37$  years. The eccentricity of the planet's orbit is  $\sim 0.07$ , an order of magnitude smaller than early estimates and consistent with a circular orbit. We discuss our findings from the standpoint of planet-disk interactions and prospects for future detection and characterization with the James Webb Space Telescope.

**Author(s):** Jean-Baptiste Ruffio, Michael Bottom, Benjamin J Fulton, Lea Hirsch, Eve Lee, Dimitri Mawet,

**Institution(s):** Caltech, IPAC, Jet Propulsion Laboratory, Stanford University  
Contributing Team(s): Olivier Absil, Charles Beichman, Brendan Bowler, Marta Bryan, Elodie Choquet, David Ciardi, Valentin Christiaens, Denis DefreÃre, Carlos Alberto Gomez Gonzalez, Andrew WHow

#### **104.07 - The Future of Exoplanet Imaging: the Fast Atmospheric Self-Coherent Camera Technique(Benjamin Gerard)**

Direct detection and detailed characterization of exoplanets using extreme adaptive optics (ExAO) is a key science goal of future extremely large telescopes. However, quasi-static wavefront errors will limit the sensitivity of this endeavor. Additional limitations for ground-based telescopes arise from residual AO-corrected atmospheric wavefront errors, generating short-lived aberrations that will average into a halo over a long exposure, also limiting the sensitivity of exoplanet detection. We have developed the framework for a solution to both of these problems using the self-coherent camera (SCC), to be applied to ground-based telescopes, called the Fast Atmospheric SCC Technique (FAST). We will present updates of the ongoing coronagraph fabrication and testing for this method as well as future implementation, including a possible upgrade of the Gemini Planet Imager. Sensitivity improvement

from this method could play an essential role in the future ground-based detection and characterization of lower mass and/or colder exoplanets.

**Author(s):** Raphael Galicher, Jean-Pierre Veran, Christian Marois, Benjamin Gerard,

**Institution(s):** University of Victoria, Lesia, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universites, UnivParis Diderot, National Research Council, Herzberg Astronomy and Astrophysics

## **105 - Extrasolar Planets: Characterization & Theory Track 1: I. Measurements and Models of Giant Atmospheres A**

### **105.01 - Wave-mediated chemical transport in the atmospheres of giant planets(Jhett Bordwell)**

The atmospheres of giant planets are composed of a lower convective region with an overlying radiative region, where waves are driven by convective motions. The release of energy and mixing due to the breaking of these gravity waves in planetary atmospheres may make significant contributions to the atmospheric dynamics and chemistry of giant planet atmospheres. We perform a study of the effects of radiative, viscous, and dissipative damping upon these waves, and find wave breaking heights using steepening and static stability criteria for hot Jupiters, directly imaged giant planets, and cold gas giants. Using linear stability and weakly nonlinear analysis, we analytically and numerically solve for the amplitudes of the fastest growing unstable modes, and explore their effects upon the energetics and mixing properties of the atmosphere. Finally, we make a set of recommendations on how to properly include wave dynamics in chemical transport models of gas giant atmospheres.

**Author(s):** Jhett Bordwell, Benjamin Brown, Jeffrey S Oishi

**Institution(s):** University of Colorado Boulder, Bates College, Laboratory for Atmospheric and Space Physics

### **105.03 - Ground-based transmission spectroscopy of GJ 1132b and LHS 1140b, rocky planets transiting small nearby M-dwarfs(Hannah Diamond-Lowe)**

GJ 1132b and LHS 1140b, two terrestrial worlds transiting nearby mid-M dwarf stars, offer an opportunity for comparative exoplanetology. GJ 1132b is highly irradiated, orbits its host star on a 1.6-day period, and receives 19 times Earth's insolation. On the other hand, LHS 1140b is in the habitable-zone of its host star, orbits on a 25-day period, and receives only 0.5 times Earth's insolation. The relatively high planet-to-star radius ratios for these two terrestrial exoplanets make them amenable to atmospheric characterization via the transmission spectroscopy method. With ground-based telescopes we can test the cases of clear, low mean molecular weight atmospheres on these worlds. We observed five transits of GJ 1132b with Magellan and the LDSS3C multi-object spectrograph, and one transit of LHS 1140b (the only one observable from Las Campanas Observatory in 2017) simultaneously with both the

LDSS3C and IMACS multi-object spectrographs on the Magellan telescopes. We completed the analysis of the GJ 1132b transits and disfavor a clear, 10 times solar metallicity atmosphere at 3.7 sigma confidence, and place limits on other hydrogen-dominated atmospheres. We will observe a second transit of LHS 1140b with both Magellan telescopes in November 2018, and I will present the results of the both transits. These ground-based measurements serve to probe an important class of atmospheres -- the clear, low mean molecular weight ones -- and prepare us for higher precision studies with JWST. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program. This project was made possible through the support of a grant from the John Templeton Foundation. The opinions expressed in this publication are those of the author and do not necessarily reflect the views of the John Templeton Foundation.

**Author(s):** Eliza Kempton, Hannah Diamond-Lowe, Zachory Berta-Thompson, Jason Dittmann, Jonathan Irwin, David Charbonneau

**Institution(s):** Harvard University, Harvard-Smithsonian Center for Astrophysics, University of Colorado Boulder, University of Maryland, MIT Contributing Team(s): Hannah Diamond-Lowe

### **105.04 - The near-infrared linear polarization of directly imaged exoplanets and brown dwarf companions to main sequence stars(Rebecca Jensen-Clem)**

The observed spectra of brown dwarfs and gas giant exoplanets are profoundly affected by the formation of clouds in their atmospheres, but the clouds' grain size distributions, depth variations, and horizontal structures remain largely unknown. Polarimetry is an emerging method for constraining both exoplanet and brown dwarf cloud models - scattering by aerosols in these objects' atmospheres induces polarization of their thermally emitted, near-infrared radiation. We present the results of a near-IR survey searching for linearly polarized thermal emission from a sample of two planetary mass companions and three brown dwarf companions to main sequence stars using the Gemini Planet Imager (GPI) and Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE). We find no polarized emission from the sample, and our deep observations allow us to probe the 0.1-1% linear polarization regime that typifies polarized free-floating brown dwarfs. We discuss the results of our survey in the context of the occurrence rates of polarized free-floating brown dwarfs as well as exoplanet cloud models and rotation rates.

**Author(s):** Max Millar-Blanchaer, Marshall Perrin, James Graham, Rebecca Jensen-Clem, Rob van Holstein, Sloane Wiktorowicz, Dimitri Mawet

**Institution(s):** UC Berkeley, California Institute of Technology, Jet Propulsion Laboratory, STScI, Leiden University, Aerospace Corporation

**105.06 - Looking for CH<sub>4</sub> and NH<sub>3</sub> in exoatmospheres: a grid of model spectra of exoplanet and brown dwarf atmospheres in chemical disequilibrium.(Theodora Karalidi)**

Observed spectra of imaged exoplanets and brown dwarfs suggest that their atmospheres are in chemical disequilibrium. Spectra of some cooler (Y and T) brown dwarfs lack strong NH<sub>3</sub> lines predicted by equilibrium chemistry, while observations of some T dwarfs and imaged exoplanets show stronger CO lines than expected from equilibrium chemistry. These observations suggest that vertical mixing in these atmospheres leads to an overabundance of CO in comparison to CH<sub>4</sub>, and underabundance of NH<sub>3</sub>. Zahnle & Marley (2014) suggested that quenching in exoatmospheres is more gravity-dependent than previously assumed. In this talk we will present a new adaptation of the Marley-Fortney state-of-the-art radiative transfer code which now includes the treatment of disequilibrium chemistry in exoatmospheres. We will present a grid of model atmospheres with disequilibrium chemistry as a function of effective temperature, surface gravity and eddy diffusivity and discuss how atmospheric quenching depends on these parameters. We will finally discuss the detectability of CH<sub>4</sub> and NH<sub>3</sub> for imaged exoplanets and brown dwarfs as a function of atmospheric effective temperature and gravity.

**Author(s):** Theodora Karalidi, Mark Marley, Jonathan Fortney

**Institution(s):** University of California Santa Cruz, University of Central Florida, NASA Ames

**105.07 - A More Informative Map: Inverting Thermal Orbital Phase and Eclipse Lightcurves of Exoplanets(Emily Rauscher)**

Only one exoplanet has so far been mapped in both longitude and latitude, but the James Webb Space Telescope should provide mapping-quality data for dozens of exoplanets. The thermal phase mapping problem has previously been solved analytically, with orthogonal maps---spherical harmonics---yielding orthogonal lightcurves---sinusoids. The eclipse mapping problem, let alone combined phase+eclipse mapping, does not lend itself to such a neat solution. Previous efforts have either adopted spherical harmonics, or various ad hoc map parameterizations, none of which produce orthogonal lightcurves. We use principal component analysis to construct orthogonal "eigencurves," which we then use to fit published 8 micron observations of the hot Jupiter HD 189733b. This approach has a few advantages over previously used techniques: 1) the lightcurves can be pre-computed, accelerating the fitting process, 2) the eigencurves are orthogonal to each other, reducing parameter correlations, and 3) the eigencurves are model-independent and are ranked in order of sensitivity. One notable result of our analysis is that eclipse-only mapping of HD 189733b is far more sensitive to the central concentration of dayside flux than to the eastward offset of that hotspot. Mapping can, in principle, suffer from

degeneracies between spatial patterns and orbital parameters. Previous mapping efforts using these data have either assumed a circular orbit and precise inclination, or have been pessimistic about the prospects of eclipse mapping in the face of uncertain orbital parameters. We show that for HD 189733b the combined photometry and radial velocity are sufficiently precise to retire this concern. Lastly, we present the first map of brightness temperature, and we quantify the amplitude and longitude offset of the dayside hotspot.

**Author(s):** Veenu Suri, Nicolas Cowan, Emily Rauscher

**Institution(s):** University of Michigan, McGill University

**105.02D - Helium, water, and carbon on low-density exoplanets(Jessica Spake)**

Low-density, transiting exoplanets present outstanding opportunities to study planetary atmospheres due to their relatively large atmospheric scale heights, and large expected absorption features in transmission. In this dissertation talk I will present observations of two of the most rarefied planets known to science - WASP-107b and WASP-127b. On WASP-107b we detected helium on an exoplanet for the first time, and showed a new way to study extended, escaping exoplanet atmospheres. Helium is the second most abundant element in the universe after hydrogen and is a major constituent of gas-giant planets in our Solar System. Early theoretical models predicted helium to be among the most readily-detectable species in the atmospheres of exoplanets, especially in extended and escaping atmospheres. However, searches for helium have until recently been unsuccessful. We detected helium WASP-107b at a confidence level of 4.5-sigma by measuring its near-infrared transmission spectrum with the Hubble Space Telescope. We identified the narrow absorption feature of excited, metastable helium at 10,830 angstroms. The large amplitude of the helium absorption feature suggests that WASP-107b has an extended atmosphere that is eroding at a total rate of  $10^{10} - 3 \times 10^{11} \text{ g s}^{-1}$  (0.1-4% of its total mass per Gyr). The detection demonstrates a new way to study the diffuse upper layers of exoplanet atmospheres and their mass-loss histories, and it comes at a fortuitous time. Several ground-based, high-resolution, infrared spectrographs have recently become (or will soon become) available, and they are capable of measuring 10,830 angstrom absorption on exoplanets at high enough resolution to probe the shape of escaping planetary winds. Our Hubble Space Telescope and Spitzer Space Telescope transmission spectrum for WASP-127b shows sodium, potassium, water, and carbon-bearing molecules in its atmosphere. WASP-127b is therefore a treasure trove of measurable atmospheric abundances.

**Author(s):** Jessica Spake,

**Institution(s):** Johns Hopkins University, University of Exeter

## **105.05D - Understanding the Smallest Gas Exoplanets - Theoretical and Observational Studies of Atmospheric Properties(Erin May)**

In our solar system, there exists a significant size gap between the largest terrestrial planet, Earth, and the smallest Jovian planet, Neptune (3.88  $R_{\text{Earth}}$ ). Until recent years, we naively understood this as a consequence of planet formation in our solar system. However, the launch of the Kepler Space Telescope brought with it the discovery of a significant number of these intermediate-sized planets. Nicknamed Super-Earths and Mini-Neptunes, we now know them to be among the most common type of planet in our galactic neighborhood.

Unfortunately, due to degeneracies imposed by composition, mass-radius relations are of limited use when classifying planets in this transitional regime without some prior knowledge of their composition. In this thesis, I take both a theoretical and observational approach to begin to break the existing mass-radius degeneracies. In the modeling portion, I have introduced a surface into a general circulation model to study the interactions between the surface and atmosphere on a global scale. These interactions point towards observable differences between gaseous and terrestrial planets which, if detectable, would prove helpful in the classification of Mini-Neptunes and Super-Earths. Observationally, we hope to one day be able to detect these signatures, however there is not currently the perfect target in this size range. Therefore, this thesis takes the approach of seeking to add to the work being done to measure atmospheric compositions of exoplanets with transmission spectroscopy. By working in optical wavelengths, I search for signs of Rayleigh scattering in the atmospheres of Neptune-sized and Neptune-mass planets which, particularly when combined with longer wavelength data, will place constraints on atmospheric composition. Together, these will push the field towards a better understanding of the dividing line between gaseous and terrestrial exoplanets.

**Author(s):** John Monnier, Tyler Gardner, Emily Rauscher, Ming Zhao, Erin May

**Institution(s):** University of Michigan, Pennsylvania State University

## **106 - Galaxy Formation and Evolution I**

### **106.01 - MOSEL : Strong [OIII]5007 Emission Identifies Emergent Galaxies at $z \sim 3.5$ (Kim-Vy Tran)**

To understand how strong emission line galaxies (ELGs) contribute to the overall growth of galaxies and star formation history of the universe, we target strong ELGs from the ZFOURGE imaging survey that have blended H $\beta$ + [OIII] rest-frame equivalent widths of  $>230 \text{ \AA}$ ... and photometric redshifts of  $2.5 < (z_{\text{phot}}) < 4.0$ . Using K-band spectroscopy with Keck/MOSFIRE, we confirm 31 ELGs at  $3 < (z_{\text{spec}}) < 3.8$  as part of our Multi-Object Spectroscopic Emission Line (MOSEL) survey. The strong ELGs have spectroscopic rest-frame [OIII]5007 equivalent widths of  $100\text{--}500 \text{ \AA}$ ... and tend to be lower mass compared to more typical star-forming galaxies. The strong ELGs lie  $\sim 0.9$  dex above the star-forming main-sequence at  $z \sim 3.5$  and have high inferred gas fractions of

$f_{\text{gas}} \sim 60\%$ , i.e. the inferred gas masses can easily fuel a starburst to double stellar masses within  $\sim 10\text{--}100$  Myr. Our analysis indicates that 1) strong [OIII]5007 signals the first major episode of stellar growth in emergent galaxies and 2) most galaxies at  $z > 3$  go through this starburst phase. If true, emergent galaxies with strong [OIII]5007 emission may be an increasingly important source of ionizing UV radiation at  $z > 3$ .

**Author(s):** Tiantian Yuan, Ben Forrest, Leo Alcorn, Kim-Vy Tran,

**Institution(s):** Texas A&M , Swinburne University, University of New South Wales

### **106.03 - Crossing the line: How often are AGN found in the star-forming region of the BPT diagram?(Christopher James Agostino)**

In this work, we investigate how often do AGN end up being classified as star-forming galaxies by the Baldwin-Phillips-Terlevich (BPT) diagram. We identify 323 true AGN by comparing X-ray luminosities from deep observations from 3XMM to star formation rates from GALEX-SDSS-WISE-Legacy Catalog. Nearly 11% of these X-ray AGN are optically classified as BPT star-forming galaxies. We find that star-formation dilution is the most probable cause of misclassification for  $\sim 80\%$  of these X-ray AGN. The remaining  $\sim 20\%$  have low star formation rates and the optical signatures consistent with inherently weak accretion. We find that the fraction of X-ray AGN in the base of the star-forming branch of the BPT diagram is 4.6%. At the tip of the star-forming branch, the fraction of X-ray AGN is lower than 0.2%. These results suggest that selection of galaxies via the BPT diagram can provide a reasonably clean ( $>95\%$ ) sample of star-forming galaxies.

**Author(s):** Samir Salim, Christopher James Agostino

**Institution(s):** Indiana University

### **106.05 - Studies of a Spectroscopically Confirmed Galaxy at $z = 9.1$ : Signatures of Star Formation 250 Million Years After the Big Bang(Takuya Hashimoto)**

We show results from our recent paper, Hashimoto et al. (2018), Nature. MACS1149-JD1 is a gravitationally lensed galaxy originally discovered by the Hubble Space Telescope (HST) in Zheng et al. (2012). Using the Atacama Large Millimeter/submillimeter Array (ALMA), we detect an emission line of doubly ionized oxygen, [OIII] 88  $\mu\text{m}$ , at a redshift of  $9.1096 \pm 0.0006$ , at a high significance level of  $7.4\sigma$ . This is the current redshift record for emission line galaxies (cf., Oesch et al. 2015). The [OIII] line has a luminosity of  $(7.4 \pm 1.6) \times 10^{11} \text{ W}$ , where we adopt a fiducial value of  $\mu = 10$  for the magnification factor. The [OIII] line width is  $154 \pm 39 \text{ km s}^{-1}$ , which is typical for low mass galaxies. On the other hand, we do not detect dust continuum emission with a stringent upper limit of  $53 \times (10^{11/4}) \text{ Jy}$  ( $3\sigma$ ). Assuming a dust temperature of 40 K and emissivity index of 1.5, we obtain the

3If upper limit on the total infrared luminosity  $< 7.7 (10/\hat{I}^{1/4})$  Å— 109 L $\hat{S}^{\text{TM}}$ . This precisely determined redshift indicates that the red rest-frame optical colour observed with the Spitzer Space Telescope arises from a dominant stellar component that formed about 250 million years after the Big Bang, corresponding to a redshift of about 15. We discuss implications for the earliest star formation.

**Author(s):** Takuya Hashimoto,

**Institution(s):** Osaka Sangyo University , NAOJ

#### **106.02D - Evolution of Dark Matter Bars in Spinning Halos(Angela C Collier)**

We analyze models of stellar disks inside spinning dark matter (DM) halos. Our previous work has shown the very strong effect that halo cosmological spin  $\hat{I}$  has on disk evolution. In halos of  $\hat{I} > 0.045$ , the stellar bar does not recover after the vertical buckling instability during subsequent secular evolution. Here we study response of that DM to the stellar bar and use high-resolution N-body simulations for a sequence of halos with  $\hat{I} = 0$  (non rotating) to  $\hat{I} = 0.09$ . We find that DM bars induced within parent halos by the stellar bars exhibit a more complex evolution than was anticipated by previous works. We analyze the evolution of these DM bars, including their amplitude and size, as well as their orbit trapping efficiency by performing spectral orbital analysis. Finally, we study the intricacies of angular momentum transfer within such disk-halo galactic systems, as well as observational corollaries of this effect.

**Author(s):** Angela C Collier

**Institution(s):** University of Kentucky

#### **106.04D - The Role of Black Hole Feedback in Suppressing Star Formation in Central Galaxies(Bryan Alejandro Terrazas)**

Cavities and bubbles in the extended X-ray emission from massive galaxies demonstrate that feedback from supermassive black holes can have a profound effect on the gaseous atmospheres that surround these systems. The consequences of these effects are thought to suppress the ability of gas to cool and condense to form fuel for star formation. However, the link between the galaxy-scale suppression of star formation, or quiescence, and relatively small-scale black hole physics is not well understood. In order to explore this link, my dissertation work has focused on understanding the relationship between black hole mass, stellar mass, and star formation rate. I found that the latest version of the Munich semi-analytic model featured a black hole mass threshold above which galaxies were quiescent due to the heating rate from black hole feedback overcoming the cooling rate of the gaseous atmosphere (Terrazas et al. 2016a). I searched for and found similar behavior in the real universe using a diverse sample of 91 local galaxies with dynamically-measured black hole masses (Terrazas et al. 2016b, 2017). In particular, I found that galaxies with more massive black holes at a given stellar mass exhibited

progressively less star formation. These results present a powerful diagnostic tool with which to test black hole feedback and its effects on star formation activity in galaxy formation models. Specifically, I used the IllustrisTNG simulation suite and dozens of model variations that alter the parameters relevant to its black hole feedback prescription. These variations can greatly effect the way black holes interact with the gas within and around galaxies, and in turn change the relationship between black hole mass, stellar mass, and star formation rate. These results present a novel approach in using black hole-galaxy scaling relations to illuminate the physics behind quiescence caused by black hole feedback.

**Author(s):** Bryan Alejandro Terrazas

**Institution(s):** University of Michigan

#### **106.06D - Revisiting the Dynamical History of the Local Group in the Era of High Precision Astrometry(Ekta Patel)**

High precision astrometric data from space observatories like the Hubble Space Telescope (HST) and Gaia are revolutionizing our ability to study the Local Group in unprecedented detail. In my thesis, I have leveraged 6D phase space information derived from precision astrometry and high-resolution state of the art simulations (e.g. the Illustris simulations) to revisit models of the Local Group's dynamical history. HST proper motion measurements for Andromeda (M31) are a recent breakthrough that have allowed me to present a revised orbital history for M31's most massive satellite galaxy, M33 (Patel et al. 2017a), which shifts the paradigm away from morphologically motivated orbital models (Patel et al. 2018b). I will show that constraining the orbit of massive satellite galaxies like M33 is crucial for reconstructing the assembly history of the M31 satellite system, refining the mass of M31, testing LCDM at small scales (Patel et al. 2018a), and for understanding how massive satellites dynamically influence M31, its low mass satellites, and its halo. Additionally, I will show how this new orbital history can be independently confirmed with Gaia DR2. Using proper motions and cosmological simulations together, I have also developed new techniques for determining the precise masses of the MW and M31 (Patel et al. 2017b, 2018a), which will be especially useful as future Gaia data releases reduce uncertainties on proper motion measurements for the MW ultra-faint dwarf satellite galaxies. Finally, I will describe how we can prepare for the the next generation of Local Group studies using upcoming simulations and observations.

**Author(s):** Ekta Patel

**Institution(s):** University of Arizona

#### **107 - Gravitational Lenses, Waves, Relativistic Astrophysics & GRBs I**

##### **107.01 - Optimizing Pulsar Timing Array Observational Cadences for Sensitivity to Low-Frequency Gravitational Wave Sources(Michael T Lam)**

Observations of low-frequency gravitational waves will require the highest possible timing precision from an array of the most spin-stable pulsars. We can improve the sensitivity of a pulsar timing array (PTA) to different gravitational-wave sources by observing pulsars with low timing noise over years to decades and distributed across the sky. We discuss observing strategies for a PTA focused on a stochastic gravitational-wave background such as from unresolved supermassive black hole binaries as well as focused on single continuous-wave sources. First we describe the method to calculate a PTA's sensitivity to different gravitational-wave-source classes. We then apply our method to the 45 pulsars presented in the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) 11-year data set. For expected amplitudes of the stochastic background, we find that all pulsars contribute significantly over the timescale of decades; the exception is for very pessimistic values of the stochastic background amplitude. For individual single sources, we find that a number of pulsars contribute to the sensitivity of a given source but that which pulsars contribute are different depending on the source, or versus an all-sky metric. Our results seem robust to the presence of red noise in pulsar arrival times. It is critical to obtain more robust pulsar-noise parameters as they heavily affect our results. Our results show that it is also imperative to locate and time as many high-precision pulsars as possible, as quickly as possible, to maximize the sensitivity of next-generation PTA detectors.

**Author(s):** Michael T Lam

**Institution(s):** West Virginia University Contributing Team(s): NANOGrav Physics Frontiers Center

### **107.03 - Multi-Component Time-Resolved Analysis of Short and Long GRB Prompt Emission from Optical to Gamma-Ray(Sylvain Guiriec)**

The Band function traditionally used for Gamma Ray Bursts (GRB) often fails to fit their prompt emission spectra. Our new model composed of three separate components provides an excellent description of the time-resolved prompt emission of both short and long GRBs: a thermal-like and two non-thermal components. For the first time, analysis of GRBs with correlated optical and gamma-ray prompt emission show that our new model describes very accurately the whole broadband spectrum from the optical regime to higher energy gamma rays. In addition, this new model enables a new luminosity/hardness relation intrinsic to one of the non-thermal components showing that GRBs may be standard candles. If statistically confirmed, this relation will be used to (i) constrain the mechanisms powering GRB jets, (ii) estimate GRB distances, (iii) probe the early Universe, and (iv) constrain the cosmological parameters. I will present this new unified model using analysis of GRBs detected with various observatories and instruments such as Fermi, CGRO/BATSE and the combination of the three instruments onboard Swift and Suzaku/WAM. I will discuss here the striking similarities of GRB spectral shapes, whose components inform on the nature of the prompt emission, as well as the possible universality of the proposed

luminosity/hardness relation in the context of our new model.

**Author(s):** Sylvain Guiriec

**Institution(s):** George Washington University / NASA Goddard Space Flight Center Contributing Team(s): Sylvain Guiriec

### **107.05 - A fast radio burst with a low dispersion measure(Emily Petroff)**

Fast radio bursts (FRBs) are millisecond pulses of radio emission of seemingly extragalactic origin. More than 35 FRBs have now been detected, with only one seen to repeat. Here we present a new FRB discovery, FRB 110214, which was detected in the high latitude portion of the High Time Resolution Universe South survey at the Parkes telescope. FRB 110214 has one of the lowest dispersion measures of any known FRB ( $DM = 168.9 \pm 0.5 \text{ pc cm}^{-3}$ ), and was detected in two beams of the Parkes multi-beam receiver. A triangulation of the burst origin on the sky identified three possible regions in the beam pattern where it may have originated, all in sidelobes of the primary detection beam. Depending on the true location of the burst the intrinsic fluence is estimated to fall in the range of  $50 - 2000 \text{ Jy ms}$ , making FRB 110214 one of the highest-fluence FRBs detected to date. No repeating pulses were seen in almost 100 hours of follow-up observations with the Parkes telescope down to a limiting fluence of  $0.3 \text{ Jy ms}$  for a 2-ms pulse. Similar low-DM, ultra-bright FRBs may be detected in telescope sidelobes in the future, making careful modeling of multi-beam instrument beam patterns of utmost importance for upcoming FRB surveys.

**Author(s):** Emily Petroff

**Institution(s):** University of Amsterdam

### **107.06 - Numerical General Relativistic MHD With Magnetically Polarized Matter(Oscar Mauricio Pimentel Diaz)**

The magnetically polarized matter in astrophysical systems may be relevant in some magnetically dominated regions. For instance, the funnel that is generated in some highly magnetized disks configurations whereby relativistic jets are thought to spread, or in pulsars where the fluids are subject to very intense magnetic fields. With the aim of dealing with magnetic media in the astrophysical context, we present for the first time the conservative form of the ideal general relativistic magnetohydrodynamics (GRMHD) equations with a non-zero magnetic polarization vector,  $\mathbf{m}^\pm$ . Then, we follow the Anile method to compute the eigenvalue structure in the case where the magnetic polarization is parallel to the magnetic field, and it is parametrized by the magnetic susceptibility  $\tilde{\chi}_m$ . This approximation allows us to describe diamagnetic fluids, for which  $\tilde{\chi}_m < 0$ , and paramagnetic fluids where  $\tilde{\chi}_m > 0$ . The theoretical results were implemented in the CAFE code to study the role of the magnetic polarization in some 1D Riemann problems. We found that independently of the initial condition,



the first waves that appear in the numerical solutions are faster in diamagnetic materials than in paramagnetic ones. Moreover, the constant states between the waves change notably for different magnetic susceptibilities. All these effects are more appreciable if the magnetic pressure is much bigger than the fluid pressure. Additionally, with the aim of analysing a magnetic media in a strong gravitational field, we carry out for the first time the magnetized Michel accretion of a magnetically polarized fluid. With this test, we found that the numerical solution is effectively maintained over time ( $t > 4000$ ), and that the global convergence of the code is  $\mathcal{O}(\Delta t^2)$  for  $\hat{I}^2 \approx 0.005$ , for all the magnetic field strength,  $\hat{I}^2$ , we considered. Finally, when  $\hat{I}^2 = 0.008$  and  $\hat{I}^2 \approx 10$ , the global convergence of the code is reduced to a value between first and second order.

**Author(s):** Oscar Mauricio Pimentel Diaz, Fabio Duvar Lora Clavijo, Guillermo Alfonso Gonzalez Villegas

**Institution(s):** Universidad Industrial de Santander, college of charleston

### **107.07 - Eccentric Black Hole Mergers in Dense Star Clusters: The Role of Binary-Binary Encounters(Michael Zevin)**

We present the first systematic study of both binary-single and binary-binary black hole interactions with the inclusion of general relativity. By including general relativistic effects in the equations of motion during strong encounters, the dissipation of orbital energy from the emission of gravitational radiation can lead to inspirals and mergers with appreciable eccentricities when entering the sensitive frequency ranges of the LIGO and Virgo gravitational-wave detectors. It has been shown that binary-single interactions significantly contribute to the rate of eccentric mergers, but no studies have looked exclusively into the contribution from binary-binary interactions. To this end, we perform binary-binary and binary-single scattering experiments with general relativistic dynamics up through the 2.5 post-Newtonian order included, both in a controlled setting to gauge the importance of non-dissipative post-Newtonian terms and derive scaling relations for the cross-section of inspirals, as well as experiments tuned to the strong interactions from state-of-the art globular cluster models to assess the relative importance of the binary-binary channel at producing inspirals and resultant eccentricity distributions. Although binary-binary interactions are 10-100 times less frequent in globular clusters than binary-single interactions, their longer lifetime and more complex dynamics leads to a higher probability for inspirals to occur during the encounter. We find that binary-binary interactions contribute 25-45% of the eccentric mergers which occur during strong black hole encounters in globular clusters, regardless of the properties of the cluster environment. The inclusion of higher multiplicity encounters in globular clusters therefore have major implications on the predicted rates of highly eccentric binaries potentially detectable by the LIGO/Virgo network. As gravitational waveforms of eccentric inspirals are distinct from those generated by merging binaries which have circularized,

measurements of eccentricity in such systems would highly constrain their formation scenario.

**Author(s):** Carl Rodriguez, Enrico Ramirez-Ruiz, Michael Zevin, Carl-Johan Haster, Johan Samsing

**Institution(s):** Northwestern University, Princeton, CIERA, University of California Santa Cruz, MIT

### **107.02D - Massive Black-Hole Binary Mergers: Dynamics, Environments & Expected Detections(Luke Zoltan Kelley)**

This thesis studies the populations and dynamics of massive black-hole (MBH) binaries and their mergers, and explores the implications for electromagnetic and gravitational-wave (GW) signals that will be detected in the near future. We base our study on the populations of MBH and galaxies from the 'Illustris' cosmological hydrodynamic simulations. Because the bulk of the binary merger dynamics are unresolved in cosmological simulations, we have developed a suite of comprehensive physical models for the merger process in post-processing. Systems typically have lifetimes of gigayears, and only a fraction of systems merge by redshift zero. From our data and models, we calculate the expected GW signals: both the stochastic, GW background of unresolved sources, and GWs from individually resolvable binaries which resound above the noise. Pulsar timing arrays are sensitive to both types of signals, and are steadily increasing in sensitivity. We find that, while the current lack of detections is unsurprising, both the background and single sources will plausibly be detected in the next decade. Unlike previous studies which have predicted the GW background to be detected much more easily than single sources, our expected times to detection are comparable. I will highlight how different characteristics of GW detections and upper-limits will inform our understanding of MBH, their host galaxies, and their binary dynamics. With traditional electromagnetic observations, there has been a dearth of confirmed MBH binary systems. We use our binary populations, combined with models of emission from accreting MBH systems, to make predictions for the occurrence rate of systems observable as periodically-variable AGN. These variables should be currently detectable, and despite a large number of false positives, we expect many candidates recently identified to be true MBH binaries. The candidates are expected to be embedded in a large fraction of false positives which we outlines methods of filtering out. We are currently developing new methods and new populations to model MBH binaries at lower masses and higher redshifts, which will be detectable by LISA.

**Author(s):** Zoltan Haiman, Laura Blecha, Luke Zoltan Kelley, Alberto Sesana, Lars Hernquist

**Institution(s):** Northwestern University, University of Florida, Harvard University, University of Birmingham, Columbia University

### **107.04D - Multi-Telescope Radio Observations for Low-Frequency Gravitational Wave Astrophysics(Megan Jones)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has the principal goal of detecting gravitational waves (GWs) using pulsar timing. This thesis presents results from radio campaigns at frequencies from 322 MHz to 10 GHz aimed at both multi-messenger constraints on GW sources and improving timing sensitivity. The primary expected source of GWs at the nanohertz frequencies to which pulsar timing is sensitive are supermassive black hole (SMBH) binaries. We investigate a purported SMBH displaced from the galactic photocenter in NGC 3115. We explore the possibilities that the source is a SMBH binary or a post-merger recoiling SMBH. We place constraints on a possible SMBH companion using observations taken with the NRAO Very Large Array. If a companion can be confirmed, this system could be a future GW source detectable with pulsar timing. To detect such sources, our pulsar timing array must be as sensitive as possible, requiring the mitigation of all other astrophysical timing delays, including those from the interstellar medium (ISM). Using wideband multi-frequency observations obtained with the Green Bank Telescope and Arecibo Observatory, we characterize frequency-dependent dispersion, quantified by the dispersion measure (DM). We analyze trends in the DM time series, propose sources of these trends, and identify timescales over which the DM varies beyond measurement errors and therefore can no longer be modeled as constant in timing. Analyzing DM variations aids in characterizing properties of the ISM and informs our timing observation strategy. Multi-telescope observations around the globe and at complementary frequencies can be used to more sensitively constrain DMs. We compare DMs measured with simultaneous dual-frequency observations obtained with the Giant Metrewave Radio Telescope (GMRT) to those calculated in the NANOGrav 11-year data release to assess the possible precision of frequency-dependent noise measurements with the GMRT. We discuss the possibility of incorporating the GMRT into international pulsar timing efforts and the anticipated challenges in future data combination.

**Author(s):** Megan Jones

**Institution(s):** West Virginia University

### **108 - Star Formation I**

#### **108.01 - Calibrating star formation with MaNGA(Jose R Sanchez-Gallego)**

While star formation is arguably the main driver of secular galaxy evolution, accurate measurements of star formation rates are only possible for very nearby, well resolved and sampled star populations. For external galaxies star formation measurements rely on indirect tracers such as H-alpha, infrared, or ultraviolet emission that are heavily affected by dust attenuation and require accurate cross-calibration. MaNGA (Mapping Nearby Galaxies at Apache Point Observatory) is one of the projects being carried out in the fourth iteration of the Sloan Digital Sky Survey. By 2020 it will

have obtained spatially resolved spectroscopy data for over 10,000 galaxies, making it the largest sample of its kind to date. We combine MaNGA data with archival infrared and ultraviolet data and a simple energy balance method to derive a new calibration of star formation. Furthermore, we leverage on the statistical wealth of the MaNGA sample to explore how the calibrations are affected by morphology, gas content, etc.

**Author(s):** Jose R Sanchez-Gallego

**Institution(s):** University of Washington  
**Team(s):** MaNGA

#### **108.03 - Probing gas inflow with GBT/ALMA mapping towards starless clump candidates(Brian Svoboda)**

Understanding the mass accretion history of high-mass stars and star clusters is a key unresolved topic in the field of star formation. Blue-skewed line profiles of optically thick molecular transitions coincident with centrally peaked optically thin transitions provide a powerful observational diagnostic to measure gas inflow velocities, and thus, mass accretion. To this end we present maps of HCO<sup>+</sup>, H<sub>13</sub>CO<sup>+</sup>, HCN, and NH<sub>2</sub>D from the GBT and ALMA towards six starless molecular cloud clumps (M ~ 200-1500 solar masses). The subset of GBT Argus observations achieve the highest angular resolution at 3 mm of any telescope without spatial filtering (0.18 pc at 4.4 kpc). The targets were identified from a blind survey of 101 starless clump candidates at 67" resolution with the ARO 12 m. The ARO survey searched for blue-asymmetric line profiles to identify global gravitational collapse or gas inflow candidates. At high-resolution, the targets show substantial blending of narrow, transonic velocity components (dispersion 0.4 km s<sup>-1</sup>) with varying HCO<sup>+</sup> optical depths that mimic a global collapse signature. ALMA Band-6 0.8" imaging of para-H<sub>2</sub>CO 3(0,3)-2(0,2) ( $\tau_{\text{eff}} = 2.0 \text{--} 105 \text{ cm}^{-3}$  at 15 K) shows multiple dense cores at or near similar velocities as the HCO<sup>+</sup> peaks. Outflows traced by CO (2-1) also complicate the interpretation of the spectra. Galactic single-dish surveys investigating clump inflow velocities and mass accretion rates at >30" resolution are likely to be similarly affected by complex density structure, varied excitation conditions, and outflows from low-luminosity protostars undetected in MIR/FIR Galactic Plane surveys. However, preliminary results show systematic blueward velocity offsets between the peak HCO<sup>+</sup> and H<sub>13</sub>CO<sup>+</sup> velocities in spatially resolved sub-structures. These may be caused by localized collapse and inflow at speeds slower than the ~1-2 km/s supersonic speeds typically inferred from the globally averaged line-profiles.

**Author(s):** Jenny Calahan, Yancy Shirley, Cara Battersby, Brian Svoboda

**Institution(s):** National Radio Astronomy Observatory, University of Connecticut, University of Arizona, University of Michigan

### **108.05 - The magnetic and turbulent properties of the Perseus B1 star-forming region(Simon Coudé)**

The Perseus molecular cloud is an active, nearby star-forming complex containing several low- and intermediate-mass regions, one of which is the Perseus B1 clump. This low-mass star-forming cloud in particular is known to host several prestellar and protostellar cores, making it an ideal laboratory to test the influence of magnetic fields and turbulence at different stages in the evolution of young stellar objects. We present the POL-2 850  $\mu\text{m}$  polarimetric observations of Perseus B1 from the B-fields In Star-forming Region Observations (BISTRO) survey at the James Clerk Maxwell Telescope, from which we inferred the plane-of-sky orientation of the magnetic field in the cloud. Specifically, we calculated the turbulence correlation length and the turbulent-to-total magnetic energy ratio inside the cloud from the dispersion of polarization angles. By combining this turbulent-to-total magnetic energy ratio with observations of  $\text{NH}_3$  molecular lines from the Green Bank Ammonia Survey (GAS), we then estimated the strength of the plane-of-sky component of the magnetic field through the Davis Chandrasekhar-Fermi method. Our results show that Perseus B1 is a supercritical molecular cloud with a magnetic field nearly dominated by its turbulent component. With complementary studies using polarimetric data from, among others, the BISTRO survey and the Stratospheric Observatory for Infrared Astronomy (SOFIA), it will soon be possible to quantify and compare the magnetic and turbulent properties of the different environments in the Perseus star-forming complex, thus providing invaluable insights into the dynamics of low-mass star formation.

**Author(s):** Simon Coudé, Steve Mairs, Doug Johnstone, Sarah Sadavoy, Pierre Bastien, James Di Francesco, Rachel Friesen, Martin Houde

**Institution(s):** Universities Space Research Association, Harvard-Smithsonian CfA, Université de Montréal, National Radio Astronomy Observatory, University of Western Ontario, University of Victoria, NRC Herzberg Astronomy and Astrophysics, East Asian Observatory

### **108.02D - Spatially Resolved Star Formation Scaling Relations in Cosmological Simulations(Matthew Orr)**

Cosmological simulations have evolved over the past two decades to match ever more restrictive constraints on galaxy formation and evolution. For much of this time, simulations struggled to match even global properties of observed galaxies: stellar mass--halo mass relations, integrated star formation rates--gas masses (integrated Kennicutt-Schmidt), etc. However, the latest generation of zoom-in simulations is just now able to spatially resolve many of these galaxy scaling relations, just as spatially-high resolution galaxy surveys and studies move the goalposts from global properties to spatially-resolved distributions. In my talk, I will discuss several studies of spatially-resolved galaxy scaling relations in the FIRE (Feedback In Realistic Environments) suite of cosmological simulations, among them: Kennicutt-Schmidt, star formation

rate profiles, and line of sight velocity dispersions and star formation rates. I will explore how modern cosmological simulations are moving closer to the observations, both in their predictions and in their ability to model observables directly. Finally, how we can use these simulations to understand what physics these scaling relations are actually sensitive to.

**Author(s):** Matthew Orr, Philip Hopkins

**Institution(s):** Caltech Contributing Team(s): FIRE Collaboration

### **108.04D - Observational Studies of Hierarchical Fragmentation in Molecular Clouds(Riwaj Pokhrel)**

Star formation is a multi-step process where a molecular cloud of size scale more than tens of parsec of size fragment multiple times in a hierarchical fashion to finally form stars at the smallest scales. During this process of hierarchical fragmentation, different physics are responsible for supporting the cloud against gravitational contraction at different levels of hierarchy. We perform the Jeans analysis to test the thermal and non-thermal fragmentation scenario over five levels of hierarchy of structures in the Perseus molecular cloud. We find that the fragmentation is consistent with inefficient thermal Jeans fragmentation, where the thermal Jeans efficiency increases from the largest to the smallest scale. We do not find evidence of non-thermal fragmentation in Perseus if we assume that the non-thermal velocity dispersion provides isotropic pressure to support a cloud structure. Stars are formed as an end result of the hierarchical cloud fragmentation, which then co-evolve with the surrounding molecular gas.

**Author(s):** Riwaj Pokhrel

**Institution(s):** University of Massachusetts, Amherst

### **108.06D - Constraining the infalling envelope of embedded protostars: BHR71 and its hot corinos(Yao-Lun Yang)**

Star formation processes such as infall, accretion, and outflows increase the complexity of molecules, allowing us to use those molecules to probe the physical environments where stars form. The most deeply embedded protostars present particularly rich spectra of molecules due to their dense envelope and active infall and outflows, making them best probed by molecular spectroscopy. Stars form via the infall of mass from a core, but direct evidence for such infall has been elusive. The most direct probe of infall is redshifted absorption against the central continuum source, which is best shown in dense gas tracers, such as  $\text{HCO}^+$  and  $\text{HCN}$ . Our ALMA observations of these two molecules show such redshifted absorption toward an isolated embedded protostar, BHR71. Both lines show a similar redshifted absorption profile, indicative of infall. We model the line profiles with 3D radiative transfer calculations to constrain the kinematics properties of the collapsing envelope. Together with a parameterized chemical abundance profile, we successfully reproduce the infall signature from the  $\text{HCO}^+$  line.

The observation matches a younger envelope, which is consistent with the outflow dynamical age, than the ones constrained by the previous dust model. We also found emissions of complex organic molecules (COMs), revealing the "hot corinos" nature of BHR71. We found that complex organic molecules emit from a compact region centered on the continuum source, corresponding to  $\sim 70$ -90 AU. Several COMs, such as methanol and methyl formate, show clear signatures of rotation, which is consistent with a ring from a part of rotating infalling envelope. The similar abundances of COMs toward isolated protostars, such as B335 and L483, suggests that the warm temperature at the inner region passively release the COMs rather than actively modifies the chemical composition of COMs.

**Author(s):** Yao-Lun Yang

**Institution(s):** University of Texas at Austin

## **109 - Space Mission Instrumentation I**

### **109.01 - High-resolution, mid-ir spectroscopy with a robotic 5-m telescope at the lunar south pole.(Gordon Walker)**

We explore the concept and advantages of a diffraction limited, 3 to 5 m aperture telescope in permanent shadow in the Shackleton Crater feeding a fibre to a compact diffraction limited spectrograph,  $\sim 105$ , covering 0.6 to 5  $\mu$ m. The absence of telluric WV, O<sub>2</sub> or CO<sub>2</sub> would allow, sensitive detection of these bio-signatures in transiting exo-planet atmospheres, among many other things. Radial velocities with a precision  $\sim 10$  cm s<sup>-1</sup> would be possible. Such a facility is possible with existing technology. Assembly, upgrades and maintenance would be robotic. The risk from lunar dust is unknown.

**Author(s):** John Pazder, Gordon Walker

**Institution(s):** UBC, National Research Council of Canada

### **109.03 - Real-time data reduction pipeline and image analysis software for FIREBall-2: first flight with a $\hat{\Gamma}$ -doped UV-EMCCDs operating in counting mode(Vincent Picouet)**

FIREBall-2 (PI: C. Martin, CALTECH, French Co-PI: B.Milliard, LAM) has been launched on the 22nd of September, 2018 from the CSBF NASA facility in Fort-Sumner, NM. The instrument comprises a one meter telescope feeding a UV multi object spectrograph coupled to a high-efficiency UV detector developed by JPL on the basis of a  $\hat{\Gamma}$ -doped and AR-coated electron multiplying charge coupled device (EMCCD) CCD201-20 (1024x2048 px). The EMCCDs' serial readout register incorporates an avalanche gain mechanism that amplifies the incoming electrons by a factor  $\sim 2 \times 10^3$  which decreases the effect of the readout noise by the same factor. This gain comes at a cost: due to its stochastic nature, the amplification process introduces an Excess Noise Factor of  $\sqrt{2}$  which can be removed by applying a non-linear threshold which discriminates single photon events. I will present the flight

reduction pipeline developed and used for the first flight of this cutting-edge EMCCD, which includes a simple cosmic-ray removal and photo-counting thresholding. I will also present an interactive image/spectrum analysis python package developed at LAM and used to perform FIREBall-2 in-flight real time analysis. This package incorporates many AIT and flight functions and is seamlessly coupled to the astronomical imaging and data visualization software DS9. The main goal in the development was to join the user friendly but general SAOImage DS9 interface with a series of both broad interest and FIREBall-2 specific python functions that can be run by a simple click using the DS9 interface. The package, based on the two-way communication between DS9 and python provides a very efficient method of interaction with the images. This includes stacking, a variety of quick calculations, and visualizations of the image in a given area defined in DS9. The different features of the package, such as aperture photometry, 2D Gaussian fits to circular or rectangular spots, stacking analysis or calibration functions (eg. through-focus, slit-scan analysis) will be presented. This package will be publicly released in January 2019.

**Author(s):** Didier Vibert, Vincent Picouet, Gillian Kyne

**Institution(s):** Laboratoire d'astrophysique de Marseille, CALTECH  
**Contributing Team(s):** FIREBall- team

### **109.04 - Diffraction analysis of Laser Guide Star enabled cophasing wavefront control for large segmented aperture space telescopes(Yeyuan Xin)**

Large segmented aperture telescopes such as LUVOIR (Large UV Optical Infrared Surveyor) are in development to achieve the improvement in resolution and contrast necessary to directly image Earth-like exoplanets, in addition to making contributions to general astrophysics. Control of these complex, large optical systems, which may have several dozen meter-sized segments, to a surface precision on the order of picometers is a challenge. A laser guide star (LGS) on a companion spacecraft can provide a 2nd magnitude or brighter source for faster wavefront sensing with a Zernike wavefront sensor than is possible with most natural target stars. We will present feedback control system simulations that show that the LGS can relax the segment stability requirements by up to two orders of magnitude and allow observations of stars with brightnesses unlimited by wavefront sensing considerations. We analyze the approach of using a hexagonal segmented deformable mirror (DM) conjugate to the primary telescope mirror to correct for segment piston, tip, and tilt errors. This control strategy provides a segment wavefront control loop concurrent with Electric Field Conjugation that uses two high actuator count DMs to dig symmetric dark holes. Assuming perfect knowledge and actuation of the system, our preliminary model with an unapodized charge 6 vector vortex coronagraph shows that correcting with the hexagonal DM can significantly improve the contrast achieved by EFC, for example from  $3.5 \times 10^{-7}$  uncorrected to  $6 \times 10^{-9}$  with correction for 100 pm RMS of telescope segment error. Dynamic diffraction effects from introducing a typical hexagonal segmented DM result in the

residual contrast floor that increases with primary telescope segment error. We present our simulation results and additional analyses of sensitivity to factors such as coronagraph choice and conjugate DM size and segment gap ratio, and discuss strategies for improving the performance of the LGS approach.

**Author(s):** James R. Clark, Yeyuan Xin, Jennifer R Lumbres, Ewan Douglas, Jared Males, Kerri L Cahoy, Gregory W Allan, Olivier Guyon

**Institution(s):** Massachusetts Institute of Technology, University of Arizona

### **109.05 - Glowbug, a Gamma-Ray Telescope for Bursts and Other Transients(J. Grove)**

We describe Glowbug, a gamma-ray telescope for bursts and other transients in the 30 keV to 2 MeV band. It was recently selected for funding by the NASA Astrophysics Research and Analysis program, with an expected launch in the early 2020s. Similar in concept to the Fermi Gamma Burst Monitor (GBM) and with similar sensitivity, Glowbug will join and enhance future networks of burst telescopes to increase sky coverage to short Gamma-Ray Bursts (SGRBs) from neutron star (NS) binary mergers, including possible SGRBs from NS-black hole mergers. With the recent discovery of the SGRB coincident with the gravitational wave transient GW170817, we know such events occur with reasonable frequency. Expanded sky coverage in gamma rays is essential, as more detections of gravitational waves from such mergers by ground-based interferometers will come in the next few years, and detecting an electromagnetic counterpart is a powerful probe of merger dynamics. Work on Glowbug at NRL is supported by NASA and the Chief of Naval Research.

**Author(s):** Colleen A. Wilson-Hodge, Matthew Kerr, Daniel Kocevski, Chi C. (Teddy) Cheung, Richard S. Woolf, Michael S. Briggs, J. Grove, Jeremy S Perkins, Eric A. Wulf, Lee J. Mitchell, Bernard F. Philips

**Institution(s):** Naval Research Laboratory, University of Alabama Huntsville, NASA Marshall Space Flight Center, NASA Goddard Space Flight Center

### **109.06 - Accurate Infrared Absolute Calibration of Faint Stars(George Rieke)**

Although accurate direct absolute calibrations are available in the infrared, they apply to very bright stars that are far above the saturation limits of modern instruments. To address this issue, we have traced Sirius to two well-understood faint calibration stars, the A1V star BD +60 1753 (a primary IRAC calibrator on Spitzer) and the G2V star P 330E (a primary NICMOS calibrator on HST). Two methods have been used: (1) photometry with Spitzer using the wings of the point spread function on saturated images; and (2) transformation of heritage photometry onto a consistent scale. We find that Sirius can be assigned a K<sub>S</sub> magnitude of -1.388 (and Vega -0.020)

on the 2MASS scale. The two calibration methods then agree on flux densities at 3.60 microns of 7.05 mJy for P 330E and 36.35 mJy for BD +60 1753, or at 2.1598 microns, 16.65 and 87.3 mJy, respectively. These values are within the non-saturated range for JWST and large groundbased telescopes, and they can be extended to large networks through existing databases (e.g., 2MASS, WISE). This work is therefore part of the foundation for establishing an accurate photometric system for JWST that can be applied uniformly to infrared measurements with modern groundbased telescopes.

**Author(s):** Rafia Bushra, Kate Su, George Rieke

**Institution(s):** The University of Arizona

### **109.07 - AdEPT, the Advanced Energetic Pair Telescope for Medium-Energy Gamma-Ray Polarimetry(Stanley Hunter)**

The Advanced Energetic Pair Telescope (AdEPT) is being developed as a future NASA/GSFC end-to-end MIDEX mission to perform high-sensitivity medium-energy (5-200 MeV) astronomy and revolutionary gamma-ray polarization measurements. The enabling technology for AdEPT is the GSFC Three-Dimensional Track Imager (3-DTI), a large volume gaseous time projection chamber with 2-dimensional micro-well detector (MWD) readout. The low density and high spatial resolution of the 3-DTI allows AdEPT to achieve high angular resolution (~0.5 deg at 67.5 MeV) and, for the first time, exceptional gamma-ray polarization sensitivity. These capabilities enable a wide range of scientific discovery potential for AdEPT. The key science goals of the AdEPT mission include: 1) Explore fundamental processes of particle acceleration in active astrophysical objects, 2) Reveal the magnetic field configuration of the most energetic accelerators in the Universe, 3) Explore the origins and acceleration of cosmic rays and the Galactic MeV diffuse emission, 4) Search for dark matter in the Galactic center, and 5) Test relativity with polarization measurements. We report on the development of AdEPT as a future NASA/GSFC MIDEX mission to perform high-sensitivity medium-energy (5-200 MeV) astronomy and revolutionary gamma-ray polarization measurements.

**Author(s):** Stanley Hunter, Lorella Angelini, Andrey Timhokin

**Institution(s):** Goddard Space Flight Center

### **109.08 - TESS Data Analysis using the community-developed Lightkurve Python Package(Geert Barentsen)**

Lightkurve is a community-developed, open-source Python package which offers a user-friendly and accessible way to analyze data from NASA's Kepler and K2 missions. The new TESS mission uses the same Kepler pipeline to generate data products for the community, and so the data can be accessed in much the same way as the original Kepler products. Since TESS has recently begun releasing data, we have adapted Lightkurve

to enable users to easily interface with TESS products from MAST. Our new tools allow users to work with TESS in the same way as Kepler and K2, with the same friendly Lightkurve API. The package is supported by a rich syllabus of tutorials which aim to lower the barrier for students, astronomers, and citizen scientists alike to analyze data from NASA's exoplanet space telescopes. In this contribution, I will demonstrate the use of Lightkurve for TESS data analysis, discuss the future of the package, and present evidence to show that making the community's expertise available in a high-quality, open source package makes our field more inclusive.

**Author(s):** Geert Barentsen, Michael A. Gully-Santiago, Thomas Barclay, Nicholas Saunders, Jessie Dotson, Ann Marie Cody, Christina L Hedges, Jose Vinicius De Miranda Cardoso,  
**Institution(s):** NASA Ames, Goddard Space Flight Center, Bay Area Environmental Research Institute Contributing Team(s): Lightkurve developers

### **109.02D - Identification and adaptive wavefront control for an exoplanet coronagraphic imaging instrument(He Sun)**

In space-based exoplanet coronagraphic imaging systems, focal plane wavefront control is needed together with the coronagraph to cancel the detrimental wavefront aberrations that are preventing the high contrast needed in the final image plane. Currently, the most efficient focal plane wavefront control algorithms, such as electric field conjugation (EFC) and stroke minimization (SM), are all model-based, so the system's performance is related to the accuracy of its Fourier optics modeling. Typically, lab characterization techniques, such as deformable mirror laser interferometry and pupil plane aberration phase retrieval, are used to improve the optical system modeling. Unfortunately, most of these approaches introduce non-common-path errors and none of them is able to eliminate time-varying errors. In this talk, I will summarize our work on a new machine-learning-based approach that enables system identification and real-time adaptive wavefront control of the exoplanet coronagraphic imaging instrument. This new technique applies the expectation-maximization (E-M) algorithm and deep neural networks to correct the model errors in real time based on wavefront control data. This greatly improves the wavefront correction speed and the final achievable contrast. Simulation and experimental results in Princeton's High Contrast Imaging Lab will be presented to demonstrate this new approach. In addition, I will also report the simulation of this new wavefront control algorithm on the coronagraph instrument for NASA's WFIRST telescope.

**Author(s):** N. Jeremy Kasdin, He Sun  
**Institution(s):** Princeton University

### **110 - White Dwarfs, Neutron Stars and FRBs**

#### **110.01 - GBTrans: A synergistic search for Fast Radio Bursts with Green Bank 20-m Telescope(Golnoosh Golpayegani)**

Pulsar searches and their need for high time resolution have opened new windows to our knowledge about the universe. The best example of this are Fast Radio Bursts (FRBs): very strong transient radio bursts that occur in a short time-duration on the order of milliseconds. The first FRB was discovered in a survey for pulsars and fast transients in 2001 by the Parkes Radio Telescope in Australia (Lorimer et al 2007). So far, only ~60 FRBs have been detected which is insufficient to adequately characterize their origin, emission mechanism, and population. The pulse properties of the bursts, including their Dispersion Measure (DM) value, suggest that they likely have a celestial origin. Although we are able to observe the flux of the bursts and the fact that FRBs are highly dispersed in radio frequency, today, eleven years since the first FRB discovery, we still don't know what is the source of the bursts; whether compact objects such as black holes, white dwarfs, neutron stars, etc. or solar flares. However, the extragalactic compact object scenario is the most likely scenario. Commensal-mode observing is especially beneficial for detecting FRBs as it maximizes the on-sky time. GBTrans is a commensal synergistic study of FRBs using the Green Bank 20-meter diameter telescope at the Green Bank Observatory which is currently active as part of the Skynet educational program since 2015. We describe the observing system and report on the non-detection of any FRBs. Single pulses from known pulsars, including ~20k verified giant pulses from the Crab pulsar were detected during this survey, which will be used in order to train a Convolutional Neural Network (CNN) algorithm for real-time detection. With current FRB rate models, along with measurements of telescope sensitivity and beam size, we estimate the redshift that this survey probed and the expected event rate. We discuss the implications of this non-detection in the context of results from other telescopes and the limitation of our search pipeline.

**Author(s):** Golnoosh Golpayegani, Duncan Lorimer,  
**Institution(s):** West Virginia University, Center for Gravitational Waves and Cosmology

#### **110.02 - Observing Pulsars with CHIME(Ingrid Stairs)**

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a new 4-cylinder 80m x 100m transit telescope located at the Dominion Radio Astrophysical Observatory in Penticton, B.C. Although built to measure the distribution of hydrogen at intermediate redshifts, the telescope will also provide a superb data set on Northern-hemisphere pulsars. With a frequency range of 400-800 MHz and the ability to track up to 10 pulsars simultaneously, the CHIME/Pulsar instrument will provide daily monitoring of the variable interstellar medium toward timing-array pulsars, as well as data sets on hundreds of other pulsars with cadences of about 10 days or less. Here we describe the pulsar backend instrument and present a sample of early results.

**Author(s):** Ingrid Stairs

**Institution(s):** University of British Columbia Contributing Team(s): CHIME/Pulsar collaboration

### **110.03 - Early Science Results from CHIME/FRB(Deborah Good)**

Fast Radio Bursts (FRBs) are millisecond duration, extragalactic radio emissions, which are as yet poorly understood, partially because only a few dozen have been detected. The paucity of detections and incomplete localization information complicates our understanding of FRBs and their origins. The CHIME/Fast Radio Burst Project (CHIME/FRB) mitigates this problem by using the Canadian Hydrogen Intensity Mapping Experiment (CHIME) located at the Dominion Radio Astrophysical Observatory in British Columbia to search for FRBs continuously. CHIME is a novel transit telescope coupled to a powerful correlator, which allows it to observe the entire Northern sky in its frequency range (400-800 MHz) each day. Pre-commissioning calculations predicted CHIME/FRB could detect a few to several dozen FRBs per day. Here, we present early scientific results, including, for the first time, the detection of FRBs at frequencies as low as 400 MHz.

**Author(s):** Deborah Good

**Institution(s):** University of British Columbia Contributing Team(s): CHIME/FRB Collaboration

### **110.04 - Radio and X-ray Monitoring of the Recently Reactivated Magnetar PSR J1622-4950(Amanda Cook)**

PSR J1622-4950 is one of four magnetars that has shown evidence of pulsed radio emission. We present radio and X-ray monitoring observations of this magnetar following its most recent radio reactivation in April 2017. The radio observations were carried out over a time span of roughly one year from May 2017 until August 2018, typically at simultaneous observing frequencies of 2.2 GHz and 8.3 GHz, using the Deep Space Network's 34-m diameter telescopes located near Canberra, Australia. Our radio measurements indicate that the magnetar exhibited significant changes in its pulse profiles, flux densities, spectral index, rate of bright single pulses, and rotational period after its radio reactivation. Short-term variability in its radio emission behavior was also observed. X-ray observations of the magnetar were performed in the 1-6 keV energy band between July 2017 and August 2018 with the NICER instrument on board the International Space Station (ISS). We searched for X-ray pulsations using contemporaneous radio ephemerides, but found no strong evidence of pulsed X-ray emission. This suggests that the magnetar has reentered an X-ray quiescence state, which we explain by the decay in the rate of soft X-ray thermal emission, inferred from fitting an absorbed blackbody model to the X-ray spectra. We will discuss the results from our multi-wavelength monitoring campaign and compare PSR J1622-4950's emission characteristics to other radio magnetars.

**Author(s):** Aaron B. Pearlman, Teruaki Enoto, Thomas Prince, Thomas Kuiper, Jonathon Kocz, Zaven Arzumianian, Keith C Gendreau, Shinji Horiuchi, Charles J Naudet, Amanda Cook, Walid Majid, Ariel Amsellem

**Institution(s):** McGill University, California Institute of Technology, University of Chicago, Kyoto University, NASA

Goddard Space Flight Center, Jet Propulsion Laboratory, California Institute of Technology, CSIRO, Canberra Deep Space Communications Complex

### **110.06 - An Independent Dynamical Mass for the White Dwarf in the Self-Lensing Binary KOI-3278(Daniel Yahalomi)**

KOI-3278 is a self-lensing stellar binary consisting of a white dwarf orbiting a Sun-like star. Kruse and Agol (2014) noticed small periodic brightenings every 88.18 days in the Kepler photometry and interpreted this as the result of microlensing by a white dwarf with about 63% of the mass of the Sun. We present the results of follow-up spectroscopy that allow us to refine the stellar parameters for the host star and derive an independent dynamical mass for the white dwarf in good agreement with the microlensing mass. The radial velocities used for the orbital solution come from two independent programs with the High Resolution Spectrograph (HIRES) on Keck and the Tillinghast Reflector Echelle Spectrograph (TRES) at the Whipple Observatory, again with good agreement. We also present the results of a global MCMC model that combines the microlensing and dynamical analysis and takes advantage of our improved knowledge of the host star from the spectroscopy and Gaia DR2 parallax. Self-lensing systems such as KOI-3278 can provide new windows into the evolution of binary systems where mass loss and/or mass transfer is involved, such as common envelope binaries and blue stragglers.

**Author(s):** Yossi Shvartzvald, David W Latham, Eric Agol, Avi Shporer, Ethan Kruse, Daniel Yahalomi

**Institution(s):** Harvard-Smithsonian CfA, Massachusetts Institute of Technology, University of Washington, NASA GSFC, IPAC

### **110.05D - Searching for compact objects within X-ray catalogs using Machine Learning(Jeremy Hare)**

Modern X-ray observatories (e.g., Chandra and XMM-Newton) have detected large numbers of Galactic sources serendipitously. The X-ray properties of these sources are extracted and then placed into catalogs, where they remain primarily unstudied. Novel discoveries and rare source classes are certain to be revealed by studying these rich datasets. However, X-ray data alone is often not enough to classify these sources, especially the faint sources whose population dominates these catalogs. Therefore, additional multiwavelength data must be used. MUWCLASS is a multiwavelength machine-learning pipeline that we have developed to classify X-ray sources. The pipeline relies on an extensive multiwavelength training dataset to carry out this task. In this talk, I will describe the training dataset, pipeline, and validation procedures used to construct MUWCLASS. I will then discuss the results of the classification of X-ray sources in multiple environments, including unidentified TeV sources, stellar clusters, and SNRs.

**Author(s):** Igor Volkov, George Pavlov, Oleg Kargaltsev, Bettina Posselt, Jeremy Hare, Blagoy Rangelov  
**Institution(s):** George Washington University, Texas State University, University of California, Berkeley, University of Maryland, Pennsylvania State University

## **111 - Milky Way & Galactic Center I**

### **111.01 - New Spectroscopic Constraints on Cool Gas in the Fermi Bubbles(Andrew J Fox)**

At the center of the Milky Way, two giant Fermi Bubbles surround the Galactic Center. We present new results from our ongoing program to study entrained cool gas clouds in the Fermi Bubbles using ultraviolet and radio observations. This includes Hubble Space Telescope/Cosmic Origins Spectrograph spectra of five AGN lying behind the southern Fermi Bubble at low Galactic latitude, a largely unexplored region where enhanced X-ray emission suggests outflow activity. We study this region via analysis of the high-velocity cloud (HVC) absorption detected in UV metal lines toward the background AGN. We also present a deep 21 cm map from the Green Bank Telescope of an entrained cool H I cloud in the northern Bubble, and discuss the implications of its existence. These results further our understanding of how nuclear activity drives the circulation of gas through the Galactic halo.

**Author(s):** Rongmon Bordoloi, Trisha L Ashley, Andrew J Fox, Felix Lockman

**Institution(s):** STScI, North Carolina State University, Massachusetts Institute of Technology, Green Bank Observatory

### **111.02 - NuSTAR Discovery of a 40 keV High-energy X-ray Source within the Central Parsec of the Galaxy(Shuo Zhang)**

Soft X-ray observations have revealed that The central parsec of the Galaxy harbors a supermassive black hole, a pulsar wind nebula candidate, a cusp of quiescent black hole systems and complicated diffuse X-ray emission components. NuSTAR's arcminute spatial resolution beyond 10 keV allowed us to investigate what the Galactic center has to offer in the high-energy X-ray band. In this talk, I would like to report our discovery of a new High-energy X-ray source located at merely 1 parsec from the Galactic center supermassive black hole Sgr A\*. This source is most significantly detected as an extended source in 40-50 keV. It spatially coincides with a region showing velocity discontinuum of the sighted ionized gas in the circumnuclear disk. I am going to discuss two possible origins of this high-energy source in the vicinity of Sgr A\*: 1) ionization of the circumnuclear disk by X-ray photon outflows from Sgr A\* or a nearby pulsar wind nebula; 2) excitation of the circumnuclear disk by MeV-GeV electrons/protons.

**Author(s):** Jae Sub Hong, Shuo Zhang, Kerstin Perez, Betsy Mills

**Institution(s):** MIT, Boston University, CfA

### **111.03 - A Phenomenological Study of Radio Pulses from the Galactic Center Magnetar PSR J1745-2900(Aaron B. Pearlman)**

The Galactic Center magnetar, PSR J1745-2900, lies at a projected distance of  $\sim 0.1$  pc from Sgr A\* and serves as an excellent probe of the magneto-ionic environment near the Galaxy's central black hole. We present results from simultaneous radio observations of the magnetar at 2.3 and 8.4 GHz with the NASA Deep Space Network 70 m antenna, DSS-43, in Tidbinbilla, Australia. We characterize the magnetar's pulse profile shape, flux density, radio spectrum, and single pulse behavior over a  $\sim 1$  year period between MJDs 57233 and 57621. When the 8.4 GHz profile is single-peaked, the magnetar exhibits an average spectral index of  $\alpha \pm \sigma = -1.86 \pm 0.02$  between 2.3 and 8.4 GHz, which is comparable to the mean spectral index of ordinary radio pulsars. The radio spectrum significantly flattens when the pulse profile becomes double-peaked. This behavior is atypical of most radio magnetars, which have relatively flat or inverted radio spectra. From an analysis of single pulses at 8.4 GHz on MJD 57479, we find that giant pulses and pulses with multiple emission components are emitted during a significant number of rotations. The single pulse flux density distribution cannot be described by a log-normal distribution due to these giant pulses. The intrinsic pulse width of the components is typically  $\sim 1.8$  ms, and the prevailing delay time between successive components is  $\sim 7.7$  ms. Many of the single pulse emission components display frequency structure over bandwidths of  $\sim 100$  MHz, which is the first observation of such behavior from a radio magnetar. We measure a characteristic single pulse broadening timescale of  $\tau_d = 6.9 \pm 0.2$  ms at 8.4 GHz, which is more than an order of magnitude larger than expected based on previous multi-frequency scattering measurements. We also find that the pulse broadening is extremely variable between emission components and cannot be explained by a static thin scattering screen at distances  $> \sim 1$  kpc from the magnetar. We will discuss potential intrinsic and extrinsic mechanisms for the magnetar's emission and compare our results to other magnetars, high magnetic field pulsars, and fast radio bursts.

**Author(s):** Shinji Horiuchi, Aaron B. Pearlman, Jonathon Kocz, Thomas A. Prince, Walid A. Majid,

**Institution(s):** California Institute of Technology, CSIRO Astronomy and Space Science, Canberra Deep Space Communications Complex, Jet Propulsion Laboratory, California Institute of Technology

### **111.04 - In Search of Galactic Center Millisecond Pulsars from Steep-Spectrum, Compact Radio Sources(Namir E Kassim)**

A leading candidate for the Fermi Galactic Center GeV Excess is a population of thousands of as yet undetected millisecond pulsars. We have conducted a search for pulsar candidates using new high sensitivity, wide-field radio observations of the Galactic Center covering  $\sim 5$  square degrees. We conducted the



search at a low frequency of  $\sim 320$  MHz in order to take advantage of the very steep spectra typical of pulsars. Follow-up 6 GHz observations of our steepest spectrum, compact targets resulted in a number of candidate pulsars. No pulsations were detected for any of the candidates in a search conducted with the GBT at GHz frequencies, presumably due to severe temporal scattering in the Galactic Center region or along the line of sight. We discuss the implications of the non-detections on pulse period and distance estimates in context of what is known about the Galactic distribution of ionized gas. We estimate that pulsations from our best candidate would have been detected up to a distance of  $\sim 8$  kpc and  $\sim 4.5$  kpc, for a normal or millisecond pulsar, respectively.

**Author(s):** Dale A Frail, T. Joseph W Lazio, Julia Deneva, Namir E Kassim, Scott D Hyman, Maura McLaughlin, Emil Polisensky, Paul S Ray

**Institution(s):** Naval Research Laboratory, NRAO, Sweet Briar College, JPL-Caltech, George Mason University, West Virginia University

#### **111.05 - IMAGINE: the Interstellar MAGnetic field Inference Engine(Tess Jaffe)**

The IMAGINE Consortium has been formed to bring together theorists and observers from the wide variety of astronomy and astroparticle areas impacted by the Galactic magnetic field (GMF). Magnetic fields in the interstellar medium are difficult to study directly but affect phenomena as diverse as: the propagation of cosmic rays; the formation of stars; the morphology of supernova remnants; the deflections in the arrival directions of extragalactic ultra-high energy cosmic rays (UHECRs); the cosmic microwave background (CMB) foregrounds. New data across the electromagnetic spectrum are giving us new and different views of the fields (for example, polarized dust emission from Planck, or anisotropies in the arrival directions of UHECRs seen with Auger or IceCube), but these data are difficult to interpret because of the complexity of the different contexts and the degeneracies in the parameter space. The Interstellar MAGnetic field INference Engine is our new framework for combining all available observables as well as theoretical knowledge into a statistically rigorous Bayesian analysis. This will allow us to incorporate \*all\* available information to break some of these degeneracies as well as to explicitly quantify how well different models reproduce the same observables with the Bayesian evidence. I will summarize the project, the infrastructure we have made publicly available, and our plans to build more realistic GMF models based on magneto-hydrodynamical dynamo equations and to attempt both parametric and non-parametric reconstructions of the GMF.

**Author(s):** Tess Jaffe

**Institution(s):** NASA/GSFC and Univ of Maryland  
Contributing Team(s): IMAGINE Consortium

#### **111.06 - MAGNETIC FIELD STRUCTURE AND Turbulence of OMC-1(Jordan Guerra Aguilera)**

We present the results of determining the magnetic field and characterizing the turbulence in the Orion Molecular Cloud 1 (OMC-1). Using multi-wavelength polarimetric data from SOFIA/HAWC+, we employed the analysis of polarization vectors dispersion along with the Davis-Chandrasekhar-Fermi method to determine the field strength and turbulent state at different regions of OMC-1. Our results show that the three main regions of OMC-1, the BN/KL object, the bar, and the HII region have different magneto-turbulent states, with the bar being the most turbulent of all and the HII region the least. Magnetic field estimates show that BN/KL has  $\sim 1$  mG strength while the HII and bar show approximately half that value. In addition, more complex structure is observed in each region. Implications of these results to magnetically-dominated BN/KL explosion, the effect of magnetic field on star formation will be discussed.

**Author(s):** C. Darren Dowell, David Chuss, Javad Siah, Joseph M. Michail, Martin Houde, Jordan Guerra Aguilera

**Institution(s):** Villanova University, University of Western Ontario, NASA Jet Propulsion Lab  
Contributing Team(s): HAWC+ Science Team

#### **111.07 - Interstellar HI: Filaments and threads(Gerrit Verschuur)**

A very long and nearly straight HI filament at about  $-60^\circ$  in the southern galactic hemisphere, seen nearly normal to the line-of-sight and well separated from low velocity gas, has been studied in several ways in order to understand its physics, structure, and morphology. Gaussian analysis of 1800 profiles show an underlying HI component, which is at least  $15^\circ$  long and about  $1^\circ$  wide, has a typical line width of  $21 \text{ km/s}$ . At a distance of  $100 \text{ pc}$  it would be confined by a magnetic field of  $18 \frac{1}{4} \text{ G}$ . Examination of 140 declination-velocity cross-sections revealed evidence for narrow, elongated features (threads) unresolved in width within the boundaries of the filament. These cooler components have an average density of  $29 \text{ cu.cm.}$  and may be confined by a magnetic field of  $5 \frac{1}{4} \text{ G}$ . These results, taken together, suggest that interstellar HI filaments may have magnetic substructure.

**Author(s):** Mahboubeh Asgari-Targhi, Joan T. Schmelz, Gerrit Verschuur

**Institution(s):** Unaffiliated, USRA, SOFIA Science Center, CfA

#### **112 - Black Holes I**

##### **112.01 - Constraining BH formation with 2M05215658+4359220(Katelyn Breivik)**

The recent discovery of 2M05215658+4359220 as a giant star orbiting a dark companion presents a unique opportunity to study the formation of compact objects. The giant star's

puzzling nature and poorly constrained mass lead to different derived companion masses, ranging from  $1.8 M_{\odot}$  to  $\sim 5 M_{\odot}$ , with the potential of a  $\sim 3 M_{\odot}$  black hole companion. In this work, we show which binary stellar evolution channels produce systems containing black holes orbiting giant stars like 2M05215658+4359220. We also show how future observations of the masses of 2M05215658+4359220 and its companion may place strong constraints on models for the supernova explosion mechanism.

**Author(s):** Jeff Andrews, Sourav Chatterjee, Katelyn Breivik

**Institution(s):** Canadian Institute for Theoretical Astrophysics, Foundation for Research and Technology-Hellas, Tata Institute of Fundamental Research, Physics Department & Institute of Theoretical & Computational Physics

### **112.01 - The population of binary black holes following advanced LIGO's second observing run(Maya Fishbach)**

I will discuss the astrophysical population of binary black holes as inferred from the LIGO/ Virgo detections to date. Combining the binary black hole detections from advanced LIGO's first and second observing runs, we place constraints on the black hole mass spectrum, spin distribution, total merger rate, and the evolution of the merger rate with redshift. We discuss evidence for various features in the distributions, including the minimum and maximum black hole mass, and aligned versus isotropic spins.

**Author(s):** Maya Fishbach

**Institution(s):** University of Chicago Contributing Team(s): LIGO Scientific Collaboration, Virgo Collaboration

### **112.02 - Black hole mergers in AGN disks: Low $\dot{M}_{\text{eff}}$ mergers & predictions for LIGO(Barry McKernan)**

Accretion disks around supermassive black holes in active galactic nuclei (AGN) are promising sites for stellar mass black hole mergers detectable with LIGO and intermediate and extreme mass ratio mergers detectable with LISA. Here we present the results of Monte-Carlo simulations of a probabilistic black hole merger hierarchy within AGN disks. Two key findings are: 1) The distribution of  $\dot{M}_{\text{eff}}$  from black hole mergers in the disk is naturally centered on zero, with  $>90\%$  of mergers occurring with  $|\dot{M}_{\text{eff}}| < 0.5$  and  $\sim 50\%$  of mergers occur with  $|\dot{M}_{\text{eff}}| < 0.2$  and, 2) the rate of black hole mergers is highest early on ( $< 0.1 \text{ Myr}$ ) in the AGN disk.

**Author(s):** Daniel Wysocki, Richard O'Shaughnessy, K.E. Saavik Ford, Barry McKernan,

**Institution(s):** CUNY-BMCC, RIT, AMNH

### **112.04 - Gravitational interactions of stars with supermassive black hole binaries: Tidal disruption events and hypervelocity stars.(Siva Darbha)**

Stars incident on supermassive black holes (SMBHs) can be disrupted in tidal disruption events (TDEs) or ejected as hypervelocity stars (HVSs). Using restricted three-body integrations, we study the statistics of TDEs and HVSs produced by a circular, binary SMBH as a function of its mass ratio  $q$  and separation  $a$ . For both outcomes, we calculate the event probabilities, the probability density functions (PDFs) of important observables, and the time-dependent event rates as the binary inspirals. For the TDEs, we compare our results to a single SMBH, and examine the fallback dynamics of the debris in the "frozen-in" approximation. We find that the TD rate is a factor of  $\hat{a}^{1/4} 2 - 7$  times larger than that of a single SMBH and is independent of  $q$  for  $q \gtrsim 0.2$ . Disruptions from close, nearly equal mass binaries can produce intense tidal fallbacks with short rise times and highly super-Eddington peak return rates. For the HVSs, we examine the velocity and angular distributions, compare our results to HVSs produced by a single SMBH (i.e. the "Hills mechanism"), and constrain the size of the HVS sample needed to distinguish between the two sources. We find that the HVS ejection probability is an increasing function of  $a$  and  $q$ , and that the mean ejected velocity scales with the binary SMBH parameters as shown in previous work but with modified scaling constants. Inspiring binary SMBHs eject stars with velocities  $v_{\infty} > 1000 \text{ km/s}$  at rates of  $\hat{a}^{1/4} 4\hat{a}^{-10-2} - 2\hat{a}^{-10-1} \text{ yr}^{-1}$  for  $q = 1$  ( $\hat{a}^{1/4} 10^{-4} - 10^{-3} \text{ yr}^{-1}$  for  $q = 0.01$ ) over their lifetimes, and can emit a burst of HVSs with  $v_{\infty} > 3000 \text{ km/s}$  as they coalesce. Roughly  $N \hat{a}^{1/4} 100$  HVS velocity samples with  $v_{\infty} \gtrsim 200 \text{ km/s}$  are required to distinguish between a binary and single SMBH origin.

**Author(s):** Eliot Quataert, Dan Kasen, Siva Darbha, Eric Robert Coughlin,

**Institution(s):** University of California, Berkeley, Columbia University, Lawrence Berkeley National Laboratory

### **112.06 - Extreme Transients Discovered with DASCH: New BH-LMXBs or new Classical Novae?(Jonathan E Grindlay)**

A prime motivation for undertaking the Digital Access to a Sky Century @ Harvard (DASCH) project to digitize the  $\sim 500,000$  glass plate images taken by Harvard telescopes over the full-sky from 1886 - 1992 was to study extreme transients. With the data releases DR6 and DR7 by the time of this AAS, we can now report on initial results for extreme transients ( $> 8$  magnitude nova-like outbursts) from over 65% of the sky. These include classical novae (many originally discovered on the Harvard plates), WZ Sge CVs, and black hole low mass X-ray binaries (BH-LMXBs), which have rare  $> 6 - 10$  magnitude optical outbursts with decay times comparable to classical novae (CNe). Precise ( $< 1 \text{ arcsec}$ ) positions for these bright transients enable identification with Gaia DR2 objects and enable WZ Sge systems to be (largely) filtered out. The distinction then between BH-LMXBs and CNe is partly enabled by outburst decay timescales and the presence of secondary outbursts (often seen in BH-LMXBs). However mass functions require photometric (or spectroscopic) binary periods and/or ellipsoidal modulation measures to constrain inclination and

primary masses. Alternatively, on these faint quiescent systems, spectroscopic measures of K2 and emission line widths can be used. These are in progress on several promising candidates, with more to come. Together with outburst Recurrence times and Duty Cycles being derived from DASCH data for X-ray discovered BH-LMXBs, this will constrain the BH-LMXB population in the Galaxy.

**Author(s):** Jonathan E Grindlay

**Institution(s):** Harvard University - CfA Contributing Team(s): DASCH Team

### **112.05D - Sowing black hole seeds: Direct collapse black hole formation and assembly with realistic Lyman-Werner radiation in cosmological simulations(Glenna Dunn)**

We study the birth and assembly of supermassive black holes from the direct collapse process and characterize the sites where these black hole seeds form. In the pre-reionization epoch, molecular hydrogen (H<sub>2</sub>) is an efficient coolant, causing gas to fragment and form Population III stars, but Lyman-Werner radiation can suppress H<sub>2</sub> formation and allow gas to collapse directly into a massive black hole. The critical flux required to inhibit H<sub>2</sub> formation,  $J_{\text{crit}}$ , is hotly debated, largely due to the uncertainties in the source radiation spectrum, H<sub>2</sub> self-shielding, and collisional dissociation rates. We test the power of the direct collapse model in a self-consistent, time-dependent, non-uniform Lyman-Werner radiation field using an updated version of the SPH+N-body tree code Gasoline with H<sub>2</sub> non-equilibrium abundance tracking, H<sub>2</sub> cooling, and a modern SPH implementation. We study how the parameter  $J_{\text{crit}}$  impacts the number of seed black holes and the type of galaxies which host them. We focus on black hole formation as a function of environment, halo mass, metallicity, and proximity to the Lyman-Werner source. We then use semi-analytic modeling to investigate the role of black hole spin and gravitational recoil in the redshift  $z=5$  massive black hole-host scaling relations and occupation fraction. We find that massive black hole seeds form more abundantly with lower  $J_{\text{crit}}$  thresholds, but regardless of  $J_{\text{crit}}$ , these seeds typically form in low-metallicity pockets of halos that have recently begun star formation. We further find that incorporation of gravitational recoil kicks more significantly affects the final MBH-host mass scaling relations than the occupation fraction, as host galaxies can be refilled repeatedly by later episodes of MBH formation.

**Author(s):** Jillian Bellovary, Glenna Dunn, Charlotte Christensen, Kelly Holley-Bockelmann, Thomas Quinn

**Institution(s):** Vanderbilt University, Queensborough Community College, Fisk University, Grinnell College, American Museum of Natural History, University of Washington

## **113 - Supernovae I**

### **113.01 - A He shell double detonation on a sub-Chandrasekhar mass white dwarf(Kishalay De)**

The detonation of a He shell on a white dwarf has been long proposed as an explosion triggering mechanism for Type Ia supernovae. Yet, there remain several issues in reconciling observations to the predicted light curves and spectra from these models, especially due to the effects of the 'ashes' of the overlying burned He shell. Here, we report the discovery of ZTF 18aaqasu (SN 2018byg), a peculiar Type Ia supernova discovered in the outskirts of an elliptical galaxy at  $z=0.066$ . With a rise time of 17 days, the transient reached a peak absolute magnitude of -18.2, exhibiting a light curve akin to sub-luminous (SN 1991bg-like) Type Ia supernovae. Spectroscopic follow-up starting from a week after explosion show that the transient exhibited blue continua at early times, superimposed with absorption features of Ti II and Fe group elements. Subsequent photospheric spectra taken near peak light exhibit prominent Si absorption features together with unusually red colors marked by nearly complete line blanketing of flux blue-wards of 5000 Angstrom. The source exhibited a fast transition to the nebular phase within 30 days after peak light, revealing evidence of a thermonuclear detonation event dominated by Fe-group nucleosynthesis. We show that the observed properties of ZTF 18aaqasu are consistent with the detonation of a massive (0.15 solar masses) He shell on a sub-Chandrasekhar mass (0.7 - 0.8 solar masses) white dwarf. These observations provide direct evidence of a likely rare class of Type Ia supernovae arising from detonations of massive He shells, in contrast to the broader population of Type Ia supernovae that are suggested to arise from thin He shell detonations or central ignitions.

**Author(s):** Abigail Polin, Lars Bildsten, Peter Nugent, Mansi Kasliwal, Kishalay De

**Institution(s):** California Institute of Technology, University of California, Santa Barbara, University of California, Berkeley Contributing Team(s): Zwicky Transient Facility (ZTF), Global Relay of Observatories Watching Transients Happen (GROWTH)

### **113.02 - The progenitor system of the peculiar white dwarf supernova 2012Z(Curtis McCully)**

Recently, observations and theoretical models have shown that not all thermonuclear white-dwarf supernovae (SNe) are normal type Ia SNe that can be used for cosmology. Type Iax SNe are one of the largest classes of "peculiar" cousins to SNe Ia. SNe Iax show similar elements to normal SNe Ia in their spectra, but have several distinguishing properties: low photospheric velocities, low luminosity given their light-curve shape, and late-time spectra dominated by permitted Fe-group elements rather than nebular features. 2012Z was one of the brightest and most nearby type Iax SNe to date. In deep HST pre-explosion imaging, we discovered a source that was consistent with the position of the SN. We interpreted this as the progenitor system, likely a white dwarf accreting from a helium star companion. To test this, we continued to observe SN 2012Z with HST and still detect the system nearly four years after explosion at an epoch when light from the supernova event should have faded away.

**Author(s):** Saurabh Jha, Griffin Hosseinzadeh, Dale Howell, Curtis McCully, Ryan Foley

**Institution(s):** Las Cumbres Observatory, Rutgers, The State University of New Jersey, University of California Santa Cruz, Harvard-Smithsonian Center for Astrophysics

### **113.03 - The Red Supergiant Progenitors of Two Nearby Recent Supernovae(Schuyler D. Van Dyk)**

We discuss the nature of the red supergiant (RSG) progenitors of the nearby Type II-Plateau (II-P) SN 2017eaw in NGC 6946 and SN 2018aoq in NGC 4151. The massive progenitors for both supernovae (SNe) were identified in archival pre-explosion Hubble Space Telescope (HST) image data, via HST Target-of-Opportunity imaging of the young SNe. The characterizations of the two progenitors were also aided by archival Spitzer Space Telescope observations. The two events appear to span the range of luminosity for SNe II-P. The progenitors themselves also lie near the two ends of the currently-known range of initial masses for RSGs terminating as SNe II-P. Support for HST programs GO-15151 and GO-14645 was provided by NASA through grants from STScI. Based in part on archival data obtained with the Spitzer Space Telescope, which is operated by JPL, Caltech, under a contract with NASA.

**Author(s):** Jennifer E. Andrews, Griffin Hosseinzadeh, Viktoriya Morozova, Alexei Filippenko, Dale Howell, Justyn R. Maund, Daichi Hiramatsu, Nathan Smith, Sundar Srinivasan, Thomas Brink, Dan Milisavljevic, WeiKang Zheng, Schuyler D. Van Dyk

**Institution(s):** California Institute of Technology, UC Berkeley, University of Arizona, Harvard University, LCO/UCSB, Purdue University, University of Sheffield, IRyA, UNAM, Princeton University Contributing Team(s): on behalf of a larger team

### **113.05 - Supernovae in the borderlands: Simulating the explosion of a low-mass supernova progenitor(Eric Lentz)**

Core collapse in stars at the lower range of massive stars (8-10  $M_{\odot}$ ) have different behaviors relative to more massive counterparts where relatively lengthy neutrino driven convection is required to relaunch the stalled bounce shock. We compute the collapse, bounce, and explosive revival of the supernova shock in a zero-metal 9.6  $M_{\odot}$  progenitor using the supernova neutrino radiation hydrodynamics code Chimera in 1D, 2D, and 3D. During collapse, about 100 ms before bounce, explosive burning ignites at the base of the silicon shell, generating a burning front that proceeds outward, while the iron-core continues to collapse and bounce. We examine the origins and impact of this front on the explosion dynamics. Like other supernovae in the borderlands between core collapse and white dwarf formation, the low density mantle around the core in this progenitor permits a rapid revival of the shock through neutrino heating. The launch of the explosion with cooler and

more neutron-rich material leads to the formation of rare neutron-rich isotopes like  $^{48}\text{Ca}$ , which we are able to track directly through the in situ use of a large (160-species) nuclear network for the ejected material.

**Author(s):** Anthony Mezzacappa, Stephen W. Bruenn, J. Austin Harris, William Raphael Hix, O. E. Bronson Messer, Eric Lentz, John M Blondin

**Institution(s):** University of Tennessee, Florida Atlantic University, Oak Ridge National Laboratory, North Carolina State University

### **113.06 - Testing explosion models with bulk properties of supernova remnants(Hector Martinez Rodriguez)**

Type Ia supernovae originate from the explosion of carbon-oxygen white dwarfs in binary systems, but the exact nature of their progenitors remains elusive. The bulk properties of Type Ia supernova remnants, such as the radius and the centroid energy of the Fe K $\alpha$  blend in the X-ray spectrum, are determined by the properties of the supernova ejecta and the ambient medium. We model the interaction between Chandrasekhar and sub-Chandrasekhar models for Type Ia supernovae ejecta and a range of uniform ambient medium densities in one dimension up to an age of 5000 years. We generate synthetic X-ray spectra from these supernova remnant models and compare their bulk properties at different expansion ages with X-ray observations from {Chandra} and {Suzaku}. We find that our models can successfully reproduce the bulk properties of most observed remnants, suggesting that Type Ia SN progenitors do not modify their surroundings significantly on scales of a few pc, although more detailed models are required to establish quantitative limits on the density of any such surrounding circumstellar material. Ambient medium density and expansion age are the main contributors to the diversity of the bulk properties in our models. Chandrasekhar and sub-Chandrasekhar progenitors make similar predictions for the bulk remnant properties, but detailed fits to X-ray spectra have the power to discriminate explosion energetics and progenitor scenarios.

**Author(s):** Patrick Slane, Shigehiro Nagataki, Daniel Patnaude, Adam Foster, Sangwook Park, Anthony Piro, Katie Auchettl, Shiu-Hang Lee, Hiroya Yamaguchi, Carlos Badenes, Eduardo Bravo, Hector Martinez Rodriguez

**Institution(s):** Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona, NASA Goddard Space Flight Center, University of Pittsburgh, E.T.S Arquitectura del Valles, Smithsonian Astrophysical Observatory, RIKEN, Astrophysical Big Bang Laboratory, Department

### **113.07 - Mechanism of the Unconfined Deflagration-to-Detonation Transition in Type Ia Supernovae(Alexei Poludnenko)**

The nature of stellar progenitors and the associated explosion mechanism of type Ia supernovae (SNIa) remains one of the

major open questions in astrophysics. Virtually all existing theoretical models require formation of a supersonic detonation wave capable of providing nearly complete combustion of the stellar material. The mechanism of detonation initiation in unconfined systems, such as the interior of a WD, remains poorly understood. Modern large-scale numerical models of SNIa are unable to capture detonation formation from first principles due to the extreme range of dynamical scales involved, and instead are forced to trigger detonations artificially. As a result, the time and location of the detonation initiation are free parameters present in all existing SNIa models. We present the general theory of turbulence-induced deflagration-to-detonation transition (tDDT) in unconfined systems. We use direct numerical simulations (DNS) of unconfined turbulent thermonuclear flames in a degenerate  $12C$  stellar plasma to show for the first time that under conditions representative of those in a SNIa explosion this tDDT mechanism can result in the spontaneous formation of strong shocks and subsequently detonation ignition. We also use the developed theory to determine the criteria for detonation initiation in the classical single-degenerate Chandrasekhar-mass model. We show that DDT can occur at densities in the range  $107 - 108 \text{ g/cm}^3$  with the maximum probability at  $\rho \approx 107.3 \text{ g/cm}^3$ . These results open path for the new generation of first-principles SNIa models, in which detonation initiation conditions can be determined self-consistently.

**Author(s):** Alexei Poludnenko, Brian Taylor, Vadim Gamezo, Kareem Ahmed, Jessica Chambers

**Institution(s):** Texas A&M University, Naval Research Laboratory, University of Central Florida, Air Force Research Laboratory

### 113.08 - The Expansion of the Young Supernova Remnant 0509-68.7 (N103B) (Brian J Williams)

We present a second epoch of *Chandra* observations of the Type Ia LMC SNR 0509-68.7 (N103B) obtained in 2017. When combined with the earlier observations from 1999, we have a 17.4-year baseline with which we can search for evidence of the remnant's expansion. Although the lack of strong point source detections makes absolute image alignment at the necessary accuracy impossible, we can measure the change in the diameter and the area of the remnant, and find that it has expanded by an average velocity of  $4170 (2860, 5450) \text{ km s}^{-1}$ . This supports the picture of this being a young remnant; this expansion velocity corresponds to an undecelerated age of 850 yr, making the real age somewhat younger, consistent with results from light echo studies. Previous infrared observations have revealed high densities in the western half of the remnant, likely from circumstellar material, so it is likely that the real expansion velocity is lower on that side of the remnant and higher on the eastern side. A similar scenario is seen in Kepler's SNR. N103B joins the rare class of Magellanic Cloud SNRs with measured proper motions.

**Author(s):** P. Frank Winkler, William Patrick Blair, Armin Rest, Brian J Williams, Robert Petre, John Raymond, Ravi Sankrit, Ivo R. Seitenzahl, Knox Long, Stephen Reynolds,

Kazimierz Borkowski, Parviz Ghavamian, Sean Hendrick  
**Institution(s):** Space Telescope Science Institute, North Carolina State University, NASA GSFC, Millersville University, Towson University, ANU, CfA, Middlebury University

### 113.04D - Revival of the Fittest: Exploding Core-Collapse Supernovae (David Vartanyan)

Massive stars at the end of their lifetimes undergo gravitational collapse and explode vigorously as core-collapse supernovae (CCSNe), enriching the interstellar medium and sourcing many of the heavy elements in the universe. In addition to hosting nucleosynthesis, these explosions revitalize ambient star formation, birth neutron stars, and produce gravitational waves. Yet the nature of successfully powering CCSNe, transforming stellar collapse to stellar explosion, has endured as a scientific mystery for over half a century. The favored mechanism for driving explosion is neutrino heating, wherein some small fraction of the neutrino energy is absorbed to revive the explosion. I employ FORNAX, a state-of-the-art hydrodynamics and radiative transfer code, to study this tenuously understood mechanism. In a series of recent multi-dimensional simulations, I explore the sensitive dependence of the outcome - explosion or dud - on the progenitor star structure, neutrino-matter microphysics, and macrophysical properties (e.g., rotation and velocity perturbations). I produce the first cutting-edge, full three-dimensional simulation of a CCSN progenitor, and find that our model explodes vigorously within 100 milliseconds and is estimated to accumulate energy at a rate of  $0.5 \text{ Bethe } (10^{51} \text{ erg})$  over 2 seconds. Because CCSNe produce gravitational waves and neutrinos in the first seconds of evolution, our results inform the study of these multi-messenger observational signatures as probes of the progenitor star and its explosion dynamics. Until recently, the field lacked high fidelity simulations that not only produced explosions, but produced robust explosions. Our work brings the field one step closer to this goal.

**Author(s):** David Vartanyan, Adam Burrows

**Institution(s):** Princeton University

### 114 - Brown Dwarfs and Planet Hosting Stars 114.01 - Ultraviolet Properties of a Large Flare on GJ 674 (Cynthia S. Froning)

As part of the Mega-MUSCLES HST Treasury Program, our team observed the exoplanet host star, GJ 674, in April of 2018. During seven orbits of HST ultraviolet spectroscopic observations with COS and STIS, GJ 674 exhibited several small flares and two large ones, the most energetic of which persisted over the entire COS orbit and has an integrated FUV (1070-1360 Å) flux of  $10^{30.8} \text{ erg}$ . The flare spectrum exhibits line emission from tracers of the stellar chromosphere (CII, CIII, SiII, SiIII, SiIV, NV) and corona (Fe XII, Fe XIX, Fe XXI). The flare spectrum is also distinguished by strong, blue continuum emission which can be fit by a blackbody with a brightness temperature of  $T_{\text{br}} = 40,000 \pm 10,000 \text{ K}$ . In this presentation,

we compare the flare UV properties to parameterizations of RHD models of chromospheric condensations and show how the flare constrains electron heating values and the development of flare layers in the chromospheres of M dwarf stars.

**Author(s):** Allison Youngblood, David Wilson, Kevin France, Cynthia S. Froning, Christian Schneider, Sarah Rugheimer, Adam Kowalski, R. Parke Loyd

**Institution(s):** University of Texas at Austin, University of Colorado, University of St Andrews, Goddard Space Flight Center, Arizona State University, University of Hamburg

#### **114.02 - Constraining the Radio Emission of TRAPPIST-1 and Implications for Planetary Habitability(Anna Hughes)**

TRAPPIST-1 is a late-type M dwarf with a system of seven terrestrial planets, at least three of which are in the habitable zone. Habitability is typically defined by the temperature range necessary to support liquid water, but additional factors like high energy radiation produced by magnetic processes can threaten surface life on surrounding planets under Earth-like conditions. M dwarf stars like TRAPPIST-1 are prone to strong magnetic fields, frequent flaring, and high levels of stellar activity. Testing for gyrosynchrotron emission, detectable at frequencies between 2 and 100 GHz, is one of the only ways to constrain the high energy particle flux incident on surrounding planets. We present 45 GHz and 97.5 GHz radio observations of TRAPPIST-1 using the VLA in the Q band and ALMA in Band 3, respectively. We use these results to constrain the radio flux densities, and place limits on the magnetic properties and outgoing high energy particle radiation from the star. While our results do not imply that the TRAPPIST-1 stellar environment must be suitable for life, we find no evidence that it is overtly unsuitable.

**Author(s):** Anna Hughes, Jacob White, Rachel Osten, Aaron Boley

**Institution(s):** University of British Columbia, Konkoly Observatory, Space Telescope Science Institute

#### **114.03 - Brown dwarfs below the Hydrogen burning limit and how to make them.(John C Forbes)**

The dividing line between brown dwarfs and stars has traditionally been a particular metallicity-dependent mass, the 'hydrogen burning limit,' around 0.07 solar masses. I will show how brown dwarfs may exceed this limit, making use of a simple analytic model and MESA simulations. I will review plausible formation channels for these objects, concluding that the most likely is via Roche Lobe overflow in binary brown dwarf systems. I will also discuss prospects for their discovery.

**Author(s):** John C Forbes, Abraham Loeb

**Institution(s):** Harvard University

#### **114.04 - A Volume-Limited Sample of L and T Dwarfs Defined by Parallaxes(William M J Best)**

As the lowest-mass objects created by star formation processes, brown dwarfs are essential to a complete understanding of the star formation history of our galaxy. To this end, a complete volume-limited sample of brown dwarfs in the solar neighborhood is critical for developing and testing formation theories. To create such a sample, we (1) conducted a wide-field (28,000 deg<sup>2</sup>) search using the Pan-STARRS1 and WISE surveys for brown dwarfs missed in previous surveys to complete the census, and (2) measured parallaxes for 348 L and T dwarfs using the wide-field infrared camera WFCAM on the United Kingdom Infrared Telescope (UKIRT) to reach well beyond the faint limit of Gaia, producing the largest single batch of parallaxes for brown dwarfs to date. We constructed a volume-limited sample of L-T dwarfs out to 25 pc, covering two-thirds of the sky (declinations -30° to +60°) and containing 350 members. Our sample contains four times more members than the previous most complete sample of L and T dwarfs and is defined entirely by parallaxes. We identified a distinct gap in the J-K color at the L/T transition, implying a phase of rapid atmospheric evolution whose  $T_{\text{eff}}$  (~1300 K) is in tension with model predictions. Using synthetic populations tied to our volume-limited sample, we calculated the most precise brown dwarf space density and luminosity function to date, and we place new constraints on the substellar initial mass function and formation history. Our volume-limited sample will continue to be a rich source of empirical constraints for studies of local brown dwarfs.

**Author(s):** Trent Dupuy, William M J Best, Eugene A Magnier, Michael C. Liu

**Institution(s):** University of Hawaii, Gemini Observatory, University of Texas  
**Contributing Team(s):** Pan-STARRS Builders

#### **114.05 - Resolving Brown Dwarf Binary Systems with HST(Denise C Stephens)**

With Gaia calculated distances to the brighter brown dwarfs, we can identify overluminous objects as potential unresolved binary systems. Many of these objects have been or may be observed in the future using the Hubble Space Telescope. With its easily reproducible point spread function, we can fit single and binary PSF functions to the archival HST data and determine the likelihood that a given object is in fact a binary system. We can then calculate the separation of the two components at the time of observation. In this poster we present some preliminary results and the technique we are using to try and identify these binaries.

**Author(s):** Denise C Stephens

**Institution(s):** Brigham Young University

#### **114.06 - Detecting Weather Patterns on Low-Gravity Brown Dwarfs(Johanna M Vos)**

Photometric variability monitoring is sensitive to atmospheric features as they rotate in and out of view, allowing us to probe the presence of features caused by inhomogeneous clouds and temperature fluctuations. Periodic variability has been detected in L and T brown dwarfs, and more recently in a small sample of free-floating, planetary-mass objects. These young, low-gravity objects share a striking resemblance with the directly-imaged planets and can be studied in far greater detail in the absence of a bright host star. The large amplitudes observed in this small sample of low-gravity objects suggests that variability may be enhanced for the exoplanet analogues. We have recently carried out the first large survey for weather patterns on low-gravity brown dwarfs and exoplanet analogues. I will present the results of this survey and discuss what we have learned about the role of surface gravity in variability properties.

**Author(s):** Wolfgang Brandner, Johanna M Vos, Ian Crossfield, Derek Homeier, Michael C. Liu, Joshua Schlieder, Mariangela Bonavita, Mickaël Bonnefoy, Esther Buenzlio, Taisiya Kopytova, Markus Janson, Jacqueline Radigan, William M J Best, Elena Manjavacas, Kately

**Institution(s):** Gemini OBservatory, oInstitute for Astronomy, ETH Zurich, Department of Astronomy/Steward Observatory, University of Arizona, Université Grenoble Alpes, Department of Physics, Massachusetts Institute for Technology, Max-Planck-Institut für Astronomie

#### **114.07 - Independent Masses for the Luhman 16AB Binary Brown Dwarf System from Gemini GEMS(Stephen Mark Ammons)**

We present the full astrometric orbit and barycentric motion of Luhman 16 AB and the first precision measurements of the individual component masses. We analyze archival observations spanning 31 years from the European Southern Observatory (ESO) Schmidt Telescope, the Deep Near-Infrared Survey of the Southern Sky (DENIS), public FORS2 data on the Very Large Telescope (VLT), and astrometry from the Gemini South Multiconjugate Adaptive Optics System (GeMS). With this new data sampling a full period of the orbit, we use a Markov chain Monte Carlo algorithm to fit a 16-parameter model incorporating mutual orbit and barycentric motion parameters and constrain the individual masses to be  $\{27.9\}^{+1.0}_{-1.1}$  {M}J for the T dwarf and  $\{34.2\}^{+1.1}_{-1.3}$  {M}J for the L dwarf. Our measurements of Luhman 16 AB's mass ratio and barycentric motion parameters are consistent with previous estimates in the literature. The GeMS-derived measurements of the Luhman 16 AB separation in 2014-2015 agree closely with Hubble Space Telescope (HST) measurements made during the same epoch, and the derived mutual orbit agrees with those measurements to within the HST uncertainties of 0.3-0.4 mas.

**Author(s):** Victor Garcia, Stephen Mark Ammons

**Institution(s):** Lawrence Livermore National Laboratory,

Tesla

#### **115 - Starburst Galaxies**

##### **115.01 - Clumpy Star-formation in Local Luminous Infrared Galaxies(Kirsten Larson)**

We present HST narrow-band imaging of Pa $\lambda$  and Pa $\lambda^2$  emission of 50 local Luminous Infrared Galaxies (LIRGs) from the Great Observatories All-Sky LIRG Survey (GOALS). These data allow us to study spatially resolved star forming regions and directly compare to star forming clumps found in both local and high-redshift galaxies. We find that in LIRGs, the star-forming clumps have sizes ranging from 90-900pc and star formation rates (SFRs) of .001 to 10 Msunyr $^{-1}$ , with median values of 170pc and 0.028 Msunyr $^{-1}$ . Not surprisingly, the detected star-forming regions are young with a median stellar age of  $8.5 \times 10^6$  yrs and they have a median stellar mass, as measured from the near-infrared continuum, of  $3 \times 10^5$  Msun. The SFRs of the clumps in local LIRGs nicely span the range of star formation rates found in normal local star forming galaxies to the clumps found in high-redshift star forming galaxies at  $z = 1-3$ . The luminosity function of the LIRG clumps has a flatter slope than found in lower-luminosity, star-forming galaxies, indicating a relative excess of luminous star-forming clumps. The LIRGs in our sample cover the entire merger sequence from isolated galaxies to advanced staged mergers and allow us to study how the size, number, luminosity, and distribution of the clumpy star formation varies with the galaxy's merger stage, mass, and global star formation rates.

**Author(s):** Tanio Diaz-Santos, Kirsten Larson, Lee Armus

**Institution(s):** California Institute of Technology, N cleo de Astronom a, Universidad Diego Portales, IPAC, California Institute of Technology Contributing Team(s): GOALS Team

##### **115.03 - Searching For Dusty Mergers In The FIR(Jillian Scudder)**

The Far-Infrared (FIR) gives a unique window into the star formation rates of high redshift, dusty galaxies, as it allows a vantage point into galaxies which would be heavily dust-obscured in the optical. Galaxies which are most luminous in the FIR are generally thought to be forming stars at a prodigious rate - young stars heat the dust within their host galaxy, which then reradiates in the FIR. Technical challenges abound, however, as even with a space-based telescope such as the Herschel Space Observatory, the resolution of the images returned is quite coarse. It is often assumed that a bright source in the FIR belongs to a single, highly star forming galaxy, but this is impossible to verify with low resolution images. In this talk I will discuss results from a statistical, multi-wavelength method of determining how many independent galaxies might be blended together in our FIR images, and what these results imply for our understanding of star formation and galaxy interactions in the earlier Universe.

**Author(s):** Seb Oliver, Jillian Scudder, Julie Wardlow, Lingyu Wang, Duncan Farrah, Peter Hurley

**Institution(s):** Oberlin College, Durham University, University of Sussex, SRON Netherlands Institute for Space Research, University of Hawaii, Data Javelin Contributing Team(s): Herschel Extragalactic Legacy Project

#### **115.04 - IC-10 3D: An IFS Survey of H II Regions in Local Starburst Galaxy IC-10(Maren Cosens)**

We present preliminary results from an integral field spectrograph survey of the entire central region of IC-10 using the W. M. Keck Observatory Keck Cosmic Web Imager (KCWI) at high-spectral resolution. IC-10 is our nearest local starburst galaxy with over 100 identified H II regions, allowing the study of low mass star forming regions at high spatial resolution. This survey will map IC-10 in two observing modes to sample the photometric, kinematic, and ionization properties of star forming regions across a wide H II region mass range. We will use a small slicer mode to obtain high spectral ( $R=18,000$ ) and spatial resolution (0.35" or 1.2 pc) data in order to study resolved kinematics of H II regions in IC-10, and the large slicer to obtain wide field of view (33" x 20.4") IFS data with broader wavelength coverage providing measurements of metallicity lines. IFS observations of ionized gas in hundreds of H II regions in IC-10 will provide a key local sample needed to constrain the size-luminosity scaling relationship of star forming regions. Employing the same IFS analysis methodology used at high-redshift will ensure a consistent comparison sample in the previously unexplored parameter space of small star forming regions (< 100pc). Velocity dispersion measurements of IC-10 H II regions will increase the available data allowing for robust investigation into the kinematic dependence of the star forming scaling relationships. At the completion of this survey we will be able to generate a 3D IFS data cube across the central region of IC-10 providing a unique legacy data set which will be made publicly available for auxiliary science.

**Author(s):** Shelley A. Wright, Gregory Walth, Andrey Vayner, James E. Larkin, Norman Murray, Maren Cosens, Lee Armus

**Institution(s):** University of California, San Diego, Carnegie Observatories, Center for Astrophysics and Space Sciences, UCSD, Canadian Institute for Theoretical Astrophysics, University of Toronto, Spitzer Science Center, California Institute of Technology, Univers

#### **115.05 - Multi-wavelength source reconstruction of gravitationally-lensed Planck-selected sub-mm galaxies(Patrick Kamieneski)**

At  $z > 1$ , a heavily dust-enshrouded population of star-forming galaxies may be observed. These submillimeter galaxies (SMGs) exhibit rapid conversion of gas into stars, with star formation rates reaching 100 - 1000  $M_{\odot}/\text{yr}$  or greater. To adequately understand the physical processes fueling this stellar mass buildup, a resolution better than 100 pc is essential, requiring  $\sim 10$  milliarcsec resolution for a  $z \sim 3$  object-unachievable with

any existing telescopes, except perhaps ALMA. In recent years, strong gravitational lensing has been used to the observer's advantage by circumventing these fundamental diffraction limits. We will present lens modeling results for a small subset of our sample of 28 Planck-selected lensed SMGs. In particular, we will apply our model to recent 6-GHz JVLA observations, combined with existing HST/WFC3 H160 imaging and ALMA CO(3-2)/dust continuum observations. Together, these observations probe the relative distribution of gas, dust, recent star formation, and existing stellar mass at high resolution. This, paired with CO spectral line kinematics, allows an initial interpretation of the galaxy structure and fueling of star formation for the SMGs in our sample. In particular, we will explore if the galaxies show signatures of an ongoing merger or an ordered rotating disk.

**Author(s):** Brenda Frye, Patrick Kamieneski, Min Yun, James D. Lowenthal, Daniel Wang, Kevin Harrington

**Institution(s):** University of Massachusetts Amherst, Max Planck Institut für Radioastronomie/Argelander Institut für Astronomie, Smith College, University of Arizona

#### **115.02D - Detailed studies of ACT gravitationally lensed dusty star-forming galaxies using NOEMA CO mapping and HST imaging(Jesus Rivera)**

Dusty star-forming galaxies (DSFGs) contribute significantly to the cosmic star-formation history of the universe, and are likely progenitors of nearby elliptical galaxies; however, they are challenging to study in detail, in part because their dusty nature makes them difficult to localize at optical wavelengths. Large-area surveys from far-infrared through millimeter wavelengths have proved to be effective at identifying DSFGs that are unusually bright, and thus easier to study, because they are highly gravitationally lensed. I will present new results on DSFGs selected from a survey of a 470 deg<sup>2</sup> equatorial field with the Atacama Cosmology Telescope (ACT), focusing on two systems with spatially resolved mapping of CO(3-2) emission from the Northern Extended Millimeter Array (NOEMA) as well as Hubble Space Telescope (HST) imaging. Lens modelling using a pixel-based algorithm that can be applied to multiple independent velocity channels yields source-plane reconstructions that support the characterization of the morphologies physical conditions, and kinematics of these extreme star-forming systems. I will also discuss the extent to which differential lensing affects the results of these analyses. This work has been supported by the National Science Foundation through grant AST-0955810 and by NASA through grant HST-GO-15160.001.

**Author(s):** Jesus Rivera

**Institution(s):** Rutgers, the State University of New Jersey

#### **116 - AGN Black Holes I: A New Hope**

**116.01 - Using Spectroscopic Signatures of Sub-parsec Supermassive Black Hole Binaries to Understand the Loudest GW Sources in the Universe(Khai Nguyen)**



Supermassive black hole binaries (SBHBs) are a natural product of galaxy evolution and the loudest gravitational wave (GW) sources in the universe. A lot of effort in this research area is presently devoted to observational searches for close SBHBs. Motivated by this, we have developed a method to model and interpret the spectroscopic signatures of sub-parsec SBHBs, which are direct progenitors of the GW binaries. The goals of this work are to determine the properties of these systems once a robust sample of binaries is available, and to test one of the leading models of binary accretion flows in the literature: a SBHB in a circumbinary disk. We model SBHB accretion flows as a set of three accretion disks: two mini-disks that are gravitationally bound to the individual black holes, and a circumbinary disk. Given a physically motivated parameter space occupied by sub-parsec SBHBs, we calculate a synthetic database of over 40 million optical broad emission-line profiles and explore the dependence of the profile shapes on characteristic properties of SBHBs. We find that the modeled profiles show distinct statistical properties as a function of the semi-major axis, mass ratio, eccentricity of the binary, and the degree of alignment of the triple-disk system. The profile shapes are a more sensitive measure of the binary orbital separation and the degree of alignment of the black hole mini-disks, and are less sensitive to the SBHB mass ratio and eccentricity. We also find that modeled profile shapes are more compatible with the observed sample of SBHB candidates than with our control sample of regular AGNs. Furthermore, if the observed sample of SBHBs is made up of genuine binaries, it must include compact systems with comparable masses, and misaligned mini-disks.

**Author(s):** Khai Nguyen, Tamara Bogdanovic, Michael Eracleous, Todd Boroson, Steinn Sigurdsson, Jessie Runnoe  
**Institution(s):** Georgia Institute of Technology, Pennsylvania State University, University of Michigan, Las Cumbres Observatory

#### **116.02 - Monsters on the move: A search for supermassive black holes undergoing gravitational wave recoil(Yashashree Jadhav)**

It has long been assumed that Active Galactic Nuclei (AGN) reside at the centers of their host galaxies, but is this really true? A galaxy merger is expected to lead to the formation of a supermassive black hole (SMBH) binary, which can shrink through dynamical processes until it eventually coalesces through the emission of gravitational waves. Such events fall outside the frequency range of the LIGO/VIRGO gravitational wave detectors and have not yet been detected through Pulsar timing arrays. However, numerical relativity simulations show that, depending on the initial spin-orbit configuration of the binary, the merged SMBH receives a gravitational recoil kick that may reach several 1000km/s. The kick causes the merged SMBH to oscillate for up to  $\sim 10^4$  Gyr in the gravitational potential well of the galaxy, during which, the recoiling SMBH may be observed as a “displaced” AGN. Displacements  $\sim 10$ -100pc may be expected even in nearby elliptical galaxies and can be measured as spatial offsets in high resolution

optical/infrared images. We present the results of a study of  $\sim 100$  early type active galaxies, in which isophotal analysis was conducted using Hubble Space Telescope archival and new optical/near-infrared images. We find evidence for significant spatial offsets between the position of the AGN and the photocenter of the galaxy in about 20% of the sample. We discuss our results in the context of the gravitational recoil hypothesis and also consider alternative displacement mechanisms. Establishing the distribution of displacement amplitudes of offset SMBH systems in the nearby universe will place constraints on the SMBH binary merger rate, galaxy merger rates and provide new insights into the interactions between SMBH and their host galaxies.

**Author(s):** Davide Lena, Bryanne McDonough, Andrew Robinson, Yashashree Jadhav  
**Institution(s):** Rochester Institute of Technology, SRON

#### **116.03 - Spectroscopic Tests Of The Bound, Binary Supermassive Black Hole Hypothesis For Quasars With Broad Balmer Lines With Single And Double Displaced Peaks(Michael Eracleous)**

Supermassive black hole binaries are a seemingly inevitable product of hierarchical galaxy evolution scenarios where galaxies and their supermassive black holes grow by mergers and accretion. Kiloparsec separation dual AGNs represent the early stages of this process. But the sub-parsec separation, bound binaries that are the late stages of the process have so far eluded observation. The detection of this population is important, because at the smallest separations they become bright sources of low-frequency gravitational waves. The efficiency with which binaries evolve to coalescence is critical for calculating gravitational wave event rates and can be determined by tracking the flow of systems through their evolutionary stages. Thus, we have undertaken a search for supermassive black hole binaries among two populations of quasars based on the hypothesis that one or both of the black holes are active and that the radial velocity curves of the broad emission lines trace orbital motion by analogy with single- or double-lined spectroscopic binary stars. Our search comprises a spectroscopic monitoring campaign to look for orbital motion in the radial velocity curves of the broad Balmer lines. The radial velocity curves for the “single-lined” candidates now include typically 3-4 epochs per object over a period of up to 12 years in the observer’s frame. From these we derive limits on the masses and separations of the hypothesized. These constraints do not yet allow us to rule out the binary hypothesis and we outline the necessary steps to making them more restrictive based on continued monitoring. We have also tested the scenario that quasars with broad, double-peaked Balmer lines represent “double-lined” candidates. For this test we used radial velocity curves spanning several decades, fitted them with elliptical orbit models, and employed an empirical prescription to describe radial velocity jitter. The resulting lower limits on the black hole masses are often unrealistically high, which leads us to disfavor this hypothesis for this subset of quasars.

**Author(s):** Jia Liu, Anh Nguyen Duy Doan, Jules Halpern, Helene M. L. G. Flohic, Tamara Bogdanovic, Michael Eracleous, Todd Boroson, Steinn Sigurdsson, Gavin Mathes, Jessie Runnoe

**Institution(s):** The Pennsylvania State University, Columbia University, The University of Michigan, Princeton University, Las Cumbres Observatory, New Mexico State University, University of the Pacific, Georgia Institute of Technology

#### **116.04 - The Accretion History of AGN: Supermassive Black Hole Population Synthesis Model(Tonima Tasnim Ananna)**

As matter accretes onto the central supermassive black holes in Active Galactic Nuclei (AGN), X-rays are emitted. We present a population synthesis model that accounts for the summed X-ray emission from growing black holes; modulo the efficiency of converting mass to X-rays, this is effectively a record of the accreted mass. We need this population synthesis model to reproduce observed constraints from X-ray surveys: the X-ray number counts, the observed fraction of Compton-thick AGN [ $\log(N_{\rm H}/\text{cm}^{-2}) > 24$ ] and the spectrum of the Cosmic X-ray "background" (CXB), after accounting for selection biases. Over the past decade, X-ray surveys by {XMM-Newton}, {Chandra}, {NuSTAR} and {Swift}-BAT have provided greatly improved observational constraints. We find that no existing X-ray luminosity function (XLF) consistently reproduces all these observations. We take the uncertainty in AGN spectra into account, and use a neural network to compute an XLF that fits all observed constraints, including observed Compton-thick number counts and fractions. This new population synthesis model suggests that, intrinsically, 50% (56%) of all AGN within  $z \leq 0.1$  ( $1.0$ ) are Compton-thick.

**Author(s):** Claudia Megan Urry, Johannes Buchner, Tonima Tasnim Ananna, Michael Tremmel, Allison Kirkpatrick, Ezequiel Treister, Claudio Ricci, Stephanie LaMassa

**Institution(s):** Yale University, Nucleo de Astronomia Universidad Diego Portales, Pontifical Catholic University of Chile, Space Telescope Science Institute

#### **116.05 - Intensive Accretion Disk Reverberation Mapping Using Swift and Ground-based Telescopes For Three Seyfert 1 Galaxies(Dale Mudd)**

Reverberation mapping has proved to be an invaluable technique to probe the innermost regions of active galactic nuclei by using temporal resolution in place of spatial resolution on these small physical scales. This has been primarily used to measure time delays of the emission lines in the broad line region and estimate supermassive black hole masses, but recently photometric reverberation mapping has also started providing insights into the accretion disk around the black hole as well. We will highlight results from ground-based campaigns targeting Mrk 509, NGC 4151, and NGC 4593

in the BVRI as well as ugriz filters. These objects were simultaneously monitored with The Neil Gehrels Swift Observatory. Combining these resources, these AGN have roughly daily photometry over the course of several months that spans X-rays through near-IR wavelengths in up to 15 bandpasses, with the UV and longer wavelengths covering approximately 1600-12000Å. From this, we measure wavelength-dependent time delays across the AGN accretion disk and provide new information on accretion disk sizes. These delays include contributions from the accretion disk itself, and from emission lines and diffuse continuum emission from the broad line region. We use new and archival Hubble Space Telescope spectra to determine the relative contributions of disk and BLR emission to each photometric bandpass and carry out simulations to estimate the time delays resulting from the accretion disk component alone.

**Author(s):** Aaron Barth, Thomas Schmidt, Diego Gonzalez Buitrago, Dale Mudd

**Institution(s):** University of California Irvine Contributing Team(s): Intensive AGN Accretion Disk Reverberation Mapping Project

#### **116.06 - The Cosmic Evolution of Relations between black hole mass and total galaxy stellar mass up to $z \sim 3$ (Hyewon Suh)**

A key unknown question is how black holes and their host galaxies establish such tight correlations in the local universe. We explore the evolution of relationship between black hole mass and host galaxy stellar mass out to  $z \sim 3$ , a critical epoch of growth of both black holes and galaxies, using a sample of  $\sim 100$  broad-line AGNs in the Chandra-COSMOS Legacy Survey. Thanks to the extensive multi-wavelength photometry available in the COSMOS field, we derive host stellar mass via a multi-component SED-fitting. The black hole masses are estimated via virial techniques using the broad H $\alpha$ , H $\beta$ , and MgII emission lines from the Keck/DEIMOS and Subaru/FMOS spectroscopy. We find that at a given total stellar mass, our sample of AGN host galaxies at  $1 < z < 3$  occupy a region below the inactive sample of local early-type galaxies in the M $_{\text{bh}}$ -M $_{\text{stellar}}$  plane. This indicates that AGN host galaxies beyond the local universe has a black hole-to-total stellar mass ratios that is lower by an order of magnitude, in contrast to the predictions of cosmological simulations that individual black holes tend to grow faster than their host galaxies. We also find that both the AGN luminosity and SFR generally increase towards the high stellar mass, while both the M $_{\text{stellar}}$  dependence is weaker towards the high-mass end, which could be interpreted as a consequence of quenching both the star formation and AGN activity in massive galaxies.

**Author(s):** Guenther Hasinger, Hyewon Suh, Francesca Maria Civano

**Institution(s):** Subaru Telescope, NAOJ, Harvard-Smithsonian CfA, ESA/ESAC

### **116.07 - Mapping Supermassive Black Hole Growth with SDSS-RM(Jonathan R. Trump)**

I will present the latest results from the pioneering new Sloan Digital Sky Survey Reverberation Mapping (SDSS-RM) project, the first multi-object reverberation mapping campaigns. Time-domain monitoring of quasars is the only way to directly measure black hole mass and accretion-disk structure beyond the local Universe. This makes reverberation mapping projects vital for measuring black hole demographics and growth over cosmic time. In contrast to the focused, single-object mode of reverberation mapping in past work, SDSS-RM has been simultaneously monitoring 850 quasars in spectroscopy and photometry since 2014. Already SDSS-RM has dramatically expanded the number of quasars with reliable black hole masses: doubling the total number and producing the first robust sample of black hole masses at  $z > 0.3$ . SDSS-RM will continue in the 2020s as the Black Hole Mapper key project of SDSS-V. I will also discuss how the photometric echo mapping of SDSS-RM is a pathfinder for LSST, paving the way for direct accretion-disk sizes of thousands of quasars.

**Author(s):** Keith Horne, Jonathan R. Trump, Neil Brandt, Yasaman Homayouni, Catherine Grier, Yue Shen

**Institution(s):** University of Connecticut, University of Illinois, University of Arizona, Penn State, St Andrews  
**Contributing Team(s):** SDSS-RM collaboration

### **117 - HAD II: Astronomical History: The Early Years**

#### **117.01 - The Significance of Zero in Hindu and Mayan Cosmologies(Aparna Venkatesan)**

The invention of the number zero in the cultures of India and central America had a profound impact not only on the development of mathematics, astronomy, and science worldwide, but on Hindu and Mayan worldviews and cultural practices. Here we present emerging results from our ongoing research on the independent invention of zero in Hindu and Mayan cultures, and how it shaped their cultural/spiritual perspectives. We suggest that the development of their complex calendars and unique cosmologies, involving timescales over many orders of magnitude and running up to billions or trillions of years, is intimately tied to the discovery of zero, and directly led to these cultures' distinctive sense of place and relation to an ever-evolving cyclic universe.

**Author(s):** Aparna Venkatesan, Sonali Verma, Isabel Hawkins

**Institution(s):** University of San Francisco, San Francisco Exploratorium  
**Contributing Team(s):** Aparna Venkatesan

#### **117.02 - Zodiacal Light: From Holy Light to False Dawn(George Latura)**

“As the voice spoke, all at once, a shaft of holy light bound together heaven and earth with its radiance.” (Euripides, Bakkhai, trans. Mueller, 2005, p. 216). In Euripides’ play (c.

405 BCE), Dionysus manifests a “‘holy light.’ Pindar links Dionysus to “‘the holy light at summer’s end’ (trans. Race, 1997, p. 381), which is best explained as the zodiacal light that is most visible at the equinox. Although Cassini is credited with the scientific discovery of the zodiacal light in Western Europe (c. 1680), this ethereal light had purportedly been known in ancient times by Egyptians, Phoenicians, and others (Gandz, 1943). The Egyptians worshipped the god Sopt, or Sopdu, “‘Lord of the East,’ as the embodiment of the zodiacal light. Sopt’s name was written with an upward-pointing triangle, the shape of the zodiacal light (Gandz, 1939). The use of the zodiacal light in the Egyptian solar cult was also proposed in a report in the ARCE Journal (Gary, Talcott, 2006), where it was seen as the herald of Ra returning from the underworld. A recent paper hypothesized that the zodiacal light might have been the astronomical component of the Mysteries of Eleusis that were celebrated near Athens for a thousand years (Latura, 2018). The Lesser Mysteries were held in the spring, while the Greater Mysteries took place in autumn (Milonas, 1961). The zodiacal light appears most prominently at the opposite equinoctial seasons (Kelley, Milone, 2005), which suggests cultic connections that were kept secret through oaths of silence (Latura, 2014). In Arabia, the zodiacal light was known at least since the time of Mohammed (c. 600 CE). Muslim tradition (hadith) refers to the zodiacal light as the “‘false dawn’ or “‘tail of the wolf’ due to its vertical shape, as opposed to the true dawn that appears horizontally. This information was important because, during the month of Ramadan, devout Muslims had to fast during the day, but could eat at night. Knowledge of the zodiacal light was necessary so that the faithful would know the correct time when eating stops and prayer begins: the true dawn. What cultural forces might have shaped the journey of the zodiacal light from holy light to false dawn?

**Author(s):** George Latura

**Institution(s):** independent researcher

#### **117.03 - Greek Development of the Stellar Magnitude System: A New Interpretation(Clifford Cunningham)**

A long-standing misinterpretation of a text by Hipparchus on stellar magnitudes leads to the conclusion Ptolemy employed two different systems to describe stellar brightness. The scale of 6 magnitudes employed by Ptolemy was based on Manilius’ Astronomicon (c. 10-20 CE), not that of Hipparchus as many modern texts claim. The numerical magnitudes Ptolemy incorporated in his star catalogue, published as part of the Almagest (c. 150CE), are at least partly his own, but descriptive magnitudes derive from Hipparchus; his work, in turn, owes its origin to Eudoxus. The inclusion of ‘dark stars’ in Ptolemy’s catalogue has been noted by a few scholars, but never explained; the lack of literature on such an important topic is extraordinary. ‘Dark star’ is an example of a descriptive magnitude that enters the work of Ptolemy from Eudoxus; the research presented here offers the first explanation of ‘dark stars’. The description of a particular small group of stars as dark and nebulous noted by Ptolemy is traced to its origin in a

Babylonian tablet that recorded astronomical information dating to the 12th century BCE, thus establishing for the first time a transmission of descriptive magnitudes spanning more than 1,200 years.

**Author(s):** Clifford Cunningham

**Institution(s):** University of Southern Queensland

#### **117.04 - Viking Sunstones for Celestial Navigation Were Certainly Not Crystals of Calcite or Cordierite(Bradley E. Schaefer)**

Viking sagas from medieval Iceland tell of a celestial navigation aid called a Sunstone, used to find the Sun's position on a cloudy day. No useful textual/archaeological/ethnographic evidence exists, so we do not know the nature of the Sunstones. In 1967, T. Ramskou speculated that the Sunstone was a crystal of calcite or cordierite, used to measure the direction of polarization in the sky, with this pattern pointing out the Sun's position. Singly scattered sunlight is polarization perpendicular to the Sun's direction. This is easily seen by holding a modern polarizing filter up to the eye and rotating it until the blue skylight is darkest to get the orientation. To test Ramskou's speculation, I have made extensive tests with many crystals, many configurations, and many cloud conditions, all throughout the North Atlantic around Iceland and Greenland. In practice, the basic crystals work poorly in perfectly blue skies, with it working better for anachronistic configurations involving pinholes. When the clouds allow only small holes of blue sky, the crystals fail. At the same time, in practice, the real position of the Sun is always obvious from simple naked eye observations, e.g., from seeing bright patches of sky, shadows on cloud edges, and crepuscular rays. With no blue patches of sky, the crystals fail, and even the polarizer filters fail. In cloud or fog conditions with no blue skies but broken or not-thick clouds, the position of the Sun is usually obvious from various light and dark areas in the sky or on the sea, albeit with only ~30° accuracy. If the clouds have no holes and are thick, then no method has any chance of working. I conclude that crystals can be used to determine the direction to the Sun only when the sky has large blue patches, in which case the position of the Sun is always easily seen directly. In cases with small blue patches or not-thick clouds, the crystals do not work, but visual examination of the sky will show the Sun's position with useable accuracy. No method works when the clouds are thick and non-broken. This is all to conclude that "Sunstones were not crystals".

**Author(s):** Bradley E. Schaefer

**Institution(s):** Louisiana State University

#### **117.05 - Disappearing the Milky Way in Medieval Europe(George Latura)**

Ancient astronomical knowledge of the Milky Way survived in medieval Western Europe through Martianus Capella's Marriage of Philology and Mercury and Macrobius'

Commentary on the Dream of Scipio (McCluskey, 1998). But these texts also transmitted a Platonist belief that ecclesiastical authorities found disturbing - the pagan belief that the celestial abode of virtuous souls was the Milky Way (according to Macrobius, Martianus Capella, Porphyry, Numenius, Manilius, Ovid, Cicero, and a student at Plato's Academy, Heraclides of Pontus). Twelfth-century Chartrian scholars who delved into related Platonist matters were censured, and at times, accused of heresy (Dutton, 2006; Ellard, 2007). Various strategies evolved to combat the perceived threat of the Platonist Milky Way. Michael Scot (c. 1225) hung the label "Demon Meridianus" on the Milky Way (Bertola, 2003; Harris, 2012) in an attempt to demonize it. Sacrobosco, whose *De Sphaera* was one of the most popular astronomical university texts of the era, ignored the Galaxy altogether (see Thorndike, 1949), as if it simply did not exist. But the most effective tactic would be provided by Plato's other student, Aristotle, who had removed the Milky Way from the heavens and placed it in the sublunary atmospheric region (*Meteorologica*, trans. Lee, 1916, pp. 57-63). Perusing Moerbeke's new translations of Aristotle's works from Greek (c. 1260), Aquinas adopted Aristotle as The Philosopher, displacing Plato from that lofty position. This coup introduced an anti-Platonism that lasted for centuries and that scholars still find difficult to comprehend (Hankins, 1996). The status of the Milky Way might provide a key to this puzzle. On the Platonist side, the Milky Way was a celestial phenomenon. On the Aristotelian side, it was an atmospheric phenomenon. How could this dilemma be resolved? Enter Galileo who, with his telescopic observations (*Sidereus Nuncius*, 1610), placed the Milky Way squarely among the stars.

**Author(s):** George Latura

**Institution(s):** independent researcher

#### **117.06 - The Confluence of Some Ideas Used by Copernicus in De Revolutionibus(Kevin Krisciunas)**

Copernicus (1473-1543) first became familiar with ancient Grecoastronomy via the *Epitome of Ptolemy's Almagest* by Georg Peurbach and Regiomontanus (ca. 1463); the full translation of the *Almagest* was published in Venice in 1515. The *Almagest* had been translated into Latin by Gerard of Cremona and Galibthe Mozarab. This was completed in Toledo about 1175. How do we know this? From an eyewitness account by the Englishman Daniel of Morley. Copernicus's great book contains a diagram almost identical to one in a work of Nasir al-Din al-Tusi (1201-1274), the founder of the Maragha Observatory. Copernicus also uses a lemma attributed to a second astronomer who worked in Maragha, Mu'ayyad al-Din al-Urdi (d. 1266). There is evidence that the insights of the Maragha school became known in Byzantium thanks in part to the efforts of Gregory Chioniadēs (ca. 1240-1320). Copernicus's model of the motion of the Moon is identical to that of Ibn al-Shatir (1304-1375). How much Copernicus's model of the motion of Mercury is similar to that of Ibn al-Shatir is controversial. Recent investigations concerning the Jewish scholar Moses Galeano, who lived in Constantinople, Crete, and the Veneto, lend credence to the notion that the insights of the Maragha school

reached Padua in the years 1497 to 1502 thanks to Galeano. This overlaps the very years that Copernicus studied astronomy in Padua. Thus, we now understand how some of the building blocks used by Copernicus were obtained by his teachers or directly by him.

**Author(s):** Kevin Krisciunas

**Institution(s):** Texas A&M University

#### **117.07 - The Path to Newton: An Interactive Infographic (Alyssa Ann Goodman)**

"The Path to Newton" is a new interactive infographic designed to tell the backstory of how the findings and ideas of observers, natural philosophers and scientists interacted in order to ultimately permit Newton to make his theory of gravity. The graphic includes images (and hyperlinked profiles) of dozens of scientists and their scholarly works, and it shows the linkages between their ideas. Some ideas are called out as steps "toward" Newton, and others as less helpful. The work was motivated by a new online edX educational resource, PredictionX (see [predictionx.org](http://predictionx.org)) that covers the history of how humans have predicted their futures, from Ancient Babylonian times up to the present. The central piece of PredictionX focuses on the evolution from detailed observations and record keeping (e.g. in Ancient Mesopotamia or Egypt) to empirically-based mathematical explanations (e.g. Ptolemy or Kepler) to truly physical, predictive, theory (Newton). In addition to calling out individuals and their ideas, the piece also highlights evolution in mathematics and instrumentation that allowed for progress along the path. The Path to Newton crosses through many cultures and regions, starting in Ancient Mesopotamia, traversing Ancient Egypt and Greece, then India and the Islamic world, and then finally Europe. While the piece was originally intended to be experienced online, as its elements are linked to rich background material, it makes a fabulous large-format printed poster, which will be displayed at the American Astronomical Meeting.

**Author(s):** Alyssa Ann Goodman, Jais Brohinsky, Katie Peek, Drew Lichtenstein

**Institution(s):** Harvard University, Freelance Designer, Radcliffe Institute for Advanced Study

#### **117.08 - William Herschel's universe as illustrated through his studies of comets and the Moon (Woodruff Sullivan)**

The remarkable astronomical career of William Herschel (1738-1822) is too often characterized as simply that he (1) discovered Uranus, (2) made big telescopes, and (3) cataloged star clusters and nebulae. But he did far more, and in this talk I will argue that, for example, his detailed observations and interpretations of several major comets and of the Moon illustrate virtually all aspects of the cosmos as he understood it. Herschel's unified universe was teleological, ordered, and ubiquitously inhabited. These principles, when combined with his

indefatigable decades of observation, led him to two more fundamental properties of the universe: it was active and changing, and vastly extended in time and space. With his unifying concept of a planet (meaning something much broader than today's definition), he brought together almost all of the objects and phenomena that he observed inside and outside the solar system.

**Author(s):** Woodruff Sullivan

**Institution(s):** University of Washington, Seattle

#### **117.09 - Explaining Algol: Eclipses or Spots? (Linda French)**

On 12 November 1782, 18-year-old John Goodricke was astonished to find the star Algol (Beta Persei) more than a magnitude fainter than usual. He wrote in his journal: "This night I looked at Beta Persei and was much surprised [sic] to find its brightness altered-It now appears of about the 4th magnitude" | I observed it diligently for about an hour-I hardly believed that it changed its brightness because I never heard of any star varying so quickly in its brightness. I thought it might perhaps be owing to an optical illusion, a defect in my eyes, or bad air, but the sequel will show that its change is true and that I was not mistaken." (Goodricke Journal) Goodricke and his friend and mentor Edward Pigott were searching for variable stars. In their time, only Mira (Omicron Ceti) had been well studied. Mira's known period of variation of approximately 11 months explains Goodricke's surprise at a star varying over a period of hours. The two went on to determine a time between dimming episodes of 2 days 20 hours, and 49 seconds. In his report, Goodricke concluded: "I should imagine [Algol's variation] could hardly be accounted for otherwise than either by the interposition of a large body revolving round Algol, or some kind of motion of its own, whereby part of its body, covered with spots or such like matter, is periodically turned towards the Earth." (Goodricke, Phil. Trans.) Through spectroscopy, Vogel (1889) was able to show that Algol is a true binary star. In the time of Goodricke and Pigott, spectroscopy was not available, and no stars had yet been confirmed to be binaries. Astronomers had seen sunspots, however, and so the spot hypothesis gained favor. The circumstances surrounding the discovery of Algol's variation, its announcement to the scientific community (including a report read by William Herschel in a pub!), and the evolution of the accepted hypotheses to explain the variation will be discussed.

**Author(s):** Linda French

**Institution(s):** Illinois Wesleyan University

#### **118 - Plenary Prize Lecture: Dannie Heineman Prize: The Dawn of Gravitational Wave Astrophysics, Vicky Kalogera (Northwestern University)**

**118.01 - The Dawn of Gravitational Wave Astrophysics (Vasiliki Kalogera)**

The detection of gravitational waves by ground-based interferometric detectors has by now revealed a previously unobserved population of merging black holes and has firmly linked the mergers of neutron stars with gamma-ray bursts and heavy element production. I will summarize the most current gravitational-wave discoveries, the measured physical properties of the compact objects involved and how these measurements enable us to probe the astrophysics of compact objects, constrain models of massive-star evolution. I will conclude with our near-term and long-term expectations for further discoveries as the sensitivity of detectors continues to improve.

**Author(s):** Vasiliki Kalogera

**Institution(s):** Northwestern U

## **121 - Beyond Photons: Astronomy in the Multi-messenger Era**

### **121.01 - Supermassive black-hole demographics in the era of multi-messenger nanohertz gravitational-wave astronomy(Stephen Taylor)**

Supermassive black holes lurk at the centers of massive galaxies, and are themselves the most massive compact objects in the Universe. Over cosmic time, galaxies grow through accretion and mergers, such that in the post-merger phase they harbor two supermassive black holes that spiral toward coalescence through a variety of dynamical processes. The subset of these with 10<sup>8</sup> - 10<sup>10</sup> solar masses and orbital periods of several years form the target population for pulsar-timing array (PTA) experiments such as the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). PTAs search for nanohertz gravitational-wave signals through induced Doppler shifts to the arrival rate of radio-pulses from millisecond pulsars. Many candidate binaries have been found through traditional electromagnetic means, although the only system with confidently detected multiple radio cores is too widely separated for PTAs to detect. Likewise, the quasi-variability of AGN in various photometric surveys (e.g. CRTS, PTF, and PanSTARRS) has produced many candidates, but none whose variability is unambiguously tied to the presence of a binary. I will review current efforts to find binary supermassive black holes through PTA searches and targeted multi-messenger campaigns, then discuss what current constraints and future detections can unveil about massive black hole demographics and the growth of galaxies.

**Author(s):** Stephen Taylor,

**Institution(s):** California Institute of Technology, Jet Propulsion Laboratory  
Contributing Team(s): NANOGrav Physics Frontier Center

### **121.02 - Supermassive black hole binaries in the era of multi-messenger astrophysics(Tamara Bogdanovic)**

Supermassive black hole binaries (SMBHBs) are a product of galaxy mergers and progenitors of coalescing binaries, considered to be the prime sources for future gravitational wave (GW) detectors. Expectations for detection of gravitational

radiation from SMBHBs have recently been raised by the success of the Laser Interferometer Gravitational-Wave Observatory, by the increasing sensitivity of the Pulsar Timing Arrays, and by selection of the Laser Interferometer Space Antenna for a large-class mission in the European Space Agency science program. In light of these developments, the rates at which SMBHBs form and evolve to coalescence remain important open questions in black hole astrophysics. Presently, the best avenue to address them is through electromagnetic observations and theoretical modeling. I will discuss how recent and anticipated advances in multi-messenger observational searches and modeling can help us to piece together the evolution of SMBHBs from galactic mergers all the way to the GW regime.

**Author(s):** Tamara Bogdanovic

**Institution(s):** Georgia Institute of Technology

### **121.03 - Future Prospects for Multimessenger Astrophysics with Supermassive Black Holes(Jonathan R. Trump)**

Future Prospects for Multimessenger Astrophysics with Supermassive Black HolesThe next two decades are bright for pushing the boundary of multimessenger astrophysics from stellar sources to supermassive black holes (SMBHs). As pulsar timing arrays (PTAs) build up signal and start to reach the (expected) low-frequency gravitational wave background, several new surveys and observatories will open the way to electromagnetic detection of the same close-separation supermassive black holes. This begins in the early 2020s with the Large Synoptic Survey Telescope (LSST) in time-domain photometry and the SDSS-V Black Hole Mapper (SDSS-V/BHM) project in time-domain spectroscopy. I will present simulated lightcurve observations of both experiments, demonstrating how the random (red-noise) variability of quasars can mimic periodic variability, and forecasting the number and parameter space of PTA+LSST multimessenger detections. Going further into the future LISA era of gravitational wave detection, I will briefly discuss how future optical (Maunakea Spectroscopic Explorer), X-ray (Lynx), and radio (ngVLA) observatories will contribute to a comprehensive multimessenger view of supermassive black hole growth and demographics.

**Author(s):** Jonathan R. Trump

**Institution(s):** University of Connecticut

### **121.04 - Cosmic Accelerators: Gamma Rays and Neutrinos(Regina Caputo)**

On September 22, 2017, the IceCube Neutrino Observatory and the Large Area Telescope (LAT) on board the Fermi Gamma-ray Space Telescope observed for the first time for an extremely high-energy neutrino (IceCube-170922) in spatial and temporal coincidence with a gamma-ray flaring blazar, TXS 0506+056. Following the original IceCube alert, the source has been

observed by several telescopes across the electromagnetic spectrum. The LAT reported an increase of the source's gamma-ray flux by a factor of ~6 compared to its average state. Emission of very high-energy gamma-ray emission was then observed by MAGIC observations. Triggered by these detections, archival IceCube events, as well as multimessenger data have been analyzed in order to better understand the physics and the time-evolution of this blazar. In my talk I will report on these observations and the implications for future multimessenger observations.

**Author(s):** Regina Caputo

**Institution(s):** NASA/GSFC Contributing Team(s): Fermi-LAT Collaboration

## **122 - Know Your Power: Understanding the Distribution of Power throughout the Academic Ecosystem**

### **122.01 - The Know Your Power Project(KeShawn Ivory)**

The Know Your Power (KYP) Project seeks to identify the types of power accessible to astronomers at each stage of the academic path. By focusing our attention on the many paths toward positive change as well as our collective knowledge, this project hopes to a) provide a list of concrete actions for creating inclusive spaces and b) lay the groundwork for sustainable collaboration with regard to equity and inclusion. In this Special Session, I will participate in a panel of astronomers and professionals at various career stages about the power we find accessible at our current and previous positions. The organizers will then facilitate small group discussions about understanding one's own power, how to hold oneself accountable, and how we can work together as a community to achieve our goals. Throughout the Special Session, organizers will consolidate the proposed ideas and later publish them in the KYP Living Document (<https://tinyurl.com/ybpsxkpm>).

**Author(s):** KeShawn Ivory

**Institution(s):** Rice University

**Dara Norman**

**Author(s):**

**Institution(s):**

## **I. Introduction + Context**

**Author(s):**

**Institution(s):**

## **II. Panel**

**Author(s):**

**Institution(s):**

## **III. Group Discussion**

**Author(s):**

**Institution(s):**

## **IV. Regroup + Review**

**Author(s):**

**Institution(s):**

**Lia Corrales**

**Author(s):**

**Institution(s):**

**Sinclair Manning**

**Author(s):**

**Institution(s):**

## **123 - Extrasolar Planets: Characterization & Theory Track 1: II. Measurements and Models of Giant Planet Atmospheres B**

### **123.01 - Taking the Temperature of a Lava Planet(Laura Kreidberg)**

We present new Spitzer observations of the thermal phase curve of K2-141b, an ultra-short period terrestrial planet (USP). With an orbit of just 6.7 hours, this world is blasted with stellar radiation that is expected to obliterate any traces of a primordial atmosphere and melt the dayside surface into a lava ocean. Previous observations of USPs have yielded several surprising results, including the measurement of an offset hotspot in the thermal phase curve of 55 Cancri e, which may indicate a thick atmosphere has survived, and a high Bond albedo for Kepler-10b, which suggests the presence of unusually reflective lava on its surface. K2-141b provides a unique benchmark for comparison with these other systems because it is the only USP with phase curve measurements in the optical (from K2) and infrared (from Spitzer). These observations can therefore break the degeneracy between signatures of reflected light and atmospheric circulation, shedding new light on the nature of atmospheres on USPs.

**Author(s):** Luca Malavolta, Roxana Lupu, Laura Kreidberg, Nicolas Cowan, Kevin Stevenson, Tom Loudon  
**Institution(s):** Harvard University, University of Padova, McGill University, NASA Ames Research Center, University of Warwick, Space Telescope Science Institute

### **123.03 - The Universal Presence of Nightside Clouds in Spitzer Phase Curve Observations of Hot Jupiters(Thomas Beatty)**

We recently observed two full orbital phase curves of the 27 MJ transiting brown dwarf KELT-1b using the Spitzer Space Telescope. Both the day-night temperature contrasts and the hotspot offsets we measure for KELT-1b are in line with the trends seen by Spitzer in lower mass hot Jupiters, despite the fact that KELT-1b should have an atmospheric advective timescale substantially longer than in a typical hot Jupiter at Spitzer wavelengths. We therefore suggest that nightside clouds are playing a noticeable role in modulating the thermal emission from all hot Jupiters, based on these observations and: 1) the lack of a clear trend in phase offsets with equilibrium temperature, 2) the sharp day-night transitions needed to have non-negative intensity maps, 3) the fact that all the nightsides of these objects appear to be at roughly the same temperature of 1050K, while the dayside temperatures increase linearly with equilibrium temperature, and 4) the trajectories of these objects on a Spitzer color-magnitude-diagram, which show colors explainable via nightside clouds.

**Author(s):** Thomas Beatty, Adam P Showman, B. Scott Gaudi, Jonathan Fortney, Knicole Colon, Mark Marley  
**Institution(s):** University of Arizona, Ohio State University, NASA Ames, UC Santa Cruz, NASA Goddard

### **123.04 - The effect of disequilibrium carbon chemistry on the atmospheric circulation and phase curves of hot Jupiters(Maria E Steinrueck)**

On hot Jupiter exoplanets, strong horizontal and vertical winds are expected to homogenize the abundances of the important absorbers CH<sub>4</sub> and CO much faster than chemical reactions can restore chemical equilibrium. This effect is called quenching and is typically neglected in general circulation models (GCMs). Quenching of CH<sub>4</sub> and CO has been suggested as explanation for discrepancies between observed infrared lightcurves and those predicted by GCMs: On the nightsides of several hot Jupiters, GCMs predict outgoing fluxes that are too large, especially in the Spitzer 4.5 microns band. We modified the SPARC/MITgcm to mimic quenching of CH<sub>4</sub>, CO and H<sub>2</sub>O by assuming that the CH<sub>4</sub>/CO ratio is constant throughout the simulation domain. The water abundance is adjusted accordingly, such that the total number of oxygen atoms is conserved. We ran simulations of hot Jupiter HD 189733b with 8 CH<sub>4</sub>/CO ratios ranging from 0.001 to 100. In the more likely CO-dominated regime, we find temperature changes around 50 K compared to the equilibrium chemistry case across large

regions and higher temperature changes in very localized regions. In the CH<sub>4</sub>-dominated regime, which is less favored by chemical kinetics models, temperature changes are even larger. This effect is large enough to affect predicted emission spectra and should thus be included in GCMs of hot Jupiters with equilibrium temperatures below roughly 1300 K. Furthermore, we find that spectra in regions with strong methane absorption, including the Spitzer 3.6 and 8 micron bands, are strongly impacted by disequilibrium abundances. We expect chemical quenching to result in much larger nightside fluxes in the 3.6 micron band, in stark contrast to observations. Meanwhile, we find almost no effect on predicted observations in the 4.5 micron band, as the opacity changes due to CO and H<sub>2</sub>O offset each other. We thus conclude that disequilibrium carbon chemistry cannot explain the observed low nightside fluxes in the 4.5 micron band. Other effects, for example, night side clouds, must be responsible for the observed shape of the phase curve.

**Author(s):** Maria E Steinrueck, Adam P Showman, Vivien Parmentier, Roxana Lupu, Joshua Lothringer  
**Institution(s):** University of Arizona, BAER Institute/NASA Ames Research Center, University of Oxford

### **123.05 - A Spitzer Phase Curve of the Warm Neptune GJ 436b(Kevin Stevenson)**

GJ 436b is a ~770 K planet on a slightly eccentric 2.64 day orbit and is currently the only warm Neptune with a definitive thermal emission constraint. With the successful launch of the James Webb Space Telescope (JWST), guaranteed time observations will obtain its thermal emission spectrum and establish GJ 436b as a benchmark object for the population of Neptune-size planets that are currently being discovered by TESS and likely to be characterized by JWST in the coming years. We will present results from a full-orbit phase curve observation of GJ 436b using the Spitzer Space Telescope at 3.6 microns. Specifically, by combining the measured nightside fluxes at 3.6 and 8.0 microns, we will discuss constraints on the planet's tidal heating and metallicity. We will also revisit the existence of a previously-reported sub-Earth-size planet candidate within the system.

**Author(s):** Nikole Lewis, Ian Crossfield, Adam P Showman, Michael R. Line, Caroline Morley, Jonathan Fortney, Kevin Stevenson, Vivien Parmentier  
**Institution(s):** Space Telescope Science Institute, University of Oxford, MIT, UC Santa Cruz, Cornell University, Arizona State University, University of Arizona, University of Texas at Austin

### **123.07 - Investigating three-dimensional cloud properties of a nine hot Jupiter sample(Tiffany Kataria)**

Observations of hot Jupiters have shown that clouds and hazes are ubiquitous in their atmospheres, but the properties of these



clouds vary significantly from planet to planet. Three-dimensional general circulation models (GCMs) for these planets show that the circulation and temperature structure, both of which influence cloud formation and transport, varies as a function of planet radius, gravity, orbital period, and equilibrium temperature. However, which of these most strongly influence cloud formation in hot Jupiters has been largely unexplored over a systematic sample. Here we utilize previous 3D GCM results of a nine-planet hot Jupiter sample to produce 3D cloud maps using a simplified cloud scheme. We examine trends in cloud types and cloud distributions that arise from differences in each planet's physical properties, and explore how they influence the pressures probed by spectroscopy. We utilize our GCM results to derive "cloudy" transmission spectra in 1D (spatially-averaged) and 3D that we compare to existing Hubble and Spitzer Space Telescope data. In doing so, we can assess the degree to which considering the 3D structure is necessary to interpret these and future observations. We also highlight the differences in cloud properties between leading and trailing limbs, each of which contribute equally to a planet's overall transmission spectrum, but can exhibit different spectral signatures. These and future analyses will have large implications for the cloud properties that can be explored with future facilities, such as the James Webb Space Telescope.

**Author(s):** David Sing, Hannah R Wakeford, Natasha E Batalha, Tiffany Kataria, Nikole K Lewis, Heather Knutson, Jonathan Fortney

**Institution(s):** JPL/Caltech, UCSC, Space Telescope Science Institute, Cornell University, California Institute of Technology, Johns Hopkins University

### **123.02D - A Uniform Analysis of Exoplanet Atmosphere Spectra Observed by HST WFC3 Is Consistent with Watery Worlds(Christina L Hedges)**

Archival data can provide a wealth of new information when revisited, either by utilizing new and updated analysis techniques, or by using the archive as a whole for a uniform analysis. The Hubble Space Telescope has provided the community with more than 1500 orbits observing exoplanet atmospheres with IR instrument Wide Field Camera 3, generating a diverse and valuable archive. These observations have been used to show robust detections of water absorption in the upper atmospheres of hot Jupiters. In my recent PhD dissertation I use this archival HST data with updated techniques to make new inferences, and intercompare exoplanet atmospheres of hot Jupiters. As part of my PhD I developed routines for uniformly reducing and analyzing this dataset. As part of this analysis I found robust evidence that the HST archive shows evidence of water across a variety of planet types, consistent with simple theoretical models. In this talk I will discuss the results of this intercomparison, how to access this software, and future directions for this work. I will also discuss preliminary results from my new HST program to investigate the atmosphere of exoplanet GJ 9827b, a small planet on the rocky/gaseous boundary orbiting a nearby M star.

**Author(s):** Christina L Hedges, Simon Hodgkin

**Institution(s):** NASA Ames, Institute of Astronomy, University of Cambridge, Bay Area Environmental Research Institute

### **123.06D - New Avenues in Atmospheric Modelling of Exoplanets(Siddharth Gandhi)**

In this thesis I explore various aspects of atmospheric characterisation of exoplanets with the primary goal of understanding their chemical compositions and physical processes. My research led to the development of new self-consistent models of exoplanetary atmospheres, a new paradigm for atmospheric retrievals of thermal emission spectra, as well as chemical detections using both high-resolution doppler spectroscopy as well as low-resolution transit spectroscopy. We are entering the era of high-precision and high-resolution spectroscopy of exoplanets. Such observations require robust self-consistent spectral models custom-built for exoplanets incorporating state-of-the-art numerical methods, opacities and conditions not seen in the solar system. I discuss a new self-consistent atmospheric modelling code, GENESIS, which models radiative-convective and chemical equilibrium atmospheres of exoplanets. I investigate models of irradiated and non-irradiated planets over a range of C/O ratios and metallicities to determine the spectra and P-T profiles of such objects. I also built a new hybrid retrieval code, HyDRA, capable of analysing the dayside atmosphere of hot Jupiters from spectral observations. Such a code was necessitated through the high precision observations available in recent years. This retrieval model was coupled to GENESIS to investigate deviation from chemical and radiative-convective equilibrium processes. This has also been used to detect H<sub>2</sub>O in the atmospheres of several hot Jupiters, as well as the first detections of TiO, CO and Li in the atmospheres of WASP-19b, WASP-18b and WASP-127b respectively. Finally, I have used the GENESIS model to enable chemical detections of molecular species using high resolution Doppler spectroscopy of hot Jupiters. I generated high resolution emission spectra of the hot Jupiter HD209458b for cross correlation with the data obtained with the VLT CRIRES spectrograph. This helped us find evidence for H<sub>2</sub>O, CO and HCN in the atmosphere. Such model spectra are vital given that the era of high resolution spectroscopy will lead to more detailed abundance constraints and atmospheric detections in the future.

**Author(s):** Siddharth Gandhi

**Institution(s):** University of Cambridge

### **124 - Extrasolar Planets: Characterization & Theory Track 2: IV. Giant Planet Formation and Evolution**

#### **124.01 - The hot Jupiter period-mass distribution as a signature of in situ formation(Elizabeth Bailey)**

More than two decades after the widespread detection of Jovian-class planets on short-period orbits around other stars,

their dynamical origins remain imperfectly understood. In the traditional narrative, these highly irradiated giant planets, like Jupiter and Saturn, are envisioned to have formed at large stello-centric distances and to have subsequently undergone large-scale orbital decay. Conversely, more recent models propose that a large fraction of hot Jupiters could have formed via rapid gas accretion in their current orbital neighborhood. In this study, we examine the period-mass distribution of close-in giant planets, and demonstrate that the inner boundary of this population conforms to the expectations of the in-situ formation scenario. Specifically, we show that if conglomeration unfolds close to the disk's inner edge, the semi-major axis - mass relation of the emergent planets should follow a power law  $a \propto M^{-2/7}$  - a trend clearly reflected in the data. We further discuss corrections to this relationship due to tidal decay of planetary orbits. Although our findings do not discount orbital migration as an active physical process, they suggest that the characteristic range of orbital migration experienced by giant planets is limited.

**Author(s):** Elizabeth Bailey, Konstantin Batygin  
**Institution(s):** Caltech

#### **124.02 - Atmospheric mass loss due to giant impacts: the importance of the thermal component for hydrogen-helium envelopes(John Biersteker)**

The Kepler mission revealed an abundance of planets intermediate in size between Earth and Neptune with orbital periods  $<100$  days and hydrogen-helium (H/He) envelopes comprising several percent of the planet's mass. Systems of these close-in super-Earths display striking diversity in planetary bulk density. Giant impacts are expected to play a role in the formation of many of these worlds. Previous works, focused on the mechanical shock caused by a giant impact, have shown that these impacts can eject large fractions of the planetary envelope, offering a partial explanation for the observed spread in exoplanet densities. Here, we examine the thermal consequences of giant impacts, and show that the atmospheric loss caused by these effects can significantly exceed that caused by mechanical shocks for H/He envelopes. During a giant impact, part of the impact energy is converted into thermal energy, heating the rocky core and envelope. We find that the ensuing thermal expansion of the envelope can lead to a period of sustained, rapid mass loss through a Parker wind, resulting in the partial or complete erosion of the H/He envelope. The fraction of the envelope mass lost depends on the planet's orbital distance from its host star and its initial thermal state, and hence age. Planets closer to their host stars and younger planets, which have rocky cores which are still hot and molten from formation, are more susceptible to impact-triggered thermal atmospheric loss. This is especially interesting because giant impacts are expected to occur early, 10-100 Myr after formation. For planets where the thermal energy of the core is much greater than the envelope energy (envelope mass fractions roughly  $<8\%$ ) the impactor mass required for significant atmospheric removal is  $M_{\text{imp}}/M_p \approx 1/4$  to 0.1, approximately the ratio of the heat capacities of the

envelope and core. For larger envelope mass fractions, complete loss can occur when the impactor mass is comparable to the envelope mass. Because of their stochastic nature, giant impacts may provide a natural explanation for the observed range of super-Earth densities.

**Author(s):** John Biersteker, Hilke E. Schlichting,  
**Institution(s):** Massachusetts Institute of Technology, University of California, Los Angeles

#### **124.03 - The World is Spinning: Constraining the Origin of Gas Giants using Planetary Spin(Marta Bryan)**

Over the past decade direct imaging searches for self-luminous giant planets have uncovered an unexpected population of young planetary-mass companions on extremely wide orbits ( $>100$  AU). The masses of these companions typically straddle the deuterium burning limit, throwing into question whether these are high mass planets or low mass brown dwarfs. These wide-separation companions pose significant challenges to three possible formation routes, namely core accretion, disk instability, and turbulent fragmentation. In this talk I will describe a program to directly test these three competing formation mechanisms for wide-separation planets by measuring their rotation rates using NIRSPEC/Keck NIR high-resolution spectroscopy. Rotation rates of young gas giant planets provide a unique window into planet accretion histories, and can be used to test how they formed. With our initial sample of rotation rates we placed the first constraints on the spin distribution and angular momentum evolution in the planetary-mass regime. With our expanded sample we aim to test new trends with rotation rate, such as how they vary with separation and mass ratio between the companion and host star, and trace these back to potential formation histories.

**Author(s):** Brendan Bowler, Marta Bryan, Konstantin Batygin, Heather Knutson, Björn Benneke  
**Institution(s):** Caltech, U Montreal, UC Berkeley, UT Austin

#### **124.04 - The Spin-Orbit Misalignments of Hot Jupiters May be Correlated with Stellar Companions, but Not with Metallicity(Marshall C. Johnson)**

Many hot Jupiters have been observed to have orbits that are highly misaligned with respect to the stellar rotation, but the origins of these misalignments are still unclear. A large number of theoretical mechanisms have been proposed to generate misaligned orbits, but observational constraints are lacking. Many of these models are related to planet migration, and so by distinguishing among these models we can obtain information on planet migration. Planets around stars hotter than the Kraft break are key for such work, as they should not have experienced significant tidal damping of any primordial misalignment. One proposed misalignment/migration mechanism is the Kozai-Lidov effect, which requires the presence of a distant stellar or planetary companion. We

present a new survey to test this mechanism by detecting stellar companions to hot Jupiters around hot stars with measured spin-orbit misalignments. We use both conventional adaptive optics imaging and non-redundant aperture masking interferometry in order to maximize our completeness over the full range of possible companion properties. Our initial results suggest that most aligned hot Jupiters around hot stars do not have stellar companions, while many, but not all, misaligned planets do have companions; however, our sample is not yet large enough to obtain a decisive result. We also perform statistical analyses of the full literature sample of measured spin-orbit misalignments, and demonstrate that there is no correlation between stellar metallicity and the presence of a misaligned orbit. This disfavors planet-planet scattering as a source of the misalignments.

**Author(s):** Eric G. Smith, Marshall C. Johnson, Aaron Rizzuto

**Institution(s):** The Ohio State University, University of Texas at Austin

#### **124.05 - Bayesian Inference of Giant Exoplanet Physics(Daniel Thorngren)**

Under the core accretion model of planet formation, giant planets are valuable records of the disks that they formed in. For my thesis work, I applied Bayesian statistics to the study of giant exoplanet populations to better understand their composition, formation history, and thermal processes. I began with the cool giant planets not affected by the hot Jupiter radius inflation effect, and determined their bulk compositions by comparing them to structure evolution models. I found that the bulk metallicity correlated with the planet mass, as expected from the core accretion model, but did not significantly correlate with the parent star metallicity. Next, I used this correlation to help break the degeneracy in hot Jupiters between the anomalous inflation power and bulk metallicity. The inflation power rises to about 2% of incident stellar flux at 1500 K, but then declines at higher equilibrium temperatures. This result was predicted by the Ohmic dissipation model of hot Jupiter inflation. With these population-level priors on metallicity and anomalous heating, I can better model planets in support of spectroscopic analysis. This is useful because the bulk metallicity is an upper limit on the atmospheric metallicity, and because the ratio between the two hints at the internal compositional structure of the planet. Finally, I have studied whether hot Jupiter radii evolve with their parent star's main-sequence brightening: whether this occurs is strongly dependant on the mechanism behind hot Jupiter inflation.

**Author(s):** Daniel Thorngren, Jonathan Fortney

**Institution(s):** University of California, Santa Cruz

#### **124.06 - Target Selection for In-depth Follow-up Transit Observations(Robert Thomas Zellem)**

The recently-launched TESS is predicted to discover thousands of transiting exoplanets ideal for in-depth characterization.

However, target selection can prove to be troublesome. Here will present two figures of merit to identify targets for both transit and eclipse follow-up observations. These ranking metrics, originally developed for the FINESSE and CASE missions, provide a relative ranking between any transiting exoplanet, agnostic of the observing platform. Thus, one can quickly identify targets to more efficiently devise an observing campaign with ground- and space-based telescopes, such as Palomar, JWST, and ARIEL.

**Author(s):** Robert Thomas Zellem

**Institution(s):** Jet Propulsion Laboratory - California Institute of Technology

### **125 - Cosmology and Astrophysics with Next Generation Cosmic Microwave Background Experiments**

#### **125.01 - CMB Facilities and Instruments in the 2020s, and Beyond(William Jones)**

A new generation of extremely sensitive experiments will extend precision measurements of the Cosmic Microwave Background (CMB) anisotropies on large angular scales in polarization, and on arcminute scales in intensity and polarization. The complementary capabilities of ground-based, orbital and sub-orbital balloon borne observatories will provide surveys of the polarized mm-wave sky of with unprecedented sensitivity, fidelity, and spectral resolution, enabling an improved understanding of Galactic emission necessary to realize the scientific potential of the CMB. In this talk we will briefly describe the observational programs underway in the coming decade.

**Author(s):** Aurelien Fraisse, William Jones

**Institution(s):** Princeton University Contributing Team(s): Input solicited broadly from the CMB community

#### **125.02 - The search for primordial gravitational waves with CMB polarization(Colin Bischoff)**

Observations of Cosmic Microwave Background B-mode polarization at large angular scales are a uniquely powerful method to search for primordial gravitational waves, such as those predicted by theories of inflation. A major milestone would be to either detect this signature of gravitational waves or else to set an upper limit on the tensor-to-scalar ratio,  $r < 0.001$ , which would rule out the most compelling models of large-field inflation. This goal will be met by Stage-3 experiments currently coming online, the CMB Stage-4 project planned for next decade, as well as new balloon-borne and satellite telescopes. Galactic foregrounds and gravitational lensing of E-mode polarization pose major challenges for these measurements, but are already being addressed by current projects. I will discuss the goals and common design features of experiments targeting the primordial gravitational wave signal, as well as forecasts developed for CMB Stage-4.

**Author(s):** Colin Bischoff

**Institution(s):** University of Cincinnati Contributing

Team(s): CMB-S4 Collaboration

Institution(s): Berkeley Center for Cosmological Physics

**125.03 - The SZ Galaxy Cluster Sample and other Legacy Products from the CMB-S4 Experiment(Lindsey Bleem)**

The next generation CMB-S4 experiment will conduct a multifrequency (40-270 GHz) survey of ~40% of the sky at an unprecedented combination of depth and resolution, reaching depths of a few  $\mu\text{K-arcmin}$  (~100s  $\mu\text{Jy}$ ) at arcmin-scale resolution in the higher frequency channels. These data will be a tremendous resource for the astronomical community: the deep multifrequency maps will enable the identification of a mass-limited sample of >100,000 galaxy clusters via the Sunyaev-Zel'dovich (SZ) effect, a significant number of higher-redshift protoclusters, galactic sources, and over a million active galactic nuclei (AGN) and dusty star-forming galaxies. Beyond these catalogs the individual frequency maps will be combined to produce maps of the matter distribution as traced by gravitational lensing of the cosmic microwave background, hot gas traced via the thermal SZ, the cosmic infrared background, and galactic dust. The observing cadence will also enable time domain science; each location in the footprint will be imaged more than 1000 times over the course of the multiyear survey enabling characterization of near earth objects, AGN lightcurves, and the discovery of transient objects. In this presentation I will highlight these legacy products, particularly focusing on the scientific impact of the new SZ galaxy cluster sample.

**Author(s):** Lindsey Bleem

**Institution(s):** Argonne National Laboratory Contributing Team(s): CMB-S4 Collaboration

**125.04 - CMB probes of neutrinos and searches for other neutrino-like particles(Marius Millea)**

The early universe, as illuminated by observations of the Cosmic Microwave Background (CMB), is a prime laboratory for probing the properties of neutrinos, and for perhaps discovering other neutrino-like particles. Measurements from the current generation of CMB experiments are consistent with 3 fully thermalized free-streaming neutrino species present in the early universe, as expected from the standard model, with a small window left for any other light thermal relic particles to exist. I will discuss the nature of these constraints and how future measurements could close the window entirely for relics which decoupled at even very early times. The CMB is also a unique probe of the neutrino mass matrix, the dominant sensitivity being to the sum of the three masses, offering complementary constraints to other laboratory experiments. I will discuss forecasts for CMB neutrino mass measurements, and prospects for determining the neutrino mass hierarchy via cosmological observations.

**Author(s):** Marius Millea

**125.05 - Growth of structure from joint analyses of cosmic microwave background and large-scale structure data(Emmanuel Schaan)**

I will describe CMB lensing measurements from current and upcoming CMB experiments. In combination with large-scale structure observables such as clustering and lensing, these will probe the growth of structure over a wide range of redshifts, thus constraining the properties of dark energy and the neutrino masses. Furthermore, CMB lensing measurements can help reduce large-scale structure systematics, such as shear calibration in galaxy lensing.

**Author(s):** Emmanuel Schaan

**Institution(s):** Lawrence Berkeley National Laboratory

**125.06 - Constraining Feedback in Galaxy Formation with Next-Generation CMB Experiments(James Colin Hill)**

The cosmic microwave background (CMB) radiation is a powerful backlight with which to illuminate structure throughout cosmic history. The thermal (tSZ) and kinematic Sunyaev-Zel'dovich (kSZ) effects, sourced by the scattering of CMB photons off free electrons, directly probe the thermal pressure and density of ionized gas, while gravitational lensing of the CMB directly measures the line-of-sight matter density. Measurements of these effects, which have only been robustly detected within the past decade, will transform our understanding of galaxy formation and evolution in upcoming CMB surveys. I will present predictions for the tSZ and kSZ signals of galaxy and cluster populations at various redshifts derived from state-of-the-art cosmological hydrodynamics simulations, with differing implementations of sub-grid feedback physics due to active galactic nuclei and supernovae. While multiple feedback implementations are able to reproduce the stellar properties of galaxies, their predictions for the tSZ and kSZ signals can be distinguished at high significance by upcoming experiments, including CMB-S4. Next-generation CMB surveys will thus provide crucial input to our understanding of galaxy formation, particularly at high redshift, where other probes have limited signal-to-noise. I will conclude by discussing implications of these measurements for the modeling of baryonic effects on the matter power spectrum, which is amongst the largest systematic uncertainties in cosmological constraints derived from weak gravitational lensing data.

**Author(s):** James Colin Hill,

**Institution(s):** Institute for Advanced Study, Flatiron Institute

### **125.07 - CMB probes of dark matter physics(Renée Hlozek)**

The Cosmic Microwave Background offers a new window on dark matter physics. It can reach beyond current direct-detection experiments to constrain both models of sub-GeV particles and models of ultra-light axions with masses around  $10^{-22}$  eV. I will highlight current CMB dark matter searches and present the exciting prospects for constraining the dark sector with upcoming CMB experiments. Several dark matter models remain feasible, and I will also consider scenarios where the dark content is made of a mix of dark matter species.

**Author(s):** Renée Hlozek

**Institution(s):** University of Toronto Contributing Team(s): Simons Observatory Team, CMB Stage Four Team

## **126 - Machine Learning in Astronomical Data Analysis**

### **126.01 - Machine learning applications with LSST: From Data Processing to Knowledge Discovery(Mario Juric)**

The Large Synoptic Survey Telescope (LSST; <http://lsst.org>) will be the most comprehensive optical astronomy project ever undertaken. The LSST will take panoramic images of the entire visible sky twice each week for 10 years, building up the deepest, widest, image of the Universe. The resulting hundreds of petabytes of imaging data for close to 40 billion objects will be used for scientific investigations ranging from the properties of near-Earth asteroids to characterizations of dark matter and dark energy. The volume, quality, and the real-time aspects of the LSST survey present significant research opportunities. They will enable studies of entire populations of objects, detections of faint statistical signals, and real-time discovery and follow-up of rare phenomena. Yet at the same time, these characteristics make it a difficult dataset to process and examine using classical techniques. In this talk, I will discuss the challenges presented by the LSST data set and areas where machine learning techniques are expected to be helpful. This includes the generation of well-characterized alert streams, to applications in data analysis and knowledge discovery. Present-day surveys such as the PTF, CRTS, and ZTF have already shown how machine learning can be an effective way to extract knowledge from astronomical data sets and streams. In the LSST era, we expect them to continue to grow in importance.

**Author(s):** Leanne Guy, Eric Bellm, Mario Juric

**Institution(s):** University of Washington, Seattle, LSST

### **126.02 - A Typical User's Ground-Level Perspective on Machine Learning in Astronomy(James Davenport)**

We have entered an era in observational astronomy in which sky surveys routinely release massive datasets. While this wealth of data is critical for determining rates of rare phenomena (e.g. transiting exoplanets or tidal disruption events), it also enables a new kind of data-driven astrophysics

(e.g. "hidden" correlations in our data that point towards new or challenging understandings of physics). Machine learning is simply one tool available to us to discover these new trends or make predictions from our growing volume of data. However, machine learning alone cannot make astrophysical discoveries, and astronomers are still required to interpret astrophysical meaning from our data. Here I will discuss some uses of machine learning in analyzing data from the Kepler and Gaia missions, and attempt to highlight some of the opportunities and limitations in its use.

**Author(s):** James Davenport

**Institution(s):** University of Washington, Seattle

### **126.03 - Investigating Galaxy Evolution with Deep Learning(Marc Huertas-Company)**

Deep learning is rapidly becoming a standard tool in many scientific disciplines including astronomy. I will review recent and on-going work on several applications of deep learning techniques to galaxy evolution related problems. I will show examples of how different network configurations can be efficiently used to classify galaxies into different evolutionary stages even when no apparent features are visible as well as to detect and measure substructures within galaxies such as bulges and clumps. I will also discuss unsupervised approaches based on generative models to compare numerical simulations and observations and detect anomalous objects. In my talk I will also try to show possible solutions to known limitations such as uncertainty estimation, small training sets and the "black box problem".

**Author(s):** Marc Huertas-Company

**Institution(s):** Observatoire de Paris

### **126.04 - astroML 2.0 - Machine Learning for Astrophysics(Brigitta Sipocz)**

We present the roadmap and updates for the second edition of astroML (<http://astroml.org>), a popular open source machine-learning library for astrophysics. astroML provides a publicly available repository for fast Python implementations of statistical routines for astronomy, as well as examples of astrophysical data analyses using techniques from statistics and machine learning. The new version further develops astroML into a general machine learning toolkit for the next generation of astrophysical surveys. New components to be included are algorithms for approximate Bayesian computation, hierarchical Bayes, and modifying the regression and regularization code to account for uncertainties within the data. We will also incorporate an interface to deep learning algorithms. Our objective is to ensure astroML scales well when working with large datasets and it exploits multicore and multiprocessing hardware. Astronomical data provide a popular testbed for developing methods applicable throughout the physical and life sciences and astroML has already been used widely beyond astronomy in other areas from cancer research and analysis of

the securities market to teach data science in astronomy.

**Author(s):** Andrew Connolly, Brigitta Sipocz, Jacob VanderPlas, Zeljko Ivezić

**Institution(s):** DIRAC Institute, University of Washington, eScience Institute, University of Washington, Google

### **126.05 - Classifying Supernova Remnant Spectra with Machine Learning(Daniel Patnaude)**

There is a clear connection between the evolutionary properties of a massive star and the properties of the resultant supernova and supernova remnant. Here we present new results where we have modeled 45,000 supernova remnants to ages of 5000 years, and synthesized spectra for both shocked circumstellar material and shocked ejecta at 10 epochs across the life of the remnant. We then used the 900,000 synthetic spectra to train and test a machine learning algorithm in classifying the spectra, in order to make concrete inferences about the progenitor evolution. We then applied these models to the population of Galactic and Magellanic Cloud core collapse remnants in order to understand the properties of their progenitor systems.

**Author(s):** Daniel Patnaude, Shiu-Hang Lee

**Institution(s):** Smithsonian Astrophysical Observatory, Kyoto University

### **127 - The Role of Magnetic Fields and Filaments in Star Formation**

#### **127.01 - Introduction to Magnetic Fields and Filaments in Star Formation(Joan T. Schmelz)**

Magnetic field extrapolations and filamentary loop substructure have been key results in understanding the solar atmosphere and coronal heating. Arecibo's 21-cm neutral hydrogen data reveal pervasive interstellar filaments that follow the galactic magnetic field lines revealed by Planck's all-sky dust polarization maps. The small scales of the solar coronal and the large scales of interstellar matter hint that there may be a role for magnetic fields and filaments at every step of the star formation process. Herschel observations established that molecular filaments are the preferred sites of star formation. SOFIA's new instrument, HAWC+, studies the role of magnetic fields in filaments on sub-parsec scales. ALMA polarization observations probe regions surrounding young protostars. Sub-orbital platforms, such as BLASTPOL and BLAST-TNG, deliver a wealth of data on magnetic fields in the interstellar medium. This talk sets the stage, allowing the session components to knit the big and small pictures together to provide a better understanding of galactic magnetic fields and filaments in star forming regions.

**Author(s):** Joan T. Schmelz,

**Institution(s):** SOFIA Observatory, USRA

#### **127.02 - Resolving the Magnetic Field of IRAS 16293-2422 with ALMA(Sarah Sadavoy)**

We present ALMA high-resolution dust polarization observations of IRAS 16293-2422. The dust polarization and inferred magnetic field are well resolved across the protostellar sources and the filamentary structures seen between them. The magnetic field is aligned parallel to the filamentary structures rather than showing a pinched morphology expected for accreting stars. We construct a simple toy model to investigate the energy balance in the filamentary bridge of dust and gas between the stars. We find high gas flow rates such that the bridge should be short-lived, and we propose that it is either a transient structure or must otherwise accrete new material. The parallel magnetic fields seen in IRAS 16293 are an unique feature and future theoretical work will need to understand both their origin and their impact on the evolution of young stars.

**Author(s):** Dominique Segura-Cox, Ian William Stephens, Thomas K. Henning, Benoit Commerçon, John Tobin, Sarah Sadavoy, Philip Myers, Leslie Looney, Woojin Kwon

**Institution(s):** Harvard-Smithsonian CfA, KASI, NRAO, MPIA, MPE, University of Illinois, University of Lyon

#### **127.03 - Magnetic Fields in High-Mass Filamentary Infrared Dark Clouds(Ian William Stephens)**

Filaments are ubiquitous in the star formation process. Planck has revealed that magnetic fields are perpendicular to dense elongations, suggesting that fields help funnel gas toward filamentary structures. However, the resolved field morphologies and strengths in these dense filaments remain poorly constrained. In this presentation, I will show HAWC+ 214  $\mu$ m polarimetric observations toward two high-mass filamentary infrared dark clouds: the Snake (G11.1) and G18.6. The magnetic field morphology is strikingly uniform and perpendicular to the filamentary structure.

**Author(s):** James M. Jackson, Ian William Stephens

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Universities Space Research Association Contributing Team(s): Other Team Members

#### **127.04 - Polarimetry with BLAST - Results from BLASTPol and Plans for BLAST-TNG(Giles Novak)**

The 2010 and 2012 Antarctic flights of the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry (BLASTPol) have advanced our understanding of the structure of cloud-scale magnetic fields in star forming clouds and provided tests for models of dust grain composition and alignment in both star forming and translucent clouds. At the time of this writing, an upgraded version called BLAST-TNG is being shipped to Antarctica and the first team members are preparing to travel there in three weeks to ready the experiment for a December 2018 launch. BLAST-TNG shares BLASTPol's observing bands at 250, 350, and 500 microns, but has an order of magnitude faster mapping speed, a larger primary of 2.5 m diameter, and a longer cryogen hold time of 28 days. I will give an overview of

the main results from our 2010 and 2012 flights and a synopsis of our plans for the upcoming flight. These plans include a 25% allocation to shared risk projects that have been proposed by investigators outside the BLAST collaboration.

**Author(s):** Giles Novak

**Institution(s):** Northwestern University Contributing Team(s): BLAST collaboration

#### **127.05 - An in-depth look at the magnetic field of NGC 1333 IRAS 4A(Erin Guilfoil Cox)**

Magnetic fields are important on all size scales of star formation. Using dust polarization observations, we can infer the plane-of-sky magnetic field morphology of protostars. Observing magnetic field morphologies in the youngest protostars is key to understanding their influence. One particular source, NGC 1333 IRAS 4A, is young (~10 kyr) protostar that has been observed often due to its brightness. NGC 1333 IRAS 4A is also quite polarized, and its polarization signature has been well studied at multiple wavelengths and resolutions. In this talk, I will give an overview of previous polarization observations of this interesting source. I will also present SOFIA data that can help us link large and small scale magnetic field morphology.

**Author(s):** Erin Guilfoil Cox,

**Institution(s):** University of Illinois, Northwestern University

#### **127.06 - Wide-Field Molecular Line Mapping of the Nessie Nebula: an Extremely Filamentary Infrared Dark Cloud.(James M. Jackson)**

We present new ~90 GHz molecular line maps, taken with the Mopra 22 m telescope in Australia, of the Nessie Nebula, an extremely filamentary infrared dark cloud. The new images at ~38" resolution cover over a degree (~100 pc) along the filament. Feedback from embedded stars alters the chemistry and creates molecular bubbles. The HCO+1-0 line profiles toward the associated clumps are asymmetric, with stronger blueshifted emission and fainter redshifted emission relative to the systemic velocity, as determined from the optically thin N<sub>2</sub>H+ 1-0 line. These asymmetries arise from infall motions due to gravitational collapse. Collapse motions are confirmed by a new indicator of collapse, the [O I] 63  $\mu$ m line observed by SOFIA at high spectral resolution. Toward the brightest star forming region in Nessie, the [O I] profiles show redshifted absorption (inverse P Cygni) or self-absorption features. These collapse motions may indicate that the entire filament is collapsing inward. Future SOFIA measurements of Nessie and other filamentary IRDCs will shed light on the interplay of magnetic fields, gravitational collapse, and feedback in the densest, most-massive filaments.

**Author(s):** Nicholas Killerby-Smith, David Allingham, James M. Jackson, Philippa Patterson, J. Scott Whitaker, Taylor Hogge

**Institution(s):** SOFIA Science Center, Boston University, University of Newcastle

### **128 - Galaxy Formation and Evolution III**

#### **128.01 - Evolution of Molecular Gas Reservoirs After Galaxies Stop Forming Stars(Decker French)**

Post-starburst (or "E+A") galaxies are in transition between star-formation and quiescence, and represent a clear path for galaxies to transform their stellar populations, ISM properties, and morphologies. Many show signs of a recent galaxy-galaxy merger and a newly-evolved stellar bulge, and most have LINER-like emission, which may indicate low luminosity AGN activity. Thus, the study of this short-lived phase of galaxy evolution can address the connections among mergers, star formation history, AGN activity, and the evolution of the nucleus as a galaxy evolves onto the red sequence. The molecular gas content of these galaxies has been studied using single-dish CO (1-0) and (2-1) observations from the IRAM-30m and ALMA observations of HCN (1-0). The recent star formation histories have been studied using UV/optical photometry and optical spectroscopy, fit using stellar population synthesis to determine the time since the recent starbursts ended. While post-starburst galaxies have stopped forming new stars, we have discovered that many have significant reservoirs of molecular gas remaining, which are depleted only after the starburst had already ended. Young post-starburst galaxies have molecular gas reservoirs similar to normal star-forming galaxies, which decline to the levels of early type galaxies within 1-2 Gyr. This rate of gas depletion is too rapid to be explained by the low star formation rates in these galaxies, so AGN feedback may be responsible. Recent ALMA observations show these galaxies also have low dense gas fractions, and the mechanisms which deplete the gas after the starburst may be the same as those which suppress the collapse of gas into denser states.

**Author(s):** Decker French

**Institution(s):** Carnegie Observatories

#### **128.03 - Linking galaxies to the large scale structure of the Universe with the Maunakea Spectroscopic Explorer(Alan McConnachie)**

The last few decades have seen a dramatic increase in our understanding of the large scale structure of the Universe. However, understanding the connection of the large scale structure to the galaxies that are embedded within it is a fundamentally difficult problem requiring extremely large datasets that probe tracers of a range of complex interactions between gas, stars and the dynamical mass distribution. The Maunakea Spectroscopic Explorer is an 11.25 m wide field telescope that observes more than 4000 targets per pointing, and which feeds fully dedicated banks of low, medium, and high resolution spectrometers. It produces the same number of spectra as the SDSS Legacy Survey every 7 weeks and has flagship programs that aim to make the connection between

galaxies and their surrounding large scale structure from before the peak of the star formation history of the Universe to the present day. US scientists make up more than a quarter of the science team that now involves more than 300 astronomers from 30 countries. Here, I will review the scientific potential of MSE for galaxy evolution science and describe its strong synergies with national facilities like LSST and the ngVLA. Entering the preliminary design phase, I will provide an update on the design of MSE and discuss the opportunities available to partners over the coming months and years.

**Author(s):** Alan McConnachie

**Institution(s):** NRC Herzberg Astronomy & Astrophysics  
Contributing Team(s): The MSE Team

#### **128.04 - On the Origin of Gas-poor Galaxies in Galaxy Clusters Using Cosmological Hydrodynamic Simulations(Seoyoung Lyla Jung)**

The environmental effect is commonly used to explain the excess of gas-poor galaxies in galaxy clusters. Meanwhile, the presence of gas-poor galaxies at cluster outskirts, where galaxies have not spent enough time to feel the cluster environmental effect, hints at the presence of preprocessing. Using cosmological hydrodynamic simulations on 16 clusters, we investigate the mechanisms of gas depletion of galaxies found inside clusters. The gas-depletion mechanisms can be categorized into three channels based on where and when they took place. First, 34% of our galaxies are gas poor before entering clusters ("preprocessing"). They are mainly satellites that have undergone the environmental effect inside group halos. Second, 43% of the sample quickly became gas deficient in clusters before the first pericentric pass ("fast cluster processing"). Some of them were group satellites that are low in gas at the time of cluster entry compared to the galaxies directly coming from the field. Even the galaxies with large gas fractions take this channel if they fall into massive clusters ( $>10^{14.5} M_{\odot}$ ) or approach cluster centers through radial orbits. Third, 24% of our sample retain gas even after their first pericentric pass ("slow cluster processing") as they fall into the less massive clusters or have circular orbits. The relative importance of each channel varies with a cluster's mass, while the exact degree of significance is subject to large uncertainties. Group preprocessing accounts for one-third of the total gas depletion, but it also determines the gas fraction of galaxies at their cluster entry, which in turn determines whether a galaxy should take the fast or the slow cluster processing.

**Author(s):** Aeree Chung, Seoyoung Lyla Jung, Taysun Kimm, Hoseung Choi, O. Ivy Wong, Suhyoung K. Yi

**Institution(s):** Yonsei University, ICRAR

#### **128.06 - FLASHES: Revealing the CGM around 50 $z=2-3$ QSOs(Donal O'Sullivan)**

The Fluorescent Lyman-Alpha Structures in High- $z$  Environments (FLASHES) survey is a multi-year, optical

integral-field unit (IFU) spectroscopy survey of QSO environments at redshifts  $z=2.3-3.1$ . It is motivated by recent observational evidence for cold flow accretion forming disks in the circumgalactic medium (e.g. Martin+15) and IFU studies of QSO environments at higher redshift (e.g. Borisova+16, Wisotzki+16, Arrigoni-Battaia+18). In this paper, we outline the survey design, present preliminary results, and discuss the upcoming work. With a sample of 50 QSO environments (selected from the QSO Catalog of the SDSS 12th Data Release) imaged, we detect bright, extended Lyman-alpha in the vast majority of our targets on a scale of 80-100 kpc. We also detect evidence for strongly sheared kinematic profiles, though this is a subject of ongoing deeper follow up using metal lines less susceptible to radiative transfer effects than the Hydrogen Lyman-alpha emission line.

**Author(s):** Prachi Parihar, Erika Hamden, Christopher Martin, Don Neill, Zeren Lin, Matt Matuszewski, Donal O'Sullivan

**Institution(s):** California Institute of Technology

#### **128.07 - The Lensed Perspective: Resolving the Inner Core of a Massive Rejuvenated Quiescent Galaxy at $z=1.9$ (Katherine E Whitaker)**

Understanding the formation and quenching of massive quiescent galaxies at cosmic noon ( $z\sim 2$ ) remains a major problem in galaxy formation theory. While clues to their formation will be imprinted on the stellar populations in their inner cores, such analyses are beyond the capabilities of current technology. Here, we present a unique analysis of Hubble Space Telescope WFC3/G141 grism spectroscopy and Large Millimeter Telescope/AzTEC 1.1mm imaging of a unique target SDSSJ0851-E, a multiply imaged gravitationally lensed massive ( $\log M^*/M_{\odot}=10.6$ ) red galaxy at  $z=1.9$ . The boost in spatial resolution and signal that strong gravitational lensing affords gives us the rare opportunity to perform spatially resolved age measurements at 0.5 kpc resolution. We find that SDSSJ0851-E formed the bulk of its stellar mass early on, with old stellar populations in the inner 2.5 kpc ( $>1.5$  Gyr). Surprisingly, SDSSJ0851-E shows clear evidence of a rejuvenation. But, as the gas fraction is constrained to  $<10\%$ , it is running on empty. In this talk, we place the results of this intriguing case study in the context of our overall understanding of the properties of the quiescent population at  $z\sim 2$ .

**Author(s):** Mohammad Akhshik, Katherine E Whitaker,

**Institution(s):** University of Connecticut, Cosmic Dawn Center  
Contributing Team(s): SGAS Team

#### **128.02D - The connection between galaxies and dark matter halos(Seunghwan Lim)**

According to the current paradigm of galaxy formation, galaxies form and evolve in dark matter halos that grow through gravitational collapse of small initial fluctuations in the cosmic density field. Not only are they hosts of galaxies, but dark



matter halos are also tracers of the large-scale structure of the Universe. Thus they are crucial components for understanding how galaxies form and evolve in and with the cosmic web. This dissertation is a systematic investigation of the galaxies and gas in the cosmic web, which was published into six first-author papers of mine and seven more papers that I contributed, using observational data of large galaxy surveys such as SDSS and CMB maps such as the Planck, simulations, and modellings. Specifically, I have identified dark matter halos in the low-redshift Universe and constructed the largest to date all-sky group catalog. I also investigated correlations between many of galaxy and halo properties, particularly finding, for the first time, an observational proxy of halo age. Finally, I developed a series of novel approaches to maximize the detection of the Sunyaev-Zel'dovich effect (SZE), and explored the gas properties in halos to find that gas mass fraction even in low-mass halos is about the cosmic mean baryon fraction, solving a long-standing mystery in astronomy, the 'missing baryon' problem. The analysis identified the 'missing' baryons in a warm-hot medium on halo scales. I also have shown that the tSZE can be used to constrain the mean relationship between thermal energy of IGM gas and local total matter density for the first time, and the results can constrain models for galaxy formation such as models for AGN feedback. I will also present some early results from using simulations to test different SZE detection methods in literature and to constrain galaxy models.

**Author(s):** Houjun Mo, Seunghwan Lim

**Institution(s):** University of Massachusetts Amherst

#### **128.05D - Accurate Identification of Galaxy Mergers with Imaging and Kinematics(Becky Nevin)**

Merging galaxies play a key role in galaxy evolution, and progress in our understanding of galaxy evolution is slowed by the difficulty of making accurate galaxy merger identifications. Mergers are typically identified using individual imaging techniques, each of which has its own limitations and biases. With the growing popularity of integral field spectroscopy (IFS), it is now possible to introduce kinematic signatures to improve galaxy merger identifications. We use GADGET-3 N-body/hydrodynamics simulations of merging galaxies coupled with SUNRISE dust radiative transfer simulations to create mockup IFS and images to match the specifications of SDSS-IV's MaNGA (Mapping Nearby Galaxies at Apache Point) survey. From the mockup galaxies, we have developed the first merging galaxy classification scheme that is based on kinematics and imaging. Utilizing a Linear Discriminant Analysis tool, we use a linear combination of kinematic and imaging predictors to identify merging galaxies from the > 10,000 galaxies in the MaNGA survey, identifying many more mergers than possible before. Through the accurate identification of merging galaxies in the MaNGA survey, we will advance our understanding of supermassive black hole growth in galaxy mergers and other open questions related to galaxy evolution.

**Author(s):** Julia Comerford, Jenny Greene, Becky Nevin, Laura Blecha

**Institution(s):** University of Colorado Boulder, Princeton University, University of Florida

#### **129 - Milky Way & Galactic Center II**

##### **129.01 - Star Formation in the Far Outer Galaxy: Tracing Efficiencies Across the Disk(William Paul Armentrout)**

We map the  $^{13}\text{CO}$  molecular gas emission from distant Galactic star forming regions in the Outer Scutum-Centaurus spiral arm (OSC) using the Argus array on the Green Bank Telescope (GBT). Argus, a new 16-pixel focal plane array for millimeter spectroscopy, allows for fast mapping of extended molecular gas, producing 5 arcmin  $^{13}\text{CO}$  maps with 8 arcsec resolution and 0.5 K sensitivity in 20 minutes. The OSC is the most distant molecular spiral arm. To date, we have detected high-mass star formation at 12 locations in the OSC, with the most distant source at 23.5 kpc from the Sun and 17 kpc from the Galactic Center. These regions represent star formation at low densities and low metallicities, similar to the conditions in galaxies like the Large Magellanic Cloud or a much younger Milky Way. We determine molecular gas masses from our Argus measurements, and we determine stellar masses at the cores of these HII regions from thermal continuum emission measurements with the Very Large Array. By comparing molecular and stellar masses, we can begin to put constraints on the star formation efficiency of these distant outer Galaxy sources, tracing efficiencies across the Galactic disk.

**Author(s):** David Frayer, Loren Anderson, Thomas Dame, Sarah Church, William Paul Armentrout,

**Institution(s):** West Virginia University, Stanford University, Green Bank Observatory, Harvard-Smithsonian Center for Astrophysics

##### **129.03 - The Edge of the Milky Way's Galactic Disk (and Beyond)(Robert A Benjamin)**

Many spiral galaxies are observed to have a stellar "break", a location where the scalelength of the exponential disk changes, usually to a smaller value. The first evidence for a break in the density profile of stars at a Galactocentric distance of 14 kiloparsecs in the Milky Way was presented by Robin et al (1992) based on deep optical observations in several low-extinction directions towards the Galactic anticenter combined with star-count models. Further evidence for a break in stellar density has accumulated over the decades based on red-giant star counts (Ruphy et al 1996, Reyle et al 2009, Minniti et al 2010, Nidever et al 2012), analysis of infrared light (Freudenreich 1998), and star-counts of A stars (Sale et al 2010). However, interpretation of the stellar density profile is complicated by the known warping and flaring of the stellar disk plus possible satellite galaxies (Momany et al 2006, Bland-Hawthorn and Gerhard 2016); if the decrease in volume density is concomitant with an increasing scale-height, the Milky Way surface density profile may have no break. Using data from 2MASS, GLIMPSE, and WISE, we present a continuous map of

the stellar break along the Galactic midplane showing the location of this volume-density break varies smoothly from 13 to 15 kpc along this swath of the sky. We argue that changing break radius is due to the warping of the stellar disk and present progress on creating a three dimensional map of the stellar density up to and beyond the break.

**Author(s):** Robert A Benjamin

**Institution(s):** University of Wisconsin-Whitewater  
Contributing Team(s): GLIMPSE team

#### **129.04 - The Southern Stellar Stream Spectroscopic Survey (S5)(Ting Li)**

Recently, more than a dozen new stellar streams in the Milky Way were discovered in the southern hemisphere with the Dark Energy Survey (DES). In this talk, I will present an ongoing spectroscopic program S5, which maps these southern streams with the 2df/AAOmega spectrograph on the Anglo-Australian Telescope. S5 is the first systematic program pursuing a complete census of known streams in the southern hemisphere. The radial velocities and stellar metallicities from S5, together with the proper motions from Gaia DR2, provide a unique sample to understand the Milky Way halo populations, the progenitors and formation of the streams, the mass and shape of the Milky Way potential, and to test the characteristics of dark matter. So far, the S5 program has obtained the 6D+1 (metallicity) phase space information for 10 streams in the DES footprint, all of which are the first-time measurements for these southern streams, and we are expanding our program beyond the DES footprint to cover more southern streams. I will give an overview of the S5 program, including target selection, observation, and data analysis, and I will end with a discussion of the implications of the preliminary results from S5.

**Author(s):** Ting Li

**Institution(s):** Fermi National Accelerator Laboratory  
Contributing Team(s): S5 Collaboration, DES Collaboration

#### **129.05 - Milky Way Stream Properties from Space Telescope(s)(Mark Fardal)**

I will discuss ongoing work on Milky Way halo streams using Gaia DR2 along with Hubble Space Telescope data. Using horizontal branch stars, RR Lyrae, and red giant branch stars, we trace the proper motion of the Orphan Stream along the entirety of its previously detected extent. The proper motion-selected color-magnitude diagram reveals a narrow red giant branch. Pruning previous spectroscopic samples with proper motion removes outliers and yields a consistently narrow metallicity distribution. A revised spatial track of the stream yields departures from an orbital path and hints at stream substructure. We also trace the Sagittarius Stream across the sky. Resolving the stream in proper motion yields information on its spatial width and substructure within the stream. We discuss implications of these streams for the Milky Way potential.

**Author(s):** Mark Fardal,

**Institution(s):** STScI, UMass Contributing Team(s):  
HSTPROMO

#### **129.06 - Reconstructing the Orphan Stream Progenitor with MilkyWay@home Volunteer Computing(Heidi Jo Newberg)**

We show that the mass and radial profile of the progenitor dwarf galaxy of the Orphan Stream can be reconstructed from the distribution of stars in the tidal tail it produced. A simulation of the disruption of a dwarf galaxy with stellar and dark matter components is compared with data for the actual tidal stream. The 0.8 PetaFLOPS MilkyWay@home volunteer computing platform is used to optimize the parameters in the simulated dwarf galaxy disruption to best match the observed stream. The algorithm fits the dark matter mass, dark matter radius, stellar mass, radial profile of stars, and orbital time, assuming a static Milky Way potential and known orbital parameters. Under these ideal conditions the dwarf galaxy parameters are fit within a few percent. We use this algorithm to fit the actual Orphan Stream data, and present the preliminary results. A comprehensive evaluation of the many sources of error in making such a measurement is underway. This research is supported by NSF grant AST 16-15688, the NASA/NY Space Grant fellowship, The Marvin Clan, Babette Josephs, Mani Limlamai, and the 2015 Crowd Funding Campaign to Support Milky Way Research.

**Author(s):** Siddhartha Shelton, Jake Weiss, Jacob Bauer, Eric Mendelsohn, Heidi Jo Newberg, Travis Desell, Malik Magdon-Ismael, Larry Widrow

**Institution(s):** Rensselaer Polytechnic Institute, Rochester Institute of Technology, Queen's University

#### **129.07 - Talk Moved to Poster**

**Author(s):**

**Institution(s):**

#### **129.08 - The GD-1 stellar stream suggests the existence of dark substructure in the Milky Way halo(Adrian Price-Whelan)**

The Milky Way halo contains several thin, dynamically-cold stellar streams that likely formed from the tidal disruption of low-mass stellar systems like globular clusters. These streams are powerful tools for testing dark matter theories: streams will enable mapping the global structure of mass in the Galaxy, and are extremely sensitive to gravitational perturbations such as interactions with dark substructure. Recent data from the Gaia mission (DR2) have enabled a high-contrast view of the longest Milky Way thin stream, the GD-1 stream, and have revealed a number of under-densities and a "spur" of stars associated with

one such density gap in this stream. The observed morphology of GD-1 (the gap and spur) is naturally reproduced in models of the stream that include an encounter with a massive ( $\sim 10^6$ – $10^8$ ), dense perturber, and is not expected in simple simulations of the stream formation. I will show models of the stream and discuss ways to test the substructure encounter scenario. If confirmed, the GD-1 stream would provide the first direct dynamical evidence of dark substructure in the Milky Way halo.

**Author(s):** Charlie Conroy, David W Hogg, Ana Bonaca, Adrian Price-Whelan

**Institution(s):** Princeton University, New York University, Harvard University, Flatiron Institute

### **129.02D - Kinematics and Evolution of Massive Star Formation in the Central Molecular Zone of the Galactic Center(Natalie Butterfield)**

Molecular gas in the central 200 parsec of the Milky Way galaxy exhibits more extreme physical characteristics (e.g., higher density, warmer gas) than gas in the Galactic disk. Recent detailed surveys of this Central Molecular Zone (CMZ) have revealed a large-scale morphology that indicates that molecular clouds are likely to be organized in an orbital structure around the dynamical center of the galaxy, Sgr A\*. However, modeling the locations and velocities of molecular clouds in the CMZ is challenging because the velocity structure of the interstellar medium is complex. Spectral line profiles of molecular clouds in the CMZ region frequently show multiple peaked structure, indicating multiple components along the same line-of-sight. For my dissertation I have observed several regions in the CMZ where the interstellar and kinematic environment is particularly complex in order to better connect observations to the proposed orbital models. The data presented in this dissertation include C (5 GHz), K (25 GHz), and Ka (36 GHz) band continuum and spectral line (NH<sub>3</sub>, H<sub>113a</sub>, CH<sub>3</sub>OH, HC<sub>3</sub>N, and others) observations from the Very Large Array radio telescope. In my dissertation, I explore feedback effects of the massive stellar Quintuplet cluster on an adjacent molecular cloud (Mo.20-0.033). Using observations of the molecular and ionized gas in this region, I present evidence that the observed kinematics represents an expanding shell, powered by the massive Quintuplet cluster. I also present initial results from a second study of the interstellar environment of the H II regions and molecular gas near the SgrB1 complex. These results in my secondary study suggest that expanding shells and the presence of massive stars are likely to be impacting this region of the CMZ as well.

**Author(s):** Elisabeth Mills, Natalie Butterfield, Juergen Ott, Adam Ginsburg, Mark R Morris, Cornelia Lang

**Institution(s):** Green Bank Observatory, Boston University, University of Iowa, UCLA, NRAO

## **130 - Black Holes II**

### **130.01 - Accretion States, Black Hole Spin, and the 2017 Outburst of MAXI J1535-571(Joseph Neilsen)**

After two decades of monitoring stellar mass black holes in outburst, there are still lingering questions about the geometry of the accretion disk and its evolution across state transitions. Does the disk extend all the way to the ISCO, or is it truncated at some distance from the black hole? How does this depend on accretion rate, luminosity, and X-ray spectral shape, and how is it connected to timing properties? The recent outburst of MAXI J1535-571, monitored extensively with NuSTAR and NICER, provides a prime opportunity to address these questions. I will present detailed analysis of the spectral evolution of the source over roughly three months, from its rising hard states through its >5 Crab peak, all the way to its soft, disk-dominated state. Applying relativistic reflection models and holding its spin constant across the outburst, I track the evolution of the inner radius of the disk from state to state. With hundreds of millions of counts in dozens of observations, these data offer an incredibly detailed view of the spectral geometry of MAXI J1535-571 for comparison to precision timing results.

**Author(s):** Gabriele Ponti, Mickael Coriat, Sara Motta, Joseph Neilsen, James Francis Steiner, Stephane Corbel, Rob Fender, Liam Dowling Jones

**Institution(s):** Villanova University, IRAP, MIT, CEA Saclay, Oxford, MPE Garching Contributing Team(s): NICER Science Team

### **130.03 - An Analytical Fourier-Transformation Model for the Production of Soft X-ray Time Lags in 1H0707-495(David Baughman)**

We develop a new, non-relativistic, time-dependent theoretical model based on a Fourier transformed radiation transport equation that is used to explore the production of soft X-ray time lags from active galactic nuclei. In our model, the soft lags result from the thermal and bulk Comptonization of photons occurring in the inner, quasi-spherical region of the accretion disk. The time-dependent transport equation we study describes the scattering of seed photons in an isothermal, inhomogeneous, spherically symmetric, accreting coronal cloud. We assume that the accretion rate is close to the Eddington limit, and that the seed photons are injected in an instantaneous burst at the peak energy of the broad iron-L line band. The electron number density  $n_e$  is assumed to be inhomogeneous, with a free-fall spatial variation given by  $n_e(r) \propto r^{-3/2}$ . Our transport model extends the previous time-dependent thermal Comptonization model of Kroon & Becker (2016) in order to include the effect of bulk Comptonization in the converging flow. We find that the model is able to reproduce the observed soft X-ray time lags in active galaxies such as 1H0707-495 without the requirement of spatial reverberation. Although the model is isothermal and does not include general relativistic effects, we believe that the results are suggestive of the important role of thermal and bulk Comptonization in producing soft X-ray time lags.

**Author(s):** Peter A. Becker, David Baughman

**Institution(s):** George Mason University

#### **130.04 - Mapping the contracting corona in a new black hole transient with NICER(Erin Kara)**

The geometry of the accretion flow around stellar-mass black holes can change on timescales of days to months. When a black hole emerges from quiescence it has a very hard X-ray spectrum produced by a hot corona, and then transitions to a soft spectrum dominated by emission from a geometrically thin accretion disc extending to the innermost stable circular orbit. Much debate, however, persists over how this transition occurs, whether it is driven largely by a reduction in the truncation radius of the disc or in the spatial extent of the corona. Observations of X-ray reverberation lags in supermassive black hole systems suggest that the corona is compact and that the disc extends in close to the central black hole. Observations of stellar mass black holes, however, reveal equivalent (mass-scaled) reverberation lags that are much larger, leading to the suggestion that the accretion disc in the hard state of stellar mass black holes is truncated out to hundreds of gravitational radii. Here we report X-ray observations of the new black hole transient MAXI J1820+070. We find that the reverberation time lags between the continuum-emitting corona and the irradiated accretion disc are 6-20 times shorter than previously seen. The timescale of the reverberation lags shortens by an order of magnitude over a period of weeks, while the shape of the broadened iron K emission line remains remarkably constant. This suggests a reduction in the spatial extent of the corona, rather than a change in the inner edge of the accretion disc.

**Author(s):** Erin Kara,

**Institution(s):** University of Maryland, NASA Goddard Space Flight Center  
**Contributing Team(s):** NICER Observatory Science Working Group

#### **130.05 - Time-domain astrophysics of galactic nuclei in radio to submillimeter(Q. Daniel Wang)**

I will briefly review ideas as to how a joint monitoring program at radio to submillimeter wavelengths may be used to study the relativistic jet formation and circumnuclear environment of supermassive black holes. At least some tidal disruption events (TDE) of (sub-)stellar objects around black holes form relativistic jets. Such a jet can first be detected in (sub)millimeter and only gradually become optically thin and observable at longer wavelengths. The jet evolution depends strongly on the density structure of the circumnuclear gas, including the accretion flow, while its associated magnetic field can be traced by the Faraday's rotation of polarization as a function of time. I will use the nearest known TDE, IGR J12580+0134, in NGC 4845 ( $d = 17$  Mpc) that we have extensively studied recently as an example to illustrate both the existing feasibility and the potential power of such a (sub)millimeter to radio follow-up program.

**Author(s):** Q. Daniel Wang

**Institution(s):** University of Massachusetts Amherst

#### **130.02D - Modeling Variability and non-Kerr Spacetime Effects in Black Hole Images(Lia Medeiros)**

The Event Horizon Telescope (EHT), a mm-wavelength very long baseline interferometer (VLBI), aims to take the first ever resolved image of a black hole at event horizon scales. I will discuss how I use numerical simulations to characterize the effect of intrinsic source variability and deviations from the Kerr geometry on interferometric observables. I show that intrinsic source variability will significantly affect conventional image reconstruction techniques and that variability must be taken in to account for both image synthesis and model fitting. Furthermore, I explore the utility of Principal Component Analysis (PCA) to characterize the structural variability in GRMHD simulations of Sgr A\* and find that simulations can be compactly represented with a PCA-derived basis of eigenimages. This allows for detailed comparisons between variable observations and time-dependent models. Finally, I use parametrized metrics that deviate from the Kerr metric and that can be used to approximate several modified gravity theories, to simulate a large number of black hole shadows. I apply PCA to the set of shadows and show that only a handful of "eigen-shadows" are necessary to reconstruct the full set of non-Kerr and Kerr shadows.

**Author(s):** Lia Medeiros,

**Institution(s):** University of Arizona, University of California-Santa Barbara

#### **131 - Supernovae II**

##### **131.01 - Superluminous Supernovae in LSST: Rates, Detection Metrics, and Light Curve Modeling(Victoria Ashley Villar)**

We explore and demonstrate the capabilities of LSST to study Type I superluminous supernovae (SLSNe). We first fit the light curves of 58 known SLSNe at  $z \sim 0.1-1.6$ , using an analytical magnetar spin-down model implemented in MOSFiT. We then use the posterior distributions of the magnetar and ejecta parameters to generate thousands of synthetic SLSN light curves, and we inject those into the OpSim to generate realistic ugrizy light curves. We define simple, measurable metrics to quantify the detectability and utility of the light curve, and to measure the efficiency of LSST in returning SLSN light curves satisfying these metrics. We combine the metric efficiencies with the volumetric rate of SLSNe to estimate the overall discovery rate of LSST, and we find that  $\sim 10^4$  SLSNe per year with  $>10$  data points will be discovered in the WFD survey at  $z < 3.0$ , while only  $\sim 15$  SLSNe per year will be discovered in each DDF at  $z < 4.0$ . To evaluate the information content in the LSST data, we refit representative output light curves with the same model that was used to generate them. We correlate our ability to recover magnetar and ejecta parameters with the simple light curve metrics to evaluate the most important metrics. We find that we can recover physical parameters to within 30% of their true values from  $\sim 18\%$  of WFD light curves. Light curves with measurements of both the rise and decline in gri-bands, and those with at least fifty observations in all bands combined, are

most information rich, with ~30% of these light curves having recoverable physical parameters to ~30% accuracy. WFD survey strategies which increase cadence in these bands and minimize seasonal gaps will maximize the number of scientifically useful SLSN light curves. Finally, although the DDFs will provide more densely sampled light curves, we expect only ~50 SLSNe with recoverable parameters in each field in the decade-long survey.

**Author(s):** Victoria Ashley Villar, Matt Nicholl, Edo Berger

**Institution(s):** Harvard, University of Edinburgh

### **131.03 - The Zwicky Transient Facility Bright Supernova Survey(Christoffer Fremling)**

We present the Zwicky Transient Facility (ZTF) Bright Transient Survey (BTS). The BTS is a public, and the survey has two components: (1) We publicly report all bright ( $<19$  mag) SN candidates found by the ZTF Northern Sky Survey to the Transient Name Server (TNS). (2) An IFU (SEDM) mounted on the Palomar 60 inch (P60) telescope is used to obtain classification spectra of these SN candidates. All P60/SEDM classifications are reported to TNS. The primary motivation for the BTS is to measure the fraction of  $z < 0.1$  galaxies that have cataloged redshifts, or the redshift completeness factor (RCF; see Kulkarni et al., 2018). Preliminary estimates of the RCF show that  $< 75\%$  of  $z < 0.03$  galaxies are cataloged, based on observations of brighter than 17 mag SNe from the ASAS-SN survey. Since the start of the BTS (2018 May 1st) until submission of this abstract (2018 Sept. 30) we have successfully classified 304 SN Ia and 96 core collapse SNe. Thus, we estimate that BTS will obtain spectra of ~900 SNe Ia over the course of 1 year, making it one of the largest systematic and untargeted SN surveys ever conducted. By increasing the sample size by nearly a full order of magnitude relative to what was possible with ASAS-SN, the BTS will enable more precise measurements of the RCF, while also extending the measurements beyond  $z = 0.03$ . Improved measurements of the RCF will help inform electromagnetic follow-up to LIGO gravitational wave events (e.g., Gehrels et al., 2016), and provide the necessary correction factors for transient rate measurements based on volume-limited samples selected from wide field-surveys, such as ZTF. Beyond the RCF, the BTS will enable a plethora of additional science ranging from SN Ia cosmography to a measurement of the core collapse SN luminosity function (see Kulkarni et al., 2018).

**Author(s):** Yashvi Sharma, Shrinivas Kulkarni, Christoffer Fremling, Dan Perley, Adam Miller, Alison Dugas

**Institution(s):** Caltech, LJMU, Northwestern, IIT Bombay  
Contributing Team(s): Zwicky Transient Facility Collaboration

### **131.05 - Low Redshift Superluminous Supernovae Discovered By Zwicky Transient Facility(Lin Yan)**

The Zwicky Transient Facility has started science operation since April 2018 with a 3-day cadence public survey over

northern sky, plus higher cadence surveys over smaller areas. In this talk, I will present the early results on Superluminous Supernovae discovered by ZTF.

**Author(s):** Ragnhild Lunnan, Dan Perley, Lin Yan, Steve Schulze, Avishay Gal-Yam

**Institution(s):** California Institute of Technology, Stockholm University, The Weizmann Institute of Science, Astrophysics Research Institute

### **131.06 - Infant Supernovae from ZTF(Avishay Gal-Yam)**

The Zwicky Transient Facility (ZTF) has begun full operations in mid-2018 and conducts a high-cadence (several visits per night) survey for transients in selected sky areas. Discovery of infant supernova (SN) explosions, within a day of explosion, is one of the main science goals of this survey. I will review the results obtained by this project so far, including the discovery of multiple very young SNe, spectroscopic studies ("flash spectroscopy") of these events, and detections of rapid transients (both rapidly rising and rapidly declining). Focussed follow-up efforts of day-old transients offer rich scientific rewards.

**Author(s):** Avishay Gal-Yam

**Institution(s):** Weizmann Institute of Science  
Contributing Team(s): The ZTF Physics of SN working Group

### **131.02D - Needles in a Haystack: Searching for Exotic Transients in the Era of Wide-Field Surveys(Peter K. Blanchard)**

The advent of wide-field transient searches has dramatically increased the transient discovery rate and directly led to uncovering new phenomena, such as superluminous supernovae (SLSNe) and tidal disruption events (TDEs). However, the opportunity offered by modern surveys requires careful consideration of methods for efficiently identifying these rare transients. My thesis project addresses this challenge by focusing on SLSNe and TDEs to develop techniques that are critical to maximizing the scientific return from ZTF and future surveys like LSST. This program draws on data streams from all ongoing optical time-domain surveys using a custom aggregator software that makes use of contextual host galaxy information to select promising candidates. In addition to increasing the identification rate of SLSNe and TDEs, science goals include connecting the early-time behavior and diversity of SLSNe with their late-time properties to form a complete picture of the power sources and ejecta properties, and to understand the influence of host environments on TDE properties. To date, we have achieved a SLSN/TDE identification rate of about 20%, a significant increase over previous efforts, and many of our classified SLSNe and TDEs have led to new insights. From deep late-time observations we have placed the most stringent constraints to date on the presence of radioactive material in SLSNe. While this firmly rules out the decay of nickel as the

dominant power source of the peak luminosities, at least some SLSNe have a large iron-group element abundance similar to SNe associated with long gamma-ray bursts, providing a new link between SLSNe and engine-powered gamma-ray bursts. In addition, we have found more SLSNe which show deviations from a uniform decline, helping to map out their diverse light curves. Finally, our program uncovered a TDE in a Seyfert galaxy, leading to interaction of the stellar debris with the pre-existing accretion disk. The emerging sample of TDEs in galaxies hosting an AGN suggests they may exhibit more efficient accretion than TDEs in quiescent galaxies.

**Author(s):** Peter K. Blanchard

**Institution(s):** Harvard University

### **131.04D - Hunting for Hidden Explosions with Spirits(Jacob E Jencson)**

The census of nearby core-collapse supernovae and other energetic massive star outbursts, even in the local 40 Mpc volume, is incomplete. Despite enormous progress enabled by wide-field transient surveys, the majority of which are operating in the optical, many such events are missed due to the obscuring effects of dust. Searches in the infrared, where these effects are significantly reduced, offer an ideal platform to discover missing stellar explosions and tackle outstanding issues related to (1) the missed fraction of core-collapse supernovae by optical searches and implications for rate measurements, (2) the progenitor systems of obscured supernovae and whether heavily extinguished events may represent new populations stemming from extreme environmental conditions, and (3) uncovering the full landscape of non-terminal massive star eruptive and explosive activity. My thesis is based on a novel search for infrared transients in nearby galaxies called SPIRITS (SPitzer InfraRed Intensive Transients Survey), an ongoing monitoring campaign of galaxies within 40 Mpc in the 3.6 and 4.5 micron imaging bands of the IRAC camera aboard the Spitzer Space Telescope. In the first five years, SPIRITS has detected 131 infrared transients (including 7 classical novae, 49 optically known supernovae, and 75 unusual events) and 2536 strong infrared variables. In this talk, I will present a sample of the 9 most luminous transients discovered by SPIRITS with detailed characterizations in the optical, infrared and radio. 5 of these events, with extinction estimates spanning 2-9 visual magnitudes, are likely heavily dust-obscured core-collapse supernovae that despite their proximity were completely missed by any optical search. The remaining events span diverse classifications including a massive stellar merger, weak or electron-capture supernovae, and multiple dust-forming, self-obscuring outbursts from evolved massive stars. This work addresses fundamental questions in evolution and deaths of massive stars, and points towards a bright future for the systematic exploration of the dynamic infrared sky.

**Author(s):** Jacob E Jencson

**Institution(s):** California Institute of Technology  
Contributing Team(s): SPIRITS Team

## **132 - Spiral Galaxies**

### **132.03 - Radial Star Formation Histories in 32 Nearby Galaxies(Daniel Dale)**

Deep optical and near-infrared imaging is combined with archival ultraviolet and infrared data for 32 nearby galaxies mapped in the Spitzer Extended Disk Galaxy Exploration Science survey. These images are particularly deep and thus excellent for studying the low surface brightness outskirts of these disk-dominated galaxies. Results from spectral energy distribution modeling will be presented, including radial trends in the star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461.

**Author(s):** Carolyn Drake, F. Alexander Slane, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Louis Marlon Bran, Nathan Lee, Jordan Turner, Henry Kobulnicky, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Kristin Anderson

**Institution(s):** University of Wyoming, Cal State UChannel Islands, Cal State ULong Beach, Whitman College, East Tennessee State U., Cerritos College, Colgate University  
Contributing Team(s): EDGES Team

### **132.04 - Timeslicing Spiral Galaxy Spectral Data Cubes in SDSS-IV MaNGA(Michael Merrifield)**

Integral field unit surveys like SDSS-IV MaNGA are generating large amounts of high-quality spectral data from large numbers of spiral galaxies, and spectral analysis codes have advanced to the point where such spectra can be decomposed into the underlying stellar components from which they are formed. Here, we illustrate the power of combining these developments to show how spiral galaxies can be timesliced into components that reveal the sequence in which these systems formed. We can also identify quite subtle temporal features such as the signature of a density wave propagating around the galaxy triggering star formation as it travels, allowing us to confirm the presence of such a wave and test whether it is propagating with a single pattern speed.

**Author(s):** Kyle Westfall, Coleman Krawczyk, Anne-Marie Weijmans, Michael Merrifield, Niv Drory, Karen Masters, Alfonso Aragon-Salamanca, Thomas Peterken

**Institution(s):** University of Nottingham, University of Portsmouth, University of Texas at Austin, University of St Andrews, Haverford College, UCO Lick  
Contributing Team(s): The MaNGA SDSS-IV Team

### **132.05 - SDSS IV MaNGA: Characteristics of edge-on galaxies with counter-rotating gaseous and stellar disks(Minje Beom)**

In the course of a study of the kinematics of extra-planar ionized gas in disk galaxies with data from the SDSS-IV MaNGA survey, we identified four edge-on galaxies in which the gas and stars rotate in opposite directions within a co-planar disk. The counter-rotating disks are of substantial size, of similar extent

to the stellar rotating disks. We analyze the kinematics and metallicities of stars and gas in the galaxies and compare them to a control sample of galaxies with similar stellar mass in order to see how the properties of stars and gas in the counter-rotating galaxies differ from those in normally rotating spirals. The four counter-rotating galaxies show relatively low star formation rate in the disk compared to the control samples. One of the counter-rotating galaxies has a metal-rich region in the gas disk which seems connected to a small "tail" feature in deep optical imaging. This may provide direct evidence of an external origin of the gas in support of the likely scenario that all counter-rotating gas disks were accreted. We will discuss possible scenarios for the accretion events. RAMW and MB acknowledge partial support for this work from the NSF under Grant No AST-1615594

**Author(s):** Rene Walterbos, Minje Beom, Yanmei Chen, Dmitry Bizyaev,

**Institution(s):** New Mexico State University, Nanjing University, Apache Observatory Contributing Team(s): Minje Beom

### **132.06 - Hot Gaseous Halos Around L\* Galaxies from S-Z Measurements(Joel N. Bregman)**

The Sunyaev-Zel'dovich effect, commonly seen around galaxy clusters, has been detected around large stacks of massive galaxies. We show that the signal should also be visible around nearby L\* galaxies due to their larger size and, from Planck SZ maps, we studied the signal for a dozen L\* galaxies with  $2 \text{ Mpc} < D < 10 \text{ Mpc}$ . A few individual galaxies are detected but the signal is more robust when they are stacked, where the median signal is detected to at least 100 kpc and implying a gas mass of  $\sim 5E10 \text{ Msun}$  to  $R_{200}$ . This is a significant mass component, comparable to the stellar component, although less than the missing baryons.

**Author(s):** Zhijie Qu, Joel N. Bregman, Edmund Hodges-Kluck

**Institution(s):** University of Michigan, Goddard Space Flight Center

### **132.07 - The HI mass function of group galaxies in the ALFALFA survey(Kelley Hess)**

We present the HI mass function (HIMF) of group galaxies based on combining four popular optically defined galaxy group catalogs from SDSS (Berlind et al, Tempel et al, Yang et al, and Lim et al) with knowledge of the neutral atomic gas (HI) content of the galaxies measured by the ALFALFA survey. We significantly improve on the statistical foundation of previous work: the four HIMFs we construct from each of the four group catalogs have approximately two to three orders of magnitude more groups and two orders of magnitude more HI detected galaxies contributing the mass function than previous attempts to measure the group HIMF. Broadly speaking, we find the group HIMF differs from the global HIMF by having an

approximately flat low mass slope, and a knee mass which is marginally higher than the global HIMF. More strictly speaking, we find there is no universal group galaxy HIMF: the different methods of constructing group catalogs lead to differences in the group HIMF. Thus a comparison of the HIMF between different groups or group catalogs requires a comparison between how the groups were constructed before the results can be interpreted. Indeed, the attempt to construct a universal group HIMF has shed light on the caveats of existing group catalogs as they are compared to one another.

**Author(s):** Lourdes Verdes-Montenegro, Elizabeth Adams, Kelley Hess, Michael Jones

**Institution(s):** Kapteyn Astronomical Institute, Instituto de Astrofísica de Andalucía, ASTRON

### **132.02D - New Photometry and Bar Properties of Barred Low Surface Brightness Galaxies(Wesley Peters)**

Using optical B- and I-band images taken with the ARCTIC imager on the 3.5m APO telescope, we present optical bar properties and relative bar pattern speeds of 15 barred low surface brightness galaxies (LSBs) identified from two large LSB catalogs. We find that bars in LSBs are shorter and weaker when compared to those in high surface brightness galaxies (HSBs). We find that 13 of the 15 galaxies in our sample are hosts to 'fast' bars, contrary to expectations from LCDM numerical simulations. We also obtain surface brightness profiles, magnitudes and (B-I) colors for 11 galaxies that have no previous data available. We find that barred LSBs are brighter than unbarred LSBs, but have comparable disk scale lengths. When using available HI 21cm fluxes, we find our barred LSBs to be just as gas rich as unbarred LSBs. We place our results in context with HSBs and expectations from cold dark matter simulations.

**Author(s):** Wesley Peters

**Institution(s):** Georgia State University

### **Open Slot 132.01 Moved**

**Author(s):**

**Institution(s):**

### **133 - Pulsars in Binaries**

#### **133.01 - Disk-Jet Alignment in the Microquasar GRO J1655-40(Greg Salvesen)**

Conventional theory predicts alignment between three axes of a microquasar system: the black hole spin axis, the relativistic jet axis, and the rotational axis of the inner regions of a geometrically thin, optically thick accretion disk. These axes need not be aligned to the binary orbital axis. Using five

Swift/XRT observations of the microquasar GRO J1655-40 in the high/soft state, we fit these data using a Markov chain Monte Carlo analysis that incorporates Gaussian priors to leverage our knowledge of independent constraints on known system parameters. The data strongly reject the binary orbital inclination as an imposed prior on the inner disk inclination, regardless of the choice for black hole spin. Instead, the data require a near edge-on disk inclination  $\sim 85^\circ$ , which is consistent with the relativistic jet axis inclination of  $85^\circ \pm 2^\circ$ . This is evidence for disk-jet alignment and provides independent confirmation of a  $\sim 15^\circ$  misalignment between the angular momenta of the black hole and binary orbit in GRO J1655-40.

**Author(s):** Omer Blaes, John Tomsick, Jordan Mirocha, Greg Salvesen

**Institution(s):** University of California, Santa Barbara, McGill University, Space Sciences Laboratory

### **133.02 - Neutron Stars and Black Holes in the Small Magellanic Cloud: The NuSTAR SMC Legacy Project(Margaret Lazzarini)**

We present initial results from a new NuSTAR Legacy Survey, the deepest hard X-ray ( $E > 10$  keV) study of the Small Magellanic Cloud (SMC). We have observed tens of X-ray sources in three fields along the main body of this nearby star-forming galaxy; these three fields were chosen for their stellar and accreting binary populations. Each field was observed 2-3 times, totalling approximately 200 ks of exposure time per field. Given the proximity of the SMC ( $\sim 60$  kpc), we are able to reach lower luminosity limits ( $L_x > \sim 10^{34}$  erg/s) than is possible for other extragalactic X-ray binary (XRB) populations. We also have the advantage of low overall extinction by observing the SMC. Previous studies of the XRB population in the SMC with softer X-rays ( $E < 10$  keV) have revealed a large Be-XRB population dominated by accreting pulsars, and with a noticeable absence of confirmed black-hole XRBs. Studying the XRB population of the SMC with NuSTAR allows us to place constraints on the compact object type due to spectral differences between accreting black holes and neutron stars in the hard X-rays ( $E > 10$  keV). In particular, by comparing the X-ray colors and luminosities of SMC XRBs with those of Galactic XRBs of known compact object type, we are able to place constraints on the nature of the accretors in these systems. Combined with age estimates from published star formation history maps, we are able to place constraints on formation timescales for compact object populations.

**Author(s):** Andreas Zezas, Daniel Wik, Neven Vulic, Vallia Antoniou, Mihoko Yukita, Margaret Lazzarini, Frank Haberl, Ann Hornschemeier, Benjamin F Williams

**Institution(s):** University of Washington, NASA Goddard Space Flight Center, Code 66, Harvard-Smithsonian Center for Astrophysics, Department of Physics and Astronomy, University of Utah, Department of Physics and Astronomy, Johns Hopkins University, Max-Planck-Insti

### **133.03 - Signatures of intra-binary shock in the pulsar binary PSR J2241-5236(Hongjun An)**

We report on our investigation of intra-binary shock (IBS) emission in the black widow pulsar binary PSR J2241-5236. In 9-yr Fermi-LAT data we find significant orbital modulation at low energies below 1 GeV. We interpret this using an IBS scenario in pulsar binaries and infer the bulk Lorentz factor in the shocked flow to be  $\sim 1$ . In addition, we find evidence for non-thermal emission in the X-ray spectrum. However, due to limited counts in these 20-ks Chandra data a meaningful X-ray light curve cannot be constructed. We have collected optical observations of the binary, which can help constrain the geometry, but more complete understanding of the IBS beaming and energetics will need a more sensitive X-ray measurement.

**Author(s):** Hongjun An, Roger W. Romani

**Institution(s):** Chungbuk National University, Stanford University Contributing Team(s): The Fermi LAT collaboration

### **133.04 - NICER observations of the 2018 outburst of the black hole candidate MAXI J1727-203(Kevin Alabarta)**

MAXI J1727-203 is a new transient discovered in June, 5 2018, and due to its spectral properties at the beginning of the outburst it was identified as a black hole candidate. MAXI J1727 has been monitored with Neutron Star Interior Composition Explorer (NICER) on almost daily basis since the beginning of the outburst. In this talk we will present the spectral and timing analysis of  $\sim 4$  months of observations (more than 75 observations). Preliminary results suggest a significant detection of a cool disk ( $\sim 0.2$  keV) and a strong hard component at the end of the outburst. We will show that MAXI J1727 might have undergone the soft-to-hard transition at 0.5-10 keV luminosities  $\sim 10^{36}$  erg/sec. This source is the the 3rd system in which we have detected the soft-to-hard transition at such low X-ray luminosities.

**Author(s):** Mariano Mendez, Diego Altamirano, Kevin Alabarta, Ronald Remillard

**Institution(s):** University of Southampton, MIT Kavli Institute, Kapteyn Astronomical Institute Contributing Team(s): NICER Team

### **133.05 - Precision X-ray Timing of HM Cnc with NICER: Probing the Evolution of the Most Compact Binary Known(Tod E Strohmayer)**

HM Cnc is a double-degenerate binary with the shortest orbital period presently known. The 5.36 minute orbital period is seen as a large amplitude, soft X-ray modulation, likely from a hot-spot produced by direct impact accretion. With such a short orbital period the source is expected to have a gravitational wave luminosity comparable to or larger than that in the X-ray, and its orbital evolution should be strongly influenced by the



angular momentum lost to gravitational radiation. Previous X-ray observations have shown that the period is decreasing at a rate consistent with that expected for a detached system radiating gravitational waves, however, long term accretion should eventually drive the components apart. Evolutionary calculations suggest a spin-up phase can persist past initial contact, and we may be seeing this in the X-ray timing, but a longer temporal baseline is needed to test this hypothesis. NICER observed HM Cnc in 2017 October and November, extending the long-term X-ray timing baseline to more than 16 years. Combined with prior X-ray measurements, this enables a new, sensitive probe of the system's orbital evolution. NICER observations clearly detect the 5.36 minute orbital period, and the X-ray modulation profile is consistent with prior measurements. We present results of a phase timing analysis, including new constraints on the orbital evolution parameters, and discuss the implications for evolutionary scenarios in this and similar systems. NICER is a 0.2-12 keV X-ray telescope operating on the International Space Station. The NICER mission and portions of the NICER science team activities are funded by NASA.

**Author(s):** Tod E Strohmayer

**Institution(s):** NASA/GSFC Contributing Team(s): on behalf of the NICER Observatory Science Working Group

### **133.06 - On the Nature of the Donor Star in 4U 1626-67(Paul Britton Hemphill)**

Ultracompact X-ray binaries (UCXBs) are binaries with a neutron star accretor and an orbital period less than 80 minutes. Here, I focus on our comprehensive review of Chandra observations of the unique UCXB 4U 1626-67, the only known UCXB to host a strongly-magnetized accreting pulsar. The hydrogen- and helium-depleted donor star in this system has been variously suggested to be an eroded helium star or a white dwarf with a CO or ONeMg composition. The Chandra gratings data unambiguously confirm previous reports of anomalously high neon abundance in the system, while simultaneously ruling out the presence of magnesium, which is difficult to reconcile with any of the possible donor compositions. Additionally, the pulsar's luminosity is approximately two orders of magnitude in excess of what evolutionary models predict for UCXBs like 4U 1626-67. I will review the existing literature on this source and UCXBs in general and present some possible paths forward to reconcile these apparently-contradictory results.

**Author(s):** Deepto Chakrabarty, Herman Marshall, Paul Britton Hemphill, Norbert Schulz

**Institution(s):** Massachusetts Institute of Technology

### **133.07 - Puzzling Emission Lines from the Optical Spectrum of NGC 4861 X-1(Hang Gong)**

The blue compact dwarf galaxy NGC 4861 (distance of  $\sim 10$  Mpc) contains a very interesting example of

ULX (variable X-ray luminosity,  $L_{\rm X} \sim \text{a few } \times 10^{39} \text{ erg s}^{-1}$ ) surrounded by an ionized nebula (Yang 2012; Thuan et al. 2014). It is a metal-poor galaxy ( $Z \approx 0.13 Z_{\odot}$ ; Mapelli et al. 2011), that reproduces some of the star-forming conditions that must have been prevalent in the early universe. We took a low-resolution optical spectrum of the nebula with the OSIRIS spectrograph on the GTC, in 2018 March, (2  $\times$  1200 s exposures) and found an intriguing set of emission lines (Gong et al. 2018, in prep.). The most significant one is an emission line at  $\lambda = 5172 \text{ \AA}$  in the OSIRIS spectrum that do not have any plausible identification and do not appear in other ULX nebulae or HII regions. This could be an instrumental problem of cross-contamination from the second-order spectrum; Or they could be highly redshifted or blueshifted lines, such as the ones we found in the optical spectrum of a bright source in M81 (Liu et al. 2015), which proved for the first time the existence of a baryonic jet from a ULX.

**Author(s):** Yu Bai, Roberto Soria, Jifeng Liu, Hang Gong

**Institution(s):** NAOC, UCAS

### **133.08 - A Candidate Colliding-Wind Binary in M33(Kristen Garofali)**

Colliding-wind binaries (CWBs), binaries containing Wolf-Rayet and OB stars that emit X-rays via strong wind interactions, are an observational touchstone for studies of stellar winds and mass loss, and their effect on massive star evolution. Multiwavelength observations of CWBs in the Galaxy and Magellanic Clouds (MCs) have revealed these systems to be important probes of short-lived phases of massive star evolution, particularly in the context of the effect of binarity on massive star evolution. Extending the sample of observed CWBs beyond the MCs has been hindered due to their relatively faint X-ray luminosities ( $\sim 10^{35} \text{ erg s}^{-1}$ ), and the rarity of observed systems given the short lifetimes of the massive components. I present identification of an X-ray bright candidate CWB in M33, the first such system observed beyond the MCs. I provide constraints on the parameters of the binary, including characterization of the WC type primary star on the basis of ground-based spectroscopy, and preliminary constraints on the periodicity from X-ray and optical light curves. I will discuss these results in the context of other known CWB systems, and the evolution of massive binaries.

**Author(s):** Emily Levesque, Benjamin F Williams, Kristen Garofali

**Institution(s):** University of Arkansas, University of Washington

### **133.09 - A Study of the 20 Day Superorbital Modulation in the High-Mass X-ray Binary IGR J16493-4348(Joel Barry Coley)**

We report on Nuclear Spectroscopic Telescope Array (NuSTAR), Swift X-ray Telescope (XRT) and Swift Burst Alert

Telescope (BAT) observations of IGR J16493-4348, a wind-fed Supergiant X-ray Binary (SGXB) showing significant superorbital variability. From a discrete Fourier transform of the BAT light curve, we refine its superorbital period to be  $20.058 \pm 0.007$  days. The BAT dynamic power spectrum and a fractional root mean square analysis both show strong variations in the amplitude of the superorbital modulation, but no observed changes in the period were found. The superorbital modulation is significantly weaker between MJD 55,700 and MJD 56,300. The joint NuSTAR and XRT observations, which were performed near the minimum and maximum of one cycle of the 20 day superorbital modulation, show that the flux increases by more than a factor of two between superorbital minimum and maximum. We find no significant changes in the 3-50 keV pulse profiles between superorbital minimum and maximum, which suggests a similar accretion regime. Modeling the pulse-phase averaged spectra we find a possible Fe K $\alpha$  emission line at 6.4 keV at superorbital maximum. The feature is not significant at superorbital minimum. While we do not observe any significant differences between the pulse-phase averaged spectral continua apart from the overall flux change, we find that the hardness ratio near the broad main peak of the pulse profile increases from superorbital minimum to maximum. This suggests the spectral shape hardens with increasing luminosity. We discuss different mechanisms that might drive the observed superorbital modulation.

**Author(s):** Aaron B. Pearlman, Felix Fuerst, Gregory Huxtable, Robin Corbet, Joel Barry Coley, Hans Krimm, Katja Pottschmidt,

**Institution(s):** Howard University Department of Physics & Astronomy, University of Maryland, Baltimore County, CRESST/Mail Code 66, Astroparticle Physics Laboratory, NASA Goddard Space Flight Center, European Space Astronomy Center (ESA/ESAC), CRESST/Mail Code 66, X-

## 134 - AGN Black Holes II

### 134.01 - Luminous WISE-selected Obscured, Unobscured, and Red Quasars in Stripe 82 (Eilat Glikman)

We present a spectroscopically complete sample of 147 infrared-color-selected active galactic nuclei (AGNs) down to a  $22 \text{ } \mu\text{m}$  flux limit of 20 mJy over the  $\sim 270 \text{ deg}^2$  of the Sloan Digital Sky Survey Stripe 82 region. Most of these sources are in the QSO luminosity regime ( $L_{\text{bol}} > 10^{12} L_{\odot}$ ) and are found out to  $z \sim 3$ . We classify the AGNs into three types, finding 57 blue, unobscured Type-1 (broad-lined) sources; 69 obscured, Type-2 (narrow-lined) sources; and 21 moderately reddened Type-1 sources (broad-lined and  $E(B - V) > 0.25$ ). We study a subset of this sample in X-rays and analyze their obscuration to find that our spectroscopic classifications are in broad agreement with low, moderate, and large amounts of absorption for Type-1, red Type-1, and Type-2 AGNs, respectively. We also investigate how their X-ray luminosities correlate with other known bolometric luminosity indicators such as [O III] line luminosity ( $L_{\text{[O III]}}$ ) and infrared luminosity ( $L_{\text{IR}}$ ). While the X-ray correlation with  $L_{\text{[O III]}}$  is consistent with previous findings, the most infrared-

luminous sources appear to deviate from established relations such that they are either underluminous in X-rays or overluminous in the infrared. Finally, we examine the luminosity function evolution of our sample, and by AGN type, in combination with the complementary, infrared-selected, AGN sample of Lacy et al. (2013), spanning over two orders of magnitude in luminosity. We find that the two obscured populations evolve differently, with reddened Type-1 AGNs dominating the obscured AGN fraction ( $\sim 30\%$ ) for  $L_{\text{IR}} > 10^{45} \text{ erg s}^{-1}$ , while the fraction of Type-2 AGNs with  $L_{\text{IR}} < 10^{45} \text{ erg s}^{-1}$  rises sharply from 40% to 80% of the overall AGN population.

**Author(s):** S. G. Djorgovski, Claudia Megan Urry, Mark Lacy, Eilat Glikman, Tanya Urrutia, Daniel Stern, Matthew Graham, Elinor Gates, Henry Daniels-Kocho, Carol Hundal, Larson Lovdal, Stephanie LaMassa, Milena Crnogorčević,

**Institution(s):** Yale University, Bowdoin College, UCO/Lick Observatory, Middlebury College, NRAO, University of Hawaii (IfA), Jet Propulsion Laboratory, STScI, Leibniz Institut für Astrophysik, California Institute of Technology, Wellesley College, University

### 134.02 - A Radio Search for Massive Black Holes in Dwarf Galaxies (Amy Reines)

Searching for and studying massive black holes (BHs) in nearby dwarf galaxies is currently our best observational probe of the origin of the first “seed” BHs in the earlier Universe. Here we present the first large-scale radio search for massive BHs in dwarf galaxies using high-resolution observations with the Very Large Array (VLA). Our targets were selected by cross matching galaxies with stellar masses less than  $3 \times 10^9$  solar masses and redshifts less than 0.055 in the Sloan Digital Sky Survey with the VLA FIRST Survey that has  $5''$  resolution at 20 cm. We observed 111 radio-selected dwarf galaxies with the VLA in the A-configuration at 10 GHz and detected compact radio emission ( $\sim 0.25''$ ) in 39 of our target galaxies. We consider various possible origins for the compact radio emission including thermal HII regions, supernova remnants, young radio supernovae, and AGNs. Our analysis demonstrates that AGNs are almost certainly responsible for the compact radio emission in at least 10 of our target dwarf galaxies, despite that the SDSS optical emission line ratios are dominated by star formation. This work highlights the promise of deep, high-resolution radio observations to gain a more complete understanding of the demographics of massive BHs in dwarf galaxies.

**Author(s):** Amy Reines, Jenny Greene, James Condon, Jeremiah K Darling

**Institution(s):** Montana State University, University of Colorado, NRAO, Princeton University

### 134.03 - Dwarf Galaxies Hosting Broad-line AGN on the Black Hole - Bulge Mass Relation (Zachary Schutte)

We present visible and near-IR Hubble Space Telescope (HST) imaging of seven dwarf galaxies with optically-selected broad-line AGNs and black hole (BH) mass estimates from single epoch spectroscopy. We perform 2D photometric modeling with GALFIT to investigate the structure of these galaxies and to determine where these systems fall on the BH-bulge mass relation. We find a large variety of morphologies in our sample of dwarf galaxies, with the majority having an inner bulge/pseudobulge component within an exponential disk. Using the modeling results and well known color-dependent mass-to-light ratios, we determine the stellar mass of each photometric component in each galaxy. We place our sample on the  $M_{\text{BH}} - M_{\text{bulge}}$  scaling relation along with a comparison sample of 79 galaxies with dynamical BH masses, in addition to a few other dwarf galaxies known to host AGN. We find a strong correlation between BH mass and bulge mass with  $\log(M_{\text{BH}}) \sim \log(M_{\text{bulge}})^{1.30}$ , which is slightly steeper than correlations found previously when only considering higher mass elliptical and classical bulge systems.  
**Author(s):** Amy Reines, Zachary Schutte  
**Institution(s):** Montana State University

#### **134.04 - The Effects of Disk Thickness on AGN Reflection and Reverberation(Corbin Taylor)**

The AGN reflection spectrum and its associated reverberation, believed to be the result of reprocessing of X-rays from a compact corona by the inner accretion disk, allow astronomers to estimate the spin of central black hole and the properties of the reprocessing material. In modelling this phenomenon, it is common to make the simplifying assumption that the disk has negligible geometric thickness (i.e. “razor-thin”), but this approximation is unlikely to hold in moderately-accreting systems due to large internal pressures resulting in a non-zero scale height. Using the new raytracing suite Fenrir, we explore the effects that disk thickness has on the X-ray spectral and timing properties of AGN, finding that the inner regions of the disk can “shield” the outer regions from the central source and thus resulting in substantial changes to the emissivity profile. The broad Fe K line (6.4-6.9 keV) and its associated timing properties were found to change drastically with disk thickness, with the late-time blue wing being truncated and the overall lag magnitude being suppressed. We conclude that neglecting disk thickness can result in significant systematic errors in estimating black hole spin and corona lamppost height once the luminosity exceeds 20% of the Eddington Limit  
**Author(s):** Corbin Taylor, Chris Reynolds,  
**Institution(s):** University of Maryland, Institute of Astronomy

#### **134.05 - Talk Moved**

**Author(s):**

**Institution(s):**

#### **134.06 - New Quasar Microlensing Constraints on the Spin of High Redshift Quasars(Xinyu Dai)**

Gravitational microlensing provides a unique probe to study the emission region of the innermost parts of quasar accretion disks and the discrete lens population in the lensing galaxy. We present new quasar microlensing constraints on the spin of high redshift quasars from a joint analysis of the excess equivalent widths of the FeK line observed in the lensed quasars. We first confirm the positive offset from the Iwasawa-Taniguchi effect for lensed quasars, and then performed microlensing analysis to constrain the emission size of the reflection region and the average spin of supermassive black holes, assuming that the X-ray corona and the reflection region, responsible for the iron emission line, both follow power-law emissivity profiles. The microlensing analysis yields an emissivity index of  $n > 5.8$  and a spin parameter of  $a > 0.9$ , suggesting that the X-ray reflection region is ultra-compact and very close to the innermost stable circular orbits of black holes, which are spinning close the maximal value. The analysis represents a new technique to measure black hole spins for high redshift quasars.

**Author(s):** Xinyu Dai, Eduardo Guerras, Shaun Steele  
**Institution(s):** University of Oklahoma

#### **134.07 - In Search of a Final-Parsec Telescope(Daniel J D'Orazio)**

Despite their importance for understanding the mutual build-up of supermassive black holes and their host galaxies, and the emission of low frequency gravitational waves, there is yet no definitive evidence for sub-parsec separation supermassive black hole binaries (SBHBs) in galactic nuclei. I will show that up to ~100's of putative SBHBs in nearby AGN have separations resolvable by mm-wavelength VLBI while also having orbital periods less than 10 years. Hence, orbital motion can be directly probed. In optical wavelengths, the astrometric precision of Gaia could similarly detect SBHB orbital motion by the end of its 5 year mission. Such observations could provide the first, and possibly only, electromagnetic form of definitive SBHB detection and also allow a precise measurement of the binary mass, or a novel measurement of the Hubble constant.

**Author(s):** Daniel J D'Orazio, Abraham Loeb  
**Institution(s):** Harvard University

#### **134.08 - The Search for Supermassive Black Hole Binaries in the Time Domain**

< />(Tingting Liu)

Supermassive black hole binaries (SMBHBs) should be common products of the hierarchical growth of galaxies and the

loudest expected sources of low-frequency gravitational waves. Periodic quasar variability has been predicted as an electromagnetic signature of SMBHBs at sub-parsec separations, due to modulated mass accretion or relativistic Doppler boosting. I will present results from a systematic search for periodically varying quasars in the Pan-STARRS1 Medium Deep Survey.

**Author(s):** Tingting Liu

**Institution(s):** University of Wisconsin - Milwaukee

### **134.09 - Bread and Butter Astrophysics with Gravitational Wave Detections(K.E. Saavik Ford)**

The LIGO measured rate of stellar mass black hole binary (sBHB) mergers can be used to constrain a variety of astrophysical processes not directly related to stellar mass black holes. In particular, the number density of stellar mass black holes in a typical nuclear star cluster, as well as the scale height, density, and lifetime of a typical AGN disk can already be usefully limited with current data. I will show current limits and explain degeneracies. I will also discuss future expectations for doing 'bread and butter astrophysics' with both LIGO and LISA measurements.

**Author(s):** K.E. Saavik Ford, Barry McKernan,

**Institution(s):** CUNY Borough of Manhattan Community College, American Museum of Natural History

### **135 - HAD III: Astronomical History: Modern Times**

#### **135.01 - Astronomers' Productive Lifetimes(Peter Broughton)**

Astronomers born since 1920 generally have had a longer formal training period than did their predecessors from the previous century when doctorates (and post-doctoral work) were less common. Does this imply that the average age at which astronomers publish their first scientific paper has increased over the years? Also, it is well-known that people generally lead longer lives now than they did in the nineteenth and early twentieth century. Should we therefore expect that the average age at which astronomers write their last paper has also increased over the years? In this paper, I attempt to answer these questions based on astronomers born between 1820 and 1919 (according to the Biographical Encyclopedia of Astronomers), supplemented with recently deceased members of the AAS as listed on their HAD Division website. I have used the SAO/NASA Astrophysics Data System (ADS) to determine the years in which their papers were published in refereed journals.

**Author(s):** Peter Broughton

**Institution(s):** Retired

#### **135.02 - AstroGen: Sixth Annual Report(Joseph S. Tenn)**

The AstroGen Team continues to compile a database of the world's astronomy-related doctoral dissertations and the institutions that have awarded the degrees. We now have approximately 27,000 theses listed. For each country we go back to the beginning of the modern Ph.D. or equivalent. More than half of the doctorates were awarded in 2000 or later. For each thesis we try to include the author (with links to a website or obituary), awarding institution, year of degree, thesis title, link to the thesis if online (nearly two-thirds are), translation of title if necessary, advisor(s), and other mentors. For universities and other doctorate-awarding institutions, we include names (both at time of degree and today), dates, and locations. Posting the database on the AAS website has been delayed by major changes in the AAS handling of IT, but we are hopeful that it will appear within the next year. I will present some summaries of our results to date and conduct a discussion of how we can expand our database. We have people currently working on France and Russia, but we need volunteers with linguistic ability and, preferably, familiarity with the academic cultures to take on Germany, Italy, and nearly all the countries of Asia.

**Author(s):** Joseph S. Tenn

**Institution(s):** Sonoma State University

#### **135.03 - Astronomy Meets the Periodic Table(Virginia Trimble)**

The world chemical community is celebrating 2019 as the 150th anniversary of Mendeleev's periodic table (there were at least 6 earlier and many later). Astronomy has been both a supplier (helium, never mind coronium and nebulium, and relative abundances of the elements not well represented on earth) and a consumer (what to look for where), though nucleosynthesis is, of course, correlated with nuclear rather than chemical properties. Among the interesting people involved over the years have been F.W. Clarke (US Geological Service and later a president of the American Chemical Society), Frederick Aston (of the mass spectrograph), Cecilia Payne (dominance of H and He in K giants), Atkinson and Houtermans (barrier penetration and something like the CNO cycle a decade before Bethe), and, most famously, A.G.W. Cameron and Burbidge, Burbidge, Fowler, and Hoyle, who put it all together in 1957. It might be fun to look back at what these colleagues and some others did.

**Author(s):** Virginia Trimble,

**Institution(s):** Univ of California Irvine, Queen Jadwiga Observatory

#### **135.04 - The Dominion Astrophysical Observatory (DAO) Celebrates 100 Years of Successes(Dennis Crabtree)**

The DAO was the world's largest operating telescope when it began operation in May, 1918, The 1.8-m telescope was the vision of John Stanley Plaskett who was also the first Director of the observatory. The DAO, and its early accomplishments firmly established Canada on the world stage of modern

astrophysics and was the foundation for 100 years of Canadian excellence in astrophysics. Construction on the telescope began just before World War I erupted and completed 6 months before the end of the war. The story of its initiation and construction is one that includes politics, international cooperation in astronomy, determination and a measure of luck!

**Author(s):** Dennis Crabtree, James E. Hesser

**Institution(s):** National Research Council Canada

### **135.05 - Aden Baker Meinel - Rocket scientist, astronomer, optical scientist, director.(James Bernard Breckinridge)**

At the age of 18 Aden was designing and fabricating optical instruments in the shops of Mt. Wilson observatory. Japan bombed Pearl Harbor during his sophomore year at Caltech and he joined the campus V-12 program of the Navy to engineer and build rockets for what became JPL. Drafted in 1944, the Navy assigned him to Patton's Army to find V-2 rocket technology. After the war, the GI bill to support the completion of his degrees in 3 years. Aden married Marjorie Pettit, a daughter of Edison Pettit who became Aden's science instrument mentor. For Aden's PhD dissertation he built a solid Schmidt spectrograph and used IR emulsions to discover the HO bands in the night sky. On the faculty at Yerkes he discovered that Protons from the sun cause Aurora and thus demonstrated the sun-earth particle connection. In 1955 Aden began site-surveys at 4 mountain tops in the SW to identify a location for KPNO. He was the founding director of KPNO. In the fall of 1961 Aden moved from KPNO to be Dir. of Steward Observatory for the three-year period before Bart Bok's arrival. Aden's reputation as a telescope builder and his writings about space telescopes attracted the interest of the Air Force space surveillance leadership. About this same time the OSA completed a study of the Nation's needs in optical science and engineering research & education. Meinel's proposals from the UofA to the NSF and the USAF to fund optical sciences research and education were funded at the several million dollars level. The Optical Sciences Center was formed in 1964 and 77,000 square foot facility was dedicated in 1967. Aden served a director until 1971, when solar energy consumed his time. Today the college of optical sciences has graduated over 2,000 scientists and engineers, occupies 180,000 sq. ft. and has over 100 teaching and research faculty. Aden received many awards during his lifetime. They include: AAS Warner Prize & Council & AIP governing board & IAU Commission #9: Vice pres. (1971-73); Pres. (1973-76) & the OSA Adolph Lomb Medal; Ives Medal; President & SPIE Kingslake & Gold Medal & Goddard awards.

**Author(s):** James Bernard Breckinridge

**Institution(s):** University of Arizona

### **135.06 - Apollo Astronaut Training at Arizona's Observatories(Kevin Schindler)**

As part of their training to explore the Moon, Apollo astronauts visited several astronomical observatories in Arizona, including Lowell, Kitt Peak, the Naval Observatory Flagstaff Station (NOFS) and the campus observatory at Arizona State College (now Northern Arizona University - NAU). This involved comparing live observations of the Moon through telescopes with photographs of the lunar surface, as well as studying charts to familiarize themselves with the depiction of topographic features. The first of this training occurred in January 1963, when the Next 9 group of astronauts traveled to Flagstaff. They visited Meteor Crater-to study an impact crater like they would see on the Moon-and Sunset Crater to explore volcanic structures. They then headed to Lowell Observatory to learn about the lunar mapping being carried out there by the Aeronautical Chart and Information Center (ACIC), a branch of the United States Air Force. Later, the astronauts split into three groups for viewing the Moon through telescopes, with one group staying at Lowell, another going to the campus observatory, and the third heading to NOFS. The following year, several smaller groups of astronauts, representing the first three classes, went to Kitt Peak during trips that also saw them study geology elsewhere in the state. At Kitt Peak they enjoyed the unusual opportunity of viewing the Moon through the McMath-Pierce Solar Telescope.

**Author(s):** William Buckingham, Kevin Schindler

**Institution(s):** Lowell Observatory, NOAO

### **135.07 - The Hubble Space Telescope and the growth of mass science(Christopher John Gainor)**

Long before it was launched in 1990, the Hubble Space Telescope (HST) was known as one of the ultimate examples of Big Science, usually thought of as massive centralized science projects. HST's first decade of operations saw scientists using it to form larger research groups than had been common for other telescopes. Driven in part by its time allocation process, HST research programs soon led to larger numbers of authors for each paper in peer-reviewed journals in astronomy and astrophysics. The creation of the HST data archive using calibrated data has made its observations available to large numbers of scientists who would otherwise not have access to them. HST has helped facilitate the shift of astronomy from a solitary pursuit to a mass activity. HST has also been impacted by the wider changes affecting astronomy, including the rise of personal computers and the internet in the 1990s. These changes fostered the creation of research groups made up of scientists from different institutions from different parts of the world. Moreover, astronomers have moved to the use of multiple instruments on Earth and in space to make their observations across the electromagnetic spectrum. This paper will examine HST's role in changes that have affected how astronomy is done since 1990. It will also place the widely publicized HST into the context of changes that have been taking place in astronomy in general.

**Author(s):** Christopher John Gainor

**Institution(s):** None

**135.08 - Radio Source Counts, Type 1a SN, and the Steady State Universe Revisted(Kenneth Irwin Kellermann)**

By the early 1960s, radio source observations made in Cambridge, UK appeared to provide convincing evidence for an evolving Universe, although radio astronomers in Sydney, Australia claimed that their data was consistent with the Steady State cosmological model. We now know that both the Cambridge and Sydney data were heavily contaminated by experimental errors, by inappropriate statistical analysis, and by a naive understanding of the theoretical predictions. The Sydney data were closer to current observations but they reached the wrong conclusions. The Cambridge data was much worse than the Sydney data; but Cambridge got the right answer. Or did they? Proponents of the Steady State cosmology argued that the Cambridge source counts could be understood in terms of a local deficiency rather than a cosmological excess. These arguments were refuted by the realization that the “local” hole would need to be hundreds of Megaparsecs in extent, a scale considered then to be “implausible.” But we now know that, indeed, there are such large scale structures in the Universe. The Steady State Universe made predictions and thus could be tested. One such prediction was that the deceleration constant,  $q_0 = -1$ , so the expansion of the Universe would be accelerating. It is interesting to speculate, how the history of cosmology might have been altered had the magnitude-redshift relation of Type 1a supernovae been recognized before the 1965 discovery of the Cosmic Microwave Background by Penzias and Wilson.

**Author(s):** Kenneth Irwin Kellermann

**Institution(s):** National Radio Astronomy Observatory

**135.09 - Historians, Meet the Square Kilometre Array: Navigating the Methodological Challenges of (Very) Contemporary History(Rebecca Charbonneau)**

Having developed in the middle of the 20th century, alongside the rise of globalization, radio astronomy is a uniquely internationalist scientific field. This talk will briefly summarize the history of international radio astronomy projects, leading up to the proposal for the Square Kilometre Array, a large, on-going international project which aims to build a radio telescope array with one-square kilometre of collecting area. Two primary questions will be addressed during this talk: First, how does the SKA fit in with the larger trend of international scientific collaborations within radio astronomy, and where does it differ? Secondly, what sort of challenges do historians face when studying highly-contemporary subjects, including projects that are still under development, as is the case with the SKA. The research this talk is based off was developed in part from the results of a summer research project at the National Radio Astronomy Observatory, using primary source documents from the collection of Kenneth I. Kellermann. It is part of a larger research project on international scientific collaboration, which is the focus of my PhD dissertation at the

University of Cambridge.

**Author(s):** Rebecca Charbonneau,

**Institution(s):** National Radio Astronomy Observatory, University of Cambridge

**136 - Instrumentation: Airborne**

**136.01 - The FIREBall-2 UV balloon telescope and 2018 flight(Erika Hamden)**

In this talk, I will describe briefly the telescope, instrument, and flight of the Faint Intergalactic medium Redshifted Emission Balloon (FIREBall-2). FIREBall-2 is a UV multi-object spectrograph fed by a 1 meter parabola mirror. The instrument was designed to observe 4 pre-selected fields and uses a UV optimized delta-doped EMCCD. The telescope flew on September 22, 2018 from Fort Sumner, NM, as part of the fall CSBF balloon campaign. The telescope collected data for several night hours before being cut down. I will describe the testing, flight, and hardware performance. Additional talks will be presented on the calibrations and data results.

**Author(s):** Erika Hamden, Christopher Martin, Bruno Milliard, David Schiminovich

**Institution(s):** University of Arizona, Laboratoire d'Astrophysique de Marseille, California Institute of Technology, Columbia University Contributing Team(s): FIREBall- Team

**136.02 - The challenging end-to-end pre-flight calibration of FIREBall-2 at the launch base(Didier Vibert)**

The NASA/CNES co-funded instrument is a balloon-borne 1-m telescope coupled to a UV (200 nm) multi-object spectrograph designed to image the circum-galactic medium (CGM) in emission from the stratosphere (~40km, 3mB). FIREBall-2 shows a wide field of view (FOV) of  $20.5 \times 37$  arcmin<sup>2</sup>, a high speed beam ( $f/2.5$ ) and a spatial and spectral resolution of respectively  $\hat{\alpha}^{1/45}$  arcsec FWHM, and  $\hat{\alpha}^{1/42000}$  ( $\hat{\alpha}/\hat{d}\hat{\alpha}$ ). Nine science or calibration masks can be selected. A guider camera in the visible uses the full pupil flux at field locations not used for UV targets. A UV multi-object spectrograph is, by its very nature, at the limit of complexity of what can be calibrated at a launch base with extremely limited GSE (Ground Support Equipment). Indeed, a major challenge of the FIREBall-2 project was to develop a 100% self-consistent method that did not require any GSE for all the pre-flight adjustments and calibration or a space facility. To this end, invaluable assets of FIREBall-2 are its siderostat which provides a full-pupil auto-collimation capability, and the good atmospheric transmission at 200 nm up to distances of a few tens meters. The auto-collimation mode has been used extensively in the calibration process, in particular to:  $\hat{\alpha}$ —□ solve the very demanding plate scale verification and absolute X, Y in-flight positioning of the targets into the 6 arc seconds slits (~80  $\hat{\alpha}^{1/4}$ m),  $\hat{\alpha}$ —□ achieve and assess a 5 arcseconds image quality over the 0.6 degree UV FOV with a  $f/2.5$  aperture ratio very sensitive to focus

changes. The auto-collimation has been completed with on-sky observation in the visible of all target fields for guidance testing and ground reference of infinity in the guider camera. A ZEMAX-coupled instrument model developed at LAM under Python has been used to support this calibration (distortion - dispersion - throughfocus analysis). This model has also been used to make an end-to-end prediction of the observations of the CGM emission from a large halo in a cosmological simulation (Ramona et al. in prep).

**Author(s):** Didier Vibert, Vincent Picouet, Bruno MILLIARD, Johan Montel

**Institution(s):** Aix Marseille Univ, CNRS, CNES, LAM, CtrNational d'Études Spatiales

### **136.03 - Direct Detections of CGM Gas with FIREBall-2: First Results(Keri Hoadley)**

Current cosmological theory predicts that galaxies get their mass from matter found between galaxies - the Interstellar Medium (IGM). One of the most compelling pieces of evidence that connects galaxy growth to the IGM and Circumgalactic Medium (CGM) is the evolution of star formation rates (SFRs). Surveys probing the pace at which galaxies form new stars (e.g., Reddy et al., 2009; Katsianis et al., 2017) show that SFRs vary over time, with SFRs at their lowest near the beginning of the universe, increasing to their peak value a few billion years after the Big Bang ( $z \sim 2$ ), and finally declining to present-day rates. The evolution of SFR over time must be physically motivated. Evidence from limited observations of gas around galaxies and computer simulations points to gas flowing into and out of galaxies. Pristine gas from the Big Bang flows into galactic halos, providing the fuel to form stars as it funnels into the dense, galactic plane. Meanwhile, stars form, evolve, and explode, expelling hot matter into the galactic halos. This exchange of matter to and from the CGM and galaxies may be the key to explaining the cosmic star formation history. A new generation of astronomical instrumentation is coming on-line to discover exactly how matter flows to and from galaxies. The Faint Intergalactic Redshifted Emission Balloon (FIREBall-2) takes advantage of state-of-the-art technology and instrument design to directly observe the IGM and CGM in emission after the epoch of peak star formation ( $z < 2$ ) for the first time. We present first results from the 2018 Ft. Sumner, NM balloon campaign in September from the first flight of FIREBall-2. FIREBall-2 was designed specifically to target HI-Lya emission, O VI, and C IV lines in the CGMs around galaxies between  $0.4 < z < 1$ . In addition, FIREBall-2 targeted a well-known MgII-absorbing QSO towards the end of its flight. We will present the data reduction and first look at the data, and discuss implications of the observations with our current understanding of CGM properties of early redshift galaxies.

**Author(s):** David Schiminovich, Keri Hoadley, Christopher Martin, Johan Montel, Didier Vibert, Bruno Milliard, Erika Hamden, Vincent Picouet, Etienne Perot, Nicole Melso, Donal O'Sullivan, Gillian Kyne

**Institution(s):** Caltech, LAM, University of Arizona, CNES,

Columbia University Contributing Team(s): FIREBall- Team

### **136.04 - BLAST-TNG Antarctic Pre-Flight Integration(Nicholas Galitzki)**

The Next Generation Balloon-borne Large Aperture Submillimeter Telescope (BLAST-TNG) is a submillimeter mapping experiment planned for a 28 day long-duration balloon (LDB) flight from McMurdo Station, Antarctica, with a launch date scheduled for December 2018. BLAST-TNG will detect polarized submillimeter emission from interstellar dust grains with the sensitivity and resolution to probe  $\sim 0.1$  parsec-scale features that are critical to understanding the origin of structures in the interstellar medium. BLAST-TNG will trace magnetic fields in galactic molecular clouds to probe the earliest stages of star formation while also providing unique measurements of emission from the diffuse interstellar medium, the single largest contributor to cosmic microwave background (CMB) foreground contamination. BLAST-TNG will also be the first balloon-borne experiment to open a quarter of its observing time to shared risk proposals. BLAST-TNG features three detector arrays operating at wavelengths of 250, 350, and 500  $\mu\text{m}$  (1200, 857, and 600 GHz) comprised of 918, 469, and 272 dual-polarization pixels, respectively. Each pixel is made up of two crossed microwave kinetic inductance detectors (MKIDs). These arrays are cooled to 275 mK in a cryogenic receiver. Each MKID has a different resonant frequency, allowing hundreds of resonators to be read out on a single transmission line. We will present preliminary results from the pre-flight testing of BLAST-TNG prior to its scheduled Antarctic launch. The tests will include measurements of instrument polarization response, beam-mapping of the optical system, detector responsivity and noise characterization, and general flight readiness tests of the completely assembled telescope in its flight configuration.

**Author(s):** Nicholas Galitzki

**Institution(s):** University of California San Diego  
Contributing Team(s): The BLAST-TNG Collaboration

### **136.05 - The Compton Spectrometer and Imager project for MeV Astronomy(John Tomsick)**

The Compton Spectrometer and Imager (COSI) is a 0.2-5 MeV Compton telescope capable of imaging, spectroscopy, and polarimetry of astrophysical sources. Such capabilities are made possible by COSI's germanium cross-strip detectors, which provide high efficiency, high resolution spectroscopy, and precise 3D positioning of photon interactions. In 2016, COSI had a successful flight from New Zealand on a NASA superpressure balloon. Science results from the flight include imaging and spectroscopy of the positron annihilation emission in the Galactic Center, polarization constraints for a gamma-ray burst, and studies of the Crab nebula and accreting black holes. In this presentation, we describe technical and scientific advances for the COSI project, including advances that would

be possible with an upgrade to the balloon payload: an Explorer Mission of Opportunity called COSI-X.

**Author(s):** Clio Sleator, Carolyn Kierans, Alex Lowell, Steven E Boggs, Jarred Roberts, John Tomsick, Andreas Zoglauer, Theresa Brandt

**Institution(s):** UC Berkeley, NASA/GSFC, UC San Diego  
**Contributing Team(s):** The Compton Spectrometer and Imager Team

## 137 - IGM and QSO Absorption Line Systems I

### 137.01 - The DEUCE payload: Sounding Rocket EUV Observations of Local B Stars to Determine Their Potential for Supplying Intergalactic Ionizing Radiation(Nicholas Erickson)

The Dual-Channel Extreme Ultraviolet Continuum Experiment (DEUCE) is a rocket-borne spectrograph operating in the 650-1150Å range at medium resolution. DEUCE is designed to observe the nearby B stars Epsilon and Beta CMA, providing the first direct measurement of the flux of hot stars across the 912Å Lyman break. No such calibrated observations exist, meaning DEUCE will serve as a unique test of current stellar models in this critically ionizing bandpass. The primary goal of DEUCE is to better constrain the potential contribution of B stars to IGM ionization balance in the modern universe and gain insight into how hot stars could have contributed to IGM ionization at higher redshifts. We present the DEUCE science motivation, instrument design and calibration data. Pending a successful December 2018 launch to observe Epsilon CMa, we will also present flight data and preliminary science results.

**Author(s):** Kevin France, Nicholas Erickson, John Stocke, James Green

**Institution(s):** University of Colorado, Boulder

### 137.03 - Exploring the CRAG: The HI Covering Factor of the ALFALFA Galaxies(Joseph Ribaudo)

We report the initial findings of our Survey of the Circumgalactic Regions of the ALFALFA Galaxies (CRAG). We combine the blindly detected 21-cm HI sources of the ALFALFA catalog with archival HST/COS G130M QSO spectroscopic observations taken from the HST Spectroscopic Legacy Archive to quantify and characterize the circumgalactic medium (CGM) around these local, HI-rich galaxies. We find the covering factor of HI, as probed by  $\text{Ly}\beta$ , to be near unity within 50 kpc of all ALFALFA galaxies, regardless of HI mass, MHI. However, we have identified a significant correlation between the extent of the HI-bearing CGM beyond 50 kpc and MHI of the ALFALFA galaxies. We find the galaxies with  $\log(\text{MHI}/M_\odot) > 9.5$  give rise to  $\text{Ly}\beta$  covering factors  $> 0.5$  out to 300 kpc, indicating the CGM of the most HI-rich galaxies of the ALFALFA sample fills a significant volume. At the same time we find the galaxies with  $\log(\text{MHI}/M_\odot) < 9.5$  give rise to substantively lower  $\text{Ly}\beta$  covering factors beyond 50 kpc. Most notably, the  $\log(\text{MHI}/M_\odot) < 7.5$  galaxies give rise to a  $\text{Ly}\beta$  covering

factor  $< 0.3$  beyond 50 kpc and negligible covering factors beyond 150 kpc. This work has been supported by NSF grant AST-1716569.

**Author(s):** Joseph N. Burchett, Joseph Ribaudo, Liam Patterson, Chelsey McMichael

**Institution(s):** Utica College, University of California Santa Cruz

### 137.05 - Using a UVJ Classification to Reveal the Dust Properties of MgII-Selected Galaxies in the UltraVISTA Survey(Darren Stroupe)

We present a study using QSO spectra to probe the halos of foreground galaxies in the COSMOS field. Intervening Mg II absorption lines in Sloan Digital Sky Survey (SDSS) quasar spectra were paired with galaxies in the UltraVISTA catalog at a impact parameter less than 200 kpc. A sample of 60 strong Mg II absorbers with a rest-frame equivalent width  $W_r(2796) \approx 0.37 \text{ \AA}$ ..., impact parameter  $r_p \approx 20.7 \text{ kpc}$ , and redshift range of  $0.30 < z < 2.21$  were analyzed within the framework of a rest-frame UVJ color distribution. A bimodal population of 43 star-forming and 17 quiescent absorbers was found, with the star-forming population further divided into 23 blue (BSF) and 20 red (RSF) star-forming absorbers. A color excess in quasars backlighting the extended halos of BSF absorbing galaxies, larger than that of RSF absorbing galaxies by more than a factor of 6, and an interstellar medium obscuration ( $A_V$ ) in RSF absorbing galaxies, larger than that of BSF absorbing galaxies by nearly a factor of 2, support a model wherein metal-enriched gas is blown out into galaxy halos by star formation-driven winds.

**Author(s):** Britt Lundgren, Darren Stroupe

**Institution(s):** University of North Carolina at Asheville

### 137.02D - Dissecting the Circumgalactic Medium of Massive Elliptical Galaxies(Fakhri S Zahedy)

While significant progress has been made in understanding galaxy evolution, a self-consistent explanation for the diffuse gas surrounding galaxies (the circumgalactic medium, CGM) still eludes us. Particularly puzzling is the presence of cool ( $T \sim 10^4 \text{ K}$ ) gas in the gaseous halos of massive elliptical galaxies, contrary to theoretical expectation that the gas is predominantly hot ( $T > 10^6 \text{ K}$ ). Characterizing the physical properties of the CGM around massive ellipticals is necessary to understand the origin of the gas and its coevolution with the galaxies over cosmic time. I have carried out a comprehensive investigation of the CGM gas of massive ellipticals at  $z \sim 0.5$ , combining high quality absorption spectra of background quasars from the Cosmic Origins Spectrograph onboard the Hubble Space Telescope and from ground-based telescopes. The study finds that despite their quiescence, massive elliptical galaxies have as much cool gas ( $\sim 10^{10}$  solar masses) in their CGM as star-forming galaxies. The observed chemical abundance pattern of the gas indicates that the inner CGM ( $\sim 10$



kpc scales) has been significantly influenced by Type Ia supernovae, whereas gas in the outer CGM ( $\sim 100$  kpc scales) likely originates from the intergalactic medium. Together with the observed large variations in gas metallicity and density within the halos of individual galaxies, these findings suggest that the CGM of massive ellipticals is a multiphase mixture of gas with different chemical enrichment histories. More importantly, these observations provide valuable insights into physical mechanisms which are effective at destroying cool gas before it reaches the galaxy, thereby preventing an accumulation of cool gas within massive ellipticals which would otherwise trigger star-formation.

**Author(s):** Fakhri S Zahedy

**Institution(s):** The University of Chicago

### **137.04D - Galactic Winds and the Circumgalactic Medium(Cassandra Lochhaas)**

The circumgalactic medium (CGM) is the conduit between the formation of galaxies and the rest of the universe. Gas that flows into the galaxy to fuel star formation must first pass through the CGM, and galactic winds launched by star formation feedback flow out of the galaxy into the CGM. Recent observations reveal puzzling aspects of the CGM: a large mass of cool gas extending to galactocentric radii of hundreds of kpc traveling at a few hundred km/s, present in the CGM of both star-forming and passive galaxies. I will discuss my dissertation research, which focuses on producing a physical picture of the CGM to explain these observations. I will present my analytic model for a galactic wind-blown bubble that shocks on and sweeps up gas in the CGM, and show that if the mass-loading of the wind is large, the bubble's shell radiatively cools to produce cool and dense gas. The bubble evolves slowly to hundreds of kpc, and continues to expand for 5-10 Gyr, long after the driving star formation feedback has ceased and the galaxy has become passive. Despite the idealized nature of this model, it captures the key pieces of physics to predict the observational results. I will also discuss my work to characterize the simulated CGM in idealized, high-resolution simulations, and show that the CGM cannot be well-characterized by a hydrostatic gaseous halo; it is strongly driven by the dynamics of outflows and accretion inflows, especially in low-mass halos. Finally, I will present my analysis of an exquisite, high signal-to-noise Hubble Space Telescope spectrum of a background quasar behind the CGM of two galaxies at different redshifts, in which I find evidence of a variety of kinematics and multiple ionization processes occurring within each gaseous halo. This three-pronged investigative approach across analytics, simulations, and observations produces a picture of the CGM as not just multiphase, but also dynamic. A complete, physically-motivated model of the CGM is crucial for understanding the cycles of gas into and out of galaxies and other open problems in galaxy formation.

**Author(s):** Todd A. Thompson, Cassandra Lochhaas

**Institution(s):** The Ohio State University

### **138 - Plenary Lecture: “Make No Small Plans” (George Ellery Hale, 1868-1938), David DeVorkin (Smithsonian Institution) 138.01 - “Make No Small Plans” (George Ellery Hale, 1868-1938)(David H. DeVorkin)**

As part of the AAS's observance of the 150th year of Hale's birth, I will recall Hale's efforts to make astronomy problem based, to promote observing programs based upon questions that arise from theory and, most of all, from applying the instruments and methods of physics. Hale was well known for advising others to “Make no small plans,” as his Mount Wilson colleague F. H. Seares recalled a year after his death. Seares interpreted this to mean the integration of physics and astronomy, but over time it came to be regarded as his creation of the world's largest telescopes, four times. Further, as Daniel Kevles has noted, Hale's call not only related to the doing of scientific research, but to its promotion, its application in wartime, and eventually to its international organization, cooperation, and control.[1]Here I will concentrate on Hale's call as it related to the doing of research and to its coordination. Vignettes will include his penchant to link the laboratory to the stars via telescopes designed specifically to solve astrophysical problems, his efforts to attract physicists to Yerkes and then Mount Wilson and Caltech, and his creation of the International Union for Cooperation in Solar Research and its extension to the stars in 1910. [1] Daniel Kevles, *The Physicists* (Vintage, 1979), 107-108.

**Author(s):** David H. DeVorkin

**Institution(s):** Smithsonian

### **139 - Plenary Prize Lecture: Newton Lacy Pierce Prize: The Obscured Early Universe, Caitlin Casey (University of Texas at Austin) The Obscured Early Universe(Caitlin M Casey)**

The rich 14 billion year-old story of our Universe - from the gravitational collapse of matter to the formation and evolution of galaxies, the growth of stars and planets, and the physics of the cosmos - has been pieced together using the world's most powerful telescopes. Predominantly, it is stellar light that has given us this story. And yet, stars themselves only shed light on a small fraction of the cosmos. Diffuse gas makes up the lion's share of baryonic material in the Universe, and dust, though negligible by mass, effectively obscures and reprocesses half of all stellar emission. I will summarize the observational leaps taken in the past ten years to study the distant, obscured Universe, and the new perspective this work has given us on our own cosmic history through the census of cold gas and dust in the first few billion years after the Big Bang.

**Author(s):** Caitlin M Casey

**Institution(s):** University of Texas at Austin

## **140 - Extrasolar Planets: Detection -- Posters**

### **140.01 - An Updated Cool Dwarf Catalog for the Transiting Exoplanet Survey Satellite Using Gaia DR2(Jay S Chittidi)**

We present an updated catalog of cool dwarf stars for the recently launched Transiting Exoplanet Survey Satellite (TESS) for the purpose of selecting targets for two-minute cadence observations. At launch, TESS was provided a similar catalog of cool dwarfs whose stellar parameters were approximated using proper motions and - where they existed - archival parallax measurements. Most targets therefore have significant uncertainties. Now, with the highly anticipated Gaia DR2 parallax measurements released in April 2018, we updated stellar parameters where we are able to determine a cross-match with confidence, as well as determined new targets from a cross-match between Gaia and 2MASS. We anticipate delivery to TESS by the end of 2018, at which point it will have completed about one fourth of its mission. With the updated catalog, we hope that TESS will discover Earth-sized and sub-Earth-sized exoplanets around late K and M-dwarf type stars with a higher planet yield. This project was supported in part by the NSF REU grant AST-1757321 and by the Nantucket Maria Mitchell Association.

**Author(s):** Philip Steven Muirhead, Regina A. Jorgenson, Barbara Rojas-Ayala, Jay S Chittidi,

**Institution(s):** Vassar College, Boston University, Maria Mitchell Observatory, Universidad Andrés Bello

### **140.02 - Tracking the TESS Pipeline(Douglas Caldwell)**

The Transiting Exoplanet Survey Satellite (TESS) Mission was launched April 18 2018 and started science observations July 25 2018. TESS will observe most of the sky over two years in a series of thirteen 28-day sectors in each of the southern and northern hemispheres. The Science Processing Operations Center (SPOC) was developed at NASA Ames Research Center based on the Kepler Mission science pipeline and will generate calibrated target pixels and light curves for 16 thousand targets sampled at a 2 minute cadence, as well as calibrated full frame images (FFIs) sampled at 30 minutes. In order to ensure this deluge of science data coming from the pipeline is being properly calibrated and processed, we have developed a series of data analysis metrics and status plots that are used to assess the instrument and pipeline performance. Originally based on the Data Analysis Working Group (DAWG) from Kepler, these metrics have been updated and further automated to allow for rapid review. We will present some of the DAWG products for TESS from pixel level calibration, through transiting planet search results.

**Author(s):** Douglas Caldwell

**Institution(s):** SETI Institute Contributing Team(s): TESS Science Processing Operations Center

### **140.03 - TESS SPOC Pipeline Data Validation Products: Now Available at MAST(Joseph Twicken)**

Two-minute data acquired by the Transiting Exoplanet Survey Satellite (TESS) for 16,000+ stellar targets in each observing sector are processed in the Science Processing Operations Center (SPOC) Science Pipeline at NASA Ames Research Center. The automated Science Pipeline generates photometric light curves for all target stars and issues Threshold Crossing Events (TCEs) for potential transiting planet candidates. Many of the TCEs are triggered by instrument artifacts, eclipsing binaries, or other astrophysical false positives. To aid in discrimination between potential planets and false positive detections, limb-darkened transiting planet models are fitted to the respective light curves and a suite of diagnostic tests is performed for all TCEs. Iterative model fitting and transiting planet search support the identification of multiple TCEs per target star. Results for each purported planetary system are written to a comprehensive PDF document called the Data Validation (DV) Report. The Report includes a summary of the primary DV findings, detailed model fit and diagnostic test results (based upon prior stellar parameters), and a variety of diagnostic figures. A one-page Report Summary is also generated in PDF format for each TCE. The Report Summary provides an overview of the key DV results for each potential transiting planet candidate. All DV products are distributed to the science community and public at large through the Mikulski Archive for Space Telescopes (MAST; [archive.stsci.edu/tess](http://archive.stsci.edu/tess)) hosted by the Space Telescope Science Institute (STScI). We present an overview of the DV archive products with the purpose of informing future users about the wealth of information that is available to them for assessing planet candidates identified in the TESS SPOC Pipeline. Specific examples are highlighted that demonstrate the utility of the DV products for distinguishing between legitimate planet candidates and false positive detections. Funding for the TESS Mission has been provided by the NASA Science Mission Directorate.

**Author(s):** Mark E Rose, Peter Tenenbaum, Douglas A Caldwell, Robert L Morris, Eric B Ting, Jie Li, Bill Wohler, Joseph Twicken, Jeffrey C Smith, Jon Michael Jenkins, Misty D Davies

**Institution(s):** SETI Institute, Leidos, NASA Ames Research Center

### **140.04 - The TESS Objects of Interest Process(Ana Glidden)**

The Transiting Exoplanet Survey Satellite (TESS) is NASA's newest exoplanet hunter. Launched in the spring of 2018, TESS began its two-year science mission to image nearly the entire sky on July 25, 2018. Each observing sector lasts for two ~13 day orbits. At perigee, data is downlinked back to MIT's Payload Operations Center (POC) through the Deep Space Network. The POC converts the data and delivers it to the NASA Ames Science Processing Operations Center (SPOC) where it is

calibrated and sent through their pipeline. The pipeline searches for threshold crossing events (TCEs) in the 2-minute postage stamp data. Concurrently at MIT, the 30-minute full-frame images are sent through MIT's Quick Look Pipeline to search for additional TCEs. TCEs with high enough significance are converted into a data validation report. These reports are then fed into MIT's TESS Exoplanet Vetter (TEV). TEV is a web-based tool that allows human vetters to view the reports and easily share their assessment with the rest of the vetting team. Vetting is split into two stages. First, each object is reviewed by up to four individual vetters to determine its disposition. Potential dispositions are Planet Candidate, Eclipsing Binary, Stellar Variability, Instrument Noise, Other Astrophysical, and Undecided. Next, objects that are potential Planet Candidates are sent to a group review for further validation. Planet Candidates that survive group review are quickly shared with the community and the TESS Follow-up Observing Program (TFOP). TFOP coordinates observations of these candidates to confirm and characterize them as planets or reject them as false positives. The TESS Objects of Interest (TOI) Catalog is crafted from the final dispositions of each object, excluding signals caused by instrument noise. The TOI Catalog will be made public no later than January 2019 on the MIT TESS website and ExoFOP-TESS.

**Author(s):** Ana Glidden

**Institution(s):** MIT Contributing Team(s): TESS Team

#### **140.05 - TESS Follow-up Observing Program Working Group (TFOP WG) Sub Group 1 (SG1):**

##### **Ground-based Time-series Photometry(Karen Collins)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two year nominal mission. The TFOP WG is a mission-led effort organized to efficiently provide follow-up observations to confirm candidates as planets or reject them as false positives. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. The TFOP WG is organized as five Sub Groups (SGs). This poster presents TFOP SG1: Ground-based Time-series Photometry. TESS has 21 arcsec pixels and photometric apertures with radius ~1 arcmin, which are often contaminated with multiple stars. The primary goals of the SG1 team are to determine the source of a TESS detection and/or identify photometric false positives prior to conducting observations with more precious follow-up resources that produce high-resolution imaging and precise radial velocities. Where possible, SG1 observations are also used to improve TESS ephemerides, light curves, and/or transit time variation (TTV) measurements. We describe the TFOP SG1 goals,

strategy, observation planning and coordination web-based tools, priorities, preferred capabilities of SG1 team members, and how to apply to join the team.

**Author(s):** Karen Collins

**Institution(s):** Harvard-Smithsonian Center for Astrophysics Contributing Team(s): TFOP SG Team

#### **140.06 - TESS Follow-up Observing Program Working Group (TFOP WG) Sub Group 2 (SG2): Reconnaissance Spectroscopy(Samuel N Quinn)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two year nominal mission. The TFOP WG is a mission-led effort organized to efficiently provide follow-up observations to confirm candidates as planets or reject them as false positives. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. This poster presents TFOP SG2: Reconnaissance Spectroscopy. While very few facilities can measure the Doppler signature of a small planet orbiting its host star, a far greater number can provide valuable spectroscopic observations to weed out false positives, assess the suitability of a star for precise radial velocity (RV) measurements, and measure the orbits of large or short-period planets. SG2 uses high-resolution spectroscopy with RV precisions ranging from 3 to 300 m/s to detect eclipsing binaries and composite spectra, derive stellar parameters, and confirm and characterize large TESS planets. These observations enable the efficient use of high-resolution imaging, precise RV, and space-based facilities. We describe the SG2 goals, strategy, and observation planning and coordination.

**Author(s):** Samuel N Quinn

**Institution(s):** Harvard-Smithsonian Center for Astrophysics Contributing Team(s): The TESS Follow-Up Observing Program Working Group (TFOP WG) and the TESS Team

#### **140.07 - TESS Follow-up Observing Program Working Group (TFOP WG) Sub Group 3 (SG3): High Resolution Imaging(David Ciardi)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two year nominal mission. The TFOP WG is a mission-led effort organized to efficiently provide follow-up observations to confirm candidates

as planets or reject them as false positives. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. This poster presents TFOP subgroup (SG) 3: High Resolution Imaging. SG3 will use ground-based facilities with high resolution imaging capabilities to obtain better than seeing limited imaging observations ( $<1''$ ) of TESS candidate host stars to search for companion stars. Detection of stellar companions is necessary for the accurate assessment of the photometric dilution of the observed transits and for the determination of accurate planetary radii, as well as, for screening candidates prior to the observation with precision radial velocity resources (SG4). We describe the SG3 goals, priorities, strategy and organization of the SG3 subgroup.

**Author(s):** David Ciardi

**Institution(s):** Caltech Contributing Team(s): The TESS Follow-Up Observing Program Working Group (TFOPWG) and the TESS Team

#### **140.08 - TESS Follow-up Observing Program Working Group (TFOP WG) Sub Group 5 (SG5): Space-based Photometry(Diana Dragomir)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two year nominal mission. The TFOP WG is a mission-led effort organized to efficiently provide follow-up observations to confirm candidates as planets or reject them as false positives. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. The TFOP WG is organized as five Sub Groups (SGs). This poster presents TFOP SG5: Space-Based Photometry. SG5 will use facilities such as HST, Spitzer, MOST and CHEOPS to confirm and/or improve the photometric ephemerides provided by TESS, but also to provide improved light curves for transit events or even transit timing variations in some cases. Planet candidates with shallow or very long transits that are challenging to observe from the ground will be prioritized for SG5 resources. We describe the SG5 goals, priorities, strategy and preferred capabilities of SG5 team members, and how to apply to join the team.

**Author(s):** Ian Crossfield, Diana Dragomir, Jessie Christiansen, Sara Seager, David Ciardi, Samuel N Quinn, Karen Collins, David W Latham

**Institution(s):** MIT, IPAC/Caltech, Harvard

#### **140.09 - TESS Follow-up Observing Program Working Group (TFOP WG): The ExoFOP-TESS Website(Rachel Akeson)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two year nominal mission. The TFOP WG is a mission-led effort organized to efficiently provide follow-up observations to confirm candidates as planets or reject them as false positives. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. This poster presents the ExoFOP-TESS website which is used by the TESS Follow-up Observing Program Working Group and the general community to share information about observations, data and parameters derived from the observations, and notes about the targets. The ExoFOP-TESS site has all of the project identified planetary candidates, and all of the TFOPWG data is being uploaded to the ExoFOP-TESS site. The site is developed and operated by the NASA Exoplanet Science Institute and can be found at <https://exofop.ipac.caltech.edu>

**Author(s):** Rachel Akeson, Jessie Christiansen

**Institution(s):** Caltech/IPAC-NExSci Contributing Team(s): The TESS Follow-Up Observing Program Working Group (TFOPWG), The TESS Team

#### **140.10 - Multiband Photometry Simulations to Predict MuSCAT and MuSCAT2 Capabilities to Distinguish TESS-discovered Exoplanets from False Positives(Dana Louie)**

The Transiting Exoplanet Survey Satellite (TESS) is currently conducting its 2-year science mission searching most of the sky for transiting exoplanets. Barclay et al. (2018) predict that TESS will discover thousands of new candidate exoplanets, but these exoplanets must be distinguished from astrophysical false positives using other instruments or techniques. The Japanese-developed 3-band Multi-color Simultaneous Camera for Studying Atmospheres of Transiting Planets (MuSCAT), as well as the 4-band MuSCAT2, can be used to validate TESS discoveries. Transits of exoplanets are achromatic when observed in multiple bandpasses, while transit depths for false positives often vary with wavelength. Our goal is to simulate MuSCAT/MuSCAT2 follow-up observations to reveal which planet candidates can be efficiently validated using MuSCAT/MuSCAT2, and which must be validated using other techniques. This will allow the TESS Follow-Up Observing Program (TFOP) working group to better prioritize and optimize validations of TESS detections. We provide two software tools to assist TFOP in planning MuSCAT follow-up

observations: 1.) A code to produce simulated light curves of exoplanets and false positives observed using MuSCAT/MuSCAT2; 2.) A code that will read a list of parameters for several TESS targets of interest (TOIs), and output the sensitivities in each MuSCAT/MuSCAT2 bandpass for effective planet versus false-positive discrimination. We model observations starting with a model stellar spectrum and ending with detection of electrons on the MuSCAT/MuSCAT2 CCD arrays. We scale the stellar flux to the star's apparent magnitude, model the effects of refraction and transmission through Earth's atmosphere, and include noise sources from the target star, comparison stars, sky background, scintillation, and CCD read noise. We model MuSCAT/MuSCAT2 instrument performance as reported by Narita et al. (2015, 2018). We demonstrate our tools by applying them to the Barclay et al. predicted TESS discoveries, as well as the Collins et al. (2018) false positive catalog.

**Author(s):** Dana Louie, Norio Narita, Drake Deming

**Institution(s):** University of Maryland, University of Tokyo

#### **140.11 - Follow-up of K2 Planet Candidates from TFOP-SG1(Allyson Bieryla)**

Using the resources of the TESS Follow-up Observing Program (TFOP) time-series photometry subgroup (SG1), we undertook a project to observe previously published K2 candidate and validated planets while practicing observing techniques that are now being applied to follow-up TESS planet candidates. Our primary scientific goal was to classify the K2 targets as false positives or "SG1 certified" candidate or validated planets using two main strategies. The first method applies to K2 events that are deep enough to be detected (for a given host star brightness) with our ground-based resources. For these cases, SG1 certification required the detection of the transit within the follow-up target star aperture and furthermore that no photometric false positive (FP) scenarios exist within the follow-up aperture. The second method applies transit events that are too shallow to be detected using our ground-based telescopes. For these cases, SG1 certification required the elimination of all potential sources of eclipsing binaries (NEBs) down to a delta magnitude that could cause the K2 detection, as well as best efforts to rule out the well known Kepler/K2 column anomaly (Coughlin et al. 2014). We later expanded our project using the Tillinghast Reflector Echelle Spectrograph (TRES) on the 1.5-m telescope at the Fred Lawrence Whipple Observatory (FLWO) to obtain reconnaissance spectra, and when possible, to search for additional false positive scenarios or to attempt to confirm a candidate as a planet. We report the SG1 certified planet candidates and confirmed false positives from this work.

**Author(s):** Andrew Vanderburg, Andrea ercolino, Allyson Bieryla, Giovanni Isopi, Kevin I Collins, Karen Collins, David W Latham

**Institution(s):** Campo Catino Astronomical Observatory, Vanderbilt University, Harvard-Smithsonian Center for Astrophysics, University of Texas Contributing Team(s): TFOP

SG

#### **140.12 - Undergraduates Can Find Planets Too(Alex D Spencer)**

Brigham Young University (BYU) has been assisting in the ground-based follow-up of extrasolar planet candidates detected by the KELT telescope using our 0.4-meter and 0.9-meter telescopes. In preparation to follow-up future planet candidates identified by TESS, we are working to optimize our data reduction process using an automated program. Currently, before any reduction can take place, someone must manually extract all the HJD times from each image, feed them into a webpage hosted by the Ohio State University, and then convert the HJD times to BJD. With busy class and work schedules, data often sits for weeks while waiting for this one simple step to be manually performed. To circumvent this problem, I am developing a program that will automatically update the headers, convert the HJD values to BJD, and then process the data in preparation for light curve analysis. We anticipate that this program will save our department up to 150 hours of research time each year. With a modest telescope, some simple computer programs, and a little bit of time, our students can assist in some of the most important extrasolar planet discoveries that will take place over the next few years.

**Author(s):** Alex D Spencer, Denise Stephens

**Institution(s):** Brigham Young University

#### **140.13 - Ephemeris Degeneration in TESS Targets(Mallory Harris)**

The Transiting Exoplanet Survey Satellite (TESS), launched April 2018, will detect exoplanet candidates around bright stars to later be confirmed using ground-based telescopes. Many of these targets will be left unobserved for some time after the TESS observations, causing knowledge of the ephemerides (the position of exoplanets in their orbit at a specific time) to deteriorate as initial measurement error compiles with each subsequent unobserved orbit. Mock observations by TESS were modeled through use of a simulated population of exoplanets to deduce the error with which predictions of future transit events can be made and how that error increases as time elapses. This knowledge of how the ephemerides expire allows prioritization of candidates for follow-up observations and the efficient use of valuable telescope time.

**Author(s):** Steven Villanueva, Diana Dragomir, Thomas Barclay, Mallory Harris, Joshua Pepper

**Institution(s):** New College of Florida, MIT, Lehigh University, NASA Goddard Space Flight Center

#### **140.14 - A Complete Survey of the Southern Sky with TESS Full-Frame Images(Adina Feinstein)**

The Kepler/K2 Mission queued us in to how many transiting planets exist in the galaxy; however, we have yet to obtain a large sample of transiting planets across the remaining 85% of the sky. The identification and follow-up observations of transiting planets can inform us about planet characteristics, such as densities and atmospheric properties, as well as differing planet-system architectures which will allow us to better understand planet formation and evolution. Every 26 days, the Transiting Exoplanet Survey Satellite (TESS) observes a new  $96 \times 24^\circ$  sector of the sky at 30 minute cadence as Full-Frame Images, enabling the detection of thousands of previously undiscovered planets across the sky. We have created open-source software that will provide light curves for 25 million sources in the TESS Input Catalog brighter than  $I=16$  with expected 1% precision throughout the Southern Hemisphere. We will use both aperture and PSF photometry to identify and characterize transiting planets. Our techniques have been tested and optimized using the TESS End-To-End 6 simulated data. We will release a catalog of objects of interest (e.g. planet candidates, eclipsing binaries, stellar astrophysics) to the community through ExoFOP-TESS; the catalogs will also contain best-fit parameters for planet candidates and eclipsing binaries to enable rapid follow-up observations. Cadence stacked images, raw, and detrended light curves for each analyzed star will be hosted on MAST and ExoFOP-TESS for everybody in the community to access.

**Author(s):** Rodrigo Luger, Benjamin Montet, Megan Bedell, Jessie Christiansen, Nicholas Saunders, Daniel Scolnic, Christina L Hedges, Daniel Foreman-Mackey, Adina Feinstein, Jose Vinicius De Miranda Cardoso

**Institution(s):** University of Chicago, Caltech/IPAC-NExScI, NASA Ames Research Center, Universidade Federal de Campina Grande, Flatiron Institute

#### **140.15 - Observations of the Kepler Field with TESS: Predictions for Planet Yield and Observable Features(Callista Christ)**

We examine the ability of the Transiting Exoplanet Survey Satellite (TESS) to detect and improve our understanding of planetary systems in the Kepler field. By modeling the expected transits of all confirmed and candidate planets detected by Kepler as expected to be observed by TESS, we find that TESS has a greater than 50% chance of detecting 277 of these signals at the 3 $\sigma$  level in one sector of observations and an additional 128 planets in two sectors. Most of these are large planets in short orbits around their host stars, although a small number of rocky planets are expected to be recovered. Most of these systems have only one known transiting planet; in only  $\sim 1/4$  5 percent of known multiply-transiting systems do we anticipate more than one planet to be recovered. When these planets are recovered, we expect TESS to be a powerful tool to characterizing transit timing variations. Using Kepler-88 (KOI-142) as an example, we show that TESS will improve

measurements of planet-star mass ratios and orbital parameters, and significantly reduce the transit timing uncertainty in future years. Since TESS will be most sensitive to hot Jupiters, we research whether TESS will be able to detect tidal orbital decay in these systems. We find two confirmed planetary systems (Kepler-2 b and Kepler-13 b) and five candidate systems that will be good candidates to detect tidal decay.

**Author(s):** Daniel Fabrycky, Benjamin Montet, Callista Christ

**Institution(s):** University of Chicago

#### **140.16 - Identifying Transiting Exoplanets in with Deep Learning in K2 Data(Anne Dattilo)**

NASA's Kepler Space Telescope looks for and has discovered thousands of transiting exoplanets. In its extended K2 mission, Kepler has searched for exoplanets across the ecliptic plane, and therefore in different galactic environments. Astronomers want to learn how the population of exoplanets are different in these different environments. However, there is a need for an automatic and unbiased way to identify the exoplanets in these regions and rule out false positive signals that mimic astrophysical signals to do this. We present a method for classifying these exoplanet signals using deep learning, a type of machine learning algorithm that has become popular in fields ranging from medical science to linguistics. We modified a neural network previously used to identify exoplanets in the Kepler field to be able to identify exoplanets in different K2 campaigns. We train a convolutional neural network to predict whether a given possible exoplanet signal is really caused by a transiting exoplanet or a false positive caused by astrophysical or instrumental phenomena. Our neural network is highly successful at identifying exoplanets, with accuracy of 98%. We use this method to identify two previously unknown exoplanets. Our method is a step towards being able to automatically identify new exoplanets and learn about how exoplanet populations depend on their galactic birthplace.

**Author(s):** Christopher Shallue, Andrew Vanderburg, Anne Dattilo

**Institution(s):** The University of Texas at Austin, Google Brain

#### **140.17 - Searching for planets around the brightest stars in K2(Ismael Mireles)**

Very bright solar type stars provide a great opportunity for radial velocity and atmospheric follow-up of transiting exoplanets. The K2 mission has largely avoided such stars because they strongly saturate the detector and are often contaminated by fainter field stars in the field of view. The brightest star with a confirmed exoplanet is EPIC 205904628, with  $KP = 8.2$ . We use the technique outlined by White et al. (2017) which analyzes the extended emission halo around the saturated central pixels in order to study the 900+ stars brighter than magnitude 8.2. We generate light curves for  $\sim 400$

uncontaminated stars and search for planetary signals. We identify stellar variability signals, including signals from Cepheid variables and eclipsing binaries. We explore at what magnitude this halo technique is comparable to traditional techniques. For the ~500 bright stars contaminated by nearby stars, we use a combination of star finding algorithms and catalog searches to separate the various stellar signals from false positives in order to better analyze the bright stars contaminated by fainter stars. These techniques may be useful for TESS and other transiting searches that deal with bright stars in crowded fields. This K2 survey, which is in the ecliptic, complements the TESS search, as TESS largely avoids the ecliptic. This work aims to analyze bright stars inaccessible to TESS and that have been problematic for the standard K2 reduction routines, in order to find planets optimal for further characterization.

**Author(s):** Michael Henderson, Ismael Mireles, Seth Redfield  
**Institution(s):** Wesleyan University

#### **140.18 - High Precision Photometry of Faint White Dwarf Stars from K2 Data(Michael Henderson)**

In order to reduce data from faint targets in crowded fields in K2, the second phase of the Kepler Space Telescope's mission, we have modified codes developed by Vanderburg et al. (2011) and Van Eylen et al. (2014) to utilize the point spread function (PSF) to obtain high quality light curves. The code is optimized for faint targets ( $K_p > 15.5$ ) in the K2 field by utilizing the concept of effective point-spread function (ePSF). The modifications are particularly useful when searching for transiting signals around white dwarf stars, such as WD1145+017, which was discovered in K2 data to have disintegrating asteroids in 4.5 hour orbits. The technique will also extract targets from a crowded field and extended emission of bright star halos in order to produce light curves and search for transiting bodies. We present comparisons of light curves using this technique to more traditional methods as well as provide the results of transit searches of the most recently observed faint white dwarfs. Future work will include applying the code to faint targets observed by the latest transiting exoplanet space mission, the Transiting Exoplanet Survey Satellite (TESS).

**Author(s):** Ismael Mireles, Michael Henderson, Seth Redfield  
**Institution(s):** Wesleyan University

#### **140.19 - Constraining Planet Occurrence Around Ultracool Dwarfs Observed by K2(Sheila Angela Sagar)**

Though we expect many planets around ultracool dwarfs, few have been detected. The K2 mission presents a unique opportunity to search for transiting planets around a large sample of ultracool dwarfs and place constraints on planet occurrence at the bottom of the main sequence. Planet detection using the transit method is dependent not only on

geometric transit probability but also the effectiveness of transit-searching methods. In this work, we use K2 observations to measure transit detection efficiency in ultracool dwarfs and use our transit detection efficiency to calculate an upper limit on the planet occurrence rate. We measure our ability to recover various types of transits around dwarfs at the M/L transition. We inject synthetic planetary transits of radii from 0.1 to 3.5 Earth radii and of periods from 0.3 to 26 days into 382 K2 light curves of late-type M and L dwarfs. We attempt to recover them using Box-Least Squares and Levenberg-Marquardt optimization methods. We then calculate a detection efficiency, or fraction recovered, and a threshold of detectability relating to orbital period and radius for each dwarf. We present an upper limit on the planet occurrence rate, as well as constraints on the probability of seeing no planets around a given number of ultracool dwarfs.

**Author(s):** Philip Steven Muirhead, Julie N Skinner, Sheila Angela Sagar  
**Institution(s):** Boston University, Smith College

#### **140.20 - The Impact of Small Statistics on Identifying Background False Positives in Kepler Data(Steve Bryson)**

Background false positives are a significant source of false positives in exoplanet transit surveys such as NASA's Kepler mission. Therefore the ability to reliably distinguish background binaries from true exoplanets is critical in the creation of high reliability exoplanet catalogs. Background binaries are typically identified via centroid analysis, which can distinguish the sky location of the transit signal from the observed target star. The Kepler mission has applied a "three-sigma" criterion, where the transit source is considered a background object if the mean of the centroid measurements is three sigma from the target star. This criterion assumes the false positive probability from Gaussian statistics. When there are few centroid measurements, however, the mean of Gaussian-distributed measurements follows Student's t-distribution instead of a Gaussian distribution. The larger tails of the t-distribution imply that the centroid mean can be farther from the target star with the same false-positive probability. This is particularly the case for long-period exoplanets, where there are few observed transits. We present an analysis of Kepler centroid data using Student's t-distribution. We find several long-period exoplanets that are currently determined to be false positives due to the Gaussian three-sigma centroid offset criterion that would not be false positives according to the t-distribution. We present a correction factor that depends on the number of centroid measurements which can be applied to the centroid offsets on the NExSci exoplanet archive. While the number of false positives returned to candidate exoplanet status is small, they are at long period where there are few such candidates. Exoplanet demographic studies oriented towards long period are potentially strongly impacted by these corrections. These considerations will also be important for surveys with shorter observation times such as TESS.

**Author(s):** Steve Bryson

**Institution(s):** NASA Ames Research Center Contributing Team(s): The Kepler Team

d'Astrophysique de Grenoble, Australian National University, Caltech, University of Rochester, Jet Propulsion Laboratory, Leiden Observatory, University

#### **140.21 - Single-transit Long-Period Giant Planet Detections with LSST(Derek Buzasi)**

The Large Synoptic Survey Telescope (LSST) plans to conduct a 10-year survey of some 18000 square degrees of the southern sky, reaching approximately 24th magnitude in six optical bands and providing coarse temporal coverage of billions of potentially variable stellar sources. Previous work has examined the utility of LSST for exoplanet science and concluded that we should anticipate the detection of thousands of transiting planets, typically hot Jupiters and other short-period systems. In this work, I examine the utility of the Deep Drilling Fields for the detection of single-transit events caused by giant transiting planets with orbital periods from 2-25 years. Fewer than 10 such transiting planets are now known, making this a relatively undersampled population despite its importance in our own solar system, and simulations have predicted that TESS will find very few (if any) such planets. Here I show that LSST has the potential to increase our detections of such planets by more than an order of magnitude, and the nature of the Deep Drilling fields makes these detections uniquely amenable to ground-based confirmation and follow-up.

**Author(s):** Derek Buzasi

**Institution(s):** Florida Gulf Coast University

#### **140.22 - Photometric results of the $\hat{\text{I}}^2$ Pictoris b Hill sphere transit as observed by bRing, ASTEP, BRITE, and the HST(Samuel N Mellon)**

The  $\hat{\text{I}}^2$  Pictoris b Hill Sphere transit occurred between early-2017 and early-2018. During this event, high precision, high cadence photometry of  $\hat{\text{I}}^2$  Pictoris was obtained by the bRing ( $\hat{\text{I}}^2$  Pictoris b Ring) and ASTEP (Antarctic Search for Transiting ExoPlanets) ground-based observatories, the BRITE (Bright Target Explorer) satellite, and the HST (Hubble Space Telescope). The data from each source were combined and analyzed to search for evidence of occultation of the star by circumplanetary matter. While the star's pulsations were detected, none of the surveys detected any unexplained fluctuations, which might have been due to circumplanetary matter. This poster presents the overall light curve of  $\hat{\text{I}}^2$  Pictoris during the Hill sphere transit and presents preliminary estimates of upper limits on the amount of circumplanetary dust at a wide range of orbital radii around the exoplanet  $\hat{\text{I}}^2$  Pictoris b.

**Author(s):** Paul Kalas, Lyu Abe, Jason Jinfei Wang, Remko Stuik, Anne-Marie Lagrange, Rudi Kuhno, François-Xavier Schmider, John Bailey, Samuel N Mellon, Geert Jan Talens, Tristan Guillot, Blaine Lomborg, Michael Ireland, Djamel Mekarnia, Konstanze Zwintz, Matthe

**Institution(s):** University of Cape Town, South African Astronomical Observatory, Institut de Planétologie et

#### **140.23 - AutoRegressive Planet Search for Ground-Based Transit Surveys(Andrew Stuhr)**

Sensitive methods of signal processing are needed to discriminate faint periodic transiting planet signals from often-dominant aperiodic trends in observational conditions in ground-based photometric surveys. Caceres et al. (2018) show that the AutoRegressive Planet Search (ARPS) method -- a combination of autoregressive integrated moving average (ARIMA) parametric modeling, a new Transit Comb Filter (TCF) periodogram, and machine learning classification -- is effective when applied to evenly spaced light curves from space-based missions. We investigate here whether ARIMA will be effective at trend removal from ground-based survey light curves that are often sparsely sampled with high noise levels from atmospheric and instrumental conditions. The ARPS process is applied to selected light curves with strong planetary signals from the Kepler mission that have been altered to simulate the cadences and conditions of ground-based exoplanet surveys. We find that the ARPS methodology recovers planetary signals from brighter stars observed with denser cadences and/or longer survey durations. Detection rates improve for shorter periods, deeper transits and more regular cadences. We report preliminary results from application of ARPS methodology to the HAT-South survey dataset in order to confirm known, and potentially discover new, candidate planets.

**Author(s):** Joel Hartman, Eric Feigelson, Gabriel Caceres, Andrew Stuhr

**Institution(s):** Pennsylvania State University, Princeton University

#### **140.24 - Project PANOPTES: Transiting Exoplanet Detection using Low-Cost Robotic Telescopes(Aru Mukherjee)**

There are multiple methods of detecting planets beyond the solar system, and one of the most prolific in detection yield is the transit method, which uses photometry to identify stars around which there exist exoplanets. For the transit method to work the planet/star plane must be aligned with the direction of the Earth, reducing the probability of capturing such a system. In order to maximize planetary detection rates using this method, many stars should be monitored simultaneously for as continuous a duration as possible. Project PANOPTES aims to survey a large fraction of the sky using a large number of continuously observing low-cost PANOPTES units, consisting of wide-field cameras that monitor tens of thousands of stars at once. Costs are kept down by using off-the-shelf DSLR cameras and telescope mounts, and weatherproofing the unit, thus



eliminating the need for a dome. A PANOPTES unit was constructed at Caltech for the dual purpose of gathering data on campus and boosting the collecting capabilities of the PANOPTES network, as well as to refine and test the build instructions for the baseline units. These instructions were followed to construct the hardware in the unit. The PANOPTES control software was installed to run the unit, modified as needed, and tested alongside assembled hardware and electronics. Once polar aligned, the unit was able to track and image target stars, and detected the planet HD189733b in a single transit light curve, despite light pollution from LA. Future plans for the unit include refinement of the data reduction pipeline, and deployment at a remote site to avoid light pollution. Once this is done, the unit, along with the other units in the PANOPTES network, can play a critical role in TESS followup studies, as well as potentially detecting other transient phenomena such as variable stars and supernovae.

**Author(s):** Montu Ganesh, Nemanja Jovanovic, Aru Mukherjee, Wilfred Gee, James Synge, Kathy Guyon, Dimitri Mawet, Garreth Ruane, Luc Boucher, Olivier Guyon  
**Institution(s):** California Institute of Technology, Gemini Observatory, Macquarie University, Subaru Telescope, Google

#### **140.25 - Preliminary Results from a Young Exoplanet RV Survey (Larissa Nofi)**

Observing and characterizing newly-formed planets around young stars is important for developing planet formation and evolution theory. However, given challenges in detecting young planetary systems, current models are primarily based on systems that are billions of years old. It is therefore unclear which exoplanetary properties are indicators of formation conditions, or of later evolution. We are conducting an infrared radial velocity survey to detect and confirm young exoplanets around T Tauri stars using the Immersion Grating Infrared Spectrograph (IGRINS) on the 4.3-m Lowell Observatory Discovery Channel Telescope (DCT). IGRINS simultaneously observes H- and K-bands at a resolution of  $\sim 45,000$ . Infrared spectroscopy is less susceptible to apparent RV variability caused by starspots on active young stars than optical observations. Our sample consists of  $\sim 100$  T Tauri stars of age 1 to a few Myr in the relatively nearby Taurus star forming region. We present early results on our search for RV variability of T Tauri stars, indicative of the presence of hot Jupiters with the IGRINS + DCT system.

**Author(s):** Brian Skiff, Kendall Sullivan, Joe Llama, Lisa Prato, Lauren Biddle, Christopher Johns-Krull, Larissa Nofi,  
**Institution(s):** Lowell Observatory, Rice University, University of Hawaii, Northern Arizona University, University of Texas, Austin Contributing Team(s): IGRINS Team

#### **140.26 - Mitigating Stellar Noise Using High Cadence Radial Velocity Observations (Stephanie Striegel)**

The search for an Earth analog within the habitable zone of a Sun-like star requires a radial velocity (RV) precision of  $\sim 10 \text{ cm s}^{-1}$ . Previous generation instrumentation and data analysis techniques paved the way for precision RV measurements, allowing for detections on the order of  $1 \text{ m s}^{-1}$ . While the community is working to break the  $1 \text{ m s}^{-1}$  barrier with further advancement in instrumentation and analysis, we also remain limited in our small planet detection capabilities by the presence of stellar noise, produced by oscillations, granulation and magnetic activity. These phenomena cause signatures in RV measurements that can effectively obscure the detection of small-mass exoplanets. Therefore, we must also address the  $1 \text{ m s}^{-1}$  barrier by better understanding how to mitigate stellar noise. In this work, we focus on how RV observing strategy can be used to mitigate the effects of stellar noise, by quantitatively determining the strategy that yields the best RV precision (lowest RMS). This work builds on that of Dumusque et al. (2011), but uses "traditional" (planet-finding) RV observations, instead of those obtained for asteroseismology, and also covers a longer observing period. Our data consist of high cadence RV measurements of three stars with spectral types F and G, taken between March 2017 and May 2018 with the Planet Finder Spectrograph (PFS) installed on the 6.5 m Magellan II telescope at Las Campanas Observatory in Chile. We apply various binning schemes to these data and calculate the resulting RMS from each binning scheme. We find that not only do stars of different spectral types have different optimal observing strategies, but such is the case for even stars of the same spectral type, suggesting that granulation size and decay time may depend on more than effective temperature.

**Author(s):** Stephanie Striegel, Johanna Teske  
**Institution(s):** San Jose State University, Carnegie Observatories

#### **140.27 - The NEID Precision Radial Velocity Spectrometer: Characterization and Operation of the NEID CCD Detectors (Mark Giovannazzi)**

NEID is a 380-930 nm precision Doppler spectrometer in development for the WIYN 3.5-m telescope at Kitt Peak National Observatory as part of the NN-Explore Partnership. The wide spectral grasp of NEID requires a monolithic CCD detector with a large area, small pixels, and excellent quantum efficiency across the NEID bandpass. NEID employs a single, deep depletion CCD290-99 device from e2v having  $9\text{K} \times 9\text{K}$  pixels with 10 micron pitch and Astro Multi-2 AR coating. We describe the operation of the CCD290-99 device as well as the results of the CCD testing and characterization efforts performed at the University of Pennsylvania.

**Author(s):** Frederick Hearty, Sam Halverson, Mark Giovannazzi, Gudmundur Kari Stefansson, Christian Schwab, Joe Philip Ninan, Arpita Roy, Zichen Tang, Joseph Tuftso, Suvrat Mahadevan, Andrew Monson, Chad Bender, Dan Li, Ryan Terrien, Michael McElwain, Cullen Blak

**Institution(s):** Semiconductor Technology Associates, University of Pennsylvania, Pennsylvania State University, National Optical Astronomy Observatory, Massachusetts Institute of Technology, California Institute of Technology, Macquarie University, Carleton College

**140.28 - Science with NEID Guaranteed Time Observations(Jason T Wright)**

The NEID spectrograph at the WIYN 3.5m telescope at Kitt Peak will be a facility instrument available to the precise radial velocity community via the NN-EXPLORE partnership between NASA and NOAO. The NEID instrument team will have 270 on-sky hours per year for 5 years of guaranteed time to conduct some of the novel science enabled by this instrument. In this poster, I describe the design and goals of the NEID team's science program with its Guaranteed Time Observations.

**Author(s):** Frederick Hearty, Lawrence Ramsey, Sam Halverson, Michael McElwain, Jason T Wright, Christian Schwab, Arpita Roy, Suvrath Mahadevan, Chad Bender, Cullen Blake

**Institution(s):** Penn State University, University of Pennsylvania, University of Arizona, Caltech, NASA Goddard, Macquarie University  
**Contributing Team(s):** The NEID Team

**140.29 - Getting to Know Your Star: A comparison of analytic techniques for deriving stellar parameters and abundances(Erin Elise Flowers)**

The detection and characterization of exoplanets - accurate measurements of their radii, masses, and insolation fluxes - depend on accurate measurements of stellar radii, masses, and temperatures. This reliance on understanding the host star - its fundamental parameters, its multiplicity, its composition, its activity - to understand the presence and/or properties of exoplanets has increased interest in the exoplanet community for reliable, fast methods of stellar characterization. In this study, we present the derived stellar parameters (effective temperature,  $\log(g)$ , and  $[\text{Fe}/\text{H}]$ ) for over 500 stars observed with the Carnegie Planet Finder Spectrograph (PFS) on the Magellan II Telescope as part of a long-term RV survey to detect and characterize Earth-like planets. As part of our analysis, we compare the performance of spectral synthesis (Empirical Specmatch and ZASPE) and equivalent width (iSpec) analysis techniques to derive stellar parameters and chemical abundances. From our results, we then determine which stars are optimal candidates for continued spectroscopy observations, as most of the stars in our sample do not currently have detected exoplanets. We also provide recommendations as to which computational tools to use for analyzing spectroscopic follow-up observations, especially for large surveys.

**Author(s):** Johanna Teske, Erin Elise Flowers

**Institution(s):** Princeton University, Observatories of the

Carnegie Institute for Science

**140.30 - ROME/REA Survey: Improved characterization of microlensing events by understanding the source stars(Rachel Street)**

The microlensing technique allows us to extend the search for planets to orbital radii where other methods are less sensitive, and to regions of the galaxy where the star formation history is different from that of the solar neighborhood. However, it shares with all other planet search techniques a requirement to properly characterize the source star in order to fully understand the lensing systems. As the source stars are typically fainter ( $I \sim 16\text{--}22$  mag) than those targeted by radial velocity and transit surveys, spectroscopy is challenging, so microlensing has historically relied on timeseries photometry in two bandpasses (V,I) to determine the spectral type of the source star. This single-color measurement has limitations when applied to often late-type source stars in highly crowded fields that suffer from strong extinction. Unfortunately, practical constraints on observing resources previously limited the rate at which color measurements could be obtained. The goal of the ROME/REA Survey is to obtain high cadence timeseries photometry in SDSS-g,r,i filters to provide better constraints on the spectral types of microlensing host stars, and by extension, the planetary and stellar binaries discovered. The resulting dataset comprises timeseries multi-band photometry of millions of stars in the Galactic Bulge, which will serve a wealth of other galactic science, and which will be made public at the end of the current 3-yr survey. Here we present results from the 2017 and 2018 observing seasons.

**Author(s):** Etienne Bachelet, Markus Hundertmark, Yiannis Tsapras, Rachel Street

**Institution(s):** Las Cumbres Observatory, University of Heidelberg  
**Contributing Team(s):** ROME/REA Team

**140.31 - Photometric variability of Earth, as an Exoplanet Proxy: Insights from DSCOVR and TSS Simulations**

**(Aronne Merrelli)**

The spectral reflectance of a Terrestrial exoplanet will vary through its orbit, due to the changing planetary phase angle and the location of the illuminated portion of the planet's surface. These variations can be used to characterize exoplanets, but separating the different effects may prove to be a challenging task. We investigate these variations in Earth's reflectance colors by using observations and simulated data as a proxy for possible future terrestrial exoplanet direct imaging observations. First, we analyze data from the Earth Polychromatic Imaging Camera (EPIC) aboard the Deep Space Climate Observatory (DSCOVR). The EPIC instrument collects full-disk imagery of Earth's sunlight side in 10 narrow spectral band passes (1-3 nm width) from the near UV to near IR. As a proxy for exoplanet observations, the EPIC dataset is unique

among Earth observing data because of the relatively distant vantage point (1.5M km from the Lagrange-1 point) and its multi-year data record (September 2015 to present). The long duration data record includes both seasonal and interannual variations. Second, we use the Terran Spectral Simulator (TSS) framework to generate synthetic observations matching the EPIC observation geometry. The simulated observations contain full spectral coverage from 0.35 to 2.7  $\mu$ m wavelength, allowing direct comparison to the EPIC observations and investigations into reflectance variability at other spectral bandpasses not directly observed by EPIC.

**Author(s):** Aronne Merrelli, Margaret Turnbull, Tristan L'Ecuyer

**Institution(s):** Space Science and Engineering Center, Dept of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, SETI Institute

#### **140.32 - Searching for Trends in Atmospheric Compositions of Extrasolar Planets(Kassandra Weber)**

Since the first exoplanet was discovered decades ago, there has been a rapid evolution of the study of planets found beyond our solar system. A considerable amount of data has been collected on the nearly 3,779 confirmed exoplanets found to date. Recent findings regarding transmission spectroscopy, a method measuring a planet's upper atmosphere to determine its composition, have been published on a limited number of exoplanets. The aim of our work is to gather existing data on atmospheric planetary composition and search for potential trends in relation to the exoplanets' orbital and planetary properties. Due to their short periods and thicker atmospheres, hot-Jupiter type planets have been our first target population. Out of 78 cases with periods shorter than 3 Earth days and radius larger than 1 RJ, we found previously-published data on the atmospheres of 15 hot-Jupiters. Only 8 cases had an overlapping wavelength range that allowed comparisons: 480 - 900 nm. We will report our findings on this set, which will be publicly available on the Habitable Zone Gallery. This statistical comparative work will be of particular importance in the era of Transiting Exoplanet Survey Satellite (TESS) and James Webb Space Telescope (JWST), whose synergy will result in a large inventory of atmospheric abundances.

**Author(s):** Kassandra Weber, Stephen Kane, Paola Rodriguez Hidalgo, Adam Turk, Troy Maloney

**Institution(s):** Humboldt State University, University of California, Riverside, University of Washington Bothell

#### **140.33 - Prospects for Astrometric Detection of Giant Exoplanets in Hot Binary Systems(Tyler Gardner)**

Current exoplanet detection methods struggle to probe the planet occurrence rate around intermediate mass ( $>1.5 M_{\text{sun}}$ ) main-sequence stars. Of the nearly 3000 planets discovered via the transit method, less than 10 have been found transiting A-type stars. Weak and broad spectral lines make the radial

velocity detection method difficult for these hot stars. Long-baseline interferometry provides a feasible method for discovering giant planets in this regime given that the star is part of a binary system. One star can be used as an interferometric reference, making it possible to achieve micro-arcsecond precision on relative position. This precision makes it possible to detect the "wobble" imparted on a star by an orbiting giant exoplanet. We present an analysis of pilot binary systems from data taken with the MIRC instrument at the CHARA array. For individual measurements of A-type binary  $\delta$  Del taken over a span of 2 years, we achieve  $<10$  micro-arcsecond precision on differential position with 10-minute observations. We find with this precision we can detect most exoplanets  $>2 M_{\text{Jup}}$  on orbits  $>0.7$  AU around individual components of hot binary stars via differential astrometry. We recently began a survey with MIRC at the CHARA array monitoring sub-arcsecond hot binary stars in order to detect the "wobbles" from substellar companions orbiting individual stars to these systems. We outline our target sample, first results from our survey, and the limits we expect to place on giant planet formation occurrence rate between 0.5-2 AU for intermediate mass stars and binary systems.

**Author(s):** Tyler Gardner

**Institution(s):** University of Michigan

#### **140.34 - Baade's Window: An astrometric calibration field for high-contrast imaging of exoplanets(Meiji Nguyen)**

Improving the quality of calibration fields available to high-contrast imagers translates to higher precision astrometry, a key component of understanding the orbits and interactions of directly imaged extrasolar planets. Baade's Window is a relatively dust free field of view with a high density of visible stars, making it a prime target when doing astrometric calibration for instruments observing at high angular resolution in the infrared wavelength regime. Using data taken from Gemini South/GPI and Keck/NIRC2, we characterized the astrometry of eight background stars in the  $2.7'' \times 2.7''$  field of view around HD 165054, a star in Baade's Window. Milliarcsecond astrometry of these stars allows for accurate prediction of their future positions so that current and future high-contrast imagers (e.g. VLT/SPHERE, Gemini South/GPI, Subaru/CHARIS) can accurately and quickly use Baade's Window as a way to calibrate their instruments and test for systematics such as position angle offsets or platescale errors. We used the GPI data reduction pipeline and advanced image processing techniques to reduce the data, a Bayesian framework with forward modeling to measure the relative positions of the stars, and MCMC computational model fitting to constrain their proper motions and parallaxes. Characterization of the astrometry of Baade's Window will provide the direct imaging community with a useful source for high precision astrometric calibration.

**Author(s):** Robert De Rosa, Jason Jinfei Wang, James Graham, Meiji Nguyen, Thomas Esposito

**Institution(s):** UC Berkeley, Stanford University, California

Institute of Technology Contributing Team(s): Gemini Planet Imager Exoplanet Survey (GPIS)

#### **140.36 - The CHARIS Integral Field Spectrograph with SCEXAO(Jeffrey Chilcote)**

The Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) is an integral field spectrograph (IFS) mounted behind the Subaru Coronagraphic Extreme Adaptive Optics (SCEXAO) and AO188 adaptive optics systems, located on the Subaru telescope. CHARIS is designed to detect objects six orders of magnitude dimmer than their parent star in the near-IR. Similar to other direct imaging IFSs, CHARIS is a lenslet-based IFS and has two fundamental operating modes. CHARIS has a “high-resolution” prism providing an as-built average spectral resolution of  $R \sim 75$ ,  $R \sim 65$ , and  $R \sim 77$  in J, H, and K bands respectively. Unique to CHARIS is a second mode designed for discovery, with a “low-resolution” prism providing an as-built spectral resolution of  $R \sim 18.4$  that spans the full J+H+K spectrum in a single image. By enabling spectral differential imaging over a wide bandpass, the low-res mode helps CHARIS achieve extremely deep contrast at small angular separations. CHARIS was completed at Princeton University and shipped to the Subaru observatory in 2016 and has been available for open use proposals since 2017. We present the current instrument operational performance, improvements, data reduction tools, and an overview of ongoing science being performed with CHARIS.

**Author(s):** Ruben Asensio-Torres, Timothy Brandt, Naruhisa Takato, Maxime Rizzo, Sean Goebel, Benjamin Gerard, O, Thayne Currie, N. Jeremy Kasdin, Jungmi Kwon, Julien Lozi, Nemanja Jovanovic, Evan A Rich, Masahiko Hayashi, Tyler Groff, Christian Marois, Jeffrey Ch

**Institution(s):** Univ of Victoria, oNRC HAA, Stockholm University, University of Oklahoma, ISAS/JAXA, University of Notre Dame, Goddard Space Flight Center, Princeton University, Subaru Telescope, UCSB, California Institute of Technology, NASA Ames, IfA, National

#### **140.37 - A New Assessment of the Candidate Protoplanets Orbiting LkCa 15 Using SCEXAO/CHARIS High-Contrast Direct Spectroscopy(John Wisniewski)**

LkCa 15 hosts three candidate protoplanets (LkCa 15 bcd) identified from sparse aperture masking and H-alpha differential imaging. However, LkCa 15's circumstellar environment is extremely complex, including a bright crescent-shaped outer disk wall and inner disk detected via polarimetry. Direct imaging and spectroscopy at high Strehl ratios could more decisively determine the nature of these candidates. Using SCEXAO/CHARIS, we present the first bona fide extreme AO observations of LkCa 15, covering wavelengths where both these candidates and the disk have been identified. We use radiative transfer modeling for the inner disk and forward-modeling to understand how planets and disk signals propagate

through our data. Based on these results, we reassess the planet inventory and inner disk morphology of LkCa 15.

**Author(s):** John Wisniewski, Kellen Lawson, Timothy Brandt, Thayne Currie, N. Jeremy Kasdin, Julien Lozi, Jeffrey Chilcote, Tyler Groff, Christian Marois, C. A. Grady, Olivier Guyon

**Institution(s):** University of Oklahoma, NASA GSFC, NASA-Ames, Princeton University, Subaru Observatory, University of Notre Dame, UCSB, Eureka Scientific, NRC Herzberg

#### **140.38 - Speckle evolution and post-processing contrast improvements with short exposure imaging on the Gemini Planet Imager(Wyatt Ian Mullen)**

The direct imaging of young exoplanets requires detection of faint signals located near the signal to noise (SNR) limit. Any improvements in our understanding of the behavior of the dominant scattered light noise (referred to as “speckles” due to their characteristic interference patterns) increase the likelihood of detecting planets. Using the Gemini Planet Imager (GPI) on the Gemini South Telescope and high-cadence detector readout strategies, we imaged bright stars in the southern sky including Sirius and Lambda Geminorum. In particular, the 1.5-second individual exposures of Sirius, an order of magnitude shorter than the standard 60 second integration timeframe, provide the deepest, highest contrast observations made to date with GPI. Although this exposure time is longer than the expected lifetime of speckles purely due to atmospheric turbulence, it allows us to study the evolution of instrumental quasi-static speckles. Shorter integration periods give us a finer sampling of the time-evolution of dynamic speckles over the image plane, information that is generally lost during longer exposures, and allow us to place new estimates on the average lifetime or stability of this noise. These finer sampled speckles may allow us to obtain improved contrast ratios between the speckle intensity and the flux of the star after point spread function subtraction with the Karhunen-Loève image processing (KLIP) algorithm. Better understanding the ideal exposure time for the GPI program will help the proposed redesign of GPI (GPI 2.0) as we consider upgrading and relocating from Gemini South to Gemini North to image northern sky targets.

**Author(s):** Jean-Baptiste Ruffio, Bruce Macintosh, Wyatt Ian Mullen, Jeffrey Chilcote

**Institution(s):** Stanford University, University of Notre Dame Contributing Team(s): GPIS Team

#### **140.39 - Using Principle Component Analysis to Search For Planets in Archival Data(Elisabeth Frischknecht)**

Herbig Ae/Be (HAeBe) stars are classified as 2-10 solar mass pre-main sequence stars with circumstellar disks. As a result, they are excellent candidates for observing exoplanets in the formative stages of their evolution. Principle component analysis is a data reduction technique that allows us to minimize the noise from the Point Spread Function (PSF) of

coronagraphic images. By constructing and then subtracting a model PSF from object frames, we are able to obtain an image of the circumstellar disk and any planets that are located within it. Using this technique, we are searching through the archival HST images of object HD100546, which is known to host at least one planet that has been detected at near-infrared wavelengths by other telescopes. Using a few different processing algorithms we are looking to see if this planet is detectable in HST images taken more than ten years ago.

**Author(s):** Loic Beus, Denise Stephens, Elisabeth Frischknecht, Emily Safsten

**Institution(s):** Brigham Young University, Pennsylvania State University

#### **140.40 - Blind Search Single-Visit Exoplanet Direct Imaging Yield for Space Based Telescopes(Dean Keithly)**

We compare exoplanet direct imaging capabilities of WFIRST and mission concepts on the scale of those considered in the Astrophysics Decadal Survey by running full mission simulations using the EXOSIMS survey simulator. We execute blind-search surveys of our universe supplanted with randomly generated planets based off the SAG13 planet population model. Mission schedules of each telescope are optimized with a Sequential Least Squared Quadratic Programming (SLSQP) scheduling algorithm to optimize single-visit completeness of fixed duration missions. We directly compare unique detection histograms, theoretical maximum completeness with no time constraints, and sum completeness over all targets of an optimized mission schedule of each telescope.

**Author(s):** Dean Keithly, Rhonda Morgan, Dmitry Savransky, Daniel Garrett,

**Institution(s):** Cornell University, Jet Propulsion Laboratory, Carl Sagan Institute

#### **140.41 - Simulating the earth-like exoplanet yield of the NASA LUVOIR 'A' architecture direct-imaging mission(Dominic Oddo)**

Direct imaging of exoplanets will increasingly become a more popular method of exoplanet detection and characterization as larger space telescopes equipped with better technology and more ambitious scientific objectives are launched. Among other scientific objectives, NASA's Large

UltraViolet/Optical/InfraRed Surveyor (LUVOIR) aims to detect and characterize exoplanets within 50 parsecs of the Sun, making the goal of direct exoplanet detection a reality. This paper describes simulations that predict that LUVOIR will detect 54 earth-like exoplanets within two years of a dedicated campaign. The simulation's detection criteria require that the exoplanet be visible within the working angle of the focal plane, be within the habitable zone, produce a signal-to-noise ratio greater than seven and a contrast ratio greater than  $10^{-10}$  with respect to the parent star. We find that although it is

possible to detect exoplanets around M dwarfs, they are not ideal targets due to their low brightness and luminosity. Although it could be included in future work, we have not produced a specific list of stars that LUVOIR could observe. Our approach determines the characteristics of stars that produce the highest completeness, which could lead to such a list in the future.

**Author(s):** Dominic Oddo, Donald Figer

**Institution(s):** Case Western Reserve University, Rochester Institute of Technology

#### **140.42 - Maximum Angular Separation Epochs for Exoplanet Imaging Observations(Stephen Kane)**

Direct imaging of exoplanets presents both significant challenges and significant gains. The advantages primarily lie in receiving emitted and, with future instruments, reflected photons at phase angles not accessible by other techniques, enabling the potential for atmospheric studies and the detection of rotation and surface features. The challenges are numerous, and include coronagraph development and achieving the necessary contrast ratio. Here, we address the specific challenge of determining epochs of maximum angular separation for the star and planet. We compute orbital ephemerides for known transiting and radial velocity planets, taking Keplerian orbital elements into account. We provide analytical expressions for angular star--planet separation as a function of the true anomaly, including the locations of minimum and maximum. These expressions are used to calculate uncertainties for maximum angular separation as a function of time for the known exoplanets and we provide strategies for improving ephemerides with application to proposed and planned imaging missions.

**Author(s):** Margaret Turnbull, Stephen Kane, Tiffany Meshkat

**Institution(s):** University of California, Riverside, SETI Institute, IPAC, Caltech

#### **140.43 - Analysis of Exoplanetary Systems as WFIRST Targets(Zhexing Li)**

As part of the WFIRST Coronagraph Science Investigation Team (WFIRST-C SIT) to study exoplanets around nearby stars, we aim to characterize nearby exoplanetary systems and provide a list of stars that would be suitable targets for WFIRST to carry out exoplanet direct imaging mission. To achieve that, we will be addressing two primary issues: characterization of stellar and orbital properties of nearby exoplanets. Having a better understanding of host star characteristics and the Keplerian orbit properties of the known nearby exoplanets are crucial in determining exoplanet targets for WFIRST direct imaging. These two aspects give us important insights such as the presence of stellar and substellar companion in the system, planet-star separation, reflected light from planets, background star fields etc. We use ExoCat as well as other online sources

such as Simbad, VizieR, and Gaia DR2 to provide the best possible stellar parameters for nearby exoplanet host stars. We provide a strategy to conduct precursor radial velocity observations to refine orbital ephemeris of nearby potential WFIRST exoplanet targets by the use of major telescopes such as the Automated Planet Finder. The combined effort will allow us to progress towards the completion of target selection for WFIRST exoplanet observing program.

**Author(s):** Margaret Turnbull, Stephen Kane, Zhexing Li  
**Institution(s):** University of California, Riverside, SETI Institute

#### **140.44 - The WFIRST Coronagraph Exoplanet Data Challenge(Avi M Mandell)**

We present the status and future plans for the WFIRST Coronagraph Exoplanet Data Challenge (EDC). The goals of the Coronagraph Exoplanet Data Challenge are to provide quantitative feedback to the specifications and requirements of the WFIRST Coronagraph Instrument (CGI) and to leverage and develop expertise in the broader community. The EDC team produces and publicly releases simulated data, with the goal of improving our understanding of the efficacy of pipeline and instrument design by coordinating a comparison between blind spectral retrieval studies conducted by team members as well as the broader exoplanet analysis community. Each team member contributes to different areas of the EDC: the atmospheric modeling, WFIRST CGI instrumental properties, the simulated data and the retrieval of planetary atmospheres. The first cycle of the CGI EDC, called Data Challenge #1, focused on improving atmospheric modeling tools for direct imaging observations at WFIRST wavelengths, with the goal of informing the choice of IFS resolution and bandpass. The upcoming Data Challenge #2 will focus on extracting planets from simulated WFIRST images, in order to test planet discrimination from the image background using photometry and proper motion, and test how well we can determine orbits and test enhanced detection/orbit determination capability with late-mission starshade images. We are currently in the process on recruiting participants for this challenge, and encourage community members to join. The numerous participants in the Coronagraph Exoplanet Data Challenge are from institutions in Asia, Europe and the US, and several teams from outside the existing WFIRST community are already engaged in the process. This presentation will focus on what has been accomplished in Data Challenge #1, what we hope to accomplish in future Data Challenges, and how the broader exoplanet community can get involved.

**Author(s):** Maxime Rizzo, Aronne Merrelli, Margaret Turnbull, Avi M Mandell, Sergi Hildebrandt, Aki Roberge, Neil T. Zimmerman

**Institution(s):** NASA GSFC, JPL, SETI Institute, Space Science and Engineering Center

#### **140.45 - The WFIRST Coronagraph Instrument: a major stepping stone in the preparation of future exoplanet direct imaging missions(Bertrand Mennesson)**

We detail here how the WFIRST Coronagraph Instrument (CGI) will benefit potential future flagship direct imaging missions aimed at the spectroscopic characterization of exoplanets, including small rocky planets in the habitable zone. CGI will demonstrate for the first time in space many of the key technologies required: pointing stabilization at the milli-arcsecond level, autonomous sub-nanometer wavefront sensing and control, broad-band coronagraphic imaging and spectroscopy, point source detection using ultra-low noise photon counting CCDs, and accurate speckles subtraction. All of these technologies will be validated in a yet unexplored high contrast / low source flux regime, at levels commensurate with the needs of future flagship direct imaging missions aimed at the characterization of exoplanetary systems, including imaging of exozodiacal dust and spectroscopy of exoplanets in the habitable zone.

**Author(s):** Jeremy Kasdin, Leonidas Moustakas, Jason Rhodes, John Terry Trauger, Tiffany Meshkat, Margaret Turnbull, Bruce Macintosh, Vanessa Bailey, Bertrand Mennesson

**Institution(s):** Jet Propulsion Laboratory, Stanford University, Princeton University, Caltech IPAC, SETI Institute  
**Contributing Team(s):** and the WFIRST Coronagraph Instrument and Science Investigation Teams

#### **140.46 - WFIRST CGI Coronagraph Design: Improving Performance and Robustness(A J Eldorado Riggs)**

The goal of the proposed Wide-Field Infrared Survey Telescope (WFIRST) Coronagraph Instrument (CGI) is to demonstrate the technologies necessary for a future exo-earth characterizing mission. After descopes, the new baseline design includes three observing modes: two for imaging and one for spectroscopy. Ongoing coronagraph design work is focused on increasing throughput and reducing aberration sensitivities. We are using our open-source software package, the Fast Linearized Coronagraph Optimizer (FALCO), to perform hybrid Lyot coronagraph design surveys. We present our design methodology and survey results.

**Author(s):** Carl Coker, A J Eldorado Riggs, Erkin Sidick, Dwight Moody, Brian Kern, Garreth Ruane

**Institution(s):** Jet Propulsion Laboratory

#### **140.47 - Expected Performance and Data Products of the WFIRST CGI Integral Field Spectrograph(Tyler Groff)**

The WFIRST coronagraphic instrument (CGI) will demonstrate exoplanet spectroscopy using an integral field spectrograph (IFS). The CGI IFS, being designed and built at Goddard Space Flight Center, has a spectral resolution of R50 and is

designed to accommodate a 20% bandpass spanning 600-970nm. The IFS is principally targeting the abundance of Methane features, with the primary coronagraph band being centered around 770nm. Key to the performance estimates are the achievable signal-to-noise (SNR) ratios and the stability of the microspectra over the course of tens and hundreds of hours. As a technology demonstration for CGI, the ability to close a wavefront control loop around the IFS, maintain a stable dark hole, and provide time resolved data that simultaneously spans spatial and spectral dimensions are crucial demonstrations for future observatories. We highlight the IFS requirements and how the on-orbit calibration is handled. We also provide further detail on the optomechanical design, its stability based on thermal and structural predictions, anticipated performance, and operations concept of the CGI IFS. The impact of these performance metrics are projected into simulated data products, demonstrating cube extraction of noisy images and the subsequent planet spectrum that can be extracted from them.

**Author(s):** Samuel Gaylin, Nicholas Nicolaeff, Maxime Rizzo, Michael McElwain, Vanessa Bailey, Rose Mountcastle, Hong Tang, Qian Gong, Neil T. Zimmerman, Eric Cady, Tyler Groff, Avi M Mandell

**Institution(s):** Goddard Space Flight Center, ATA, Genesis Engineering, Jet Propulsion Laboratory, Lentech Inc

#### **140.48 - The WFIRST Starshade: Simulated Images of Exoplanetary Systems(Margaret Turnbull)**

We have developed a suite of software forming an end-to-end starshade imaging tool that produces images of an arbitrary user-defined exoplanetary system and background as observed by a starshade and a telescope. The starshade imaging characteristics include both the diffraction from an ideal or perturbed starshade as well as solar glint from the starshade edges, the largest source of local instrument scatter. The telescope model assumes an ideal telescope with a user-defined obscured pupil (e.g. secondary obstruction and struts). It incorporates a vanilla detector model with read noise and dark current. Finally, the astrophysics scenario incorporates Keplerian orbits, phase angles, geometric albedo, different atmospheric scattering/absorption laws, any kind of host star (by default the user can choose among any of the +10,000 stars from ExoCat) and a large variety of extragalactic background fields (galaxies, Quasars). Exo-dust emission is accurate for a solar system and flexible for an arbitrary elliptical user-defined profile in the inner habitable zone. As a result, it can virtually build a large variety of extra-solar systems with an arbitrary number of exo-planets of multiple types and any host star, adding an optional background field, to obtain a series of images throughout the proposed mission. Proper motion and parallax are also taken into account when background fields are added to the simulated images. There are default systems, like the Solar System at any distance from us. We have employed the tool to support WFIRST-S mission probe studies. NOTE: A subset of these images will be used for the WFIRST CGI Exoplanet Data Challenge, for which our team is actively

seeking participants. Please contact the author at turnbull.maggie@gmail.com, for details.

**Author(s):** Margaret Turnbull, Sergi Hildebrandt, Stuart Shaklan

**Institution(s):** SETI Institute, Jet Propulsion Lab

#### **140.49 - Recent Progress on Image Processing Methods for Exoplanet Detection in Starshade Observations(Mengya Hu)**

Direct imaging of exoplanets is extremely difficult as the star is about 10-10 times brighter than the planets tens of milliarcseconds away. Using a starshade to suppress the starlight is a promising solution. However, various factors will make the exoplanets hard to detect. For example, bright spots caused by light diffracted from starshade defects are indistinguishable from the real planets' signal and when it overlaps with the real signal, it dramatically degrades the accuracy of the estimation of planet intensity. Image post-processing can help eliminate those effects. In our previous work, we applied the generalized likelihood ratio test (GLRT) as a starshade image processing method. It decides if the hypothesis that planets exist is more probable than not despite not knowing the planets' intensity or position. GLRT performed well for planet detection, but needed improvement for the estimation of position and intensity. In this work, we further investigate factors that may influence the performance of GLRT. For example, we demonstrate that using different reference point spread function (PSF) at different position improves estimation results, while observation methods and integration time have no significant influence. Moreover, we add exozodiacal dust to the image and discuss the effect dust has on the GLRT result.

**Author(s):** N. Jeremy Kasdin, Mengya Hu, Anthony Harness

**Institution(s):** Princeton University

#### **141 - Beyond Photons: Astronomy in the Multi-messenger Era Posters**

##### **141.01 - Development of Multi-Band Astrophysics Capabilities for LISA Data Challenges(Joey Shapiro Key)**

The Laser Interferometer Space Antenna (LISA) will detect low frequency gravitational waves from space in the 2030s. Multi-band gravitational wave astronomy will be enabled through the development of data analysis strategies for joint detections with LISA and ground-based observatories. The LISA Data Challenges provide simulated LISA data to enable investigations of multi-band astrophysics, including designs for alerts for ground-based gravitational wave detectors and electromagnetic follow-up of transient signals that will rely on timely communication of source identification and characterization.

**Author(s):** Joey Shapiro Key

**Institution(s):** University of Washington Bothell

Contributing Team(s): LISA Consortium

**141.02 - Searching for wobbles in the FeKa line as an EM counterpart to LISA detectable mergers(Barry McKernan)**

The broad FeKa line probes the geometry of gas in the innermost accretion disk around supermassive black holes (SMBH). The distribution of such gas is disturbed by the presence of a secondary black hole, which could be intermediate or stellar mass. The decay of a secondary's orbit will perturb the gas disk in ways that can be tested with present and future X-ray missions. Variability in the broad FeKa line offers the possibility of detecting precursor EM signatures before LISA detects SMBH-IMBH and EMRI mergers.

**Author(s):** Shane L. Larson, K.E. Saavik Ford, Barry McKernan,

**Institution(s):** CUNY-BMCC, Northwestern, AMNH

**141.03 - Why LISA should care about AGN driven stellar mass black hole binary mergers(K.E. Saavik Ford)**

LISA will enable, for the first time, multiband gravitational wave observations of stellar mass black hole binary sources. Such sources, in isolation, will take  $O(10^8)$  years to evolve from the LISA to the LIGO band. However, in an AGN disk, the gas-driven evolution will proceed much faster, and waveforms in the LISA band will be substantially different from those in the gas-free case. We show the evolutionary path for a gas-driven merger and argue that sources may pass quite rapidly through the relevant detection bands. Gas-driven mergers should provide a unique signature in the LISA band waveform, which must also be included in the global solution for LISA data.

**Author(s):** K.E. Saavik Ford, Barry McKernan,

**Institution(s):** CUNY Borough of Manhattan Community College, American Museum of Natural History

**141.04 - Gravitational Wave Survey of Galactic Ultra Compact Binaries(Tyson Littenberg)**

Ultra-compact binaries (UCBs) are systems containing compact or degenerate stars with orbital periods less than one hour. Tens of millions of UCBs are predicted to exist within the Galaxy emitting gravitational waves (GWs) at mHz frequencies. Combining GW searches with electromagnetic (EM) surveys like Gaia and LSST will yield a comprehensive, multimessenger catalog of UCBs in the galaxy. Joint EM and GW observations enable measurements of masses, radii, and orbital dynamics far beyond what can be achieved by independent EM or GW studies. GW+EM surveys of UCBs in the galaxy will yield a trove of unique insight into the nature of white dwarfs, the formation of compact objects, dynamical interactions in binaries, and energetic, accretion-driven phenomena like Type

Ia superonovae.

**Author(s):** Tyson Littenberg

**Institution(s):** NASA Marshall Space Flight Center

**141.05 - Honing in on MBH binary mergers with LISA(John Baker)**

Multimessenger observing campaigns to study massive black hole mergers will depend on localizing these systems through gravitational-wave measurements. LISA will enable precise measurement of binary merger properties, sometimes including sky localization to within a few arcminutes. Unlike recent ground-based gravitational-wave observations, however, LISA may detect binaries as long as years before merger. The information about the binary including its location will develop over time. We apply Bayesian analysis methods to study the how information about black hole merger systems develops over the months to hours leading to merger.

**Author(s):** John Baker

**Institution(s):** NASA-GSFC

**141.06 - Large-Scale Structure Measurements with Gravitational Waves: How biased are LISA sources?(Murti Nauth)**

The Laser Interferometric Space Antenna (LISA) is a gravitational wave mission expected to observe supermassive black hole mergers from the present day to before reionization, providing a set of standard 'sirens' with accurate distances that span the universe and are unperturbed by dust. As such, LISA observations hold great promise in constraining cosmology, such as non-gaussianity from inflation and the existence of dark radiation. Many of these constraints, however, rely on the supposition that the supermassive black hole mergers themselves are non-biased tracers of the matter distribution, as are LISA observations of these mergers. We use large-volume cosmological hydrodynamic simulations with supermassive black hole physics to measure the clustering properties of binary black hole mergers in the universe, and present preliminary results on the potential for biased structure measurements from the LISA data stream.

**Author(s):** Kelly Holley-Bockelmann, Murti Nauth,

**Institution(s):** Vanderbilt University, Fisk University

**141.07 - Immediate EM Counterparts of Binary Black-Hole Mergers in the LISA Regime(Bernard Kelly)**

Massive binary black-hole (BBH) mergers provide a prime source for LISA. These mergers will often take place in plasma-rich environments, leading to the possibility of a concurrent EM signal observable by traditional astronomical facilities. However, many critical questions about the generation of such counterparts remain unanswered. We explore mechanisms that may drive EM counterparts, using ideal



magnetohydrodynamical simulations to treat a range of toy-model scenarios involving equal-mass BBHs immersed in an initially homogeneous fluid with uniform, orbitally aligned magnetic fields. We find that the time-development of Poynting luminosity, which may drive jet-like emissions, is remarkably insensitive to aspects of the initial configuration. In particular, over a significant range of initial values, the central magnetic field strength is effectively regulated by the gas flow to yield a Poynting luminosity of  $10^{45} \text{--} 10^{46} \text{ } \square_{-13} \text{ M}_8^2 \text{ erg s}^{-1}$ . We also calculate the direct plasma synchrotron emissions processed through geodesic ray-tracing. Despite lensing effects and dynamics, we find the observed synchrotron flux varies little leading up to merger.

**Author(s):** Zachariah Etienne, Bruno Giacomazzo, Bernard Kelly, Jeremy Schnittman, John Baker

**Institution(s):** University of Maryland Baltimore County, West Virginia University, NASA Goddard Space Flight Center, Universita di Trento

#### **141.08 - Extracting gravitational-wave sources from incomplete listening sessions with LISA(Quentin Simon Baghi)**

By listening to gravity in the low frequency band, between 0.1 <u>mHz</u> to 1 Hz, the future space-based gravitational-wave observatory LISA will be able to detect tens of thousands of astrophysical sources from cosmic dawn to the present. The detection and characterization of all resolvable sources is a challenge in itself, but we foresee that the LISA data analysis will be further complicated by interruptions occurring in the <u>interferometric</u> measurements. These interruptions will be due to various causes occurring at various rates, such as laser frequency switches, high-gain antenna re-pointing, orbit corrections, or even unplanned random events. Extracting long-lasting gravitational-wave signals from <u>gapped</u> data raises problems such as noise leakage and increased computational complexity. We address these issues by developing a Bayesian method that reintroduces the missing data as auxiliary variables in the sampling of the posterior distribution of astrophysical parameters. This provides a statistically consistent way to handle gaps while improving the sampling efficiency and canceling leakage effects. We apply the method to the estimation of galactic binaries parameters with different gap patterns, and we compare the results to the case of complete data.

**Author(s):** James Ira Thorpe, Nikos Karnesis, Natalia Korsakova, Jacob Slutsky, Quentin Simon Baghi

**Institution(s):** NASA Goddard Space Flight Center, Laboratoire Astroparticule et Cosmologie (APC), University of Glasgow Contributing Team(s): Work Package 9 of the LISA Consortium Simulation Working Group, NASA Goddard Gravitational Astrophysics Group (663)

#### **141.09 - Behind the Curtain: Revealing the effect of sub-grid models on supermassive black hole merger rates, for LISA(Olivia A Greene)**

Predictions of supermassive black hole merger rates vary by several orders of magnitude, based on simple models of the accretion and dynamics involved. We aim to understand the effect that more realistic sub-grid physical models have on supermassive black hole merger rates. Using the Illustris TNG simulation as a testbed, we add in more accurate dynamical friction, 3-body scattering, and gravitational wave timescales to correct the actual time of merger, and model the effect of gravitational wave recoil as well. We also add an initial spin to each black hole, and track the spin evolution and change in accretion caused by considering spin. This suite of experiments will allow us to dissect the importance of the hidden assumptions in black hole evolution within current semi-analytic models and cosmological simulations, and explore the interplay between these sub-grid physical assumptions. We present preliminary mass functions and event rates for LISA, a gravitational wave observatory designed to detect supermassive black hole mergers from the present day to redshifts above 20.

**Author(s):** Olivia A Greene, Kelly Holley-Bockelmann,

**Institution(s):** Vanderbilt University, Fisk University

#### **141.10 - Dancing to ChaNGa: The Formation of Close Pairs of Supermassive Black Holes in Cosmological Simulations and Implications for LISA(Michael Josef Tremmel)**

I present a self-consistent prediction for close Supermassive Black Hole (SMBH) pair formation timescales following galaxy mergers. Using Romulus25, the first large-scale cosmological simulation to accurately track the orbital evolution of SMBHs within their host galaxies down to sub-kpc scales (Tremmel+ 2015, 2017, 2018), we predict that it is relatively rare for galaxy mergers to result in the formation of close SMBH pairs with sub-kpc separation and those that do form are often the result of Gyrs of orbital evolution following the galaxy merger. The likelihood and timescale to form a close SMBH pair depends on the mass and morphology of the merging galaxies. When galaxies are disrupted during a merger, their SMBHs are deposited on long lived, kpc-scale orbits resulting in a population of “wandering” SMBHs. I discuss the implications of these results for predictions of SMBH merger rates, which have important consequences for the interpretation of future LISA observations. Finally, I examine the population of “wandering” SMBHs that we predict to exist in massive galaxies, like the Milky Way.

**Author(s):** Marta Volonteri, Michael Josef Tremmel, Thomas Quinn, Andrew Pontzen, Fabio Governato

**Institution(s):** Yale University, Institut d'Astrophysique de Paris, University of Washington, University College London

#### **141.11 - Multi-Messenger Science with Dual Radio AGN and Pulsar Timing Arrays(Joseph Simon)**

Pulsar timing arrays are galactic-scale nanohertz gravitational wave observatories, whose primary source population are supermassive black hole binaries. The most massive binary systems ( $> 10^8 M_\odot$ ) will soon be detectable in pulsar timing datasets from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). Each binary inspiral creates an extended interaction between the black holes and their host galaxy throughout which there is potential for numerous electromagnetic tracers to accompany the binary's evolution. When illuminated as radio-emitting sources, binaries can be detected and tracked by their dual radio-emitting cores, large-scale jet structures, and periodic variability. Currently, the most robust method of identifying these systems is direct imaging of radio cores. We will report results from a simulation of the supermassive black hole binary population in which we have included a predictor for radio emission. We analyze the bulk statistics and properties of sources that will potentially be detectable by both NANOGrav and by future radio instruments, like the ngVLA.

**Author(s):** Joseph Simon, Sarah Burke-Spolaor

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology, West Virginia University

#### **141.12 - LISA Design Sensitivities(Andrew Kaiser)**

With the recent acceptance of LISA as the ESA L3 mission, and the renewed investment from NASA, it is necessary to revisit and update models for the scientific capabilities of LISA. Because of the large number of parameters involved in describing the astrophysical signal as well as the LISA instrument, it is useful to study performance as a function of multiple parameters and over the full range of relevant values simultaneously. To that end, we examine LISA's scientific capabilities using the L3 mission proposal as a base model to probe the present variation in design sensitivities. We use the phenomenological, non-precessing, unequal mass and generic spin waveform model, IMRPhenomD, to produce the binary black hole IMR signals expected to be in the milliHertz band. Combining the variations in both source parameters and LISA instrument parameters allows us to model the SNR and produce Fisher matrices for any LISA-esque design and source.

**Author(s):** Andrew Kaiser, Sean McWilliams

**Institution(s):** West Virginia University

#### **141.13 - A Sea of Black Hole Binaries: Characterizing expected signature of stellar origin binaries in the LISA band(Krystal Ruiz-Rocha)**

LIGO's detection of binary black hole mergers revealed stellar mass black holes that were much more massive than expected. It immediately became clear that they would be detectable by LISA in their earlier phase as an inspiraling binary system. We

expand on the work of (Mapelli et al. 2017), which combined Illustris, a cosmological nbody simulation, with a suite of stellar population models to calculate the number of stellar origin binary mergers in the LIGO band; by rewinding these mergers in time, we predict the background of stellar origin binaries in LISA. We also present the expected number of stellar origin binaries that are resolvable by LISA; these will constrain location and alert electromagnetic and ground-based gravitational wave observers of an impending merger.

**Author(s):** Krystal Ruiz-Rocha, Kelly Holley-Bockelmann

**Institution(s):** Vanderbilt University, Fisk University

#### **142 - Cosmology and Astrophysics with Next Generation Cosmic Microwave Background Experiments -- Posters**

##### **142.01 - How sound are (ultra-light axion) approximations?(Jonathan Cookmeyer)**

One promising dark matter candidate is the ultra-light axion (ULA), a generic prediction of string theory. The ULA field oscillates with a frequency on time scales much shorter than the age of the universe, and they suppress structure on scales smaller than the ULA Jeans length. The latter leads to an effect on the cosmic microwave background (CMB) that can be used to constrain the ULA abundance, but the former renders exact calculations difficult due to the many oscillations that need to be resolved. A standard technique in the literature is to evolve the ULA field with an effective fluid description instead. Using a Boltzmann code that uses an exact treatment for much longer, the error of this approximation is systematically studied by computing the bias on cosmological ULA parameters from past and future experiments.

**Author(s):** Daniel Grin, Tristan Smith, Jonathan Cookmeyer,

**Institution(s):** University of California, Swarthmore College, Haverford College

##### **142.02 - The Simons Observatory: Project overview and status(Nicholas Galitzki)**

The Simons Observatory (SO) will make precise temperature and polarization measurements of the cosmic microwave background (CMB) using a set of telescopes which will cover angular scales between 1 arcminute and tens of degrees, contain over 60,000 detectors, and observe at frequencies between 27 and 270 GHz. SO will consist of a 6 m aperture telescope coupled to over 30,000 transition-edge sensor bolometers along with three 42 cm aperture refractive telescopes, coupled to an additional 30,000+ detectors, all of which will be located in the Atacama Desert at an altitude of 5190 m. SO will measure fundamental cosmological parameters of our universe, constrain primordial fluctuations, find high redshift clusters via the Sunyaev-Zel'dovich effect, constrain properties of neutrinos, and trace the density and velocity of the matter in the universe over cosmic time. The complex set of technical and science requirements for this experiment has led to innovative instrumentation solutions. We will present the designs of the

SO telescopes and receivers, including the cold optical components and detector arrays and the current production status of the observatory components.

**Author(s):** Nicholas Galitzki

**Institution(s):** University of California San Diego

**Contributing Team(s):** The Simons Observatory Collaboration

### **142.03 - Weak gravitational lensing & CMB probes of spatially varying fine-structure constant and baryon/dark-matter relative abundances.(Daniel Grin)**

Cosmic microwave background (CMB) anisotropies are Gaussian and isotropic at linear order. The presence of long wavelength modulating fields, however, can introduce non-Gaussianity and statistical anisotropy in the CMB. For example, the dark matter present along the line of sight between observers and the last-scattering surface gravitationally lenses the background CMB. Weak gravitational lensing of the CMB has already been detected at  $\sim 40 \sigma$  in Planck satellite data! There are discrepancies between the observed CMB lensing signal and expectations from  $\Lambda$ CDM theory, offering the opportunity to explore the possibility of other long wavelength modulating field, which might be able to relieve the tension between the predicted and observed amplitude of CMB weak lensing. A variety of particle-physics models for the origin of the baryon asymmetry and density fluctuations in the universe predict compensated isocurvature perturbations, spatial fluctuations in the relative densities of baryons and cold dark matter. It is also possible that the strength of the electromagnetic interaction is set by a novel scalar field with couplings to the standard model, sourcing spatial fluctuations in the fine structure constant. Here, the observational motivation for these models is reviewed and the imprint of both these possibilities on CMB statistics (and weak lensing observables in particular) is computed. Current data are used to probe these models, forecasts are made for the sensitivity of upcoming efforts like CMB Stage IV and the Simons Array, and a variety of other theoretical considerations are explored.

**Author(s):** Tristan Smith, David Robinson, Davy Qi, Julian Munoz, Daniel Grin, Ely Kovetz, Rhiannon Smith, Kyle Yee

**Institution(s):** Haverford College, Swarthmore College, Harvard University, Johns Hopkins University

### **143 - Dust Posters**

#### **143.01 - Micrometeoroid Population Inference on LISA Pathfinder Data(Sophie Hourihane)**

The LISA Pathfinder (LPF) was a joint ESA / NASA technology demonstration mission for the Laser Interferometer Space Antenna (LISA) that operated from December 2015 through July 2017. Designed to be the most sensitive accelerometer ever flown, the LPF surpassed its mission goals and proved sensitive enough for future gravitational wave detection with the LISA constellation. An ancillary benefit of the LPF's sensitivity was its response to perturbations like those from micrometeoroids impacts. Taking advantage of this, the LPF became the first in-

situ micrometeoroid detector in the first Earth-Sun Lagrange point (L1). We use our catalog of 44 events to derive properties of the micrometeoroid environment around L1, estimate impact rates for future missions, and explain the process for similar analyses in the future.

**Author(s):** James Ira Thorpe, John Baker, Tyson Littenberg, Sophie Hourihane, Jacob Slutsky

**Institution(s):** University of Michigan, NASA/MSFC, NASA/GSFC

#### **143.02 - What and where is the dust surrounding Eta Carinae?(Theodore Gull)**

Eta Carinae, the brightest, massive binary in our Galaxy, ejected prodigious amounts of material in two major eruptions in the 19th century. Highly polarized starlight scatters off of the  $10'' \times 20''$  bipolar Homunculus. Extinction is very grey from the UV to deep red, indicating dust in the form of large grains. Composition of the dust is likely very different from interstellar dust and dust formed in less massive stars. Carbon and oxygen are greatly depleted relative to nitrogen, which is thought due to the ejecting star having an initial mass exceeding 60 solar masses. Spectral emissions and absorptions of strontium, scandium, vanadium (never seen in the ISM) and many other metals are seen in abundance with the ejecta. A census of identified molecules is very different from that of stars rich in carbon or oxygen. Since the 1940s, Eta Carinae has been gradually brightening, but recent evidence suggests that the visible brightness of the Homunculus is nearly constant. Spectra of the scattered light show variations of Balmer alpha relative to continuum across the nebula. Very bright emission clumps (the Weigelt blobs) located within  $0.1$  to  $0.3''$  of Eta Carinae have far less extinction, but are fading relative to the star. An explanation is that the clumped gas and dust, located close to the luminous binary, obscures starlight in many directions, including our own, but is gradually dissipating. Much can be learned about this complex system as Eta Carinae has a 5.52-year very eccentric orbit that leads to turning off the FUV radiation for several months across periastron, which next occurs in February, 2020. We encourage thoughts and comments on the character of the dust, how it formed in gas already depleted of oxygen and carbon. We solicit observations and modeling of this fascinating, evolving system.

**Author(s):** Theodore Gull

**Institution(s):** NASA/GSFC **Contributing Team(s):** The Eta Carinae Bunch

#### **143.03 - Constraining DSFG Multiplicity and Clustering with Comparisons of Empirical Submillimeter Map Models(Laney Blair Wicker)**

DSFG multiplicity, the spatial blending of sources' flux densities due to the low spatial resolution of FIR/submm maps, can be attributed to chance projections of sources, physically associated sources, or a combination of both. If DSFG

multiplicity is predominantly due to chance projections of sources along the line of sight as opposed to physically associated sources, this effect would impact our interpretation of DSFG evolution. In particular, cosmological simulations struggle to reproduce DSFGs as single bright sources; a significant population of DSFG multiples would ease tension between cosmological predictions and DSFG observations, as each DSFG would have an effectively lower SFR (e.g. Hayward et al. 2013). The goal of this project is to compare results of predictive empirical models of (sub)millimeter emission across the literature to constrain the role of chance projections of physically unassociated sources with simulated data. Specifically, we compare mock output of the models of Casey et al. 2018a,b -- which is an empirical model of the (sub)mm sky which does not account for cosmological clustering but allows for variable histories of obscured cosmic star formation -- with the SIDES model described by Bethermin et al. 2017 who account for cosmological clustering yet only one possible history of obscured cosmic star-formation at early times. Our results indicate that the high single-dish flux density sources across all submm/mm wavebands can be mostly (>70%) attributed to a single bright source, whereas lower flux density sources are statistically more likely to be a compilation of several lower flux density sources. We recover the same multiplicity fraction in both the Casey et al. and Bethermin et al. models, despite the difference in clustering prescriptions between them; thus we conclude that the cause of DSFG multiplicity (line-of-sight projection or physical associated pairs) is not directly constrainable through empirical models alone.

**Author(s):** Jorge Zavala, Johannes G Staguhn, Justin Spilker, Laney Blair Wicker, Elisabete Cunha, Caitlin M Casey, Patrick Drew, Jacqueline Hodge, Steven Finkelstein, Chao\_Ling Hung  
**Institution(s):** The University of Texas at Austin, Leiden Observatory, The Australian National University, NASA Goddard Space Flight Center, Manhattan College, Johns Hopkins University, Bloomberg Center for Physics and Astronomy

#### **143.04 - Optical Polarimetry of AGB star Circumstellar Envelopes(Miranda Caputo)**

We present visual light multi-wavelength polarimetry of stars behind the circumstellar envelopes (CSE) of the asymptotic giant branch (AGB) stars IRC+10216 and IK Tau. We find significant polarization attributable to the CSEs with unusual polarization curve characteristics. These extinction polarimetry observations complement recent SOFIA/HAWC+ emission polarimetry, allowing better constraints on the modeling of the grain characteristic and alignment in the CSEs.

**Author(s):** B-G Andersson, Miranda Caputo, Andrei Berdyugin, Vilppu Piirola, Sloane Wiktorowicz, Thiem Hoang, Archana Soam,

**Institution(s):** SOFIA Science Center, Turku University, USRA, Korea Astronomy & Space Science Institute, The Aerospace Corporation

#### **143.05 - Circumstellar Dust around Mira Variables and the Importance of Maser Emission: Preliminary Results(Lisa Shepard)**

Asymptotic Giant Branch (AGB) stars are major contributors of cosmic dust to the interstellar medium. Understanding the formation of cosmic dust ejected from these stars is essential to understanding the broader topics of evolution and composition of stellar and interstellar objects in our universe. We investigate the formation of circumstellar dust by studying the relationship between maser emission and dust spectral features for a sample of Mira variables. This project requires investigating the infrared spectra of a sizeable sample of stars for which maser emission has been quantified. Using high-resolution space-based spectroscopy data along with ancillary data from the published literature, we determine the nature of dust grains around these stars. This is achieved using two separate but complementary methods. First, we match the positions and widths of observed spectral features with those seen in laboratory spectra. This is achieved by modeling the star as a blackbody, which is subtracted from the observed spectrum to leave a residual dust-only spectrum. Then we fit a continuum to the dust only spectra and divide to obtain the emission efficiency  $Q$  of the observed spectral features. These are then compared to laboratory spectra of potential astrominerals. The second method determines the composition of the dust shell star using radiative transfer modeling. The dust shell parameters that result from these analyses will then be compared to the parameters of maser emission to determine whether trends exist. Here we present the first results of modeling the dust composition.

**Author(s):** Angela Speck, Lisa Shepard

**Institution(s):** University of Missouri

#### **144 - Evolution of Galaxies I Posters**

##### **144.01 - Cluster-z: Using Correlation Functions to Measure Redshift Distributions(Rebecca L Larson)**

Photometric redshift estimates for large populations of galaxies are traditionally found with template fitting, which requires many bands of photometric data to do accurately. Often, galaxy samples of interest do not have sufficient photometric or spectroscopic coverage with which to measure accurate redshifts. In these circumstances, we can leverage overlapping large samples of galaxies with known redshifts to estimate the redshift distribution of our unknown sample via spatial cross-correlation. The power in the cross-correlation is high when the samples overlap in redshift due to large-scale structure and clustering of galaxies in halos. We have used the large number of galaxies with known redshifts (>30,000) in the COSMOS field (Laigle et al. 2015) as our overlap sample to get an estimated redshift distribution of the Herschel-detected sources in this field. To do this we are running the code The-wiZZ, described in Morrison et al. (2017). It computes a spatial cross-correlation between the two samples by binning the known galaxies in redshift space and comparing the unknown sample with each bin. This correlation can then be used to estimate the

redshift distribution of the unknown sample. We have done this for the Herschel-detected sources and compared this to traditional photometric redshift fitting results and find they are mostly in agreement, with some intriguing offsets. We have also tested the code's ability to recover redshifts from a simulated field of galaxies with different selection biases and find that with sufficient numbers The-wiZZ can accurately recover the redshift distribution of galaxies. Clustering is a powerful method with which to assess redshift distributions (e.g., of optically faint galaxies) in large surveys, hence it will be of crucial importance for Euclid, LSST, and WFIRST.

**Author(s):** Andreas Faisst, Peter Capak, Rebecca L Larson, Daniel C Masters

**Institution(s):** University of Texas at Austin, JPL, IPAC

#### **144.02 - Analysis of Lyman Alpha Halos in High Redshift Galaxies(Noah Lamb)**

Galaxies emit light across all wavelengths and are surrounded by circumgalactic gas, including substantial hydrogen in its ground state. The Lyman-alpha emission of these galaxies is prime for scattering by this gas, creating a significant Lyman-alpha "halo" around each galaxy. We present a study of galaxies at  $z=2-3$ , taken from eight quasar fields, and separated into bright galaxies selected by their brightness in the UV continuum, and faint galaxies selected by their brightness in the Lyman-alpha line. For both sets of galaxies, we model the flux in the galaxy radially from the center using a Markov chain Monte Carlo algorithm in order to quantify the exponential scale length of the Lyman-alpha halo, the fraction of total Lyman-alpha flux in the halo, and any degeneracies between these properties and the uncertain sky background. Using the bright and faint galaxy samples, we also explore the dependence of these halo properties on galaxy luminosity and other characteristics.

**Author(s):** Ryan Trainor, Noah Lamb

**Institution(s):** Franklin and Marshall College

#### **144.03 - Finding Galaxies at $z\sim 8-10$ with the Hubble Space Telescope.(Sofia Rojas Ruiz)**

Looking for bright galaxies born in the early universe is fundamental to investigating the Epoch of Reionization, the era when the first stars and galaxies in the universe ionized the intergalactic medium. The purpose of this research is to find galaxy candidates at a time only 500 to 650 million years after the Big Bang, which corresponds to redshifts  $z\sim 8-10$ , and study their luminosity function to help define the timeline and evolution of reionization. This project is carried out using data from The Brightest of Reionizing Galaxies Survey (BoRG) from the Hubble Space Telescope, which consists of pure-parallel imaging in 120 different lines of sight that sum up to an area of 550 arcmin<sup>2</sup>. This survey uses five filters and has the advantage of adding imaging in the JH140 band, covering continuous wavelengths in the visible and near-infrared ( $\lambda = 0.35\text{--}1.4\text{ }\mu\text{m}$  -

$1.7\text{--}4\text{ }\mu\text{m}$ ); allowing reliable selection of galaxies at  $z\sim 8$  using the photometric redshift technique. These galaxy candidates will be used to determine the bright end of the luminosity function and the results will provide targets for follow-up observations with ground-based and space telescopes. In the near future, the James Webb Space Telescope will observe at longer wavelengths, confirming the results from this research and uncovering even more distant bright galaxies, pushing the boundaries of our understanding about the Epoch of Reionization.

**Author(s):** Mira Mechtley, Sofia Rojas Ruiz, James Diekmann, Matthew L. Stevans, Steven Finkelstein

**Institution(s):** University of Texas at Austin, Arizona State University

#### **144.04 - The SFACT Survey - Star Formation Across Cosmic Time(Jennifer Sieben)**

SFACT is a new wide field, narrowband survey designed to detect faint emission line galaxies (ELGs). The survey uses the One Degree Imager camera (0.5 sq deg FOV) on the WIYN 3.5m telescope, plus three narrowband filters. By selecting ELGs via several different emission lines ( $\text{H}\delta$ ,  $[\text{O III}]$ ,  $\text{H}\beta$ ,  $[\text{O II}]$ ), we are able to access redshift windows between  $z\sim 0$  and 1.0. We also identify QSOs over a more extensive redshift range. We plan to use these data to construct robust samples for studying star formation and AGN activity over a large range of cosmic lookback time, as well as to measure accurate star formation rate densities. We observe moderate-to-strong emission lines from objects as faint as  $r\sim 24$ . Our survey method detects approximately 100 ELG candidates per square degree per filter. We obtain confirming follow-up spectra with the Hydra multi-filter instrument on WIYN, yielding useful spectra for even the faintest objects. Here we present preliminary results from our on-going survey that demonstrate the effectiveness of our method.

**Author(s):** Jennifer Sieben, John Salzer, David James Carr

**Institution(s):** Indiana University

#### **144.05 - Constraining the Redshift Evolution of Lyman-Alpha Halos with HETDEX(Brianna Thomas)**

Lyman-alpha emitters (LAEs) are young, powerful galaxies with high star formation, so much so that their emission can extend into the halo of the galaxy. This emission has been detected, but the details of the emission and its extent are somewhat contentious. Several small studies have provided hints that redshift evolution may explain some discrepancies. We present here initial work investigating extended Lyman-alpha emission using early commissioning data from the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). When complete, HETDEX will survey  $\sim 0.8$  million LAEs with redshifts  $1.9 < z < 3.5$ . With 150 integral field spectrographs known collectively as Visible Integral-Field Replicable Unit Spectrographs (VIRUS), we can detect their halo extents. This

redshift range is well-matched to provide a large sample of LAEs to carefully examine both extended emission at individual redshifts and redshift evolution of Lyman-alpha halos. Using preliminary HETDEX observations of sources and CANDELS spectroscopy, we are able to produce flux profiles of each source and determine their redshifts to begin constraining possible evolution.

**Author(s):** Brianna Thomas, Sarah Tuttle

**Institution(s):** University of Washington

#### **144.06 - The Ly $\alpha$ and UV luminosity-dependent clustering of typical Ly $\alpha$ emitters up to $z \sim 6$ (Ali Ahmad Khostovan)**

The current consensus of galaxy formation is that it occurred inside dark matter halos and that galaxies continue to reside in their host halos up to the present-day. The main fundamental question that arises is how are galaxies evolving with their host halos? How much of a galaxy's evolution is driven by the properties of its host halo? In this talk, I will address these questions using a sample of  $\sim 4000$  Ly $\alpha$ -selected emission line galaxies (LAEs) from the Slicing COSMOS 4K (SC4K) and  $\sim 1200$  LAEs from archival NB497 imaging of SA22 split in 15 discrete redshift slices between  $z \sim 2.5$  to  $6$ . These samples are optimal for making clustering and halo property measurements as the narrowband imaging allows for reliable redshifts (based on emission line identification), the narrow redshift distributions removes the effects of redshift-space distortions, and the source selection picks up primarily star-forming galaxies. We find strong, redshift-independent trends between host halo mass and Ly $\alpha$  luminosity normalized by the characteristic Ly $\alpha$  luminosity,  $L^*(z)$ . We find a wide, dynamical range in halo masses with the faintest LAEs ( $L \sim 0.1 L^*(z)$ ) in  $10^{10} M_{\odot}$  halos and the brightest LAEs ( $L \sim 7 L^*(z)$ ) in  $\sim 5 \times 10^{12} M_{\odot}$  halos. Similar redshift-independent trends with halo mass are also observed in terms of  $1500 \text{ \AA}$  UV luminosity and dust-corrected UV star formation rates. The wide, dynamical range in halo masses suggests that LAEs are likely progenitors of a wide range of galaxies, from dwarf-like, to Milky Way-type, to bright cluster galaxies, making LAEs great tools in investigating the early formation and evolution of the galaxies we see in the local Universe. I will conclude this talk by discussing the implications of my results in terms of the importance of the host halo property in the overall evolution of LAEs.

**Author(s):** Nima Chartab Soltani, Sérgio Santos, Marziye Jafariyazani, Ana Paulino-Afonso, David Sobral, Joao Calhau, Bahram Mobasher, Rachel Cochrane, Jorrry Matthee, Ali Ahmad Khostovan,

**Institution(s):** University of California, Riverside, Lancaster University, NASA Goddard Space Flight Center, Royal Observatory of Edinburgh, Leiden University, Instituto de Astrofísica e Ciências do Espaço

#### **144.08 - Radial Growth of Massive Galaxies from {HST} H $\alpha$ Maps at $0.7 < z < 1.5$ (Aliza Beverage)**

We present H $\alpha$  maps for the most massive star-forming galaxies at  $0.7 < z < 1.5$  using the Wide Field Camera 3 grism on the {Hubble Space Telescope (HST)}. The massive galaxy population at these redshifts are in the process of transitioning from star-forming to passive. By targeting the most massive ( $M_* > 10^{10.5} M_{\odot}$ ) star-forming galaxies in this redshift range, we probe where and how the most massive galaxies are growing. Drawing from the WISP, 3D-{HST}, and AGHAST surveys, we present a sample of 702 massive star-forming galaxies. By creating deep stacked H $\alpha$  maps and rest frame optical images, we can directly compare the spatial extent of instantaneous star formation to the spatial extent of the older stellar population. We find that the regions of ongoing star formation, while centrally peaked, are more extended than the older stellar population. At a time in cosmic history when star formation quenching pervades the most massive galaxy population, our results indicate that the most massive galaxies continue to grow in size by in-situ star formation in the outer-most regions.

**Author(s):** Aliza Beverage, Gabe Brammer, Micaela Bagley, Claudia Scarlata

**Institution(s):** University of Minnesota - Twin Cities, University of Texas, Austin, Cosmic Dawn Center, Niels Bohr Institute, University of Copenhagen

#### **144.09 - Galaxy Spectroscopy at the Half age of the Universe (Angelina Ramona Gallego)**

With the LEGA-C survey, we have obtained about 2000 high-resolution, very high-quality spectra of galaxies, observed at half the age of Universe. These spectra allow us to measure the properties of these galaxies with unprecedented precision. We aim to use such data to measure the full star formation histories of individual galaxies and thus understand how galaxies grow and eventually shut off their star formation to become quiescent. Before doing so, we have to find the optimal way to interpret the spectra and we need to assess potential biases and the uncertainties in the derived star formation histories. Our optimized analysis run on 10 galaxies shows a correlation between uncertainty in the derived star formation histories and spectral properties, such as the average signal-to-noise ratio of the spectra and the wavelength range covered. We plan on exploring additional parameters such as redshift and stellar mass for every galaxy in the entire sample and derive average estimated uncertainties that can be used to plan for future surveys.

**Author(s):** Angelina Ramona Gallego, Camilla Pacifici

**Institution(s):** Hampton University, Space Telescope Science Institute

#### **144.10 - Morphological Parameters of Galaxies at $z \sim 8$ in the BoRG and CANDELS Survey(Samir Kusmic)**

We analyze the Gini value  $G$  and asymmetry value  $A$  of a sample of 10 high-redshift galaxies. These galaxies were confirmed high-redshift and discovered in the BoRG and CANDELS surveys. From this, we can confirm that the sample is from the same population and is not contaminated. The morphological values lay in the ranges  $0.18 < G < 0.3$  and  $0.3 < A < 0.8$  with errors included. These morphological parameters also do not appear to correlate with each other nor with photometric redshift, IRAC color [3.6]-[4.5], and half-light radius. Being one of the first analyses of high-redshift morphology, this may lay the foundation for what to look for within these galaxies and implications and practices to be used in the future. This includes use in redshift candidacy and galaxy and stellar formations in this epoch.

**Author(s):** Joanna Bridge, Samir Kusmic, Benne Holwerda  
**Institution(s):** University of Louisville

#### **144.11 - Oxygen Abundance Gradients and Kinematics in $z \sim 2$ -2.5 Galaxies(Chelsea Adelman)**

Studying galaxies that were forming early in the universe's history can help shed light on the formation of the Milky Way and galaxies in the local universe. Specifically, understanding the spatial distribution of metals in galaxies can provide constraints on theories of galaxy formation and evolution. To address this issue, we have measured metallicity gradients and kinematics in four  $z \sim 2$ -2.5 galaxies from the Keck Baryonic Structure Survey (KBSS) using near-infrared spectroscopy from Keck/MOSFIRE to analyze the HII regions in these galaxies. Our sample has galactic-radii of  $\sim 6.15$ -7.65 physical kpc, and we use the strong line ratio method, specifically the indicators  $[\text{NII}]\lambda 6583/\text{H}\beta$  and  $[\text{OIII}]\lambda 5007/\text{H}\beta^2$ , to determine the oxygen abundance. The metallicity measurements in one galaxy exhibit a negative gradient, consistent with inside out-growth models of galaxy formation, which predict that the formation of galaxies begins at the central regions, followed later by the formation of the outer edges. If this is the case, galaxies should present more metal enriched gas closer to the center than the edges. In contrast, one galaxy exhibits an inverted gradient with higher oxygen abundance at larger galactic radii, which could be attributed to gas inflow from filaments in the cosmic web. The remaining two galaxies in our sample do not show a distinct chemical gradient. The kinematics in our sample were measured, and the indicators in the spectra of three galaxies show ordered rotation, with rotational velocities consistent with similar  $z \sim 2$  galaxies in other spectroscopic samples.

**Author(s):** Allison L Strom, Chelsea Adelman,  
**Institution(s):** Cal Poly Pomona, Carnegie Observatories

#### **144.12 - The Deepest Near-Infrared Spectroscopic Observation for Ly $\alpha$ emission at $z > 7$ (Intae Jung)**

Ly $\alpha$  emission provides a presently accessible tool to trace the evolution of the intergalactic medium (IGM) during the epoch of cosmic reionization. As Ly $\alpha$  photons are easily attenuated, resonantly scattered by neutral hydrogen, the presence of neutral hydrogen in the IGM can be constrained by estimating Ly $\alpha$  strength, often represented by the equivalent-width (EW) distribution of Ly $\alpha$  emission. Aiming to constrain the end of reionization, we carried out 14 nights of deep spectroscopic observations, named the Texas Spectroscopic Search for Ly $\alpha$  Emission at the End of Reionization, using the Keck DEIMOS (optical) and MOSFIRE (near-infrared, NIR) spectrographs to search for Ly $\alpha$  emission from 178 photometric-redshift selected galaxies at  $z = 5.5 - 8.3$  from the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS) survey. Particularly, the MOSFIRE dataset where we observed 72 galaxies provides the deepest NIR spectroscopic data for Ly $\alpha$  search at galaxies  $z > 7$  with  $>15$  hr integration time for six observed galaxies. We will present new results from the deepest MOSFIRE dataset for the six galaxies, discovering a new  $z = 7.6$  Ly $\alpha$  detection as well as providing an updated measure of the previously confirmed  $z=7.51$  Ly $\alpha$  emission in Finkelstein et al. (2013) with longer exposure.

**Author(s):** Steven Finkelstein, Intae Jung  
**Institution(s):** The University of Texas at Austin

#### **144.13 - Testing a Dust-Immune Metallicity Diagnostic in Nearby Metal-Poor Dwarf Galaxies with Far-Infrared Spectroscopy(Gabriella Sanchez)**

The gas-phase metallicity is an important element of galaxies as metals follow gas inflows and outflows, regulate heating and cooling, and reflect the history of star formation. Presently, traditional optical strong-line diagnostics are subject to a factor of 5 in systematic uncertainties, due to the strong effect of dust present along the line of sight. However, far-infrared (FIR) fine structure lines are unaffected by extinction and less susceptible to temperature effects. The most sensitive FIR line ratio to metallicity is predicted to include the  $[\text{OIII}]\lambda 52\mu\text{m}$  and  $88\mu\text{m}$  lines and the  $[\text{NIII}]\lambda 57\mu\text{m}$  line. Using a combination of archival Herschel/PACS and SOFIA/FIFI-LS data for the low-metallicity dwarf galaxy He 2-10, we measured the metallicity-sensitive FIR line ratio to determine the validity of the predicted diagnostic. We find that the FIR line ratio recovers the optically-derived metallicity to within 20%, suggesting that this diagnostic can be applied down to sub-solar metal abundances. We look to validate this method to lower metallicities with upcoming SOFIA observations in order to establish the full dynamic range over which the FIR-based diagnostic is applicable. This diagnostic will be especially useful for highly dust-obscured systems, which become increasingly abundant in the early universe.

**Author(s):** Gabriella Sanchez, Justin Spilker  
**Institution(s):** University of Hawaii at Manoa, University of

#### **144.14 - The MOSDEF Survey: Probing Resolved Stellar Populations at $z \sim 2$ using a New Bayesian-defined Morphology Metric (Tara Fetherolf)**

Studying the resolved structure of high-redshift galaxies can give insight into the evolution of galactic properties, such as the amount and distribution of stars and interstellar dust. In particular, we are interested in investigating how the distribution of dust changes as galaxies increase in stellar mass at redshift  $z \sim 2$ , when star-formation activity was at its highest. To completely characterize the galaxies, we pair high-resolution, multi-waveband CANDELS/3D-HST imaging with  $H\alpha$  and  $H\beta$  emission line observations from the MOSFIRE Deep Evolution Field (MOSDEF) survey and construct stellar population and dust maps of  $\sim 300$  star-forming galaxies at spectroscopic redshifts  $1.36 < z < 2.66$ . We highlight three of our primary results, as follows. 1) Voronoi binning schemes based exclusively on the H-band signal-to-noise distribution result in systematically redder resolved and global color excesses. 2) Galaxies with large effective radii ( $> 3$  kpc at  $z \sim 2$ ) may have higher  $H\alpha$ -to-UV SFR ratios towards their centers compared to compact galaxies, suggesting more recent star-formation towards the centers of these galaxies. 3) We quantify resolved stellar continuum color excess distributions by using the Gini and M20 coefficients alongside a newly defined parameter, “patchiness” (P). High-mass galaxies exhibit patchier stellar continuum color excess distributions with lower Gini coefficients compared to low-mass galaxies. Our results support a picture where dust is smoothly distributed in low-mass galaxies, suggesting efficient mixing of dust throughout their ISM. On the other hand, the dust distribution is patchier in high-mass galaxies, such that dust is concentrated near regions of active star-formation and dust mixing timescales are expected to be longer.

**Author(s):** Tara Fetherolf, Naveen A Reddy

**Institution(s):** University of California Riverside  
Contributing Team(s): MOSDEF

#### **144.15 - LOCAL HIGH- $z$ GALAXIES ANALOGS (Skarleth Melissa Motino Flores)**

Understanding the physical processes driving galaxy formation and evolution is one of the most important goals of observational cosmology. It is also one of the most difficult problems to address due to the large distances involved. We have therefore selected a sample of nearby star-forming galaxies from the Brown et al 2014 (UV to MIR spectroscopic sample) that successfully fit broadband photometric data of high redshift galaxies ( $z > 4$ ) and, hence, are potential local analogs of high redshift galaxies. These galaxies are young, star-forming and are likely to have star formation histories similar to high redshift ( $z > 4$ ) galaxies. We are using SOFIA HAWC+ (53, 89, 154 and 214  $\mu\text{m}$ ) to obtain photometry of the local

analogs and Herschel photometric FIR data (70, 100, 160, 250, 350 and 500  $\mu\text{m}$ ) of a sample of high redshift galaxies. Combined with optical/NIR data we can derive the Spectral Energy Distribution (SED) from UV to FIR wavelengths for both the local analogs and the high redshift galaxies. We also use SOFIA/FIFI-LS to observe the [CII] 158  $\mu\text{m}$  and [OIII] 88  $\mu\text{m}$  fine-structure lines in our sample of local analogs. These lines are accessible with ALMA for high redshift objects and can be used to characterize the ISM. Our overall aim is to characterize the properties of the local galaxies and determine their star formation history (SFH). These will be compared with photometric and spectroscopic results for  $z > 4$  galaxies obtained using Herschel and ALMA. We are exploring ways of deriving Herschel FIR photometry for blended sources using ALMA submm data as priors, either as detections or upper limits.

**Author(s):** Rafael Eufrazio, Skarleth Melissa Motino Flores, Tommy Wiklind,

**Institution(s):** Catholic University of America, NASA  
Goddard Space Flight Center, University of Arkansas  
Contributing Team(s): SOFIA, GOODS

#### **144.17 - Spatially resolved star-formation histories and the connection to galaxy physical properties (Kate Rowlands)**

Understanding where and how galaxies build up their stellar mass over time is key to understanding galaxy evolution. Galaxies grow in stellar mass through the conversion of gas into stars, and by accretion of material via galaxy mergers. We do not have a complete picture of where mass is being built in galaxies with different properties, and what processes regulate star formation. Using spatially resolved spectra from the MaNGA survey, we map the star-formation histories of 980,000 spaxels in 2404 galaxies. We examine the spatial distribution of star-forming, starburst, quiescent, post-starburst and green valley spaxels as a function of stellar mass and morphology. Using the spatially resolved gas-phase metallicity and a gas mass proxy, we explore why some regions in galaxies are rapidly building up their stellar mass, and why others are not. Characterizing these local galaxy populations in unprecedented detail will serve as a pathfinder for studies in the early Universe using next generation observatories such as JWST.

**Author(s):** M  d  ric Boquien, Joel Brownstein, Jonathan Brinkmann, Tim Heckman, Kate Rowlands, Hsiang-Chih Hwang, David Thilker, Jorge Barrera-Ballesteros, Vicente Rodriguez-Gomez, Vivienne Wild, Rebecca Smethurst, Nadia Zakamska, Brett Andrews, Jennifer Lotz,  
**Institution(s):** Johns Hopkins University, Space Telescope Science Institute, University of St Andrews, Apache Point Observatory, University of Pittsburgh, University of Nottingham, Universidad de Antofagasta, University of Utah



**144.18 - The  $H\pm$  luminosity and star formation rate dependent clustering of galaxies at  $0.7 < z < 1.5$  from 3D-HST(Callie Clontz)**

We present measurements of the dependence of the clustering amplitude of galaxies on their  $H\pm$  luminosity, and hence star formation rate, at  $0.7 < z < 1.5$  to assess the extent to which environment effects these properties. While these relations are well determined in the local universe they are much more poorly known at earlier times. For this analysis we make use of near-IR HST WFC3 grism spectroscopic data in the five CANDELS fields obtained as part of the 3D-HST survey (Brammer et al. 2012; Skelton et al. 2014; Momcheva et al. 2016). We make projected 2-point correlation function measurements using  $\sim 6,000$  galaxies with accurate redshifts, and  $H\pm$  luminosity determined star formation rates. We find a strong dependence of clustering amplitude on  $H\pm$  luminosity and star formation rate (SFR). Our sample is large enough that we can control for stellar mass and we show that there remains some residual dependence of clustering amplitude on SFR even when the mass is fixed.

**Author(s):** David Wake, Callie Clontz

**Institution(s):** University of NC Asheville

**144.19 - Star Formation Rates of 1000 Intermediate Mass  $0.3 < z < 0.4$  Galaxies in the COSMOS Field(Brian Lorenz)**

Recent advances in theoretical modeling of galaxy evolution make striking predictions for the present-day properties of intermediate mass galaxies (IMGs) and their evolution over cosmic time. Due to their faintness, there exist few unbiased samples of IMGs to test such predictions, with only a handful of IMGs in the Local Group. However, deep observations in the COSMOS field allow for the collection of cosmologically representative samples of IMGs. We here present properties measured from Magellan/IMACS flux-calibrated spectra for 1249 quiescent and star-forming galaxies selected from the deep UltraVISTA catalog, with stellar masses ranging from  $10^9$  to  $10^{10} M_\odot$  and at redshifts  $0.3 < z < 0.4$ . As few observational samples of IMGs exist in this redshift range, these data provide a benchmark for future theoretical work. We (a) derive cross-correlation, spectroscopic redshifts for 1026 galaxies, and (b) measure fluxes for nine strong emission lines from [OII] $\lambda 3727\text{\AA}$ ... through  $H\pm\lambda 6563\text{\AA}$ . These measurements are used to study the star-forming main sequence in the IMG mass range with Balmer decrement corrected  $H\pm$  SFRs, one of the deepest such observations at these redshifts.

**Author(s):** Shannon G. Patel, Louis E. Abramson, Brian Lorenz, Thomas Connor, Stephanie Tonnesen, Daniel D. Kelson

**Institution(s):** Pomona College, Center for Computational Astrophysics, Carnegie Observatories

**144.20 - Star Formation in Galaxies in Undergraduate ALFALFA Team Groups and Clusters(Aiyana Poulin)**

The Undergraduate ALFALFA Team (UAT) Groups project is a coordinated study of gas and star formation properties of galaxies in and around more than 50 nearby ( $z < 0.03$ ) groups and clusters of varied richness, morphological type mix, and X-ray luminosity. We aim to probe mechanisms of gas depletion and morphological transformation by considering the spatial distributions of star formation in galaxies inhabiting a wide range of group and cluster environments. Here we present recent results from our wide area  $H\pm$  and broadband R imaging project carried out with the WIYN 0.9m+MOSAIC/HDI at KPNO. This work has been supported by NSF grant AST-1211005 and AST-1637339.

**Author(s):** Martha P Haynes, Adriana Durbala, Aiyana Poulin, Rebecca Koopmann, Rose A Finn, Max Libre

**Institution(s):** Union College, Siena College, University of Wisconsin Stevens Point, Cornell University Contributing Team(s): Undergraduate ALFALFA Team, ALFALFA Team

**144.21 - The Galaxy Evolution Probe: A Mid to Far-Infrared Space Observatory Concept to Characterize the Cosmic History of Star Formation(Jason Glenn)**

A new observational data set comprising an unprecedented survey of star formation in galaxies will be a crucial tool for understanding the processes that drove the growth and decline of star formation in galaxies. The Galaxy Evolution Probe (GEP) is a concept for a mid-to-far-infrared NASA Astrophysics Probe whose purpose is to characterize the star formation history in galaxies and to measure the physical process that drove that history. Mid and far-infrared observations yield star formation rates and measurements of the physical conditions of the interstellar medium directly affected by feedback by star formation. GEP surveys will include a deep few-square-degree survey, a survey of tens of square degrees to overcome cosmic sample variance at the peak of cosmic star formation density, and an all-sky survey providing a census of local-universe star formation and a large sample of gravitationally lensed high-redshift galaxies. The GEP surveys will span redshifts that encompass the bulk of cosmic star formation, over a range of galaxy-density environments. The surveys will come in two forms. A low-resolution spectral imaging survey, with spectral coverage from 10 to 400  $\mu\text{m}$  and a spectral resolution of  $R = 8$ , will measure infrared spectral energy distributions of galaxies and measure their redshifts photometrically. Photometric redshifts will be obtained using bright polycyclic aromatic hydrocarbon emission features. Deep, moderate-resolution ( $R = 200$ ) spectroscopy from 24 to 193  $\mu\text{m}$  will detect atomic fine-structure lines over a range of ionization states to measure the impact of star formation and AGN on the interstellar medium. The NASA funded GEP concept design study is nearly complete, with a planned launch in early 2029. The science objectives and implementation of the space observatory will be described.

**Author(s):** Jason Glenn

**Institution(s):** University of Colorado Boulder

**144.22 - Tidal Tales of Minor Mergers: Star Formation in the Tidal Tails of Minor Mergers(Karen Knierman)**

While major mergers and their tidal debris are well studied, equal mass galaxy mergers are relatively rare compared to minor mergers (mass ratio  $<0.3$ ). Minor mergers are less energetic than major mergers, but more common in the observable universe, and thus likely played a pivotal role in the formation of most large galaxies. Tidal debris regions have large amounts of neutral gas but a lower gas density and may have higher turbulence. We use star formation tracers such as young star cluster populations and H-alpha and CII emission to determine the different factors that may influence star formation in tidal debris. These tracers were compared to the reservoirs of molecular and neutral gas available for star formation to estimate the star formation efficiency (SFE). The SFR in tidal debris can reach up to 50% of the total star formation in the system. The SFE of tidal tails in minor mergers can range over orders of magnitude on both local and global scales, and include several star forming regions with higher than normal SFE. From the tidal debris environments in our study, this variance appears to stem from the formation conditions of the debris. New results of more distant galaxies from the first survey of molecular hydrogen in minor merger tidal debris will be presented. Current surveys of the 2.12 micron line of molecular hydrogen, CO(1-0), and HI for 15 minor mergers, are providing a larger sample of environments to study the threshold for star formation that can inform star formation models, particularly at low densities.

**Author(s):** Karen Knierman, Paul Scowen, Jacqueline Monkiewicz, Chris Groppi

**Institution(s):** Arizona State University

**144.23 - Correlation between Stellar Tidal Disruption Events and Extreme Mass Ratio Inspirals(Patrick Adams)**

We examined how the rates of stellar tidal disruption events (TDEs) might correlate to the rates of extreme mass ratio inspirals (EMRIs). To do so we analytically calculated the density and distribution of stars in a simplified galaxy model. This galactic stellar distribution was then used to computationally model the differential flux and total rate at which stars diffuse into the TDE and EMRI loss cones, a threshold point at which stars will eventually be consumed or accreted by a supermassive black hole. We found some clear theoretical differences between TDEs and EMRIs and limitations in how they are correlated, while we also verified some basic aspects of these phenomena.

**Author(s):** Michael Kesden, Patrick Adams

**Institution(s):** Haverford College , University of Texas at Dallas

**144.24 - Star formation in low mass isolated galaxies and interacting pairs(Jing Sun)**

Studies on the star-formation activities in low-mass interacting galaxies are of critical importance for enlarging our knowledge on the evolution of galaxies. We explored the current star-formation rate in both isolated and interacting low-mass galaxies. We select our galaxy pair candidates to include two low-mass galaxies with a projected separation smaller than 150 kpc; our isolated galaxy sample do not have neither massive nor low-mass galaxies within 1500 kpc. This sample intentionally excludes galaxies with a massive galaxy neighbor within 1500 kpc as massive neighbors can harass low-mass companion galaxies and can cause them to become quenched. With these selected galaxies, we discuss how interactions between low-mass galaxies can alter their star-formation activity. This project is the first attempt to systematically study how the internal star-formation activities of low-mass galaxies are influenced by outer environment. Our investigation is based on the spatially resolved data from the Mapping Nearby Galaxies at Apache Point Observatory (MaNGA), which is one of the core projects of the fourth-generation Sloan Digital Sky Survey (SDSS-IV).

**Author(s):** Jing Sun, Peter Frinchaboy, Kat Barger

**Institution(s):** Texas Christian University

**144.25 - Identifying and Comparing Centrally Star-Forming Galaxies Using MaNGA(Myles A McKay)**

We have discovered a group of face-on Sloan Digital Sky Survey (SDSS) spiral galaxies that have primarily central star formation. Identified through the imaging survey, and confirmed through central spectroscopy, we look to integral field spectroscopy to identify specific regions forming stars. Conventional “inside-out” models of galaxy evolution might lead one to believe these galaxies should primarily be found in dense environments where the materials for star formation could be removed from the disks. However, we find these galaxies in a broad range of environments. A small number of galaxies from the original sample have been serendipitously observed with MaNGA. The Mapping Nearby Galaxies at APO (MaNGA) survey is an ambitious project with an objective to obtain spectral measurements of the nuclei of over 10,000 galaxies. We used the spatially resolved observed galaxies from MaNGA to improve our measures and localize the star-forming processes. Our goal is to explore if these objects are a single class of galaxies or if this a quick stage of galaxy evolution that occurs. In this poster, we explain the data reduction and how we identified and compared the primary location of the star-formation.

**Author(s):** Myles A McKay, Sarah Tuttle, Stephanie Tonnesen

**Institution(s):** University of Washington, Center for Computational Astrophysics in New York

#### **144.26 - Stellar populations in the tidal debris of NGC 520(Shawn McLain)**

Galaxy interactions lead to a redistribution of stellar material into the intragalactic medium. This material, visualized in tidal debris, contains stellar material both drawn from the progenitor galaxies and formed in-situ, combined together in the diffuse light. Newly formed star clusters are subject to external and internal forces, which disrupt them and disperse their contents into the diffuse stellar light, along with stars originating from the host galaxies. Our previous work on NGC 3256 was able to distinguish between these populations, providing ages and masses for each stellar component, along with the surviving star clusters. With Gemini GMOS imaging, we extend our work to NGC 520, a nearby merger boasting a sweeping tidal tail. We report on our results for stellar populations in the tidal debris of this unique merger, both in star clusters and in the tidal debris.

**Author(s):** Michael Rodruck, Shawn McLain, Jane Charlton

**Institution(s):** Pennsylvania State University

#### **144.27 - Star Formation Stochasticity Measured with the Burst State Indicator(Adam Broussard)**

One of the key questions in understanding the formation and evolution of galaxies is how starbursts affect the assembly of stellar populations in galaxies over time. We define a Burst State Indicator ( $\hat{I}$ ), which compares a galaxy's star formation rates on short ( $\sim 10$  Myr) and long ( $\sim 100$  Myr) timescales in order to differentiate between galaxies with increasing, decreasing, or constant star formation rates. To estimate  $\hat{I}$ , we apply the detailed temporal response of  $H\alpha$  and near-ultraviolet emission to star formation histories (SFHs) from Semi-Analytic Models and the Mufasa hydrodynamical cosmological simulations. Analyzing the width of the distribution of  $\hat{I}$  for ensembles of galaxies at a given epoch allows us to characterize the level of burstiness in a galaxy population's recent star formation history. We find that top-heavy IMFs can suppress measurements of burstiness by a factor of  $\sim 1.5$  relative to a standard high mass IMF slope, while changing metallicity has little effect. We apply realistic noise and selection effects to the models to generate mock Hubble Space Telescope (HST) and James Webb Space Telescope (JWST) galaxy catalogs and compare these catalogs with 3D-HST observations of  $z \sim 1$  galaxies detected in  $H\alpha$ . Measurements of  $\hat{I}$  are unaffected by dust measurement errors under the assumption that  $E(B-V)_{\text{stars}} = 0.44 E(B-V)_{\text{gas}}$  (i.e.  $R_{\text{star}} = 0.44$ ). However, setting  $R_{\text{star}} = 0.8$  resolves several discrepancies between 3D-HST observed data and that of simulations. On the other hand, setting  $R_{\text{star}} = 0.8$  implies that the average SFH in the 3D-HST sample is declining rapidly, which is both surprising and in contrast with the models. Hence even varying the dust law cannot resolve the discrepancy between the models and the observed burstiness of the 3D-HST galaxies. JWST will offer greatly improved  $H\alpha$  measurements, reducing measurement noise and uncertainty, particularly for

low mass galaxies. Support for Program number HST-AR-14564.001-A was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555.

**Author(s):** Kartheik Iyer, Peter Kurczynski, Intae Jung, Rachel Somerville, Camilla Pacifici, Adam Broussard, Romeel Dave, Steven Finkelstein, Eric Gawiser,

**Institution(s):** Rutgers University, University of the Western Cape, Center for Computational Astrophysics, University of Texas at Austin, South African Astronomical Observatories, Goddard Space Flight Center, Space Telescope Science Institute

#### **144.28 - Deriving stellar population models of galaxies through spectroscopic analysis(Oscar Antonio Chavez Ortiz)**

Using spectroscopic data from the MOSFIRE Deep Evolution Field (MOSDEF) survey we study stellar population properties of distant galaxies. The MOSDEF survey is a rest-frame optical spectroscopic survey of  $\sim 1500$  galaxies in three different redshift regimes: 1.37-1.70, 2.09-2.61, and 2.95-3.80. We utilize the MOSDEF survey to calculate and compile deep spectra of galaxies that have been observed in more than one mask. These deep spectra are composites of the multiple single-observation spectra, such that emission or absorption lines previously indistinguishable become evident. By comparing the deep spectra with stellar population synthesis models we can derive stellar population properties. We also compared the spectra of the same galaxies observed in different masks and assessed the robustness of the corresponding spectroscopic measurements. The research will further galaxy evolution models and give insight into anomalies present in the deep spectra.

**Author(s):** Oscar Antonio Chavez Ortiz

**Institution(s):** UC Berkeley Contributing Team(s): MOSDEF

#### **144.29 - Deriving star formation histories from photometric spectral energy distributions with diffusion k-means(Gregory Mosby)**

The star formation histories of galaxies give us insight into how galaxies have changed over time and continue to evolve as factories of the universe's gas, dust, and metal content. We can measure these star formation histories coarsely from integrated spectra of galaxies, but as we look back farther in the universe's history even marginal signal to noise spectra become costly. We have shown in previous works that a reduced basis set of averaged stellar populations determined by the machine learning diffusion k-means (DFK) algorithm can be used to recover precise and accurate star formation histories from low signal to noise spectra. In this work, we use this reduced basis set to analyze photometric galaxy spectral energy distributions (SEDs) that may be available in the absence of a spectrum. To compare a DFK basis set to current methods used to analyze

galaxy SEDs, we look at the 3D-HST photometry catalog of galaxies observed in the GOODS-N field. We compare the stellar population results using FAST from the catalog to the results using the DFK basis set. Precise and accurate stellar populations from photometric SEDs using the DFK basis set would provide a unique tool for analyzing galaxy star formations histories out to high redshift.

**Author(s):** Gregory Mosby

**Institution(s):** NASA Goddard Space Flight Center

#### **144.30 - Using Convolutional Neural Networks to predict Galaxy Metallicity from Three-Color Images(Steven Boada)**

We use a deep residual convolutional neural network (CNN) to predict the gas-phase metallicity (Z) of galaxies measured using spectroscopic information from the Sloan Digital Sky Survey. Using a full sample of  $\sim 130,000$  RGB (irg)  $128 \times 128$  pixel images, we find a root mean squared error (RMSE) of 0.085 dex between predicted and true metallicities, which significantly surpasses the performance of a random forest algorithm (RMSE = 0.130 dex) trained on broadband photometry of the same data set. We construct a low scatter (0.1 dex) mass-metallicity relation (MZR) using the CNN-predicted metallicity and the stellar mass inferred from the spectroscopy. Because our predicted MZR shows a similar level of scatter as the empirical MZR, the difference between the CNN-predicted and spectroscopically derived metallicity can not be due to purely random error. This suggests that the CNN has learned a representation of the gas-phase metallicity, from the optical imaging, beyond what is accessible with oxygen spectral lines. This work is partially supported by NASA Astrophysics Data Analysis grant number NNX14AF73G and NSF Astronomy and Astrophysics Research Program award number 1615657.

**Author(s):** Steven Boada, John Wu

**Institution(s):** Rutgers University

#### **144.31 - Find the Quenching Mechanism of a $z \sim 0.7$ Post-Starburst Galaxy(Qiana Hunt)**

The process by which massive galaxies transition from blue, star-forming disks into red, quiescent galaxies remains one of the most poorly-understood aspects of galaxy evolution. In this investigation, we attempt to gain a better understanding of how star formation is quenched by focusing on a massive post-starburst galaxy at  $z = 0.747$ . We look for indicators of star formation suppression mechanisms in the stellar kinematics and age distribution of the galaxy obtained from spatially resolved Gemini Integral-Field spectra and in the gas kinematics obtained from ALMA. Based on these properties, we believe the target may represent the product of a merger-induced starburst or of morphological quenching; however, our results are not completely consistent with any of the prominent quenching models currently favored in the literature.

**Author(s):** Mariska Kriek, Rachel Bezanson, Jenny Greene,

Qiana Hunt, Wren Suess

**Institution(s):** University of Michigan, Princeton University, University of Pittsburgh, University of California, Berkeley

#### **144.32 - Ultra Diffuse Galaxies in the (Simulated) Wild(Anna C Wright)**

Ultra Diffuse Galaxies (UDGs) have stellar masses similar to dwarf galaxies, but physical sizes more akin to  $L_{*}$  galaxies. The vast majority thus far discovered have been observed within clusters, but UDGs are known to exist in a wide variety of environments. Previous studies of UDG evolution in cosmological simulations have been limited to a handful of field galaxies, making it difficult to produce clear predictions for their overall abundances or to identify how their formation channels may depend on environment. We present results from the first large sample of isolated and satellite UDGs from a fully cosmological simulation. Using Romulus25, a  $25^{\circ}3'$   $\text{Mpc}^3$  high-resolution uniform volume box run with N-body + smoothed particle hydrodynamics code ChaNGa, we examine the evolution and  $z=0$  properties of these galaxies and show that UDGs are not a separate population, but the low surface brightness, high effective radius tail of the dwarf galaxy population.

**Author(s):** Thomas Quinn, Daisuke Nagai, Anna C Wright, Andrew Pontzen, Michael Josef Tremmel, Ferah Munshi, Alyson Brooks

**Institution(s):** Rutgers, The State University of New Jersey, University of Oklahoma, Yale University, University College London, University of Washington

#### **144.33 - Satellite Galaxy Quenching in Simulations(John William Montano)**

Observations of satellite galaxies in the local Universe suggest that the suppression of star formation (or “quenching”) is a relatively inefficient process for intermediate-mass satellites, such that quenching typically occurs on timescales of 4-7 Gyrs following infall. Using the Illustris simulation suite, we investigate whether this timescale is reproduced in modern hydrodynamic models of galaxy formation, with the goal of better understanding the relevant physical processes at play. In addition, we explore the variation in satellite infall times within Illustris, investigating the role of tidal stripping associated with the inclusion of baryons in the hydro simulations relative to the dark matter-only simulations. We find that this effect is non-negligible with infall times skewed towards later times when including baryonic effect

**Author(s):** Michael C. Cooper, John William Montano,

**Institution(s):** California State University San Bernardino, University of California Irvine

**144.34 - What Lights up a Galaxy Bridge? Star Formation within Galaxy Bridges(Luis Angel Martinez Patino)**

Galaxy tails and bridges are the hallmark of the most spectacular galaxy-galaxy interactions in the sky. In this work, we investigate the physics behind the formation and evolution of galactic bridges. We employ a suite of 27 high-resolution galaxy merger simulations, which rely on the novel "Feedback In Realistic Environments" (FIRE) model. This model is capable of resolving individual Giant Molecular Clouds, and of capturing the small-scale physics of the interstellar medium. With this framework, we can investigate how bridges are formed, their extent and duration, the amount of in-situ star formation within them, and the importance of stellar and gaseous migration as these features form. Our key science goal is to determine which orbital parameters controlling our mergers drive the intensity and duration of these bridges. Future work includes a thorough comparison with low redshift systems, to determine the relative importance of bridges in galaxy evolution.

**Author(s):** Paul Torrey, Luis Angel Martinez Patino, Jorge Moreno,

**Institution(s):** Harvey Mudd College, Pomona College, Harvard Smithsonian Center for Astrophysics, University of Florida Contributing Team(s): FIRE Collaboration

**144.35 - Automatic Detection and Analysis of Debris from Galactic Accretion Events(Shifra Mandel)**

Recent surveys of galaxies have allowed us to observe them at lower surface brightness than previously possible, revealing a plethora of enveloping substructures, which are believed to be signatures of galactic debris resulting from hierarchical mergers. Traditionally, this tidal debris has been classified, modeled and interpreted manually, as detection of these substructures was limited to modest numbers of galaxies. Upcoming observations promise to significantly decrease the surface brightness limit (with WFIRST) and increase the sample size (with LSST) of substructures that can be observed. Here we present a method for automatically classifying and characterizing the morphology of tidal debris, which will enable us to efficiently handle the forthcoming data onslaught. The method is capable of distinguishing shell-like and stream-like tidal debris, which are the most distinct morphologies, and measuring their luminosities and scales. The morphology of the debris encodes information about the shape of the satellite orbit, as well as the duration of the epoch of accretion and the relative masses of the satellite and host galaxy. We use N-body simulations to test our method and to demonstrate how identifying the properties of these substructures will help us unravel the accretion histories of galaxies in our Universe.

**Author(s):** Kathryn V. Johnston, David Hendel, Shifra Mandel

**Institution(s):** Columbia University

**144.36 - Galaxy Mergers On FIRE: Stellar Shell Evolution in Post-Mergers(Angela Twum)**

Galaxyshells are low surface brightness regions that appear as concentric arcs of dense stellar particles within the stellar halo of massive galaxies. Shells form as a result of galaxy mergers and can be an indicator of how recently the merger took place. To study how the structure and mass distribution within these shell structures evolve, we utilize a suite of 24 high resolution galaxy merger simulations. Our simulations employ the Second Version of the "Feedback in Realistic Environments" (FIRE2-2) model. In this preliminary work, we focus primarily on a representative fiducial run of the merger suite, one designed to maximize both duration and the impact of the encounter. We visually identify a number of shell structures in both configuration and phase space, and then trace the distribution of star particles forward and backward in time to observe how these shell structures evolve. In addition, we test the feasibility of our analyses as a method that can be used by observers to identify and study the brightness evolution of shells in the local universe.

**Author(s):** Paul Torrey, Angela Twum, Jorge Moreno,

**Institution(s):** Pomona College, University of Florida, Harvard University Contributing Team(s): Fire Collaboration

**144.37 - Recovering Specific Star Formation Rate of Simulated Galaxies with Spectral Energy Density Fitting(Brooke Polak)**

Robustly measuring the specific star formation rate in galaxies - the star formation rate per unit stellar mass -- is crucial to understanding galaxy evolution over cosmic time. Future missions, such as the James Webb Space Telescope (JWST) and the Wide Field Infrared Space Telescope (WFIRST) will observe the stellar component in galaxies out to the first galaxies, but the inferred stellar mass and star formation rates can be severely biased by the presence of dust. Model galaxies of various types, luminosities, and redshifts with a range of star formation rates and stellar masses were generated with Flexible Stellar Population Synthesis for Python (Python-FSPS). The spectral energy densities (SEDs) were fit with multiple combinations of photometric bands from current-generation instruments as well as next-generation instruments spanning wavelengths from optical to millimeter wavelengths. Our goal is to study the optimal combination of photometric measurements in order to robustly recover a galaxy's specific star formation rate. Our work will inform how well future missions will be able to measure the specific star formation rates in galaxies of different types and redshifts from SED fits, as well as inform which long wavelength bands will be best in breaking the degeneracies in the model fits caused by dust.

**Author(s):** Kedar A. Phadke, Joaquin Daniel Vieira, Brooke Polak

**Institution(s):** University of Illinois Urbana-Champaign

## **145 - Evolution of Galaxies II Posters**

### **145.01 - The Empirical Metallicity Distribution**

#### **Function of RESOLVE and ECO Galaxies(Amanda J Moffett)**

We use optical spectroscopy for the highly complete, volume-limited RESolved Spectroscopy Of a Local Volume (RESOLVE) survey along with its larger but less complete Environmental Context (ECO) catalog to derive a novel population-level constraint on models of chemical evolution in dwarf and giant galaxies. For this analysis, we use public Bayesian inference codes, which allow us to move beyond point estimates of gas-phase metallicity and consider the full metallicity PDF for each galaxy. By combining individual PDFs, we then construct the population metallicity distribution functions for both RESOLVE and ECO samples, which we find to be comparable in spite of their differing selection functions. We also explore systematic effects on the form of the derived metallicity functions by varying the stellar population and photoionization models included in our Bayesian inference.

**Author(s):** Chris Richardson, Amanda J Moffett, Sheila Kannappan, Andreas Berlind, Mugdha Polimera

**Institution(s):** Vanderbilt University, Elon University, University of North Carolina

### **145.02 - Investigating ALMA Observing Configurations for Detecting CO Power Spectra from Faint Star Forming Galaxies(Roxana Popescu)**

The star formation history of the Universe is a key component to understanding galaxy evolution and it can be inferred by observing a number of tracers. The Carbon Monoxide (CO) molecule through its rotational transitions has emerged as one of the most abundant and accurate tracers of the dense molecular gas content in galaxies which forms the fuel for star formation. Numerous deep and wide CO observations using ALMA and other instruments have provided important information about the distribution of star forming galaxies in the recent universe ( $1 < z < 3$ ). A number of future experiments using intensity mapping techniques are being planned to observe the molecular gas content of galaxies at even earlier epochs, such as the Epoch of Reionization (EoR) at  $z = 6$ . Direct detection of CO is limited by the sensitivity of the instruments and therefore faint CO-emitting galaxies may remain undetected. Observations of CO power spectra can provide information about faint CO emission that cannot be directly observed. In this study, we aim to understand the optimal observing configuration with ALMA in Band 3 (85-115 GHz) for detecting CO power spectra in order to understand the contribution of faint CO emitting galaxies to the spatial distribution of the molecular gas content on large scales in the Universe that cannot be directly detected. We simulated observations of emission from the CO 3-2 transition line from galaxies in a data cube centered at  $z = 2.47$ . Using a fiducial luminosity function, we placed galaxies randomly in a cube of volume  $6253.94 \text{ Mpc}^3$  with luminosities ranging up to  $0.00265 \text{ Jy/beam}$ . The data cube is then processed through CASA

software to simulate observations with ALMA. Using the simulated measurements, we present the preliminary results from the power spectrum estimates.

**Author(s):** Nithyanandan Thyagarajan, Roxana Popescu

**Institution(s):** University of Maryland, National Radio Astronomy Observatory

### **145.03 - Black Hole Feedback at Cosmic High Noon Revealed by HST Grism Spectroscopy(Jillian Rastinejad)**

The period of Cosmic High Noon is characterized by rapid star formation rates that exceed those at any other point in the universe. However, a large population of galaxies during this time do not exhibit the color characteristics of rapid star formation that we expect to observe; rather, we conclude these galaxies are quiescent. Using a sample of galaxies from the 3D-HST Survey of redshift  $1.0 < z < 1.6$ , we look for consistencies between quiescence and signatures of active galactic nuclei (AGN). We identify quiescence by taking measurements of H-alpha and H-delta emission lines from the stacked spectra of 39 galaxies. Using this stacked spectrum, we look for AGN signatures in the form of hard-ionizing ultraviolet radiation and nuclear [OIII] and [NeIII]. We then compare the results from these quiescent galaxies with a control sample of the general population of galaxies at the same redshift range. Looking forward, similar studies will be possible for individual objects due to the ground-breaking capabilities of JWST grism spectroscopy.

**Author(s):** Jillian Rastinejad, Jonathan R. Trump

**Institution(s):** University of Connecticut

### **145.04 - The Dragonfly Galaxy: Searching for Outflows in a Radio-loud Triple Merger(Sophie Lebowitz)**

The Dragonfly Galaxy (MRC 0152-209) is the most infrared-luminous radio galaxy at redshift of  $z=2$ . It is a unique system of three merging galaxies containing a powerful radio jet and tremendous rates of gas displacement. We discovered that large amounts of cold molecular gas are being displaced at a rate of  $\sim 3000 \text{ Msun/year}$ , which matches the star-formation rate in this system. We present new, high resolution data from the Atacama Large Millimeter Array (ALMA) and the Very Large Array (VLA) of the emission of carbon monoxide (6-5), dust, and synchrotron emission. In this study, we examine the contribution of tidal forces from merging versus outflows of gas and dust from the jet or starbursts towards the rapid displacement of molecular gas in this system. These new studies show that the gravitational effect of the merger is the dominant factor in driving the gas displacement, not AGN-feedback. Surprisingly, only a modest outflow was found to be associated with the powerful radio jet, questioning the importance of jet-driven outflows of molecular gas in the evolution of this massive galaxy.

**Author(s):** Sophie Lebowitz,

**Institution(s):** The Ohio State University, National Radio Astronomy Observatory  
**Contributing Team(s):** Dr Bjorn Emonts

#### **145.05 - Galaxy Gradients Across Simulations(Jennifer Mead)**

We are examining and comparing the age and metallicity gradients of galaxies in cosmological hydrodynamical zoom simulations across different codes. Usually, when we attempt to simulate galaxies in order to understand these gradients and on a larger scale, galaxy formation theory, the focus tends to be on galaxies of similar mass and size to the Milky Way, within a single code and simulation. What is not well explored is how age and metallicity gradients of galaxies vary over different simulations and codes. We examined several galaxies both qualitatively and quantitatively between codes and across redshifts and we see that the age and metallicity gradients each follow similar qualitative trends. We observe that age gradients seem to show that the age of the stellar population decreases with radius within the disk and increases with radius as the population becomes halo dominant. Additionally, the metallicity fraction decreases with radius consistently, and over time, the overall metallicity fraction at each radius also generally decreases. However, while the qualitative trends remain the same, there are numerous quantitative variations in the gradients between codes at the same redshift and within a single code at different redshifts including in the positions and ages of the youngest stars and the metallicities observed at each radius. Studying these differences across simulations and codes, and comparing these to observations, is a powerful way for us to better constrain galaxy formation models.

**Author(s):** Jennifer Mead, Ariyeh Maller,

**Institution(s):** Rutgers University, The State University of New Jersey, New York City College of Technology, American Museum of Natural History

#### **145.06 - Redefining the E+A Galaxy: A Spatially Resolved Spectral Analysis & Synthesis of Nearby Post-Starburst Systems in SDSS-IV MaNGA (MPL-5)(Olivia A Greene)**

Using data from the Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) Survey (MaNGA Product Launch-5), in the Sloan Digital Sky Survey (SDSS-IV), we identified 29 post-starburst (E+A) systems, all of which lie within the Green Valley. We identify E+A candidates by single fiber spectra, u-r color, and spatially resolved spectral line-indices, but our work also examines the spectra in each spaxel to determine how well the E+A classification holds throughout the galaxy. We found that our sample of E+As exhibit post-starburst properties across the entire galaxy, not just in the single-fiber region. Our sample has a wide range of morphologies, including barred spirals, reinforcing the view that E+A morphology is not confined to ellipticals. Our sample will be a tested to examine

star formation history and quenching properties in E+A galaxies, and investigate their role in galaxy evolution as a whole.

**Author(s):** Olivia A Greene, Mariarosa Marinelli, Kelly Holley-Bockelmann, Miguel R Anderson, Charles T Liu,

**Institution(s):** Vanderbilt University, American Museum of Natural History, Fisk University, City University of New York, Staten Island, Bloomberg LP, Virginia Commonwealth University

#### **145.07 - Reduction and Analysis of GMOS Spectroscopy for Herschel Sources in CANDELS(Isabella Cox)**

I present a spectroscopic survey of galaxies in the COSMOS and UDS fields detected using the Gemini Multi-Object Spectrograph (GMOS). The survey was designed to target Herschel-detected galaxies with a photometric redshift between 0.7 and 1.4. Currently, there is no standardized pipeline for reducing GMOS data, which is nuanced because of the "nod and shuffle" technique used to pass charge in order to observe the sky and target quasi-simultaneously. I have developed a method using IRAF to reduce the spectroscopy and extract one-dimensional spectra to measure redshifts. Measured spectroscopic redshifts were found to be in good agreement with pre-existing photometric redshifts. This confirmation validates the reduction process. Further analysis on the spectroscopy, including emission line flux measurements, provides more information on the properties of the selected sources. Building on the base of this work will add to the completeness of knowledge about galaxy properties and environments in COSMOS and UDS.

**Author(s):** Isabella Cox, Jeyhan Kartaltepe, Stephanie Juneau, Janine Pforr, Mark Dickinson

**Institution(s):** Rochester Institute of Technology, NOAO, European Space Agency

#### **145.08 - Probing the Evolution of Galaxies by Stacking Stellar Mass**

##### **Selected Samples(Marcell Howard)**

The properties of gas and dust in galaxies' interstellar media are a valuable tool for understanding their cosmic evolution. Unfortunately, for many ISM tracers the signal that is detected from any individual galaxy tends to be very faint (i.e., the ratio of signal to noise [S/N] is low). By using stacking, a technique in which one averages the flux densities at the positions (and in some cases redshifts) of sources in a large sample, we can boost S/N and achieve an overall statistical detection. In support of the forthcoming LADUMA (Looking At the Distant Universe with the MeerKAT Array) survey of neutral atomic hydrogen (HI) in galaxies out to  $z = 1.4$ , we have characterized a stacking sample of 2248 galaxies with spectroscopic redshifts  $z < 1.4$  in the MUSYC (Multi-wavelength Survey by Yale-Chile) survey of the well-studied ECDFS

(Extended Chandra Deep Field South). We have used the "Prospector" Markov Chain Monte Carlo (MCMC) implementation of the Flexible Stellar Population Synthesis code to find the maximum posterior probabilities for stellar mass, metallicity, dust attenuation, stellar age, and exponential star formation timescale. As a first test, we have stacked stellar mass-selected samples in maps made by BLAST (the Balloon-borne Large-Area Sub-millimeter Telescope) at 250, 350, and 500 microns. Looking ahead to the start of LADUMA observations, we will use stacking samples that are defined by their stellar mass, redshift, and possibly dust attenuation and stellar age to probe the evolution of galaxies' HI content across cosmic time. This project has been supported by funding from National Science Foundation grant PHY-1560077.  
**Author(s):** Marcell Howard, Andrew J. Baker, John F Wu  
**Institution(s):** Case Western Reserve University, Rutgers University

#### **145.09 - Imaging and Analysis of Hickson Compact Groups (Diego Lopez Gutierrez)**

Hickson Compact Groups (HCG) are groups of 4-8 galaxies that are relatively isolated from their environment and that act as unique laboratories for studies of galaxy interaction. HCGs show a range of HI deficiencies, suggesting a possible link between HI content and evolutionary state. Verdes-Montenegro et al. (2001) theorized an evolutionary sequence in which these groups lose their HI gas by means of ionization, interactions, or other mechanisms. In order to explore these scenarios, we present HI images of HCG 16, 22, 56 and 61 using archival data from the Very Large Array. We examine the HI morphology and dynamics at a variety of angular resolutions, and compare our results to optical imaging of each compact group.

**Author(s):** John M. Cannon, Michael Jones, Ancor Damas-Segovia, Sanchayeeta Borthakur, Diego Lopez Gutierrez, Lourdes Verdes-Montenegro  
**Institution(s):** Macalester College, Arizona State University, Instituto de Astrofísica de Andalucía

#### **145.10 - Probing Galaxy Environment to $z=2$ in the SERVS/DeepDrill Fields (Nicholas Krefting)**

We need deep and wide surveys to probe the assembly of galaxies through cosmic time across a full range of galaxy environments. The SERVS/DeepDrill survey, complemented by HerMES, VIDEO, and HSC, provides unprecedented uniform coverage with  $\sim 15$  bands from u-band through the mid- and far-IR. The data are wide enough to sample a cosmic volume of roughly  $1 \text{ Gpc}^3$ , yet deep enough to study galaxies below  $M^*$  at cosmic noon. I present results determining 2D density maps from  $z \sim 0-2$ . We use a simulated lightcone to translate observed overdensities into likely halo masses, and to test the reliability of recovered overdensities given redshift uncertainties. We reliably recover known X-ray selected clusters in the field. We demonstrate that statistical studies using these density maps

allow us to probe the density field significantly below the cluster scale.

**Author(s):** Nicholas Krefting  
**Institution(s):** Tufts University

#### **145.11 - Galaxy Pairs in SDSS-IV MaNGA: Duty Cycles of Active Galactic Nuclei and Radial Profiles of Star-Formation Rate (Joshua L Steffen)**

We use the MaNGA integral field unit (IFU) survey to investigate how tidal interactions between galaxies influence super-massive black hole (SMBH) accretion and star formation. The SDSS photometric catalog is used to identify pair candidates in each MaNGA field, and IFU spectra are used to confirm kinematic pairs. We identify  $\sim 300$  kinematic pairs out of the 4688 galaxy datacubes in the MaNGA DR15 sample, more than doubling the pair sample from DR14 (Fu, Steffen, et al. 2018). We simultaneously fit models of stellar populations and emission lines to each IFU spectrum and use the extracted parameters to measure rates of SMBH accretion and star formation. Among pairs with separations below 30 kpc, we find an excess of binary/dual active galactic nuclei (AGN) over random pairing and stochastic feeding, although the overall AGN duty cycle in pairs is consistent with that of isolated galaxies. A radial profile of star-formation rate is built for each galaxy in a pair and is compared with those of mass-matched control galaxies to look for evidence of enhanced central star-formation in mergers. In future works on our MaNGA pair sample, we will explore (1) the impact of merger-induced shocks, and (2) the radial profiles of gas metallicity.

**Author(s):** Dylan Paré, Arran Gross, Joshua L Steffen, Hai Fu  
**Institution(s):** University of Iowa

#### **145.12 - Measuring the Geometry and Extent of Large-Scale Winds around $z \sim 1$ Mg II Selected Galaxies using Infrared Imaging from the Hubble Space Telescope (Samantha Creech)**

Simulations of disk galaxies predict that gas from the intergalactic medium should be primarily accreted along the plane of the galactic disk, while outflowing winds form approximately cone-shaped structures centered about the rotation axis of the galaxy. It is predicted that, in the early universe, higher star formation rates should drive galactic winds to greater distances than in the modern universe. Our study pairs quasar spectra from the Sloan Digital Sky Survey and follow-up near-infrared data from the Hubble Space Telescope to measure the extent and shape of large-scale winds around 160 galaxies between redshift 0.65 and 1.6. We have investigated the morphologies of these galaxies using GalFIT, and will be presenting our findings on the distribution of the galaxies' azimuthal angles with respect to the quasar. We compare this distribution for galaxies that are and are not matched with Mg II absorption features detected in the quasar spectra. Although a small sample size limits our analysis, our



results support a bimodal distribution of gas around disk galaxies and shows evidence of winds reaching distances as far as 120 kpc from their host galaxies.

**Author(s):** Britt Lundgren, Nathan Kirse, Samantha Creech

**Institution(s):** University of North Carolina at Asheville, UNC Wilmington

#### **145.13 - Offset $H\text{I}\pm$ Emission and Ram Pressure Stripping in Satellite Galaxies(Makennah Bristow)**

We present our efforts to observe evidence of the ram pressure stripping of cold gas in satellite galaxies as they move through the intracluster/group medium. We have been looking for a statistical offset of  $H\text{I}\pm$  emission (representing the gas) and the r-band light (representing the stars) of  $\sim 3,000$  galaxies using integral field data from the SDSSIV MaNGA survey. Using Marvin, a Python package developed for interactively working with MaNGA data cubes, we have mapped out the galaxies and determined their  $H\text{I}\pm$ /r-band offsets. We will present results on the dependence of the  $H\text{I}\pm$  offset on the the properties of the satellite galaxies, their alignment to and distance from the cluster/group center and on the cluster/group mass.

**Author(s):** Makennah Bristow, David Wake

**Institution(s):** University of North Carolina at Asheville

#### **145.14 - The Largest Sample of Extreme Emission-Line Galaxies(Katherine Chworowsky)**

The importance of low-mass, star-forming galaxies in the process of galaxy formation cannot be understated. Recent studies point to these objects as the leading candidates responsible for the reionization of the Universe, they are the building blocks of the larger galaxies in the present day and they are perfect laboratories to study the effect of star-formation feedback on galaxy evolution. The most efficient way of selecting these galaxies is by identifying emission lines in their spectra. Broadband selection of emission line galaxies (ELGs) has recently emerged as a viable technique that circumvents the short-comings of traditional selection techniques such as narrow band imaging and spectroscopy. If the line emission is strong enough, it can contribute significantly to the broadband flux, allowing us to select ELGs by their broadband colors. In this poster, we present the results of a search for extreme ELGs in the low redshift Universe ( $z \sim 0.3 - 0.7$ ), over 5000 square degrees and down to two magnitudes fainter than what has previously been done.

**Author(s):** Lucy Fortson, Hugh Dickinson, Katherine Chworowsky, Claudia Scarlata, Vihang Mehta

**Institution(s):** University of Minnesota

#### **145.15 - Galaxy Group Properties from Sunyaev-Zel'dovich Measurements(YANSONG YUN)**

The hot gaseous medium in galaxy clusters is easily detected both from X-ray emission and the SZ effect. The SZ effect weakens with halo mass as  $Y \sim M^{5/3}$ , so galaxy groups are more challenging to detect. However, the signal is larger for the nearest systems due to solid angle considerations, so we used Planck SZ maps to search for detections by nearby galaxy groups. We find that a fraction of individual groups are detected, which gives us powerful constraints on the mass of the hot gas. When combined with X-ray emission data, we obtain an independent measure of the X-ray mass and the metallicity of the gas.

**Author(s):** Joel N. Bregman, YANSONG YUN, Edmund Hodges-Kluck

**Institution(s):** Peking University, Goddard Space Flight Center, University of Michigan

#### **145.16 - Evolution of Extended X-ray Emission in Dual Active Galactic Nuclei(John Staunton)**

We investigate the physical properties of the extended X-ray emission in a sample of nearby dual Active Galactic Nuclei (dual AGNs): Mrk 266, Mrk 463, NGC 6240 and Arp 220. We find that the dual AGNs in an intermediate merger stage, Mrk 266 and Mrk 463, have shock heated gas, which is the result of accelerating cold gas, with temperatures greater than 0.9 keV or star forming regions with temperatures below 0.9 keV. Late stage mergers show similar soft X-ray spectra, but have an additional hard X-ray power law as a result of reflection and scattering of AGN outflows on hot ions. We conclude that the extended emission of dual AGNs varies with merger stage, with intermediate stages characterized by heated gas emitting in the soft X-ray regime, while late stage systems are characterized by AGN outflows contributing to the hard X-ray regime. These results are also consistent with the simple analytic model put forward here, using results from magnetohydrodynamics and radiative processes. Further analysis of larger dual AGN samples could confirm this as the general process by which X-rays are emitted in these events.

**Author(s):** Claudio Ricci, John Staunton, Ezequiel Treister

**Institution(s):** Columbia University, Universidad Diego Portales, Pontificia Universidad Catlica

#### **145.17 - Minor Mergers and Hidden Nuclei in Luminous Infrared Galaxies(John S. Gallagher)**

High angular resolution maps with mm/submm interferometers reveal extreme central concentrations of molecular gas in several galaxies with the properties of LIRGs. We utilized WFC3 on the Hubble Space Telescope (Program GO-14728) to study the optical/near-infrared structures of examples of nearby galaxies with unusually dense central molecular zones. The systems in our sample are early-type systems, with unusual kiloparsec-scale dust features that are

mainly located along the minor axis. We hypothesize that these systems are products of minor mergers and now are in late post-merger, post-starburst evolutionary stages. The central dust features evidently connect to and possibly feed bipolar outflows containing substantial amounts of molecular mass. An exploration of the recent evolution of these unusual galaxies thus hinges on understanding the nature of gas flows into and out of the nuclear regions, along with the properties of the power source for this activity, AGN and starbursts. We prefer a model where a substantial fraction of the mechanical power to drive the gas flows originates in AGN, in which case these galaxies represent a largely hidden growth phase of central star clusters and their supermassive black holes. Support for Program number HST-GO-14728 was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555.

**Author(s):** John S. Gallagher, Tova Yoast-Hull, Lauren Laufman, Kazushi Sakamoto, Aaron Evans, Sebastien Muller, Susanne Aalto, Sabine Koenig, Youichi Ohyama

**Institution(s):** University of Wisconsin-Madison, Chalmers University, Chalmers University, University of Virginia, CITA, ASIAA, Onsala Space Observatory

#### **145.18 - HI Content in MaNGA Galaxies(Emily Harrington)**

MaNGA (Mapping Nearby Galaxies at Apache Point Observatory) is one of the projects under SDSS (Sloan Digital Sky Survey) that aims to better understand galactic evolution. MaNGA specializes in obtaining spatially resolved spectra of galaxies via pluggable spectrographs that collect spectra at different points along the face of a galaxy. Since 2014, MaNGA was able to collect detailed accounts of the physics within over 10,000 galaxies including their internal kinematics, stellar populations, and gas content. Even better, since the data are spatially resolved, we can begin to understand how properties like star formation depend on environment. In conjunction with the Greenbank Telescope, a radio telescope, the MaNGA team is able to follow up on MaNGA galaxies and gather new data on neutral Hydrogen (HI) content in MaNGA galaxies. Since HI is the fuel of stars and entire galaxies, it is imperative to understand how its content is related to other galactic functions. We cannot understand galactic evolution from stellar, ionized gas alone. From here, we can work on formulating a better idea on how galaxies evolve, form stars, stop forming stars, and more

**Author(s):** Emily Harrington,

**Institution(s):** Bryn Mawr College, Haverford College  
Contributing Team(s): Karen Masters

#### **145.19 - The Detection of [O III]4363 and the Direct Measurement of the Oxygen Abundance in a Lensed, Dwarf Galaxy at $z=2.59$ (Timothy Gburek)**

The stellar mass - gas-phase metallicity relation (MZR), critical to constraining models of star formation and feedback, has not been well-measured below a stellar mass of 109 solar masses at high redshift. This project will extend the MZR down to  $\sim 10^7$  solar masses using strong-line calibrations and rest-optical spectra - obtained with the MOSFIRE spectrograph on Keck I - of  $>100$  dwarf galaxies, lensed by 3 foreground clusters, at  $1.5 < z < 3.7$ . We will compare our estimates in this lower-end mass range with predictions from analytical models and simulations to better understand the processes controlling star formation and feedback. We are also studying the accuracy of locally-calibrated, strong-line metallicity indicators at high redshift. Our sample contains a 107.8 solar mass, [O III]4363 source at  $z=2.59$ , with which we have calculated and compared a direct, Te-based metallicity estimate ( $12+\log(O/H) = 7.98 \pm 0.20$ ) with locally-calibrated strong-line estimates. We find that our direct metallicity estimate is consistent with local calibrations as well as with the positions of other low, intermediate, and high-redshift galaxies along these strong-line - direct metallicity relations. While the scatter is large in these relations, our findings support that these strong-line methods are accurate at high redshift. We also show that this galaxy lies roughly 1.5 sigma above a slight extrapolation of the low-mass end of the Fundamental Metallicity Relation (FMR), though it is likely consistent within this end's large scatter. Deeper exposures of our sample will lead to additional [O III]4363 detections or limits that will better constrain this low-mass end of the FMR and strong-line calibrations at high redshift.

**Author(s):** Anahita Alavi, Johan Richard, Timothy Gburek, Najmeh Emami, Daniel Stark, William R. Freeman, Brian Siana

**Institution(s):** University of California - Riverside, Université Lyon , Caltech/IPAC, University of Arizona

#### **145.21 - The faint end of the Centaurus A satellite luminosity function(Denija Crnojevic)**

The Panoramic Imaging Survey of Centaurus and Sculptor (PISCeS) is constructing a wide-field map of the resolved stellar populations in the extended halos of these two nearby, prominent galaxies. I will present new Magellan/Megacam imaging of a  $\sim 3 \text{ deg}^2$  area around Centaurus A (CenA), which filled in much of our coverage to its south, leaving a nearly complete halo map out to a projected radius of  $\sim 150 \text{ kpc}$  and allowing us to identify two new resolved dwarf galaxies. We have additionally obtained deep Hubble Space Telescope (HST) optical imaging of eleven out of the thirteen candidate dwarf galaxies identified around CenA and presented in Crnojevic et al. 2016: seven are confirmed to be satellites of CenA, while four are found to be background galaxies. We derive accurate distances, structural parameters, luminosities and photometric metallicities for the seven candidates confirmed by our HST/ACS imaging. We further study the stellar population along the  $\sim 60 \text{ kpc}$  long (in projection) stream associated with

Dw3, which likely had an initial brightness of  $M_V \sim -15$  and shows evidence for a metallicity gradient along its length. Using the total sample of eleven dwarf satellites discovered by the PISCeS survey, as well as thirteen brighter previously known satellites of CenA, I will present a revised galaxy luminosity function for the CenA group down to a limiting magnitude of  $M_V \sim -8$ , which has a slope of  $-1.14 \pm 0.17$ , comparable to that seen in the Local Group and in other nearby groups of galaxies.

**Author(s):** Denija Crnojevic,

**Institution(s):** Texas Tech University, University of Tampa

#### **145.22 - Galaxies and supermassive black holes in the local universe: the Velocity Dispersion Function and Black Hole Mass Function(Farhanul Hasan)**

We study the distribution of velocity dispersions,  $\tilde{\sigma}$ , and supermassive black hole masses, MBH, for galaxies in the SDSS at  $0.03 \leq z \leq 0.1$ . We construct the velocity dispersion function (VDF) and the Black Hole Mass Function (BHMF) from a sample complete for all  $\tilde{\sigma}$ , where galaxies with  $\tilde{\sigma}$  greater than the  $\tilde{\sigma}$ -completeness limit of the SDSS spectroscopic survey are included. We compare two different  $\tilde{\sigma}$  estimates; one based on SDSS spectroscopy ( $\tilde{\sigma}_{\text{spec}}$ ) and another on photometric estimates ( $\tilde{\sigma}_{\text{mod}}$ ) and find that the VDF measured from  $\tilde{\sigma}_{\text{spec}}$  rises gently with decreasing  $\tilde{\sigma}$ , while the VDF from  $\tilde{\sigma}_{\text{mod}}$  falls with  $\tilde{\sigma}$ . The shape of our  $\tilde{\sigma}_{\text{spec}}$  VDF is in close agreement with previous determinations for the local universe; however, the  $\tilde{\sigma}_{\text{mod}}$  VDF doesn't reproduce the typically observed results from spectroscopy, implying that rotational velocity may affect  $\tilde{\sigma}_{\text{spec}}$  measurements. In fact, both late and early type galaxies have  $\tilde{\sigma}_{\text{spec}} > \tilde{\sigma}_{\text{mod}}$ , suggesting that the rotational component of most galaxies figure significantly into  $\tilde{\sigma}_{\text{spec}}$  measurements. Early-type galaxies dominate the population of high  $\tilde{\sigma}$  galaxies, while late-type galaxies dominate the low  $\tilde{\sigma}$  statistic. Very few galaxies are observed to have  $\tilde{\sigma} > 350 \text{ km s}^{-1}$ . The BHMF derived from the VDF requires many more SMBHs with masses  $6 \leq \log(\text{MBH}/M_\odot) \leq 8$  than larger ones with  $\log(\text{MBH}/M_\odot) > 9$ . Assuming an average radiative efficiency, the mass density accreted by local SMBHs matches that observed from high-redshift AGNs, implying that the same phenomenon powers both types of objects and that mass accretion is the primary mode of growing SMBHs.

**Author(s):** Farhanul Hasan, Alison Crocker

**Institution(s):** Reed College, New Mexico State University

#### **145.23 - Dwarf Galaxy Mergers Trigger Extended Starbursts(George Privon)**

Mergers of massive galaxies are understood to funnel gas to the nuclei and drive nuclear starbursts. The higher gas fractions and shallower potential wells of dwarf galaxies may both affect the ways in which mergers affect star formation in dwarf galaxy interactions. Due to their low metallicities and high gas fractions, dwarf galaxy interactions at low-redshift may also be

partial analogues to high redshift protogalaxies. We have assembled the TiNy Titans (TNT) survey of low-redshift dwarf galaxies to disentangle the effects of mergers and environment on the evolution of these systems. We will present MUSE integral field unit observations of an interacting dwarf pair from TNT. Using these observations we will demonstrate that dwarf interactions may trigger extended starbursts, as opposed to the nuclear starbursts seen in more massive galaxies. Finally, we will discuss the implications for dwarf galaxy evolution and for our understanding of hierarchical assembly at high redshift.

**Author(s):** Sarah Pearson, K. E. Johnson, George Privon, Nitya Kallivayalil, Mary Putman, Gurtina Besla, Sandra E Liss, David Patton, Sabrina Stierwalt

**Institution(s):** University of Florida, Trent University, California Institute of Technology, Flatiron Institute, University of Arizona, University of Virginia, Columbia University, Radford University

#### **145.25 - Comparison of the HI Signal Extraction Algorithms of SoFiA and ALFALFA(Bo Peng)**

Driven by the unparalleled size of datasets expected from the next generation HI surveys with ASKAP, MeerKAT and APERTIF, SoFiA (Serra et al. 2015) has been developed as the automated HI spectral signal extraction software to be deployed in these future survey programs. Prior to exploiting the HI catalogues of upcoming surveys for galaxy evolution and cosmological studies, it is critical to understand the statistical properties and robustness of catalogue derived by different HI line identification and measurement algorithms. Here we compare SoFiA against the match-filtering source detection algorithm implemented in ALFALFA, the largest extragalactic HI survey to date. Based on tests run on mock spectral cubes, we present here a comparison of detection statistics such as reliability and completeness, along with key parameters including the HI mass and velocity width obtained through each algorithm. We also describe a novel method used in constructing mock cubes utilising actual HI spectral profiles extracted from the ALFALFA grid data. This work has been supported by a grant from the Brinson Foundation to M.P. Haynes.

**Author(s):** Martha P Haynes, Bo Peng

**Institution(s):** Cornell Center for Astrophysics and Planetary Science

#### **145.26 - A Unified View of Angular Momentum and Galaxy Formation(Aaron Romanowsky)**

The observed sizes and rotation speeds of spiral galaxy disks can be explained through a simple model where angular momentum (AM) is conserved through the collapse of baryons within dark matter halos that are spun up by tidal torques. However, it is less clear how the spheroidal (bulge) components of galaxies fit in with this picture. Here we present a new, unified analysis of wide-field kinematics in galaxies across the

Hubble Sequence, from spiral to elliptical. We find the galaxies to lie on a surface in the 3D space of mass, AM, and bulge fraction that can be explained by disks and bulges following separate but parallel mass-AM scaling relations. We also discuss how the bulge properties may be shaped by mergers or biased collapse.

**Author(s):** S. Michael Fall, Aaron Romanowsky

**Institution(s):** San Jose State University, Space Telescope Science Institute

#### **145.27 - SDSS-IV/MaNGA: A PCA-based approach to Stellar Mass Estimation for IFS observations(Zachary Pace)**

We obtain estimates of resolved stellar mass for galaxies in the SDSS-IV/MaNGA integral-field-spectroscopic survey, using a principal component analysis (PCA) model trained on synthetic star-formation histories. To examine the differing systematics resulting from dynamical- and stellar-population-synthesis-derived stellar mass estimates, we compare the stellar-mass surface-densities we find to dynamical-mass surface-densities from the DiskMass Survey (DMS). We show that by allowing for a (approximately factor of 1.5) galaxy-wide, systematic overestimate in the disk scale height on the part of DMS, it is possible to obtain better agreement between the two sets of measurements. We test two methods of aperture-correcting galaxies with incomplete spatial sampling, in order to obtain total stellar-masses; and we compare those total masses to estimates from two previous photometric studies, finding our estimates systematically larger by approximately 0.1 dex, on average. We compare total masses found using IFU-integrated spectra to the sum of spaxel-resolved masses, finding that unequal measured attenuation across the face of a galaxy correlates with a mass deficit for integrated spectra of up to 0.1 dex. Finally, we describe the near-future release of the resolved stellar mass-to-light ratios and galaxy total masses as a SDSS-IV/MaNGA Value-Added Catalog (VAC).

**Author(s):** Kyle Westfall, M  d  ric Boquien, Joel Brownstein, David Wake, Matthew A Bershady, Yanmei Chen, Adam Schaefer, Brett Andrews, Niv Drory, Kate Rowlands, Zachary Pace, Christy Tremonti

**Institution(s):** University of Wisconsin - Madison, University of California Observatories, Nanjing University, University of Pittsburgh, Universidad de Antofagasta, University of Utah, Johns Hopkins University, University of North Carolina Asheville, University o

#### **145.28 - Roles of Cosmic Rays & Magnetic Fields in Galactic Disk & Halo Evolution(Daven Cocroft)**

Magnetic fields and cosmic rays are decidedly important aspects of galactic disk and halo evolution, however, their precise roles are not yet completely understood. While there are many simulations studying galactic evolution, few have deeply explored the exact impact of cosmic rays and magnetic fields in

the evolutionary process. The current goal of our research is to learn more about how cosmic rays and magnetic fields contribute to the evolutionary process by looking at how magnetic fields grow and change in the circumgalactic medium (CMG) under the influences of cosmic rays. Using a suite of simulated, isolated disk galaxies, we investigated the role of cosmic rays in magnetic field growth and galaxy evolution by comparing different galactic models, each possessing slightly varied cosmic ray and magnetic field properties. We will present the role of cosmic ray transport on the geometry, strength, and growth rate of magnetic fields in these simulated galactic halos.

**Author(s):** Iryna Sotolongo Butsky, Daven Cocroft

**Institution(s):** University of Washington Contributing Team(s): UW N-Body Shop

#### **145.30 - Rapid Supermassive Black Hole Growth in Merger-Free Host Galaxies(Jesse Carla Shanahan)**

Understanding the relationship between supermassive black holes and their host galaxies is integral to understanding their co-evolution. While a correlation between black hole mass and classical bulges has been observed that theoretically results from galaxy mergers, we have identified a sample of nearby ( $z < 0.35$ ) disc-dominated galaxies with luminous broad-line active galactic nuclei (AGN). These galaxies' disk-dominated dynamics strongly constrain their evolutionary histories to be free of significant mergers since  $z \sim 2$ , yet they lie on the same co-evolution relation as dispersion-supported galaxies. Utilizing the Hubble Space Telescope's Advanced Camera for Surveys, we observed this sample in order to further explore the black hole-galaxy relationship in a merger-free environment. We accomplished this by acquiring accurate bulge-disk decompositions for galaxies hosting unobscured AGNs across a wide range of masses and luminosities. In contrast to the known pathways for growing supermassive black holes, e.g. galaxy mergers or violent secular processes, this suggests an alternate secular pathway by which supermassive black holes can grow to quasar-like luminosities: a significant departure from the standard model of AGN evolution.

**Author(s):** Alison Coil, Brooke Simmons, Jesse Carla Shanahan, Chris Lintott, Rebecca Smethurst,

**Institution(s):** Galaxy Zoo, Lancaster University, University of California San Diego, University of Nottingham, University of Oxford Contributing Team(s): MAGNUS Team, Galaxy Zoo Team

#### **145.31 - Seeing Red: Spectroscopy of Galactic Globular Clusters from 6500   ... to 1   m(Joel Roediger)**

The globular clusters that orbit the Milky Way are a treasure trove, providing evidence on a wide range of topics of astrophysical interest, from the scale of individual stars to the entire Galaxy itself. The relative ease with which they can be observed, the massive volume of published data on them, and

their very nature have also garnered the population of Galactic globular clusters (GGCs) an exalted status in the field of stellar population synthesis (SPS). This field seeks to interpret the integrated light from extragalactic stellar systems in terms of their underlying physical characteristics and relies on GGCs to enable baseline calibrations of the models that connect data to inference. Over the past decade, SPS analyses have begun to target galaxies at red/optical wavelengths and found tantalizing evidence that the stellar IMF varies systematically with galactic properties, like mass and metallicity. These results motivate the study of GGCs over an as-yet little explored wavelength regime and in this talk I will describe our survey with the Gemini Observatory to obtain integrated red/optical spectroscopy of these objects. By combining our data with published blue/optical spectroscopy for the same targets, we are able to address pressing issues surrounding SPS, such as (i) the limiting accuracy of model-inferred ages, chemical abundances, and mass functions for old stellar populations; and (ii) systematic biases between the analysis of blue versus red spectroscopy. This talk will focus on the urgent need for these data, highlight interesting empirical trends, and present detailed examinations of our modelling for a few clusters.

**Author(s):** Ricardo Schiavon, Charlie Conroy, Joel Roediger, Stephane Courteau

**Institution(s):** National Research Council Canada, Liverpool John Moores University, Queen's University, Harvard-Smithsonian Center for Astrophysics

#### **145.32 - Galaxy Mergers On FIRE: Stellar Shell Evolution in Post-Mergers(Angela Twum)**

Galaxy shells are low surface brightness regions that appear as concentric arcs of dense stellar particles within the stellar halo of massive galaxies. Shells form as a result of galaxy mergers and can be an indicator of how recently the merger took place. To study how the structure and mass distribution within these shell structures evolve, we utilize a suite of 24 high resolution galaxy merger simulations. Our simulations employ the Second Version of the "Feedback in Realistic Environments" (FIRE2-2) model. In this preliminary work, we focus primarily on a representative fiducial run of the merger suite, one designed to maximize both duration and the impact of the encounter. We visually identify a number of shell structures in both configuration and phase space, and then trace the distribution of star particles forward and backward in time to observe how these shell structures evolve. In addition, we test the feasibility of our analyses as a method that can be used by observers to identify and study the brightness evolution of shells in the local universe.

**Author(s):** Paul Torrey, Angela Twum, Jorge Moreno

**Institution(s):** Pomona College, University of Florida  
Contributing Team(s): FIRE Collaboration

#### **146 - Instrumentation: Ground Based or Airborne Posters**

##### **146.01 - Demonstrating Predictive Wavefront Control at Keck II(Eden McEwen)**

The success of ground-based, high-contrast imaging instruments depends on the degree to which adaptive optics (AO) systems can mitigate atmospheric turbulence. Predictive wavefront control (pWFC) can significantly improve contrast ratios in comparison to traditional AO systems by compensating for the time lag between wavefront measurement and correction. Our three year project aims to demonstrate pWFC on Keck II's recently integrated pyramid wavefront sensor. Here, we discuss the set up and use of the Adaptive Optics Simulation Engine (AOSE), a UC Berkeley server environment which mirrors the processes of the Keck II pyramid real time control computer. Both systems are structured around Compute and Control for Adaptive Optics (CACAO), a modular code package that makes use of data streams and high speed computing. AOSE is built both to support our current demonstration at Keck and the development of WFC algorithms for the next generation of extreme AO systems.

**Author(s):** James Graham, Rebecca Jensen-Clem, Sylvain Cetre, Eden McEwen, Peter Wizinowich, Dimitri Mawet

**Institution(s):** UC Berkeley, WMKeck Observatory, California Institute of Technology

##### **146.02 - Design and Performance of NEID Ultra-Stable Environmental Control System(Emily Lubar)**

NEID is an ultra-stable, optical spectrometer designed to achieve Radial Velocity (RV) precision on the order of 10cm/s. Achieving this level of measurement precision requires extreme thermo-mechanical stability within the instrument which we achieve by maintaining a vacuum on the order of microTorr as well as sub-milliKelvin temperature stability. In this poster, we will outline NEID's Environmental Control System (ECS) and Temperature Monitoring and Control (TMC) System, which were both inherited and improved upon from that of the Habitable-zone Planet Finder (HPF) infrared spectrograph. We have achieved our target stability by demonstrating < 0.4mK RMS temperature variability over the course of a 30 day stability run in the lab. We expect our stability to improve at the observatory as the WIYN instrument room is more stable than our instrument development lab. NEID will be commissioned in midwinter 2019 at Kitt Peak National Observatory on the 3.5m WIYN Telescope. It will serve the exoplanet community as a vital follow up asset for Earth-like planets targeted by the TESS survey.

**Author(s):** Frederick Hearty, Lawrence Ramsey, Paul Robertson, Joe Ninan, Sam Halverson, Gudmundur Kari Stefansson, Jason T Wright, Christian Schwab, Shubham Kanodia, Cullen Blake, Arpita Roy, Suvrath Mahadevan, Colin Nitroy, Emily Lubar, Chad Bender, Sarah E. Logsdo

**Institution(s):** The Penn State University, University of Arizona, University of California, Irvine, Massachusetts

Institute of Technology, University of Pennsylvania, California  
Institute of Technology, NASA Goddard Space Flight Center,  
Macquarie University Contri

#### **146.03 - The Las Cumbres Observatory's Network of Robotic Echelle Spectrographs in 2019: Current status and next steps(Daniel Rolf Harbeck)**

Over the last two years, the Las Cumbres Observatory (LCOGT) has deployed the Network of Robotic Echelle Spectrographs (NRES), which consists of optical high-precision spectrographs that are fed by 1-meter telescopes at four sites: In Chile (CTIO), USA (McDonald Observatory), South Africa (SAAO), and Israel (Wise Observatory). These spectrographs are identically designed and built, and they cover a wavelength range from 390nm to 860nm at a resolution of  $\sim 45000$ . After  $\sim 1.5$  years of installation and commissioning efforts, fully robotic science operations are now regularly underway with the NRES system. Although significant telescope time is currently assigned in support of NASA's TESS mission, NRES is a valuable resource for the entire astronomical community via open access through the NSF / NOAO. In this report we describe the current performance of the spectrographs for both radial velocity measurement and stellar classification and also discuss opportunities and plans for further improvement.

**Author(s):** Robert Siverd, Cary Smith, Daniel Rolf Harbeck, Brook Taylor, Jon de Vera, Tim Brown, Jon Nation, Annie Kirby, Steve Foale, Curtis McCully, Todd Henderson

**Institution(s):** Las Cumbres Observatory, Vanderbilt University

#### **146.04 - Characterizing Instrument Profiles of High-Resolution Spectrographs with a Laser Frequency Comb(David Phillips)**

Continuing improvements in both instruments and analysis techniques for determining stellar radial velocities are enabling the search for exoplanets below the 1 m/s level. Amongst improvements required to reach the 10 cm/s level, necessary for detecting Earth-mass planets in the habitable zone of Sun-like stars, is better characterization and control of spectrograph variability beyond wavelength calibration. This includes the spectrograph response function (or Instrument Profile) which varies both as a function of wavelength across the spectrograph and also as a function of time. I will present observations of the instrument profile of the HARPS-N spectrograph using an astro-comb, a laser frequency comb optimized for spectrograph calibration. We observe Instrument Profiles with long, asymmetric tails with substantial structure which affect the centroids of calibration and stellar spectral lines, and thus the observed radial velocity. Evidence for the temporal variability of the line profile from the HARPS-N/TNG solar telescope will also be presented. Techniques for mitigation of these issues to enable improved spectrograph RV stability will be discussed.

**Author(s):** David Phillips

**Institution(s):** Smithsonian Astrophysical Observatory  
Contributing Team(s): HARPS-N Collaboration

#### **146.05 - Development of pETSI: prototype Exoplanet Transmission Spectroscopy Imager(Taylor Plattner)**

The prototype Exoplanet Transmission Spectroscopy Imager (pETSI) is an optical multispectral camera used to demonstrate a method capable of identifying and directly measuring atmospheres of a large number of exoplanets orbiting bright stars. Light from the telescope is collimated by a 200 mm focal length commercial lens and dispersed by a prism. After dispersion, the light passes through a multi-band filter which transmits a number of well-defined bands that are focused by a 50 mm focal length commercial lens onto the detector. The multi-band filter converts the continuous spectra of both target and comparison stars into sets of discrete multi-color images. Relative color changes in the resulting spectra over the course of a transit will signify the presence of an exoplanet atmosphere and can be used to further characterize the exoplanet atmosphere. After additional prototyping and development, ETSI will be used to conduct a campaign to observe hundreds of targets from the Transiting Exoplanet Survey Satellite (TESS). ETSI will observe these identified targets using relatively small telescopes (1-2m-class), with the goal of determining which targets are most valuable for follow-up by larger and more precious resources such as the James Webb Space Telescope (JWST) and large ground-based facilities.

**Author(s):** Luke Schmidt, Travis Prochaska, Mary Anne Limbach, Sarah Hughes, Jennifer Marshall, Leonardo Barba, Darren DePoy, Taylor Plattner,

**Institution(s):** University of Kansas, Royal Holloway, University of London, Texas A&M University

#### **146.06 - The Key Science Drivers for MICHl: a thermal-infrared instrument for the TMT(Christopher Packham)**

With the imminent launch of the JWST, the field of thermal-infrared (TIR) astronomy will enjoy a revolution. It is easy to imagine that all areas of infrared (IR) astronomy will be greatly advanced, but perhaps impossible to conceive of the new vistas that will be opened. To allow both follow-up JWST observations and a continuance of work started on the ground-based 8m's, we continue to plan the science cases and instrument design for a TIR imager and spectrometer for early operation on the TMT. We present the current status of our science cases and the instrumentation plans, harnessing expertise across the TMT partnership. This instrument will be proposed by the MICHl team as a second-generation instrument in any upcoming calls for proposals.

**Author(s):** Mark Chun, Jayne Birkby, Ian Crossfield, Christopher Packham, Itsuki Sakon, Manoj Puravankara, Christian Marois, Yoshiko Okamoto, Michael R. Meyer, Masatoshi Imanishi, Hirokazu Katata, Thayne Currie, Matthew

Richter, Kohei Ichikawa, Thomas Greathouse, G  
**Institution(s):** MIT, University of Amsterdam, NAOJ, NASA/AMES, SwRI, University of Lyon, Kavli, UTSA, University of Hawaii, Kurume University, UC Davis, University of Tokyo, Herzberg Institute of Astrophysics, ISAS/JAXA, Tata, University of Michigan

#### **146.07 - Modification, Characterization, and Re-commissioning of KOSMOS at the Apache Point 3.5-m (Debby Tran)**

Our group at the University of Washington is currently working to upgrade the optical spectroscopic capabilities of the Astrophysical Research Consortium (ARC) 3.5-meter telescope at Apache Point Observatory (APO) in New Mexico. The first part of this project involves modifying the KOSMOS spectrograph. The Kitt Peak National Observatory Ohio State Multi-Object Spectrograph (KOSMOS) is a spectrograph originally built for the Kitt Peak National Observatory (KPNO) through a collaboration between Ohio State University (OSU) and the National Optical Astronomy Observatory (NOAO). It is now being modified and moved to the APO 3.5-m. KOSMOS is a longslit instrument that improves efficiency and brings the possibility for multi-object capabilities across 360-1000 nm. Upgrades are being made that will provide slit viewing, as well as possibilities for internal calibration. The multiple configurations of slits, filters, and grisms make KOSMOS versatile instrument for the wide range of science interests in the ARC collaboration. In this poster, we present the current status of modifications and characterization of KOSMOS.

**Author(s):** Myles McKay, Kal Kadlec, Sarah Tuttle, Conor Sayres, Debby Tran

**Institution(s):** University of Washington, Seattle

#### **146.08 - The Redesign of the Guider Optics of 6.5-M Magellan Telescopes (Kutay Nazli)**

Many modern optical telescopes utilize a variety of guider optics that allow the quality of the images to be monitored and corrections to be made to overcome imperfections in real time. This work focuses on the updated optical and mechanical designs for the re-imager, Shack-Hartmann (SH) array and the new atmospheric dispersion compensator (ADC) as a part of the ongoing revision of the guider optics on the 6.5-m Magellan Telescopes at Las Campanas Observatory in Chile. We have redesigned the re-imager optics with less magnification (from 0.42 to 0.26) to compensate for the decreased pixel size (from 26  $\mu$ m in 2x2 binned setup to 14.6  $\mu$ m). We designed the SH optics to match the optical length of the re-imager optics and to ensure that small-scale errors in optical length will not be miscategorized as defocus. The mechanical design for the tubes that hold the guider optics were designed for simplicity as the optics have been assembled in house. In this work, the theoretical performance of the new optics are discussed. The actual performance of the instruments will be thoroughly

discussed when the manufacturing is completed and when they are installed on the 6.5-m Magellan Telescopes.

**Author(s):** Stephen A. Shectman, Kutay Nazli

**Institution(s):** Pomona College, Carnegie Observatories

#### **146.09 - Optical Design for the ROSIE Integral Field Unit on the Magellan IMACS (Rosalie Cushman McGurk)**

We are designing an image slicer integral field unit (IFU) to go on the IMACS wide-field imaging spectrograph on the Magellan Baade Telescope, the Reformatting Optically-Sensitive IMACS Enhancement IFU, or ROSIE IFU. The 60"x49" field of view will be pre-sliced into four 15"x49" subfields, and then each subfield will be divided into 23 0.6"x49" slices. The four main image slicers will produce four pseudo-slits spaced six arcminutes apart across the IMACS f/2 camera field of view, providing a wavelength coverage of 1800 Angstroms at a spectral resolution of 2000. This IFU will enable the efficient mapping of extended objects such as nebulae, galaxies, or outflows, making it a powerful addition to IMACS.

**Author(s):** Chung-Pei Ma, Rosalie Cushman McGurk, Regina Lee, Stephen A Shectman

**Institution(s):** Carnegie Observatories, Caltech, UC Berkeley

#### **146.10 - Mounts and Alignments of Optics for the ROSIE Integral Field Unit on the Magellan IMACS (Regina Lee)**

Integral field spectroscopy (IFS) delivers spatially resolved spectroscopy over an entire galaxy or field of view more efficiently than traversing a field of view using long slit spectroscopy. This project focuses on designing an image slicer integral field unit (IFU) to go on the Inamori-Magellan Areal Camera and Spectrograph (IMACS) on the Magellan Baade Telescope in order to utilize IFS. The instrument will be named the Reformatting Optically-Sensitive IMACS Enhancement IFU, or ROSIE IFU. The field will be divided into 92 slices by four image slicers, and then those slices will be reformatted into four spectrographic slits and input into IMACS. The project's goal is to create adjustable and accurate optic mounts for the fold mirrors. The fold mirror mount model will have to isolate tilts in the X and Y-axes as well as be easily constructible and repeatable as there are many that will be made. A deflection and strain analysis were done on the different models, and the best performing prototype was used. The prototypes were made on SolidWorks then milled out of aluminum. The most practical design which fulfills these criteria includes two flaps to isolate the X and Y-axis tilts and connects to a base that controls the angle. There is also an endcap designed to hold the mirror in place without need for epoxies and thermal analyses. The design chosen has a universal mirror mount with an easily changeable base, therefore making it easier to create many multiples of these mounts at different angles. The mounts have been fabricated to practice aligning the optics to properly direct

the light into the spectrographic slit.

**Author(s):** Regina Lee,

**Institution(s):** Carnegie Observatories, California Institute of Technology Contributing Team(s): Regina Lee

#### **146.11 - Exploration of the Calibration and Development of the Spectral Extraction Procedure for the Rapid IMager - Spectrometer(Jillian Kunze)**

The Rapid IMager - Spectrometer (RIMAS) will study the afterglow of gamma-ray bursts in the near-infrared. In order to produce useful astronomical data, RIMAS must be calibrated to establish what wavelength corresponds to each pixel on the spectrometer's H2RG detectors. In the first phase of this study, several methods of determining the pixel number of spectral peaks were developed in Python and compared to find which produced the most accurate calibration curve. Three different approaches were attempted using test spectra taken by RIMAS of elements with known emission lines: finding the pixel number of peaks in a one-dimensional line spectrum, fitting two-dimensional Gaussians over the peaks and finding the pixel number of their maxima, and finding the centers of mass of the peaks at a certain intensity threshold, which was then varied. Once the pixel numbers of peaks were found, a linear regression with the known wavelengths of the spectral lines was performed to produce a calibration curve. After a comparison of the  $r^2$  value and the maximum percent difference between library and calibrated wavelengths produced by the different methods, the best calibration curve was shown to be produced by finding center of mass with an intensity threshold of 35%. The next phase of this project is to establish the spectral extraction pathway for RIMAS using Spextool. This requires the construction of line and wavelength calibration files specific to RIMAS, which will be incorporated into the existing Spextool pathway. Using this package, observers will have a pipeline to create calibration files and extract the spectrum of their target object. The extraction of data from RIMAS that this enables will be integral to researching distant gamma-ray bursts.

**Author(s):** Joseph Durbak, Jillian Kunze, Alexander Kuttyrev,

**Institution(s):** University of Maryland, NASA GSFC

#### **146.12 - Achieving 100mK: the Cryogenic Systems of TolTEC(Miranda Eiben)**

TolTEC is a next generation millimeter camera for the Large Millimeter Telescope (LMT). It utilizes Lumped Element Kinetic Inductance Detectors (LEKIDs) operated at cryogenic temperatures of approximately 100 mK. TolTEC has three arrays of LEKIDs at wavelengths of 1.1 mm, 1.4 mm and 2.0 mm, each featuring a few thousand detectors. TolTEC's focal planes and optics bench require a unique large-scale cryostat with multiple nested temperature stages. To cool the system, we rely on two cryogenic systems; an Auxiliary Pulse Tube Cooler which extracts the heat at the 45K and 4K stages, and a Dilution Refrigerator which extracts the heat at the 1K and 100 mK

stages. Here we describe the design, modeling and characterization of each stage including both the thermal and mechanical challenges of working with meter-scale cryostats. We are currently transitioning from the design phase to assembly and testing and expect TolTEC to be commissioned at the LMT between Spring to Summer 2019.

**Author(s):** Miranda Eiben, Natalie DeNigris, Grant Wilson

**Institution(s):** University of Massachusetts, Amherst

#### **146.13 - GBT Metrology: Laser Active Surface Scanning Instrument ( L.A.S.S.I. )(Andrew Seymour)**

The GBO has received NSF-MSIP funding to implement a laser metrology system for measuring the surface of the GBT precisely and quickly. The 2008 panels of the primary surface of the GBT can be adjusted in real time to maintain its parabolic shape. At present, the surface is measured using "out-of-focus" holography, which takes ~30 min but remains valid for many hours at night. During the day, however, thermal gradients in the antenna backup structure can vary on timescales approaching 1 hour, requiring calibration measurements at least this often. This is extremely inefficient, and as a result, observations at 3mm are rarely made during the day. Recent advances in commercial technology have made it possible to purchase a laser scanner, that if mounted near the GBT focus, will produce a hundred million angle and range measurements of the surface every few minutes. Any given measurement has a range uncertainty ~2 mm, but the data can be averaged to reduce the errors to tens of microns on the relevant angular scales. Measured surface distortions can then be corrected using the active surface. Measurement of the GBT surface in real time will allow operation at the highest frequencies night or day, doubling the available telescope time at 3mm wavelength, and increasing the observing efficiency for all projects that operate above 25 GHz. This project takes advantage of the GBT active surface and large collecting area, which makes it the largest telescope in the world operating at mm wavelengths.

**Author(s):** Felix Lockman, Andrew Seymour

**Institution(s):** Green Bank Observatory

#### **146.14 - The Calibration and Performance of the GBT at High Frequency(David Frayer)**

We summarize the current performance and calibration of the 100-m diameter Green Bank Telescope (GBT) at high-frequency. We discuss the performance of the current Zernike-gravity model that has significantly improved the gain of the telescope as a function of elevation. New calibration results are presented based on observations taken within the 3mm atmospheric window (70-115 GHz) using the W-band 68-92 GHz receiver and the Argus 75-115 GHz focal-plane array. For typical conditions scheduled on the telescope, the aperture efficiency derived by measurements of 3mm calibrators correspond to an effective average surface rms of 237 microns using the standard Ruze's equation. We provide results for the aperture efficiency, beam



efficiency, and beam sizes as a function frequency measured during normal operations from the recent observing seasons.  
**Author(s):** David Frayer, Ronald Maddalena, Frank Ghigo  
**Institution(s):** Green Bank Observatory

#### **146.15 - Wideband Digital Sampling and Interference Excision for the Green Bank Telescope(Ryan S Lynch)**

The Green Bank Observatory is a leader in the development of wide-band digital detectors that have enabled major discoveries in the fields of pulsars, fast radio bursts, astrochemistry, and star formation (to name but a few). These previous generation systems have all sampled the signal of interest after substantial analog conditioning, but advances in heterogeneous computing solutions are now making it feasible to digitize very wide bandwidths directly at radio frequencies or after a single down-conversion, with both greater dynamic range and more powerful on-board digital signal processing using machine learning algorithms. This in turn allows for real-time detection of astrophysical signals and excision of radio frequency interference, resulting in higher quality science data products. GBO is exploring implementing these new technologies in a new, ultrawideband receiver for the Green Bank Telescope covering ~0.7--4 GHz. The primary science driver for the receiver is the direct detection of nanohertz frequency gravitational waves via pulsar timing, and it will also have applications in the wideband detection and study of radio transients and regions rich in molecular lines. This project will be the first step towards complete upgrades of the GBT's signal path. Such an upgrade will be transformational, increasing the maximum available instantaneous bandwidth by factors of 5--20 at frequencies above 15 GHz and thus providing faster observations of widely separated spectral lines, improving spectral baseline stability and operational efficiency at all frequencies, and incorporating real-time RFI excision into all GBT observations.

**Author(s):** Jason Ray, Ryan S Lynch, Luke Hawkins, Randy McCullough

**Institution(s):** Green Bank Observatory Contributing Team(s): Green Bank Observatory

#### **146.16 - Comparing field measurements with specifications for prototype HERA feed.(Justin Stanley Bracks)**

Observations of the redshifted 21 cm line of atomic hydrogen offer the potential of opening a new window into the epoch of reionization (EoR). Reflectometry measurements made on a prototype antenna feed at the Green Bank Observatory (GBO) are compared to initial specifications set forth by the Hydrogen Epoch of Reionization Array (HERA) collaboration. Our analysis indicates a strong agreement between the field measurement and simulated antenna models. Overall the measurement tend to surpass the specifications.

**Author(s):** Justin Stanley Bracks, Jacqueline N Hewitt

**Institution(s):** California State University Northridge, Massachusetts Institute of Technology

#### **146.18 - The Argus+ Program: Next Generation Mapping(Robert Lim)**

**Abstract:** Argus+ is a high-fidelity 3mm atmospheric window widefield mapping receiver. The plan is for the Green Bank Observatory's receiver to be general purpose to support the U.S. scientific community. Argus+ will have an angular resolution of  $6.5'' - 8''$ , the high sensitivity enabled by a filled aperture, and a wide field of view. This maps molecular clouds within hundreds of square arc-minutes with a spatial dynamic range (map area/pixel size) of  $10^4$  to  $10^5$ . Based on the original 16-pixel Argus receiver commissioned in 2016, Argus+ will allow scientists to ask key science questions about star formation and astrophysics. Argus demonstrates unique scalable array technology that could be developed into Argus+'s 144-pixel camera. This technology combined with GBT metrology improvements commissioned in 2018 will increase the scientific output in the 3mm window by 20x. The team tasked with creating Argus+ will be the original Argus team and GBO staff for combined decades of experience in designing, developing, and operating instruments for the U.S. science community. The AAS poster shall display the science of the instrument, how systems engineering was implemented in the project, possible designs, and broader impact within the U.S. community. Using systems engineering and agile techniques, the requirements, processes, and matrices were modeled for technical design and development. The instrument provides an exploration of the tools to develop model-based processes as the use of Unified Modeling Language (UML) and Systems Modeling Language (SysML) for organizational models providing an opportunity for learning techniques for managing and defining technical projects.

**Author(s):** Robert Lim,

**Institution(s):** University of Colorado - Boulder, Green Bank Observatory

#### **146.19 - Instrument Characterization for HIRAX, the Hydrogen Intensity and Real-time Analysis eXperiment(Emily Kuhn)**

The Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX) is a 21 cm neutral hydrogen intensity mapping experiment to be deployed in the Karoo Desert in South Africa. It will consist of 1024 6m dishes, and will map much of the southern sky over the course of four years. HIRAX will operate at 400-800MHz, thereby exploring the redshift range  $0.8 < z < 2.5$  and allowing us to make new measurements of BAOs and in turn constrain the Dark Energy equation of state parameters. As with all 21cm science, galactic foregrounds contaminate our band, and so meeting our science goals will require precise characterization of our instrument. I will present two aspects of our instrument characterization: noise temperature

measurements and drone beam mapping. I will discuss a novel apparatus for determining antenna noise temperature in which we use identical loads, one cryogenic and the other at room temperature, to take a differential measurement (y-factor measurement) to infer the noise of our system. Simulations predict this set up will allow us to understand our noise temperature to within 10%. The apparatus is currently being built at Yale, and will be used to test current and future generations of feeds. Additionally, I will describe the status of drone calibration measurements, which will be critical to understanding our beams and controlling potential systematic errors. I will specifically touch on requirements to achieve accurate beam calibration and methods for checking in flight data sets for accuracy. I will also report initial data, and describe future plans.

**Author(s):** Benjamin Saliwanchik, Laura Newburgh, Emily Kuhn

**Institution(s):** Yale University **Contributing Team(s):** HIRAX Collaboration

#### **146.20 - Calibrating ZEUS-2 to Study Star Formation in the Early Universe(Hannah Tidwell)**

The Second-Generation redshift (z) and Early Universe Spectrometer (ZEUS-2) is a submillimeter grating spectrometer optimized to detect far-IR fine-structure lines in high redshift galaxies. These far-IR fine-structure emerge from the interstellar medium (ISM) and are good probes for the stellar radiation field (and thus stellar age) and the gas density in these galaxies, allowing us to study their physical conditions during the epoch of maximum star formation density in the Universe. We made laboratory observations of the rotational transitions of CO J=7-6 and J=13-12 lines across the 400  $\hat{1}/4$ m and 200  $\hat{1}/4$ m arrays respectively in order to improve the grating calibration (grating angle vs spectral dispersion along detector pixels). So far, we have opened up for new science in the 200  $\hat{1}/4$ m telluric window, and ZEUS-2 is undergoing further calibrations and updates in preparation for observations in 2019 on APEX for the first time since the telescope's 10  $\hat{1}/4$ m resurfacing.

**Author(s):** Christopher Rooney, Gordon Stacey, Hannah Tidwell

**Institution(s):** Georgia Southern University, Cornell University

#### **146.21 - Latest Science and Status of Your Flying Observatory - SOFIA(Kimberly Ennico)**

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a unique community-driven airborne observatory. It provides regular access to the mid-infrared and far-infrared sky at wavelengths impossible to observe from the ground or any current space-based mission. Because half of the radiant energy in the universe emerges at these wavelengths, SOFIA investigates a diverse range of targets in the Solar System, in

the Milky Way, and in distant galaxies, and addresses NASA's astrophysics three Big Questions: How does the Universe work? How did we get here? Are we alone? By design, SOFIA has continued to mature its mission systems as part of a planned spiral development approach, particularly with upgradable instrumentation that opens up new science directions for the Observatory. Just recently, a far-infrared photometer polarimeter achieved first light and is delivering new insights about the role of magnetic fields in star forming regions and in other galaxies. A third generation mid/far-infrared imager/spectrometer instrument is planned for commissioning in 2019, which will enable studies of the mass and composition of protoplanetary disks. In this next decade, deeper studies of the infrared and submillimeter universe are enabled by the James Webb Space Telescope (JWST, launch, March 2021), and the Atacama Large Millimeter/submillimeter Array (ALMA, operational since 2013). As exceptional as these facilities are, coverage of the wavelengths where JWST ends and where ALMA begins, the part of the spectrum most important to understanding the physics of the interstellar medium, is provided by SOFIA. Additionally, SOFIA has and continues to enable long-term studies and follow-up work initiated by Spitzer, Herschel, Hubble, Chandra, and several ground-based submillimeter observatories. These are exciting times for infrared and submillimeter astronomy. Here we summarize recent SOFIA-enabled science results, its current instrument suite performance, and developments in the science program through the SOFIA Legacy Science Program and transfer of the science archive to IRSA. <https://www.sofia.usra.edu>

**Author(s):** George Sarver, Jeanette Le, Eric Becklin, Eddie Zavala, Harold Yorke, Kimberly Ennico, Alan Rhodes, Thomas Roellig, William Reach, Pasquale Temi, Naseem Rangwala

**Institution(s):** NASA Ames Research Center, NASA Armstrong Flight Research Center, SOFIA Science Center, USRA

#### **146.22 - Benchmarking simulations of the Compton Spectrometer and Imager with calibrations(Clio Sleanor)**

The Compton Spectrometer and Imager (COSI) is a balloon-borne gamma-ray (0.2-5 MeV) telescope designed to study astrophysical sources. COSI's main science goals are to measure polarization from gamma-ray bursts and compact objects, map the 511-keV positron annihilation line from the Galactic bulge and plane, and image diffuse Galactic emission with nuclear lines. COSI employs a compact Compton telescope design utilizing 12 high-purity germanium double-sided strip detectors and is inherently sensitive to polarization. In 2016, COSI was launched from Wanaka, New Zealand and completed a successful 46-day flight on NASA's new super-pressure balloon platform. In order to perform imaging, spectral, and polarization analysis of the sources observed during the 2016 flight, we must accurately simulate the detector response. To achieve this goal, we have built a comprehensive mass model of the instrument and developed a detailed detector effects engine which applies the intrinsic detector performance to Monte

Carlo simulations. The simulated detector effects include energy, position, and timing resolution, thresholds, dead strips, dead time, and detector trigger conditions. After this step, the simulations closely resemble the measurements, and the standard analysis pipeline used for measurements can also be applied to the simulations. In this presentation, we will describe the detector effects engine and the benchmarking tests performed with calibrations. We will also describe the application of these benchmarked simulations to create COSI's detector response, focusing on the spectral analysis pipeline.

**Author(s):** Clio Sleator, Carolyn Kierans, Alex Lowell, Steven E Boggs, John Tomsick, Andreas Zoglauer

**Institution(s):** Space Sciences Lab, UC Berkeley, NASA GSFC, University of California - San Diego

#### **146.23 - A balloon payload for infrared stellar astronomy.(Timothy Cook)**

Many nearby Milky Way stars, especially those in the late stages of low- and intermediate-mass evolution, are saturated in modern survey instruments like 2MASS, WISE, or IRAC. Older surveys, such as those from IRAS and DIRBE, are limited by confusion near the Galactic plane. This leaves us in the maddening position that the stars which appear to be the easiest to observe are among the most poorly characterized and, as a result, our understanding of the late stages of stellar evolution is hampered by our inability to characterize the brightest stars. Our lack of good photometry for potential standard stars complicates the calibration of new infrared space missions, such as JWST and WFIRST. We present the design of a high altitude balloon payload intended to rectify this situation. The payload uses a 0.6 m clear aperture off axis Gregorian telescope designed for the PICTURE mission. The telescope feeds a stack of dichroic beam splitters which pick off individual bands to simultaneously record flux in 5 different bands approximately corresponding to JHKL and M bands. Because we are observing single IR bright stars, we record the signal of a series of discrete diodes. This allows us to establish the IR colors necessary to characterize the spectral energy distributions of ~1000-3000K objects, particularly first-ascent red giants and asymptotic giant branch stars, without the unsupportable cost and complexity of five different focal plane arrays. The design includes a visible aspect camera in the dichroic stack to validate the instrument point spread function (PSF) and pointing and to allow us to estimate the centroid of the PSF relative diode position. We have also included an in-flight calibration source to provide a stable traceable calibration.

**Author(s):** Gregory C. Sloan, Timothy Cook, Kathleen Kraemer, Jason Martel, Susanna C Finn

**Institution(s):** University of Massachusetts - Lowell, Boston College, Space Telescope Science Institute, Baltimore, MD, University of North Carolina, Chapel Hill

#### **146.25 - GLUV: A balloon borne high cadence ultra violet survey telescope(Ryan Gordon Ridden-Harper)**

Transient astronomy is pushing towards shorter time domains to uncover the nature of short transients. Few high cadence telescopes operate at short near-ultraviolet wavelengths, due to the atmospheric opacity at short wavelengths, which may lead to key transient phenomena being overlooked. Key examples are the early time shock interactions of SNIa, shock breakouts of SNII and early ultraviolet emission from gravitational wave counterparts. The GLUV instrument, under development at the Australian National University, is a high altitude balloon based ultraviolet survey telescope, designed with the purpose of detecting short duration transients in the near-ultraviolet. We will present the instrument design and expected rates of SNIa shock interactions and gravitational wave counterparts.

**Author(s):** Brad Tucker, Ryan Gordon Ridden-Harper, Shanae King, James Gilbert, Rob Sharp

**Institution(s):** Australian National University Contributing Team(s): GLUV Collaboration

#### **146.26 - CHARA Remote Operations and Archiving(Jeremy Jones)**

The CHARA Array is a six-telescope interferometer that provides sub-milliarcsecond resolution in the optical and near-infrared. The Array enables a variety of scientific studies, including measuring stellar angular diameters, imaging stellar shapes and surface features, mapping the orbits of close binary companions, and resolving circumstellar environments. We recently implemented a new remote observing system that allows the Array to be operated from anywhere with an internet connection. The new system has been used successfully for all of the Array's beam combiners. In addition to allowing remote observing, this system also allows those PIs who are not taking their own observations to watch as their data are collected. In addition to the remote observing system, we highlight the progress we have made in our data archive, public database, and remote data reduction system. These are all part of a larger effort to provide open access to the CHARA Array to the broader astronomical community.

**Author(s):** Christopher Farrington, Douglas Gies, Jeremy Jones, Theo ten Brummelaar, Gail Schaefer

**Institution(s):** GSU/CHARA

#### **146.27 - Key Science Mission for the Magdalena Ridge Observatory Interferometer(Michelle J. Creech-Eakman)**

The Magdalena Ridge Observatory Interferometer (MROI) is an ambitious project to deploy a 10-telescope optical/near-infrared interferometer capable of imaging statistical samples of galactic and extra-galactic objects with sub-milliarcsecond resolution and sensitivities several magnitudes deeper than feasible today. In 2018 first-light with the first telescope was achieved, and

having placed the order for the second telescope and associated infrastructure, we are poised to realize the milestone of first-fringes in 2020. Funding for the MROI facility is presently via an agreement between the Air Force Research Lab (AFRL) and the New Mexico Institute of Mining and Technology (NMT) to demonstrate operational capabilities and risk reduction experiments for studying geosynchronous objects with three telescopes. In the early 2000's a key science mission was developed in order to design and deploy the complete facility. In the interim, tremendous progress has been made in astrophysical observations, modeling of phenomena, and theoretical studies in many of these arenas. We present the major elements of our key science mission, grouped into three broad categories: A) the environs of Active Galactic Nuclei, B) star and planet formation, and C) fundamental stellar physical phenomena in time-resolved studies, pulsation/rotation, mass-loss and interactions between binary/hierarchical systems. Additionally, science related to: D) solar system objects, and E) human-made geosynchronous objects will be reviewed. Even in the earliest stages of MROI's operations new science will be possible with only two telescopes owing to our greater sensitivity and reconfigurable array. As more telescopes are deployed imaging will rapidly become feasible, at 4 telescopes, and will surpass currently existing facilities when 7 telescopes are operational. We anticipate making MROI available to the astrophysical community once operational status is achieved and encourage early inquiries into capabilities and ideas for new observations with the facility. We wish to acknowledge our funding through Cooperative Agreement (FA9453-15-2-0086) between AFRL and NMT.

**Author(s):** David Buscher, Michelle J. Creech-Eakman, John Young, Chris Haniff

**Institution(s):** New Mexico Inst of Mining and Technology., University of Cambridge, Magdalena Ridge Observatory Interferometer Contributing Team(s): MROI Team

#### **146.28 - Making Fuzzy Clear: toward sub-millimagnitude precision at the Thacher Observatory.(Piper Stacey)**

Attaining sustained sub-millimagnitude photometric precision on small, altitude-azimuth (Alt-Az) telescopes presents a variety of challenges. The changing parallactic angle of sources results in a changing orientation of the telescope optics with respect to the camera. This, in turn, can result in a flat field that is a function of camera orientation due to, for example, vignetting. To address this issue we have furthered our work employing both a near and far field flat to calibrate non-uniform illumination of the CCD, and we present on-sky demonstrations of the measured improvement in photometric accuracy and precision. In addition, we have added the option of using two different diffusers to the optical path of our system which allows us to spread the light from targets over 1-2 orders of magnitude more pixels than a focused image thereby reducing the Poisson noise accordingly. We demonstrate the performance of the diffusers with observations of bright stars with transiting exoplanets.

**Author(s):** Piper Stacey, David Rowe, Colin Poole Kirkpatrick, Jon Swift

**Institution(s):** The Thacher School, Plane Wave Instruments

#### **147 - Large Efforts in Education & Public Outreach Posters**

##### **147.01 - Messaging in Public Science Education and Outreach(Douglas Arion)**

Many outreach and education programs do a good job of showing people celestial wonders, and wowing them with information and the mind-boggling scale of the cosmos. However, outreach and education should best be utilized to motivate public participants to change or adopt behaviors and attitudes as a result of the interaction. Doing so requires that the outreach and education activity be based on messaging. In the Mountains of Stars and Presidential Stargazing outreach and education programs, conducted through a partnership among Carthage College, the Appalachian Mountain Club, Dartmouth College, Smith College, and Stony Brook University, messaging has been an essential component, and has been built into the training programs for student astronomy guides and others involved in program delivery. In this effort, the goal is to restructure participants attitudes and actions towards the environment by using a 'cosmic perspective'. The program has been successful in doing is - and in mentoring undergraduate physics and astronomy students in science communication skills. This presentation will summarize the messaging utilized in the program, as well as the methods that are employed to train those engaged in outreach. This work has been supported in part by the National Science Foundation through grant number 1625316, the Gordon and Betty Moore Foundation, Toomey Foundation, and VWR Foundation.

**Author(s):** Douglas Arion

**Institution(s):** Carthage College

##### **147.02 - Astronomy in Chile Educator Ambassadors Program (ACEAP)(Timothy Spuck)**

The Astronomy in Chile Educator Ambassadors Program (ACEAP) is a collaboration between AUI, the National Radio Astronomy Observatory, AURA, National Optical Astronomy Observatory, and Gemini Observatory, and is supported by the National Science Foundation (NSF 1439408 and 1723697). The Program brings amateur astronomers, planetarium personnel, and K-16 formal and informal astronomy educators to US astronomy facilities in Chile. While at these facilities, ACEAP Ambassadors receive extensive training about the instruments, the science, data products, and communicating science, technology, engineering, and mathematics (STEM) concepts. When they return home, the Ambassadors share their experiences and observatory resources with schools and community groups across the US through a variety of outreach activities. Through these outreach activities, on average, ACEAP ambassadors reach approximately 400,000 people annually.

**Author(s):** Charles Blue, Timothy Spuck

**Institution(s):** Associated Universities Inc., NRAO

**147.03 - Multicultural Milky Way: Ethnoastronomy and Planetarium Shows for Under-served Arizonans(Karen Knierman)**

The astronomy outreach initiative, Multicultural Milky Way, partners the School of Earth and Space Exploration (SESE) at Arizona State University with under-served populations in Arizona in learning about our Milky Way and other galaxies. Arizona is home to many diverse populations with rich cultural histories such as Maya, Navajo, and Apache. Linking astronomy practiced by one's indigenous culture to that of Western astronomy may increase the interest in science. Through multicultural planetarium shows and associated hands-on activities, under-served students and families will learn how the Milky Way is represented in different cultures and about the science of galaxies. New planetarium shows using the Mesa Community College Digital Planetarium and STARLAB portable planetarium explore how the Milky Way is interpreted in different cultures. STARLAB shows and associated new hands-on activities have been featured during school visits, teacher trainings, and Community Astronomy Nights around Arizona. A website with resources including scripts and activities will be presented. For authentic assessment, evaluation techniques and procedures were developed.

**Author(s):** Karen Knierman

**Institution(s):** Arizona State University

**147.04 - The West Virginia Science Public Outreach Team(Ronald Maddalena)**

The West Virginia Science Public Outreach Team (WV SPOT) recruits and trains WV undergraduates and graduate students in giving highly interactive presentations on current topics in engineering, science, and technology to K-12 classrooms, as well as museums and youth programs. Our Mission is to inspire an appreciation of STEM and STEM careers in the youth of WV through presentations that highlight the innovative research that is occurring in the Mountain State, the Observatory, and NASA. The college 'Ambassadors', recruited from any WV college or university, receive training in how to use slides, videos, and animations to relay the excitement of new discoveries. Our team develops each module to make sure it aligns with the state's science content standards. The K-12 students increase their confidence with STEM topics while being exposed to college STEM role models. Large portions of the K-12 students come from rural, low-income communities and represent potential first-generation college-goers. Ambassadors also gain from their experiences -- they see improvements in their science communication and public speaking skills; they increase their science content knowledge while also improving their resume and networking opportunities. Since 2013, we have delivered nearly 600 presentations to over 200 schools and impacted the lives of

over 19,000 K-12 students. The program was adapted from a similarly named program that originated at Montana State University, funded by that state's NASA Space Grant Consortium. The WV SPOT program started as a partnership in 2013 between the Green Bank Observatory and NASA. Currently, the program receives support from the Observatory, NASA WV Space Grant Consortium, DOW Chemical Company, West Virginia University Physics, and NSF-EPSCoR. Additionally, STEM faculty with NSF or NASA grants are using SPOT as part of their broader impact. States like Georgia are interested in starting similar programs.

**Author(s):** Ronald Maddalena, Sophie Knudsen, Sue Ann Heatherly, Kathryn Williamson

**Institution(s):** Green Bank Observatory, West Virginia University

**147.05 - A Journey to Mars: HPUniverse Day and Its Impact on Young Minds and a Community(Kyle A Corcoran)**

Once every fall semester, the High Point University Department of Physics hosts an astronomy-themed public outreach event called HPUniverse Day. More than one hundred faculty and students come together to expose local kids and their families to space, science, and beyond through twenty different discovery stations. Examples include hovercraft rides, water-bottle rockets, virtual reality demonstrations, the fabric of spacetime, and many other experiments. In order to keep the event from feeling stagnant, we invoked a new cohesive theme this year that took advantage of mainstream discussions about the colonization of Mars and its recent 2018 opposition. Upon arriving to HPUniverse Day, visitors were greeted as if they were cadets arriving for mission training for their "Journey to Mars." The newly enlisted cadets started at the World of Physics station where they learned about basic physics that could help them later in their training. Next the cadets listened to informational seminars on the environment of Mars, equipment to help during their tenure on the planet, and techniques to ease their interplanetary travel. Volunteers demonstrated how to use thermal and high-speed cameras, taught about relativity and methods for exoplanet discovery, and modulated standing waves in a Reubens' tube. Volunteers from the biology, chemistry, and education departments then provided insight into searching for and analyzing life on Mars as well as using robotic technologies for conducting research and building a colony. Getting closer to their final goal, the cadets conducted test launches with water-bottle rockets and blasted off to Mars. Finally, the cadets navigated across the surface of Mars using hovercrafts designed by students and faculty. HPUniverse Day enhances the collaborative nature of our physics department, while also strengthening the bond between our university and the surrounding community.

**Author(s):** Stephen Walser, Nolan Roth, Brad Barlow, Michael Welter, Kyle A Corcoran, Erin Brady, Thomas Macaulay Boudreaux

**Institution(s):** High Point University

#### **147.06 - NANOGrav Space Public Outreach Team (SPOT)(Joey Shapiro Key)**

The North American Nanohertz Observatory for Gravitational waves (NANOGrav) Space Public Outreach Team (SPOT) is a nationwide network of undergraduate and graduate students trained to bring presentations about current discoveries in astronomy to K-12 schools and community groups. The Tuning Into Einstein's Universe presentation introduces black holes, pulsars, gravitational waves, and pulsar timing arrays. The goal of SPOT is to inspire student interest in astronomy and STEM, including providing hands-on activities and classroom materials, following the SPOT model established by Montana State University. Highlights from the NANOGrav SPOT program include weekly collaboration with the US Space & Rocket Center's Space Camp and a nationwide reach through the NANOGrav collaboration. Program data collected from presenters and teachers demonstrates the overall impact of the program.

**Author(s):** Joey Shapiro Key, Jessica Page, Tyson Littenberg

**Institution(s):** University of Washington Bothell, University of Alabama Huntsville, NASA Marshall Space Flight Center  
**Contributing Team(s):** NANOGrav Physics Frontiers Center

#### **147.07 - LSST: Education and Public Outreach(Amanda Bauer)**

The Large Synoptic Survey Telescope (LSST) will conduct a 10-year wide, fast, and deep survey of the night sky, and will have a unique EPO program that will go live when the telescope starts operating in late 2022. EPO will enable public access to a subset of LSST data so anyone can explore the universe and be part of the discovery process. In this poster I will present major components of the EPO program, including online notebooks that will enable educators to provide LSST data in their classrooms without needing to download and maintain software or data files, an interactive Skyviewer, original multimedia for informal science centers and planetariums, and citizen science projects that use LSST data. LSST EPO will engage with the Chilean community through Spanish-language versions of all programming.

**Author(s):** Amanda Bauer

**Institution(s):** LSST/AURA  
**Contributing Team(s):** LSST Education and Public Outreach Team

#### **147.08 - The Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC)(Christina Peters)**

PLAsTiCC was a data challenge on the Kaggle platform designed to engage those outside the astronomical community with LSST-like data and develop new techniques to address the problem of photometric classification. We summarize the development and validation of the PLAsTiCC data, hosting a challenge on the public platform Kaggle, and developing a

metric to determine the winning entry. We also describe the challenges of making an astronomical problem accessible to the broader community and taking the new techniques developed by participants in the challenge and comparing them to existing methods in astronomy.

**Author(s):** Christina Peters,

**Institution(s):** University of Toronto, University of Toronto  
**Contributing Team(s):** The LSST PLAsTiCC Collaboration, The LSST Dark Energy Science Collaboration, The LSST Transients and Variable Stars Science Collaboration

#### **147.09 - Dark Skies, Bright Kids! - Year 10(Molly Finn)**

We present updates from our tenth year of operation including new club content, continued assessments, and our eighth annual Star Party. Dark Skies, Bright Kids (DSBK) is a graduate student lead outreach organization based out of the Department of Astronomy at the University of Virginia. Our core mission is to enhance elementary science education and literacy in Central Virginia through fun, hands-on activities that introduce basic Astronomy concepts. The fundamental program of DSBK is an 8-10 week long after-school Astronomy camp at surrounding elementary schools, where each week introduces new concepts through interactive hands-on activities. Over the past three summers, we have traveled to four rural Virginia locations to bring week-long Astronomy camps to otherwise overlooked elementary school districts. These programs aim to inspire a curiosity for science and include inquiry based activities in topics ranging from the electromagnetic spectrum to the classification and evolution of galaxies. We strive to be self-reflective in our mission to inspire scientific curiosity in the minds of underserved demographics. In this effort, we continually assess the effectiveness of each activity through feedback in student-kept journal pages and observed excitement levels. This self-reflection has led to the development of new curriculum. In addition, differing from our normal collaboration with local elementary schools, we have found great success partnering with local youth organizations, who may better represent target demographics and have infrastructure to support incoming outreach groups.

**Author(s):** Jacqueline Villadsen, Christian R Hayes, Matthew Pryal, Robert Forrest Wilson, Sandra E Liss, Andrew Taylor, Luca Beale, Zhe-Yu Lin, Xiaoshan Huang, Danielle Hancock, Whitney Richardson, Mengyao Liu, Brian Eisner, Richard Seifert, Eryn Cohen, Yiqing Song,

**Institution(s):** University of Virginia, National Radio Astronomy Observatory

#### **147.10 - Girl Scout Space Science Badges for Daisies, Brownies and Juniors(Pamela Harman)**

Reaching for the Stars: NASA Science for Girl Scouts (Girl Scout Stars) engages Girl Scouts in NASA astrophysics and planetary science through badge programs and summer camps, disseminates STEM education-related resources, and fosters

interaction between Girl Scouts and Subject Matter Experts (SMEs). Space science badges have been released for three levels of Girl Scouts: Daisies, Grades K-1; Brownies, Grades 2-3; and Juniors, Grades 4-5. Space science badges for Cadettes, Grades 6-8; Seniors, Grades 9-10; and Ambassadors, Grades 11-12 are scheduled for release next year. The badges consist of space science activities, identifying role models (SMEs), and opportunities for girls to share their findings and excitement with others. Badge steps capitalize on NASA resources available through the Sci Act Collective. In Girl Scouting, girls discover their skills, talents and what they care about; connect with others in their community; and take action to change the world. This is called the Girl Scout Leadership Experience (GSLE). With girl-led, hands-on activities where girls can team up and work together-they successfully achieve the five leadership outcomes: strong sense of self, positive values, challenge seeking, healthy relationships, and community problem solving. When girls exhibit these attitudes and skills, they become responsible, productive, caring, and engaged citizens. The badges' activities are aligned with these principles. This session will highlight the evaluation indicators of success, the badge activities, how SMEs can connect with their local Girl Scout council or troop. Funded by NASA: NNX16AB90A.

**Author(s):** Pamela Harman, Jessica Henricks, Don McCarthy, Elspeth Kersh, Wendy Chin, Wendy Friedman, Vivian White, Larry Lebofsky, Louis Mayo, Jean Fahy, Theresa Summer, Cole Grissom

**Institution(s):** SETI Institute, Girl Scouts Research Institute, Girl Scouts USA, ARIES Scientific, University of Arizona, Astronomical Society of the Pacific, Girl Scouts of Northern California

#### **147.11 - CosmoQuest: Streaming Science(Patrick R. Durrell)**

As an online-based research facility, CosmoQuest endeavors not only to engage our digital community in the research projects that we offer, but also to disseminate the knowledge and resources that we have at our disposal. Online streaming media platforms such as Twitch and YouTube allow us to have intriguing science conversations with the greater internet community, as we promote our projects while also developing personal relationships with the members of our online research community that support our science investigations. In this presentation, we discuss the methods we use to stream, and highlight the educational streaming activities that CosmoQuest offers.

**Author(s):** Patrick R. Durrell, Nancy J. Graziano, Susie Murph, Joseph L. Myers, Pamela Gay, Annie Wilson, Matthew Richardson,

**Institution(s):** Youngstown State University, Astronomical Society of the Pacific/CosmoQuest, CosmoQuest, SIUE, Planetary Science Institute  
**Contributing Team(s):** CosmoQuest Team

#### **147.12 - Sonification of Transient Lightcurves: Supernovae Case Studies(Locke Patton)**

While detailed analyses and spectroscopic follow-up of transient events requires professional experience and access to observing facilities, lightcurve classification - distinguishing between several subtypes of supernovae, or identifying different classes of variable stars - can be accomplished by citizen scientists through template matching and comparisons. In a first for citizen science astronomy, we're moving beyond visual inspection analysis to the sonification of lightcurve data for classification by public volunteers on Zooniverse. Our approach to sonification maps each magnitude data point to a corresponding audible frequency, producing audio files that depict magnitude variations as perceptually uniform changes in pitch through time. Using this method, auditory classification can be applied to lightcurves that vary by up to  $\Delta m = 1.47$  magnitudes, encompassing most known lightcurves for variable stars, supernovae, and other transient events such as LBV eruptions, while allowing the listener to perceive a minimum difference of  $\Delta m = 0.02$  mags. We present the successfully sonified audio light curves of a collection of transient phenomena, including a large and diverse sample of supernova lightcurves and test cases for RR Lyrae, LBVs, and short- and long-period eclipsing binaries. We demonstrate that linear and plateau supernova light curves can be audibly differentiated. This approach offers a new method for lightcurve classification and, for the first time, opens citizen science astronomy to participants who are visually impaired. TransientZoo will be launched in the next few years on Zooniverse and will ultimately be optimized and scaled for use with LSST.

**Author(s):** Emily Levesque, Locke Patton,

**Institution(s):** University of Washington, Harvard-Smithsonian Center for Astrophysics

#### **148 - LUVOIR -- Posters**

##### **148.01 - Observing the Solar System with LUVOIR: high angular resolution with a segmented aperture(Shawn David Domagal-Goldman)**

LUVOIR (Large UV Optical Infrared telescope) is a concept for a large multi-wavelength observatory, which would enable transformative advances across a broad range of astrophysics. Two architectures are being studied: LUVOIR-A (15-m) and LUVOIR-B (8-m). The High Definition Imager (HDI) instrument is the primary astronomical imaging instrument for observations in the near UV through the near IR. The HDI design provides a  $2 \times 3$  arcminute field-of-view, taking full advantage of the angular resolution provided by the telescope, and consists of two channels - UVIS (200 nm - 950 nm) and NIR (800 nm - 2500 nm). HDI would enable orbiter- and flyby-quality observations of many solar system bodies, both large and small. For instance, Pluto, which has a spatially heterogeneous surface, can be spatially and spectrally characterized with LUVOIR. LUVOIR could also obtain images of Jupiter with resolution comparable to the JUNO orbiter, and it could perform long-term monitoring of many outer solar

system bodies that have not been visited by spacecraft in recent decades (e.g. Uranus, Neptune) at high spatial resolution. In this poster we will present simulations of observations of Solar System bodies with the LUVOIR-A and LUVOIR-B instruments, and compare them with past, present and future space telescopes, from real and simulated observations.

**Author(s):** Roser Juanola-Parramon, Shawn David Domagal-Goldman, Giada Arney, Aki Roberge

**Institution(s):** NASA Goddard Space Flight Center, University of Maryland Baltimore County  
**Contributing Team(s):** The LUVOIR Team

#### **148.02 - Telling the Story of Life in the Cosmos: Overview of the LUVOIR Space Observatory Concepts(Aki Roberge)**

The Large UV/Optical/Infrared Surveyor (LUVOIR) is a concept for a powerful general-purpose observatory spanning the far-UV to the near-infrared. A major goal for LUVOIR is characterizing a wide range of exoplanets with direct images and spectra, including rocky Earth-sized planets in the habitable zones of solar-type stars. These data will allow a diverse set of investigations, including analysis of terrestrial planet atmospheres, explorations of planet surfaces, discovery of potentially habitable exoplanets, and searches for evidence of global biospheres. A key objective is to conduct these studies on a set of candidate habitable exoplanets large enough to constrain the frequency of habitable conditions (dozens of rocky planets orbiting solar-type stars). LUVOIR would simultaneously enable a great leap forward in a broad range of astrophysics - from the epoch of reionization, through galaxy formation and evolution, to star and planet formation. Powerful remote sensing observations of Solar System bodies will also be possible. Here we provide a high-level overview of the LUVOIR mission science goals and current observatory architectures. Two variants are being designed in preparation for the Astro2020 Decadal Survey. LUVOIR-A features a 15-m diameter on-axis primary mirror and LUVOIR-B has an 8-m off-axis primary mirror. Four candidate instruments are being studied: 1) a NUV to NIR high-performance coronagraph (ECLIPS), 2) a wide-field NUV to NIR imaging camera (HDI), 3) a FUV to optical multi-resolution, multi-object spectrograph (LUMOS), and 4) a high-resolution UV spectropolarimeter (POLLUX). Finally, perhaps LUVOIR's most important scientific capability is its ability to address the science questions of the 2040s and beyond that astronomers have not yet thought to ask.

**Author(s):** Debra Fischer, Bradley Peterson, Aki Roberge

**Institution(s):** NASA Goddard Space Flight Center, Ohio State University, Yale University  
**Contributing Team(s):** LUVOIR Mission Concept Study Team

#### **148.03 - LUVOIR: Probing the Epoch of Reionization and Constraining Dark Matter(Marc Postman)**

In the 2020s, we will use new telescopes to make significant inroads in understanding the cosmic "dark sector" and the properties of galaxy building blocks in the early universe. Yet these telescopes will not break beyond a specific frontier that we recognize as critical for a comprehensive understanding of structure formation. This frontier exists at the lowest mass scales (stellar masses  $\sim 10^6$  MSUN), from the first sparks of galaxy formation at  $z > 10$  to dwarf galaxies in the present day. At these size and mass scales, competing scenarios for the evolution of the dark matter density field, and its associated baryonic structures, make predictions that can be tested with observations that reach to AB = 33.5 mag. The Large UV-Optical-IR (LUVOIR) space observatory will be capable of resolving 60 parsec scales at all redshifts while reaching a 5-sigma point source limiting AB magnitude of 33 (0.23 nJy) in 10 hours and  $\sim 35$  mag (0.04 nJy) in  $\sim 10$  days. We summarize the signature science that LUVOIR can accomplish in two novel regimes: The dark matter (DM) power spectrum on scales below 100 kpc: Between the universe's horizon scale and galactic scales, the structure we measure is consistent with DM being entirely non-relativistic and non-interacting. The imprint of DM microphysics, however, manifests at scales below 100 kpc (corresponding to halos of a few million solar masses) in the statistics and shapes of these small-scale structures as functions of size and mass over cosmic time. We show how deep LUVOIR surveys around local dwarf galaxies can constrain the mass fluctuation power spectrum and distinguish between interacting DM, WDM, and CDM models. The low-mass limits of galaxy assembly: the steepening of the faint end slope of the UV luminosity function cannot continue to indefinitely faint limits - there must be a turnover or cutoff. As such, the behavior of the luminosity function at the faint end should reveal the degree to which faint galaxies powered cosmic reionization. Ultra deep field observations, achievable only with LUVOIR, can test competing scenarios for how reionization impacts the growth of the low mass end of the galaxy distribution.

**Author(s):** John O'Meara, Jane Rigby, Marc Postman, Stephen McCandliss, Leonidas Moustakas, Steven Finkelstein  
**Institution(s):** Space Telescope Science Institute, StMichael's College, Jet Propulsion Laboratory, Johns Hopkins University, University of Texas, NASA Goddard Space Flight Center  
**Contributing Team(s):** LUVOIR Science and Technology Definition Team

#### **148.04 - LUVOIR: Galactic Star Formation and Gas Flows with a Revolutionary UV Capability(Jason Tumlinson)**

We demonstrate the power of UV multi-object spectroscopy with the Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR) and its LUMOS instrument. LUMOS will deploy hundreds of thousands of individually configurable 0.25" shutters over a 2x3 arcmin field of view. LUMOS can cover wavelengths between 1000-3000Å resolution at spectral resolution up to  $R \sim 30,000$  and effective area up to 30 times larger than Hubble's COS, while observing 100 or more objects simultaneously. This poster demonstrates some of the compelling applications of this



capability to star formation, the interstellar medium, and circumgalactic gas flows in nearby and distant galaxies.

**Author(s):** Kevin France, John O'Meara, Jason Tumlinson

**Institution(s):** Space Telescope Science Institute, University of Colorado, Saint Michael's College  
**Contributing Team(s):** the LUVOIR Team

#### **148.05 - The LUVOIR Mission Concept: Technologies to Enable the Next Great Observatory(Matthew Bolcar)**

The Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR) is one of four mission concepts being studied by NASA for the 2020 Decadal Survey in Astronomy and Astrophysics. LUVOIR will be capable of a broad range of science, including: direct imaging and characterization of a wide range of exoplanets and the search for biosignatures on Earth-like planets around sun-like stars; studying galaxy formation and evolution; investigating star and planet formation; and remote sensing of bodies within the Solar System. Enabling a mission as ambitious as LUVOIR requires an array of technologies, such as ultra-stable structures and optics, precision metrology and wavefront sensing, high-contrast imaging techniques, large-format detectors with very low noise, and high-throughput ultraviolet instrumentation. Critically, a systems-level approach must be taken to developing these technologies, guided by architecture studies to place each technology in the appropriate system context. In this poster, we describe LUVOIR's technology needs, as well as current efforts that are actively developing these technologies. We will discuss recent advancements in: measuring picometer-level displacements of optical and structural elements- sub-milli-kelvin thermal sensing and control- non-contact vibration isolation for pointing and dynamic stability- coronagraph design for achieving 10<sup>-10</sup> contrast on a segmented system- high-speed metrology for optical system alignment- low-order and out-of-band wavefront sensing for maintaining high-contrast images- low-noise detectors across the ultraviolet, optical, and near infrared bands- broadband coatings with high-reflectivity below Ly- $\alpha$ . We will also describe a systems approach to coordinating the development of these technologies to achieve the necessary maturity for a LUVOIR mission start in the next decade.

**Author(s):** Manuel Quijada, Sang Park, Garreth Ruane, Aki Roberge, J. Scott Knight, Kevin France, Matthew Bolcar, William Hayden, Lee Feinberg, Bernard Rauscher, Larry Dewell, Laurent Pueyo, David Redding, Julie Crooke, Babak Saif, Neil T. Zimmerman

**Institution(s):** NASA Goddard Space Flight Center, LASP, University of Colorado - Boulder, Lockheed Martin Space, Advanced Technology Center, Harvard Smithsonian Center for Astrophysics, Ball Aerospace & Technologies, NASA JPL, Space Telescope Science Institute Cont

#### **148.06 - Evaluating the LUVOIR Coronagraph Sensitivity to Telescope Aberrations(Roser Juanola-Parramon)**

Direct imaging of exoplanets in their habitable zone is extremely challenging due to two main factors: the proximity of the planet to the parent star and the flux ratio between the planet and the parent star, usually on the order of 10<sup>-10</sup> in the visible. The LUVOIR space observatory concept uses a large, segmented primary mirror (8-15 meters in diameter) paired with a high-performance coronagraph to meet its scientific objectives. The Extreme Coronagraph for Living Planet Systems (ECLIPS) is the coronagraph instrument on the LUVOIR Surveyor mission concept. It is split into three channels: UV (200 to 400 nm), optical (400 nm to 850 nm), and NIR (850 nm to 2.0 microns), with each channel equipped with two deformable mirrors for wavefront control, a suite of coronagraph masks, a low-order/out-of-band wavefront sensor, and separate science imagers and spectrographs. The Apodized Pupil Lyot Coronagraph (APLC) is one of the mask technologies baselined to enable 10<sup>-10</sup> contrast observations in the habitable zones of nearby Sun-like stars. For the LUVOIR observatory architecture, the coronagraph performance depends on active wavefront sensing and control, as well as metrology subsystems to compensate for errors in segment alignment, secondary mirror alignment, and global low-order wavefront errors. Here we present the latest simulations of these effects for different working angle regions and discuss the achieved contrast for exoplanet detection and characterization under these circumstances. Finally, we show simulated observations using high-fidelity spatial and spectral input models of complete planetary systems generated with the Haystacks code framework, setting boundaries for tolerance of such errors.

**Author(s):** Roser Juanola-Parramon, Maxime Rizzo, Matthew Bolcar, Laurent Pueyo, Aki Roberge, Tyler Groff, Neil T. Zimmerman

**Institution(s):** NASA Goddard Space Flight Center, STScI

#### **148.07 - Probing the cosmos with POLLUX on LUVOIR: the power of high-resolution UV spectropolarimetry(Jean-Claude Bouret)**

POLLUX is a high-resolution, UV spectropolarimeter proposed for the 15-meter primary mirror option of LUVOIR. The instrument study is supported by the French Space Agency (CNES) and performed by a consortium of European scientists. POLLUX will operate over a broad spectral range (90 to 400 nm), at high spectral resolution ( $R \geq 120,000$ ), with a unique spectropolarimetric capability. It is designed to address a range of questions at the core of the LUVOIR Science portfolio. POLLUX' high resolution will permit to resolve narrow UV emission and absorption lines, thus to follow the baryon cycle over cosmic time, from galaxies forming stars out of interstellar gas and grains, and stars forming planets, to the various forms of feedback into the interstellar and intergalactic medium (ISM and IGM), and active galactic nuclei (AGN). The

most innovative characteristic of POLLUX is its unique spectropolarimetric capability, that will enable detection of the polarized light reflected from exoplanets or from their circumplanetary material, and moons, and characterization of the magnetospheres of stars and planets, and their interactions. The magnetospheric properties of planets in the solar system will be accessible to exquisite level of details, while the influence of magnetic fields at the galactic scale and in the IGM will be measured. Circular and linear polarisation in the UV will provide a full picture of magnetic field properties, and impact for a variety of media and objects, from AGN outflows to all types of stars. It will probe the physics of accretion disks around young stars and white dwarfs, or supermassive black holes in AGNs, and constrain the properties, especially sphericity, of stellar ejecta and explosions. In this poster, we introduce the science case of POLLUX, and outline its potential for ground-breaking discoveries.

**Author(s):** Jean-Claude Bouret, Luca Fossati, Chris Evans, Vianney Lebouteiller, Jean-Yves Chaufray, Ana I. G3mez de Castro, Steve Shoreo, Frédéric Marin, Coralie Neiner, Cécile Gry, Boris Gaensicke, Pasquier Noterdaeme

**Institution(s):** AIM, CEA, CNRS, Université Paris-Saclay, Université Paris Diderot, Sorbonne Paris Cité, oDipartimento di Fisica "Enrico Fermi" Università di Pisa, Aix Marseille Univ, CNRS, CNES, LAM, Space Research Institute, Austrian Academy of Sciences, LESIA, Observ

#### **148.08 - The Search for Exo-Earths and Biosignatures with the LUVOIR Mission Concept(Giada Arney)**

The Large Ultra Violet-Optical-Infrared (LUVOIR) Surveyor is one of four mission concepts being studied by NASA in preparation for the 2020 Astrophysics Decadal Survey. LUVOIR is a general-purpose space-based observatory with a large aperture in the 8-15 m range and a total bandpass spanning from the far-ultra violet to the near-infrared. One of LUVOIR's main science objectives is to directly image temperate Earth-sized planets in the habitable zones of sunlike stars, measure their spectra, analyze the chemistry of their atmospheres, and obtain information about their surfaces. This direct imaging of exoplanets is enabled by LUVOIR's Extreme Coronagraph for Living Planet Systems (ECLIPS). LUVOIR can also observing potentially habitable exoplanets transiting nearby M dwarf stars. Such observations will allow us to evaluate these worlds' potential for habitability and search for the presence of remotely detectable signs of life known as "biosignatures." We will discuss the strategies for Exo-Earth detection and characterization, including specific observational requirements for astrobiological assessments of exoplanetary environments with LUVOIR. The survey of the atmospheric composition of dozens of potentially habitable worlds would bring about a revolution in our understanding of planetary formation and evolution, and may usher in a new era of comparative astrobiology.

**Author(s):** Giada Arney

**Institution(s):** NASA Goddard Space Flight Center

Contributing Team(s): The LUVOIR Team

#### **148.09 - POLLUX, an innovative instrument providing a unique UV spectropolarimetric capability to LUVOIR(Marc Ferrari)**

The Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR) is one of four large mission concept studies led by NASA for the 2020 Decadal Survey. Under the leadership of French Institutes and French Space Agency, European institutes have come together to propose an instrument, POLLUX, that would be onboard the 15-meter primary mirror option of LUVOIR. POLLUX will operate over a broad spectral range (90 to 400 nm), at high spectral resolution ( $R \geq 120,000$ ), with a unique spectropolarimetric capability. It is designed to address a range of questions at the core of the LUVOIR Science portfolio. The working range is split into 3 channels: Far (90-125 nm), Medium (119-200 nm), and Near (200-400 nm) ultraviolet. MUV and NUV channel, separated by a dichroic splitter, can be recorded simultaneously. The FUV channel is recorded separately (temporal separation), using a dedicated flip-mirror. The coatings on the optical elements of POLLUX are optimized for each channel, to maximize the throughput. Each channel will include an optimized echelle spectrograph integrating advanced technologies, i.e. high groove densities, holographic recording on a freeform surface for the cross-dispersors, etc. The polarimeters design were optimized for each channel accounting for the technological feasibility. They are retractable in the MUV and NUV to allow the pure spectroscopic mode. The FUV modulator is retractable while the analyzer is kept in the optical path to direct the beam towards the collimator. Detectors will be delta-doped EMCCDs, combining the linearity of CCDs with photon-counting ability, which is a key capability enabling detection of faint UV signals. Furthermore, these detectors deliver high quantum efficiency thus offering the possibility to reach very high signal-to-noise ratios. CMOS are also considered as a viable option in the development time-frame of POLLUX. The complete study will be included as a dedicated POLLUX chapter in the document presenting the final study of LUVOIR to the NASA decadal 2020 committee. In this poster, we present the instrument concept, as well as the challenges offered by the development of POLLUX.

**Author(s):** Maelle Le Gal, Jean-Claude Bouret, Eduard Muslimov, Marc Ferrari, Arturo Lopez Ariste, Coralie Neiner

**Institution(s):** Aix-Marseille Univ / CNRS / CNES, IRAP - CNRS UMR 577, LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne University, UPMC Univ Paris 06, Univ Paris Diderot

#### **148.10 - The Composition and Distribution of Protoplanetary Material at $r < 10$ AU: from Hubble to LUVOIR(Kevin France)**

Ultraviolet spectroscopy is a powerful tool for observing molecular gas in the inner regions of planet-forming disks as strong electronic band systems of H<sub>2</sub>, CO, H<sub>2</sub>O, and OH reside in the 100 - 320 nm bandpass. Fluorescent H<sub>2</sub> spectra are sensitive to trace amounts of gas, making them extremely useful probes of radial distribution of circumstellar material at  $r < 10$  AU during the dissipation of the primordial disk. Absorption line spectroscopy through high-inclination disks is the only direct observational technique to characterize co-spatial populations of key molecules (e.g., CO, H<sub>2</sub>O, OH, etc.) with H<sub>2</sub>. High sensitivity UV absorption spectra offer unique access to absolute abundance and temperature measurements of the warm molecular layers of the disk, without relying on conversion factors or geometry-dependent model results. This poster will present a brief overview of the state-of-the-field in UV observational studies of protoplanetary environments and present a prospectus on the exciting observational possibilities offered by the Large/Ultraviolet/Optical/InfraRed (LUVOIR) Surveyor. We will describe the performance of the LUVOIR Ultraviolet Multi-Object Spectrograph (LUMOS) and present a signature science program to study various disk composition, disk structure, and protostellar mass accretion as a function of age and environment in Orion.

**Author(s):** Kevin France

**Institution(s):** University of Colorado Contributing Team(s): LUVOIR STDT, LUMOS Science and Instrument Team

#### **148.11 - Ionizing radiation detection capabilities of future far-UV missions from small to large(Stephan R McCandliss)**

NASA has commissioned the study of large and probe class missions with far-UV spectrographs that vary in effective area and instantaneous field-of-view. These include, the Large Ultraviolet Optical Infrared (LUVOIR), the Habitable Exoplanet Observatory (HabEx), and the Cosmic Evolution Through Ultraviolet Spectroscopy (CETUS) missions. In addition, NASA has recently selected a cube-sat for development named SPRITE (Supernova remnants, Proxies for Reionization, and Integrated Testbed Experiment). It seeks to address the key question of, "how do galaxies provide ionizing radiation to the intergalactic medium?"; a key question shared by the larger missions. Here we compare the relative capabilities of each mission for broadening our understanding of the relative contributions of star forming galaxies and active galactic nuclei to the problem of the emergence and sustenance of the metagalactic ionizing background that pervades the universe. Support for this work was mainly provided by NASA to the Johns Hopkins University through APRA grant NNX17AC26G.

**Author(s):** John O'Meara, Paul Scowen, Stephan R McCandliss, Kevin France, Brian Fleming, Sara Heap

**Institution(s):** Johns Hopkins University, University of

Colorado, Boulder, Center for Astrophysical Sciences, Arizona State University, Goddard Space Flight Center (emerita), WMKeck Observatory Contributing Team(s): LUVOIR, HabEx, CETUS, SPRITE

#### **148.12 - Transmission Spectroscopy of Exoplanets with LUVOIR(Eric Lopez)**

Transmission spectroscopy is one of our most powerful tools for characterizing exoplanet atmospheres and thanks to the recent launch of NASA's TESS mission we will soon have a large sample of planets around bright stars, ideally suited to this technique. With its unique combination of UV to NIR wavelength coverage and incredibly high S/N, LUVOIR would build upon the powerful legacy of Hubble and revolutionize our ability to characterize the atmospheres of a wide range of transiting exoplanets. At FUV wavelengths the LUVOIR Ultraviolet Multi Object Spectrograph (LUMOS) will obtain high S/N transmission spectra and high spectral resolution, allowing us to detect transiting planetary exospheres and constrain the physics of atmospheric escape. Meanwhile, using the UVIS channel on the High Definition Imager (HDI) instrument we can obtain high S/N spectra at  $\sim 500$  nm in the optical and NUV, which allow us to constrain the properties of clouds and search for absorption from alkali metals. Finally, with the NIR channel in HDI we will be able to detect molecular absorption and measure abundances for a wide range of species including H<sub>2</sub>O, CO<sub>2</sub>, and O<sub>2</sub>.

**Author(s):** Eric Lopez

**Institution(s):** NASA Goddard Space Flight Center Contributing Team(s): The LUVOIR Team

#### **148.13 - Comparative Planetary Science with the LUVOIR Mission Concept(Courtney Dressing)**

LUVOIR is powerful and flexible observatory designed to revolutionize our view of the universe. Operating at the Sun-Earth Lagrange 2 point, LUVOIR will gaze at the skies at far-UV to near-IR wavelengths, with a large aperture of 8-15 m and a sophisticated instrument suite: an ultra-high contrast coronagraph (ECLIPS); a high-resolution imager (HDI); a multi-resolution, multi-object UV spectrograph and imager (LUMOS); and a UV spectropolarimeter (POLLUX). LUVOIR will be capable of detecting and characterizing hundreds of planets orbiting nearby stars, simultaneously advancing the field of "comparative exoplanetology" and potentially discovering inhabited worlds. In addition to conducting searches for biosignatures in the atmospheres of potentially habitable planets, LUVOIR will probe the properties of planets with a wide range of radii and orbital separations. Direct imaging and spectroscopy with ECLIPS will enable a systematic investigation of system architectures and the diversity of exoplanet atmospheres. Many of the planets detected by LUVOIR will be new discoveries while the most massive worlds are likely to have previous mass measurements from Gaia or

radial velocity surveys. For newly discovered planets, astrometric observations with HDI or ground-based radial velocity observations will constrain planet masses, thereby creating a powerful data set for testing theories of planet formation, atmospheric evolution, photochemistry, and cloud processes.

**Author(s):** Courtney Dressing

**Institution(s):** University of California, Berkeley  
Contributing Team(s): The LUVUOIR Team

## **149 - NANOGrav -- Posters**

### **149.01 - The NANOGrav 11-year Data Set: Solar Wind Sounding Through Pulsar Timing(Dustin Madison)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has observed dozens of millisecond pulsars for over a decade. We have accrued a large collection of dispersion measure (DM) measurements sensitive to the total electron content between Earth and the pulsars at each observation. All lines of sight cross through the solar wind which produces correlated DM fluctuations in all pulsars. We develop and apply techniques for extracting the imprint of the solar wind from the full collection of DM measurements in the recently released NANOGrav 11-yr data set. We filter out long time scale DM fluctuations attributable to structure in the interstellar medium and carry out a simultaneous analysis of all pulsars in our sample that can differentiate the correlated signature of the wind from signals unique to individual lines of sight. When treating the solar wind as spherically symmetric and constant in time, we find the electron number density at 1~A.U. to be  $7.9 \pm 0.2 \text{ cm}^{-3}$ . Our data shows little evidence of long-term variation in the density of the wind. We argue that our techniques paired with a high cadence, low radio frequency observing campaign of near-ecliptic pulsars would be capable of mapping out large-scale latitudinal structure in the wind.

**Author(s):** James Cordes, Dustin Madison

**Institution(s):** Cornell University, West Virginia University  
Contributing Team(s): NANOGrav timing working group

### **149.02 - Searching for Planets Around Millisecond Pulsars(Erica Behrens)**

We search for extrasolar planets around millisecond pulsars (MSPs) using pulsar timing data and seek to determine the minimum detectable planetary masses as a function of orbital period. Using the 11-year data release from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), we look for variations from our models of pulse arrival times due to the presence of exoplanets. No planets were detected around the MSPs in the NANOGrav 11-year data set, but taking into consideration the noise levels specific to each pulsar as well as the sampling rate of our observations, we develop limits that suggest we are sensitive to planetary masses as low as those of the moon and even large asteroids.

**Author(s):** Dustin Madison, Scott M. Ransom, Erica Behrens

**Institution(s):** Ohio State University, West Virginia University, NRAO  
Contributing Team(s): The NANOGrav Collaboration

### **149.03 - The NANOGrav 11-year Dataset: Pulsar Timing Constraints on Gravitational Wave Memory(Paul T Baker)**

The merger of supermassive black hole binaries (SMBHB) promises to be an incredible source of gravitational waves (GW). While the oscillatory part of the gravitational waveform will be outside the frequency sensitivity range of pulsar timing arrays (PTA), the non-oscillatory GW memory effect is detectable. We searched the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) 11-year data set for GW memory from SMBHB mergers. Finding no evidence for GWs, we placed limits on the strain amplitude of GW memory passing the Earth or pulsars during the observation time. We then used the strain upper limits to place limits on the rate of SMBHB mergers.

**Author(s):** Paul T Baker

**Institution(s):** West Virginia University  
Contributing Team(s): NANOGrav Physics Frontiers Center

### **149.04 - A Second Chromatic Timing Event of Interstellar Origin toward PSR J1713+0747(T. Joseph W Lazio)**

The frequency dependence of radio pulse arrival times provides a probe of structures in the intervening media. We present observations of the pulsar PSR J1713+0747 from 2016 (approximately MJD 57510) in which a short-term (~ 100 day) reduction in the electron content along the line of sight is apparent. The reduced electron column is manifest by a pulse time arrival residual of approximately 0.5 microseconds (scaled to 1.4 GHz). This event is the \*second\* such event, following one identified by Demorest et al. in 2008 (approximately MJD 54750), with similar characteristics. A timing analysis indicates possible departures from the standard (frequency)<sup>-2</sup> dispersive-delay dependence expected from a cold plasma. We have considered whether these events could be due to independent structures, structures local to the pulsar, or plasma lensing. We find the most likely scenario to be lensing of the radio emission by a structure in the interstellar medium, which causes multiple frequency-dependent pulse arrival-time delays. The NANOGrav project receives support from NSF Physics Frontier Center award number 1430284. The Arecibo Observatory is operated by SRI International under a cooperative agreement with the NSF (AST-1100968), and in alliance with Ana G. M'endez-Universidad Metropolitana and the Universities Space Research Association. The National Radio Astronomy Observatory and the Green Bank Observatory are facilities of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Part of this research was carried out at the Jet Propulsion Laboratory,

California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

**Author(s):** Duncan Lorimer, Elizabeth Ferrara, H. Thankful Cromartie, Robert D Ferdman, Renee Spiewak, Jacob Turner, Justin Ellis, Paul Brook, Nathaniel Garver-Daniels, David Nice, Sarah Vigeland, Harsha Blumer, Timothy Dolch, Joe Swiggum, Scott M. Ransom, Emmanuel

**Institution(s):** University of British Columbia, oNational Radio Astronomy Observatory, McGill University, University of East Anglia, Green Bank Observatory, Swinburne University of Technology, Oberlin College, Eotvos Lorand University, Hillsdale College, Jet Propu

#### **149.05 - The NANOGrav STARS Program at Franklin and Marshall College(Fronefield Crawford)**

The NANOGrav Student Teams of Astrophysics ResearcherS (STARS) program engages teams of undergraduate students in pulsar and gravitational wave research. STARS members at Franklin and Marshall College use the Arecibo 305-m radio telescope to remotely conduct pulsar survey and timing observations in support of NANOGrav's search for low-frequency gravitational waves. This program also serves as an effective introduction to radio pulsar concepts and research practicalities for students who are just beginning their involvement in research. Leadership opportunities are provided through a team structure, and the program helps students develop critical presentation, organization, and speaking skills. Our poster provides some general background about the NANOGrav STARS program at Franklin and Marshall College and serves as a catalyst for in-person conversations and discussions at the poster about NANOGrav, pulsars, gravitational waves, and undergraduate student involvement in this research. This work is supported by the NANOGrav NSF Physics Frontiers Center award no. 1430284.

**Author(s):** Victoria Bonidie, Md Faisal Alam, Fronefield Crawford

**Institution(s):** Franklin and Marshall College

#### **149.06 - Investigating the evolution of binary supermassive black holes in ongoing galaxy merger 1015+364(Rodney D. Elliott)**

Successful detections of high-frequency gravitational waves from stellar-mass compact object mergers in recent years has ushered in a new and exciting era in astronomy. The next step on this journey is the detection of longer-period, nanohertz-scale continuous gravitational waves from binary supermassive black holes (SMBH) in the cores of galaxy merger remnants. According to the currently accepted model of galaxy formation, many such sources should exist. The method of detection for these low-frequency gravitational waves will be through the analysis of precision pulsar timing data collected from an array of millisecond pulsars over the course of several years. Here, we employ multimessenger astronomy techniques to investigate

the state of evolution of the binary SMBH that should reside---or have recently resided---in the ongoing galaxy merger 1015+364. Using optical and radio-wavelength observations, we conclude that the core of this merger remnant should contain at least one SMBH on the order of 108 solar masses. While we were not able to rule out the possibility that the binary may have recently coalesced, we were able to rule out the possibility that the smaller of the two SMBHs is still wandering far outside the core by comparing the estimated dynamical friction timescale of the binary with the relaxation timescale of the merger remnant. Using the constraints established by our analysis of available electromagnetic observations, we significantly reduced the parameter space required for a gravitational wave search of this system. To that end, we ran a targeted search of the 11-year pulsar timing dataset from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) in an attempt to place limits on the continuous gravitational waves from this object. Preliminary results reveal that the upper limit on the chirp mass of this binary is approximately  $7.7 \times 10^9$  solar masses.

**Author(s):** Caitlin Witt, Sarah Burke-Spolaor, Rodney D. Elliott

**Institution(s):** West Virginia University Contributing Team(s): NANOGrav Physics Frontiers Center

#### **149.07 - Arecibo pulsar scintillation results: implications for Pulsar Timing Arrays(Didier Banyeretse)**

In January 2018 we observed 10 intermediate-DM pulsars with the Arecibo radio telescope. The dispersion measures for these pulsars were between 50 and 100 pc cm<sup>-3</sup>. We made observations at 430 MHz and 1450 MHz with a range of bandwidth and channel spacing. We formed dynamic and secondary spectra for all of the data sets, detecting scintillation arcs in a number of the pulsars. We present results for these pulsars, tying them in with our previous results for a lower-DM sample. We discuss how observations such as these can be used as a diagnostic of interstellar medium conditions along a particular line of sight. By comparing lower-DM and higher-DM objects we are able to assess the relative importance of time-variable scattering delays for high-precision pulsar timing. This is of value in evaluating newly discovered pulsars for inclusion in pulsar timing arrays (PTA), and it may be of use in mitigating time delay fluctuations in PTA observations. This poster is one of a collection of NANOGrav PFC posters and talks at the AAS meeting, which present detailed results of our research activities, outreach programs, and the important scientific broader impacts of our work.

**Author(s):** Olivia Young, Dan Stinebring, Jillian Doane, Maura McLaughlin, Didier Banyeretse, Gabriella Agazie

**Institution(s):** Oberlin College, West Virginia University Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.08 - Probing the Neutron Star Equation of State via Millisecond Pulsar Shapiro Delay(H. Thankful Cromartie)**

Despite its importance to our understanding of physics at supranuclear densities, the neutron star equation of state (EoS) remains poorly understood. Millisecond pulsar (MSP) timing - a technique which involves very accurately predicting the arrival time of every pulse from an MSP - continues to place some of the most stringent constraints on the neutron star interior EoS. In highly inclined MSP binary systems, the gravitational potential of the pulsar's companion induces a discrepancy between expected and measured pulse times of arrival. Measurement of this general relativistic phenomenon, called Shapiro Delay, can yield the mass of both the MSP and its companion. We have conducted orbital-phase-specific observations using the Green Bank Telescope of four MSPs in systems resembling J1614-2230, the most massive neutron star ever observed. One of the MSPs of interest, which is additionally observed as part of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) experiment, shows promise as an ultra high-mass neutron star candidate capable of meaningfully constraining the neutron star EoS. We present updates to the pulsar timing results for these systems and constraints on their orbital inclinations and constituent pulsar masses.

**Author(s):** Scott M. Ransom, H. Thankful Cromartie

**Institution(s):** University of Virginia, National Radio Astronomy Observatory Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.09 - A Noise Model Portrait of PSR J1944+0907 in the NANOGrav 11yr Dataset(Min Young Kim)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) uses an array of galactic millisecond pulsars to search for low frequency gravitational waves. The stability of millisecond pulsars allows their pulse time of arrival (TOA) to be used as precise clocks. Gravitational waves will produce timing delays that are correlated across pulsars. In order to detect such correlations in TOAs, we must also understand the noise processes in the pulsar signal. Noise model selection aims to produce custom noise descriptions for each pulsar. Using NANOGrav's search code enterprise, a Markov chain Monte Carlo (MCMC) algorithm is used to search for the most favored model. A hyper model framework is used to explore across a set of models, which have different red noise and dispersion measure (interstellar medium effect) processes. The posterior odds ratio is then represented by the relative amount of time the chain spends in a model. An iterative approach is taken, where one model selection analysis is used to inform the next set of models from which to choose. The resulting noise descriptions will aid in mitigating its effects within the pulsar signals, increasing chances of gravitational wave detection.

**Author(s):** Stephen Taylor, Joseph Simon, Min Young Kim, Jeffrey Shafiq Hazboun

**Institution(s):** University of Washington - Seattle, California Institute of Technology, University of Washington Bothell, Jet Propulsion Laboratory - California Institute of Technology Contributing Team(s): NANOGrav PFC

#### **149.10 - Simulating Pulsar Scintillation in the ISM: Wave Optics vs Ray Tracing(Jakob Faber)**

Going back more than four decades, wave optics has been a powerful tool in radio-wave simulation, particularly in the study of scintillation from pulsars. Fourier transforms streamline computation of the electric field  $E(x, y, \nu)$ , where  $x$  and  $y$  are spatial coordinates and  $\nu$  is the observing frequency. It is possible and customary to set up one or more phase-changing screens through which the radiation passes on the way from source to observer. Typically, stochastic phase fluctuations are produced with a particular power spectrum (e.g. as consistent with Kolmogorov turbulence) and the possible presence of short and long wavelength cutoffs. Although this technique is fast and accurate for primarily diffractive fluctuations, it becomes computationally expensive when both diffractive and refractive fluctuations are included. We show examples of wave optics simulations using the Kirchhoff Diffraction Integral (KDI). In addition, however, we present results from a novel phase-tagged ray simulation (Jussila 2018). It allows the inclusion of lens-like and stochastic refractive features in the phase-changing screen as well as ray wander caused by small-scale diffractive irregularities. Since the total electromagnetic phase of each ray is tracked along its propagation path, interference effects can be computed at the observer plane. This is done efficiently by calculating the total path length  $L$  of a ray and  $dL/dt$ . Together, these are sufficient to produce a dynamic spectrum (radio power as a function of frequency and time) and a secondary spectrum (fluctuation power as a function of delay and fringe frequency; for details see, e.g. Cordes et al. 2006). We compare results from this phase-tagged ray tracing with full KDI wave simulations for several test cases.

**Author(s):** Jakob Faber, James Cordes, Adam P. Jussila, Dan Stinebring, Shami Chatterjee

**Institution(s):** Oberlin College, UC San Diego, Cornell University Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.11 - A Method for Mitigating Jitter Noise in Pulsar Timing(Karen Isabel Perez)**

Detecting nanohertz gravitational waves requires timing the arrival of radio pulses from pulsars to extraordinary precision. Pulse localization precisions below 100 ns are already routinely achievable using matched filtering. However, for high signal-to-noise ratio, pulsar timing precision remains limited by jitter in the amplitude and phase of pulse components. We present a method for reducing this jitter noise using pulse shape information in the form of a shape parameter called the skewness function. We can find the correlation between the

skewness function and the times of arrival (TOA) produced by a pulse-generating code; a larger correlation indicates that the TOA can be corrected. The correction is most effective when the separation between pulse components is comparable to their width and the phase jitter is small. To test the real-world performance of this analysis, we have applied it to data from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav).

**Author(s):** James Cordes, Karen Isabel Perez, Ross Jennings  
**Institution(s):** Cornell University Contributing Team(s):  
NANOGrav Physics Frontiers Center

#### **149.12 - Multi-frequency scintillation arc study of pulsar B1133+16 using the Arecibo radio telescope(Stella Koch Ocker)**

The arrival times of pulsar radio signals at Earth observatories can be used as a clock precise enough to detect gravitational waves. Performing such a detection requires the mitigation of time-variable delays in the interstellar medium. We investigate interstellar delays using a powerful tool: scintillation arcs, fluctuations in frequency and time of the pulsar signal intensity that are manifested as parabolic arcs in the pulsar's secondary spectrum. While scintillation arcs were first observed almost two decades ago, the structures that cause them are still unknown. There is accumulating evidence that the scattering from many pulsars is extremely anisotropic resulting in highly elongated, linear brightness functions. We present a three-frequency (327 MHz, 432 MHz, 1450 MHz) Arecibo study of scintillation arcs from one nearby, bright, high-velocity pulsar, PSR B1133+16. We show that a one-dimensional, linear brightness function is in good agreement with the data at all three observing frequencies. Using two separate methods we find that the broadening of the arc is less frequency-dependent than expected by standard scattering theory. Our results place the scattering screen at a distance that is broadly consistent with an origin at the boundary of the Local Bubble.

**Author(s):** Barney J. Rickett, Dan Richard Stinebring, Stella Koch Ocker

**Institution(s):** Cornell University, Oberlin College, University of California, San Diego Contributing Team(s):  
NANOGrav Physics Frontiers Center

#### **149.13 - Detecting hyperbolic scattering of interstellar objects with NANOGrav pulsar timing data(Ross Jennings)**

The extraordinary stability of pulsars as clocks makes them highly sensitive probes of a number of astrophysical phenomena, up to and including gravitational waves. In particular, the first extrasolar planets ever discovered were around a pulsar (Wolszczan & Frail 1992). In its ongoing observing campaign, the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has collected over 500 pulsar-years of high precision pulsar timing data. In

such a large dataset, even rare events may be observed to occur with some frequency. With this in mind, I consider whether scattering of rogue planets or planetesimals, or other similarly-sized interstellar objects such as dark matter clumps, by pulsars or by the solar system, may be detectable in current or future NANOGrav data. I find that objects as small as  $10^{-10}$  solar masses (around the size of the largest asteroids) may be detected at impact parameters of order 1 AU with current sensitivities. While the probability of a scattering event involving an interstellar planetesimal of this size occurring in the present NANOGrav dataset is small, NANOGrav may be sensitive enough in this respect to place significant constraints on the occurrence of dark matter clumps in this mass range.

**Author(s):** Ross Jennings

**Institution(s):** Cornell University Contributing Team(s):  
NANOGrav Physics Frontiers Center

#### **149.14 - Testing the NANOGrav Pipeline with the Pulsar Signal Simulator(Brent Jacob Shapiro-Albert)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) uses pulsar timing arrays (PTAs) to detect nanohertz gravitational waves from sources such as supermassive black hole binary systems. These arrays are made up of many millisecond pulsars (MSPs), which are extremely precise timers. In order to accurately time the MSPs in the array, each one has its own timing model. However, some of the timing model parameters are covariant, such as the dispersion measure (DM), with other frequency dependent terms, such as pulse profile variation. We use a new software package, the Pulsar Signal Simulator, to model signals from a pulsar, including noise induced from the interstellar medium and our telescopes, and compare the timing model parameters recovered after the simulated data has been processed by the NANOGrav data reduction pipeline. In particular we focus on how variations in the input DM and other frequency dependent terms, such as pulse profile evolution and pulse scattering from the ISM, affect the values recovered by the NANOGrav pipeline. This simulation allows us to study how the length of the timing baseline affects the recovered values, allows us to study the covariance between the frequency dependent term in our timing models, and build confidence that our pipeline is recovering our input parameters.

**Author(s):** Paul Brook, Maura McLaughlin, Brent Jacob Shapiro-Albert, Jeffrey Shafiq Hazboun, Paul T Baker

**Institution(s):** West Virginia University, University of Washington Bothell Contributing Team(s): NANOGrav Physics Frontiers Center

#### **149.15 - Pulsar-timing Constraints On The Stochastic Gravitational-wave Background With The NANOGrav 11-year Dataset(Stephen Taylor)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) searches for inter-pulsar correlations

induced by extra-galactic gravitational waves (GWs) in the pulse arrival-time data of many millisecond pulsars. We searched for an isotropic stochastic gravitational-wave background (GWB) in NANOGrav's newly released 11-year dataset. While we find no significant evidence for a GWB, we place constraints on a GWB from a population of supermassive black-hole binaries, cosmic strings, and a primordial GWB. For the first time, we find that the GWB upper limits and detection statistics are sensitive to the Solar System ephemeris (SSE) model used, and that SSE errors can mimic a GWB signal. We developed an approach that bridges systematic SSE differences, producing the first PTA constraints that are robust against SSE uncertainties. We thus place a 95% upper limit on the GW strain amplitude of  $A < 1.45 \times 10^{-15}$  at a frequency of  $f = 1/\text{year}$  for a fiducial  $f^{2/3}$  power-law spectrum, and with inter-pulsar correlations modeled. We use our constraints to characterize the combined influence on the GWB of the stellar mass-density in galactic cores, the eccentricity of SMBH binaries, and SMBH--galactic-bulge scaling relationships. We constrain cosmic-string tension using recent simulations, yielding an SSE-marginalized 95% upper limit on the cosmic string tension of  $G\mu^2 < 5.3 \times 10^{-11}$ . Our SSE-marginalized 95% upper limit on the energy density of a primordial GWB (for a radiation-dominated post-inflation Universe) is  $\Omega_{\text{GWB}}(f) h^2 < 3.4 \times 10^{-10}$ . This poster is one of a collection of NANOGrav PFC posters and talks at the AAS meeting, which present detailed results of our research activities, outreach programs, and the important scientific broader impacts of our work.

**Author(s):** Stephen Taylor,

**Institution(s):** California Institute of Technology, Jet Propulsion Laboratory  
Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.16 - Bayesian Monitoring of Solar Electron Density using NANOGrav Data Sets(Jeffrey Shafiq Hazboun)**

The North American Nanohertz Observatory for Gravitational Waves Physics Frontiers Center (NANOGrav) collects timing data from over 70 millisecond pulsars. Using the 11yr data set, Madison, et al. recently showed that small scale changes in the dispersion measure for pulsars due to the solar wind can be modeled as a common signal among all pulsars in the NANOGrav array. In this work we discuss using a fully bayesian approach, based on the data analysis framework ENTERPRISE, to model the solar wind as a common signal amongst all pulsars- simultaneously modeling the pulsar timing model, various forms of pulsar-specific noise and the stochastic gravitational wave background. The ability to model the solar wind is becoming a crucial tool as pulsar timing array analyses use more individually tailored noise models for pulsars. The high cadence of observation, and ever increasing number of pulsars in the array, means that in the near future this type of analysis will allow nearly continuous monitoring of the integrated electron density fluctuations in the solar wind.

**Author(s):** Jeffrey Shafiq Hazboun

**Institution(s):** University of Washington Bothell

Contributing Team(s): NANOGrav PFC

#### **149.17 - The NANOGrav observing program and 12.5-year data release(Paul Demorest)**

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) Physics Frontiers Center runs a program of long-term, high-precision timing of millisecond pulsars (MSPs) with the aim of direct detection of gravitational waves (GW) from merging supermassive black hole binary systems. GW passing through our galaxy induce correlated fluctuations in the observed pulse arrival times from MSPs; monitoring a large ( $> \sim 50$ ) set of pulsars with sub- $1\mu\text{s}$  precision is necessary for GW detection. The NANOGrav observing program currently monitors a set of 71 MSPs using primarily the Green Bank and Arecibo radio telescopes; a smaller set of pulsars is observed with the Very Large Array. Our observational results are organized around a set of data releases; every few years, data from all pulsars is compiled, reduced, and used as the basis for a new set of GW analyses. Here we will describe the NANOGrav observing program, and the latest in-preparation data release, the NANOGrav "12.5-year" data set. This includes observations of 48 MSPs taken through mid-2017 with the GBT and Arecibo. This analysis incorporates new advances in removal of spurious instrumental signals, improvements in calibration and RFI excision, and automated identification of outlier data points. It also makes use of new methods for processing wide-bandwidth radio data into a single time of arrival. This approach accounts for intrinsic variation in pulse shape as a function of frequency, and will result in an order of magnitude less data needed for subsequent GW analyses. This is one of a collection of NANOGrav PFC presentations at the AAS meeting, which present detailed results of our research activities, outreach programs, and the scientific broader impacts of our work.

**Author(s):** Paul Demorest

**Institution(s):** National Radio Astronomy Observatory  
Contributing Team(s): NANOGrav Physics Frontiers Center

#### **149.18 - NANOGrav: Data Accessibility, Analysis and Automation using Python(Adam Brazier)**

Pulsar timing array detectors require the collection of large and continually growing volumes of data for the purpose of the detection and characterization of low-frequency gravitational waves. Because the timescales involved are between months and decades, a system of automated handling and processing of data has become of extreme importance. We describe two aspects of the computing resources and infrastructure behind the NANOGrav project, a highly distributed collaboration supported by an NSF Physics Frontiers Center. Our data reduction tools are nearly automated, yielding data products immediately usable for gravitational-wave detection analysis via a fully-reproducible Jupyter/iPython notebook framework. This system allows easy access for astronomers both inside and outside of the collaboration to check our data processing and



results. We also describe the development of PyPulse, a pure-Python package for handling pulsar data in the PSRFITS format and subsequent analyses. These systems are being expanded for the ever-growing quantity of data, for new analysis methods, for data sharing with collaborations, and for educational access at both the student and public levels.

**Author(s):** T. Joseph W Lazio, Adam Brazier, Timothy Dolch, Robert D Ferdman, James Cordes, Michael T Lam, Nathaniel Garver-Daniels, Paul Demorest

**Institution(s):** Cornell University, National Radio Astronomy Observatory, West Virginia University, University of East Anglia, Hillsdale College, California Institute of Technology, Jet Propulsion Laboratory Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.19 - Balancing The Solar System: Constructing A Bayesian Solar-System Ephemeris for Pulsar Timing Arrays(Joseph Simon)**

Pulsar timing arrays are galactic-scale nanohertz gravitational wave observatories, whose primary source is the stochastic gravitational wave background produced by a population of inspiring supermassive black hole binaries. Analysis of pulsar timing data requires accurate knowledge of the motion of the Earth around the Solar System barycenter. Current pulsar timing datasets, like those produced by the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), have reached a sensitivity where searches for the gravitational wave background have become biased by the errors in current Solar System ephemerides. NANOGrav has developed a novel approach to marginalize gravitational wave results over the uncertainties in Earth's orbit, thus producing the first pulsar timing constraints on the stochastic background that are robust against ephemeris error. We present this work and comment on the prospects for pulsar timing data to be used in conjunction with direct observations to enhance our understanding of the orbits of Solar System bodies.

**Author(s):** Stephen Taylor, Joseph Simon, Michele Vallisneri, **Institution(s):** Jet Propulsion Laboratory, California Institute of Technology Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.20 - New PTA-Caliber Millisecond Pulsars from the GBNCC Survey(Joe Swiggum)**

One of the main science goals of the Green Bank North Celestial Cap (GBNCC) pulsar survey is to find new millisecond pulsars (MSPs) and rapidly assess their suitability for inclusion in pulsar timing arrays (PTAs). The International Pulsar Timing Array (IPTA) currently monitors about 100 MSPs with sub-microsecond RMS residuals in an effort to detect low-frequency gravitational waves from merging supermassive black hole binaries. One of the best ways to improve our sensitivity to the stochastic gravitational wave background is to add high-caliber MSPs to PTAs. Over the past two years, ten MSPs have been

discovered in the GBNCC pulsar survey and several have already been added to the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) PTA, and these sources will likely be incorporated into regular monitoring programs by other IPTA member groups soon. In this poster, we will describe the vetting process for new GBNCC MSPs and the timing properties of the latest discoveries incorporated into NANOGrav and other PTAs.

**Author(s):** Hind Al Noori, Victoria Kaspi, Vlad Kondratiev, Jason Hessels, Ryan S Lynch, Joe Swiggum, Scott M. Ransom, Lina S. Levin, Joeri van Leeuwen, Emmanuel Fonseca, Renee Spiewak, David Kaplan, Maura McLaughlin, Megan E. DeCesar, Ingrid Stairs, Pragma Chawla

**Institution(s):** NYU Abu Dhabi, oUniversity of Virginia, UW-Milwaukee, Lafayette College, Green Bank Observatory, McGill University, University of Manchester, West Virginia University, ASTRON, University of British Columbia, Swinburne University

#### **149.21 - Limits on Gravitational Waves from Individual Supermassive Black Hole Binaries from the NANOGrav 11-year Data Set(Sarah Vigeland)**

We have searched the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) 11-year dataset for GWs from individual supermassive black hole binaries (SMBHBs). As we find no evidence for GWs in the the data, we present upper limits on the GW strain amplitude for GW frequencies between 3 and 300 nHz, and show how our sensitivity varies with sky location due to the distribution of pulsars in our array. We use these limits to constrain the luminosity distance to individual sources and to place constraints on the mass-ratios of SMBHBs in local galaxies. We use simulations of local SMBHBs to estimate the expected number of detectable sources with our current strain upper limits. We also show advanced noise modeling and detection techniques that we have developed to distinguish between true GW signals and other spurious signals in the residuals.

**Author(s):** Sarah Vigeland

**Institution(s):** University of Wisconsin Milwaukee Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.22 - Recipe for a Pulsar: Using the NANOGrav Pulsar Signal Simulator as a Teaching Tool(Kyle Gersbach)**

As ground-based gravitational wave detectors continue to detect signals, pulsar timing arrays are now sitting on the cusp of their first detection. The North American Nanohertz Observatory for Gravitational waves (NANOGrav) is a group of scientists that use an array of pulsars to detect ultra-low frequency gravitational waves. NANOGrav is working to create a software tool to model signals sent by a pulsar. The Pulsar Signal Simulator (PsrSigSim), aims to test various analysis software packages and techniques by generating simulated

signals with known parameters. This software tool is also being used for teaching. With fine parameter control that the PsrSigSim will achieve, the implementation of software that a user can easily manipulate to visualize the resulting data becomes possible. Along with a Graphical User Interface (GUI), the PsrSigSim can provide a gentle introduction into the subject of Pulsar Timing.

**Author(s):** Kyle Gersbach, Jeffrey Shafiq Hazboun

**Institution(s):** University of Washington Bothell Contributing Team(s): NANOGrav Physics Frontier Center

#### **149.23 - Predicting the Performance of Future Pulsar Timing Arrays: An analysis of the millisecond-pulsar population (Tyler Cohen)**

The fastest rotating and most stable pulsars, millisecond-period pulsars (MSP), are the most precise clocks in the universe. This level of precision makes MSPs ideal for detecting gravitational waves generated by in-spiraling super-massive black hole binaries. The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) searches for inter-pulsar correlations induced by these extra-galactic gravitational waves in the pulse arrival-time data of many MSPs. Pulsar surveys and MSP-timing observations must be optimized to get the highest timing precision of as many MSPs as possible. Planning such observations requires an understanding of the expected galactic MSP population. Since the full MSP population is not known, I model a galactic population of MSPs. I then calculate the timing precision distribution of the simulated population for a given telescope with variable survey parameters. These results will be used to inform NANOGrav observations with the future generation of timing-capable telescopes such as the Next Generation VLA. Through this analysis I explore optimizing parameters including frequency, bandwidth, integration time per source, and the collecting area of dish arrays. This analysis will also help constrain parameters of the MSP population. Varying population parameters to reproduce results from multiple existing pulsar surveys will help to avoid biases toward a particular type of survey. In contrast, most previous analyses have focused on a single survey. I explore how varying the probability distributions of population parameters including the luminosity, scale height, pulse sharpness, period, spin-down rate, spectral index, and radial distribution changes the overall timing precision distribution. Utilizing existing and future radio telescopes to their full potential will ultimately reduce the time until pulsar timing array experiments detect gravitational waves.

**Author(s):** Kevin Stovall, Tyler Cohen, Paul Demorest

**Institution(s):** New Mexico Institute of Mining and Technology, National Radio Astronomy Observatory

#### **149.24 - The NANOGrav search for nanohertz gravitational waves (Xavier Siemens)**

Supermassive black hole binaries (SMBHBs), and possibly other sources, generate gravitational waves in the nanohertz part of the spectrum. For over a decade the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has been using the Green Bank Telescope, the Arecibo Observatory, and, more recently, the Very Large Array to observe millisecond pulsars. Our goal is to directly detect nanohertz gravitational waves, which cause small correlated changes to the times of arrival of radio pulses from millisecond pulsars. We currently monitor 71 millisecond pulsars with sub-microsecond precision and weekly to monthly cadences. A detection of the stochastic gravitational-wave background produced by all the SMBHBs in the universe is close at hand. I will present an overview of NANOGrav Physics Frontiers Center (PFC) activities and summarize our most recent gravitational-wave search results. This poster is one of a collection of NANOGrav PFC posters and talks at the AAS meeting, which present detailed results of our research activities, outreach programs, and important scientific broader impacts of our work.

**Author(s):** Xavier Siemens

**Institution(s):** University of Wisconsin -- Milwaukee Contributing Team(s): NANOGrav Physics Frontiers Center

#### **150 - Planetary Nebulae and SNRs Posters**

##### **150.01 - Revised Simulations of the Planetary Nebulae Luminosity Function (Lucas Valenzuela)**

We describe a revised procedure for the numerical simulation of planetary nebulae luminosity functions (PNLF), improving on previous work (Méndez & Soffner 1997). The procedure now is based on new H-burning post-AGB evolutionary tracks (Miller Bertolami 2016). For a given stellar mass, the new central stars are more luminous and evolve faster. We have slightly changed the distribution of the [O III] 5007 intensities relative to those of  $H\beta^2$  and the generation of absorbing factors, while still basing their numerical modeling on empirical information extracted from studies of Galactic planetary nebulae (PNs) and their central stars. We show that the assumption of PNs being completely optically thick to H-ionizing photons leads to conflicts with observations, and show that it is necessary to account for optically thin PNs. We then use the new simulations to estimate a maximum final mass and discuss the effect of internal dust extinction as a possible way of explaining the persistent discrepancy between PNLf and Surface Brightness Fluctuation (SBF) distances. By adjusting the range of minimum to maximum final mass, it is also possible to explain the observed variety of PNLf shapes at intermediate magnitudes. The new PN formation rates are calculated to be slightly lower than suggested by previous simulations based on older post-AGB evolutionary tracks.

**Author(s):** Lucas Valenzuela, Marcelo Miller Bertolami, Roberto Méndez

**Institution(s):** Faculty of Physics, Ludwig Maximilian University, Instituto de Astrofísica de La Plata, UNLP-

CONICET, Institute for Astronomy, University of Hawaii

**150.02 - Median Energy Imaging of Supernova Remnants with Chandra X-ray Observatory(Annie E Blackwell)**

Supernova remnants (SNRs) play an important role in shaping the energy density, chemical enrichment, and surrounding interstellar medium (ISM) structure of galaxies. Due to the high plasma temperatures of SNRs, they primarily emit in X-rays. Chandra's sub-arcsecond resolution allows for spatially-resolved spectroscopic studies in the 0.1-10 keV band. Using data collected from Chandra, we apply a novel statistical technique to analyze SNR and probe the underlying structure and physical properties of SNRs. Rather than binning X-ray photons into counts, we used the statistical properties of the photons within a bin, such as the median energy, to make images of the energetics across the SNR. Median energy is a robust statistic, meaning only a few photons are required to determine the median energy with high confidence. We have applied this technique to two SNR: DEM L71 and Tycho. Median energy images produced for both SNR reveal new structures that had not yet been identified. We outline our process to identify these features and provide spectral analysis to uncover their physical origin. This project was supported in part by the NSF REU grant AST-1757321 and by the Nantucket Maria Mitchell Association.

**Author(s):** Rodolfo Montez, Daniel Castro, Annie E Blackwell,

**Institution(s):** The College of William and Mary, Harvard-Smithsonian Center for Astrophysics, Maria Mitchell Observatory

**150.03 - The Cygnus Loop's Distance, Properties, & Environment Driven Morphology(Kathryn E. Weil)**

The Cygnus Loop is among the brightest and best studied evolved Galactic supernova remnants. However, its distance has remained uncertain thus undermining quantitative understanding about many of its fundamental properties. Here we present moderate-dispersion spectra of stars with projected locations toward the remnant. Spectra of three stars revealed Na I 5890,5896 Å and Ca II 3934 Å absorption features associated with the remnant's expanding shell, with velocities ranging from -160 to +240 km/s. Combining Gaia DR2 parallax measurements for these stars with other recent observations, we find the distance to the Cygnus Loop's centre is  $735 \pm 25$  pc, only a bit less than the 770 pc value proposed by Minkowski some 60 years ago. Using this new distance, we discuss the remnant's physical properties including size, SN explosion energy, and shock velocities. We also present multi-wavelength emission maps which reveal that, instead of being located in a progenitor wind-driven cavity as has long been assumed, the Cygnus Loop lies in an extended, low density region. Rather than wind-driven cavity walls, these images reveal in unprecedented clarity the sizes and locations of local

interstellar clouds with which the remnant is interacting, giving rise to its large-scale morphology.

**Author(s):** Kathryn E. Weil, Robert Fesen, William Patrick Blair, Ignacio A. Cisneros, John Raymond

**Institution(s):** Dartmouth College, Harvard-Smithsonian Center for Astrophysics, Johns Hopkins University

**150.04 - The Northern Rims of SNR RCW 86: Chandra's Recent Observations and their Implications for Particle Acceleration(Daniel Castro)**

The Chandra observations towards the northwest (NW) and northeast (NE) rims of supernova remnant (SNR) RCW 86 reveal great detail about the characteristics of the shocks, particle acceleration and the local environments in these 2 distinct regions. Both the NW and NE of RCW 86 show clear evidence of non-thermal X-ray emission, identified as synchrotron radiation from shock-accelerated electrons with TeV energies, interacting with the compressed, and probably amplified, local magnetic field. Magnetic field amplification (MFA) is broadly believed to result from, and contribute to, cosmic ray acceleration at the shocks of SNRs. However, we still lack a detailed understanding of the particle acceleration mechanism, and with this study we address the connection between the shock properties and ambient medium with MFA. The Chandra observations of RCW 86 allowed us to constrain the magnitude of the post-shock magnetic field in the NE and NW rims by deriving synchrotron filament widths, and also the densities in these regions, using thermal emission co-located with the non-thermal rims. I will discuss our analysis in detail and comment on how MFA appears to be related to certain characteristics of the SNR shock.

**Author(s):** Daniel Castro

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

**150.05 - The Progenitor Mass of the Planetary Nebula in the M31 Open Cluster B477-Do75(George H Jacoby)**

Using HST/STIS, we have obtained spectra of a planetary nebula that appears to be a member of the M31 open cluster B477-Do75 (Bond 2015). The spectra, combined with the [O III] 5007 flux measured from HST archival imaging (Massey, HST program 9794), and corrected for extinction using the STIS spectra, provide sufficient constraints on a Cloudy photoionization model (Ferland et al. 2013) to derive the central-star mass. That mass ( $\sim 0.7$  Msun) corresponds to a progenitor mass of  $\sim 3.0$  Msun according to a theoretical initial-mass/final-mass relation derived from the stellar-evolution models of Miller Bertolami (2016). This mass is in good agreement with a main-sequence turnoff mass of  $\sim 3.3$  Msun derived from isochrone fitting to photometry (PHAT project, Dalcanton et al. 2012) of the 350 Myr-old host cluster. This consistency provides strong evidence that the planetary nebula is truly a member of the cluster. We also derive very approximate chemical abundances for oxygen and nitrogen.

This work was supported in part by STScI grant HST-GO-14794.003-A.

**Author(s):** George H Jacoby, Brian D Davis, Howard E Bond, Robin B Ciardullo

**Institution(s):** Lowell Observatory, Penn State University

### **150.06 - Ionization Corrections for Determining Bromine, Rubidium, and Xenon Abundances in Ionized Nebulae(Nicholas Sterling)**

We present new analytic ionization correction factor (ICF) prescriptions, based on grids of photoionization models, for computing abundances of the neutron(n)-capture elements Br, Rb, and Xe in ionized nebulae. Neutron-capture elements (atomic number  $Z > 30$ ) are of particular interest in planetary nebulae (PNe), as their abundances can be enhanced by s-process nucleosynthesis during the asymptotic giant branch (AGB) stage of the progenitor stars. Until recently a lack of atomic data has prevented accurate nebular abundance determinations of Br, Rb, and Xe. We added these elements, including newly-calculated photoionization cross sections and recombination rate coefficients for low-ionization states (Kerlin et al., in prep.; Sterling & Kerlin, in prep.), to the atomic database of the Cloudy photoionization code (Ferland et al. 2013, RMxAA&A, 49, 137). The ability of these atomic data to reproduce the ionization balance of Br, Rb, and Xe in individual objects has been tested (Sterling et al. 2017, 230th AAS, #318.10). We computed grids of Cloudy models, over a wide range of central star temperatures and luminosities, nebular densities, chemical composition, and dust physics, that encompass the physical conditions of most PNe. We searched for correlations between the fractional abundances of observed Br, Rb, and Xe ions -- and combinations thereof -- and the ionic fractions of commonly detected ions of He, O, Ne, S, Cl, and Ar. Analytic functions were fit to the correlations to produce ICF formulae that correct for unobserved ionization states of these elements. We apply the new ICFs to optical and near-infrared spectra of PNe (see also Matteson et al. and Dinerstein et al. posters) to derive abundances of Br, Rb, and Xe. We find higher Rb abundances in PNe than those derived using earlier, approximate ICFs (Sterling et al. 2016, ApJ, 819, L9), bringing [Rb/Kr] ratios into better agreement with predictions from AGB nucleosynthesis models. These results enable Br, Rb, and Xe abundances to be accurately determined from nebular spectra for the first time. We are grateful for support from NSF awards AST-1412928 and 1715332.

**Author(s):** Cameroun G Sherrard, Kyle F Kaplan, Nicholas Sterling, Ryan L Porter, Briana T Lewis-Marshall, Harriet L Dinerstein

**Institution(s):** University of West Georgia, Georgia Institute of Technology, Unaffiliated, University of Arizona, University of Texas

### **150.07 - Assessing Planetary Nebulae as Sources of Neutron-Capture Elements(Harriet L Dinerstein)**

We present measurements of the enrichments of several trans-iron elements - which are synthesized by neutron-capture reactions - in a sample of 47 planetary nebulae (PNe), the ionized, ejected envelopes of stars that begin their lives with  $10^1$  to  $10^8 M_{\odot}$ . These stars are agents of galactic chemical evolution through their contributions to the ISM of certain light elements (e.g. He, C, N) and neutron-capture products. Synthesis of the latter via the slow neutron-capture or "s-process" during the Asymptotic Giant Branch (AGB) produces nearly all trans-iron elements, albeit in different proportions than the rapid neutron-capture or "r-process" that occurs in binary neutron star mergers (and perhaps elsewhere). Our goal is to quantify the contributions of AGB stars in individual elements in order to separate the different sources of enrichment and test models of AGB evolution and nucleosynthesis. The data were taken with IGRINS, a panoramic H and K-band high-spectral resolution spectrometer (Park et al. 2014, SPIE, 9147, 91471D) at the University of Texas' McDonald Observatory and the Discovery Channel Telescope at Lowell Observatory. A third of the sample is detected in at least two of the [Se IV] 2.287, [Kr III] 2.199, and [Te III] 2.102  $\mu\text{m}$  lines. Since Kr and Te are traced by low ionization states in our study, they are favored for detection in PNe with cool central stars, while elements such as Rb and Br that are traced by higher ionization states are seen only in PNe with hotter central stars (Sterling et al. 2016, ApJL, 819, L9; Madonna et al. 2018, ApJL, 861, L8). In s-enriched PNe, Kr is more strongly enhanced than Se, as previously found by Sterling & Dinerstein (2008, ApJS, 174, 158), while Te correlates with Kr but tends to be even more highly enriched. Our results are generally in good agreement with abundance enhancements predicted by recent AGB models for stars of solar to moderately subsolar metallicity (Karakas & Lugaro 2016, ApJ, 825, 26; Karakas et al. 2018, MNRAS, 477, 421). This research was supported by (U.S.) NSF AST grants 1715332 (HLD) and 1412928 (NCS) and Australian Research Council Discovery Project 170100521 (AIK).

**Author(s):** Nicholas Sterling, Amanda I Karakas, Harriet L Dinerstein, Kyle F Kaplan

**Institution(s):** University of Texas, Austin, Monash University, University of Arizona, University of West Georgia

### **150.08 - Near-Infrared Spectroscopy of Neutron-Capture Elements in Southern Hemisphere Planetary Nebulae(Justin A Hill)**

We present K band spectra (2.0--2.4  $\mu\text{m}$ ) of six southern hemisphere planetary nebulae (PNe), obtained with the OSIRIS spectrometer on the 4.1-m SOAR Telescope at a spectral resolution of  $R = 1200$ . We observed He 2-86, He 2-131, IC 1297, IC 4776, NGC 5882, and Te 1 with the aim of detecting emission lines of neutron(n)-capture elements (atomic number  $Z > 30$ ), including [Kr III] 2.199, [Se IV] 2.287  $\mu\text{m}$ , and the recently identified [Te III] 2.102  $\mu\text{m}$  (Madonna et al. 2018, ApJ, 861, L8). These species can be enriched in PNe if their progenitors experienced slow n-capture nucleosynthesis (the "s-process") during the asymptotic giant branch (AGB)

evolutionary stage. Se and/or Kr are detected in all objects in our sample, and Te is marginally detected in IC 4776. We determined the abundances of Se and Kr using the Sterling et al. (2015, ApJS, 218, 25) formulae to correct for unobserved ions of these species, and of Te following the methods of Madonna et al. (2018). In the low-ionization, fullerene-containing PN Tc 1, we find that Kr is strongly s-process enriched, by  $1.3 \pm 0.3$  dex relative to O, and the upper limit on the Te abundance allows for significant enrichment as well. The other objects in our sample show marginal (He 2-86, He 2-131, IC 1297) or no enhancement of Se, Kr, and Te. The lack of s-process enrichment in NGC 5882, combined with its low N/O ratio, suggests that its progenitor had an initial mass below  $1.5 M_{\odot}$ , while the binary companion and common envelope evolution of IC 4776 (Sowicka et al. 2017, MNRAS, 471, 3529) likely truncated the AGB before convective dredge-up and the s-process could occur. We also detected [Fe III] emission lines in four of the six targets, and we derive Fe depletion factors ranging from 1.5--2.2 dex. We acknowledge support from NSF award AST-901432.

**Author(s):** Nicholas Sterling, Justin A Hill, Nathan D Morgenstern

**Institution(s):** University of West Georgia, Georgia Institute of Technology

#### **150.09 - Abundances of the Planetary Nebulae NGC 3242 and IC 2003 from High-Resolution Optical Spectra (Lilly S Matteson)**

We present high-resolution ( $R = 36,700$ ) optical spectra of the planetary nebulae (PNe) NGC 3242 and IC 2003 over the spectral range 3600--10,400 Å, obtained with the 2D-coude echelle spectrograph on the 2.7-m Harlan J. Smith telescope at McDonald Observatory. The goal of these observations is to investigate the nebular chemical compositions, with particular focus on neutron(n)-capture elements (atomic number  $Z > 30$ ), which can be produced by slow n-capture nucleosynthesis (the "s-process") during the asymptotic giant branch (AGB) phase of PN progenitor stars. We detected approximately 350 distinct emission lines in NGC 3242, and 200 in IC 2003, including [Kr IV] and [Xe IV] in each object. We computed physical conditions and ionic abundances with the PyNeb nebular analysis package (Luridiana et al. 2015, A&A, 573, A42). Elemental abundances were determined by correcting for unobserved ionization states, using the ionization correction factor (ICF) schema of Delgado-Inglada et al. (2014, MNRAS, 440, 536) for light elements, Sterling et al. (2015, ApJS, 218, 25) for Kr, and new ICF prescriptions for Xe based on recently determined atomic data (see Sterling et al. poster). The light element abundances agree well with previous determinations, with the exception of the highly uncertain N abundance in NGC 3242. In both objects, Kr and Xe are enriched by 0.5-0.6 dex, and we estimate upper limits to the abundances of other n-capture elements. Along with Se enrichments found from near-infrared spectra of these objects (Sterling et al. 2015), these results indicate that the progenitor stars experienced s-process nucleosynthesis and convective dredge-up during the AGB stage

of evolution. We also derived ionic abundances from recombination lines of C, N, and O ions, and compare these to abundances from collisionally-excited lines to study the abundance discrepancy problem in each PN. We acknowledge support from NSF awards AST-901432 and AST-0708429.

**Author(s):** Nicholas Sterling, Lilly S Matteson, Briana T Lewis-Marshall, Harriet L Dinerstein, Amanda Turbyfill  
**Institution(s):** University of West Georgia, University of Texas

#### **150.10 - A Hard (X-ray) Look at the SW Region of SNR RCW 86 (Jorge R. Padial)**

That SNRs accelerate particles to CR energies is no longer in doubt, but there are many questions yet to be answered. We still lack detailed knowledge about the efficiency of the process of particle acceleration at SNR shocks, the effect of CR production on the evolution of SNRs, and the properties of magnetic fields in these systems and how these are amplified. In order to address these outstanding issues, we have observed the SW region of SNR RCW 86 with NuSTAR, in two segments totalling 250 ks, approximately. These observations have allowed us to: (1) determine the morphology of the non-thermal X-ray emission in this region in the NuSTAR band, and contrast it to observations with XMM-Newton and Chandra; (2) constrain the spectral shape of the electron population that underlies the non-thermal emission. Our analysis suggests the morphology of the source in hard X-rays closely resembles the hard X-ray emission detected with Chandra and XMM-Newton in this region. This suggests, as expected, that the X-ray emission above 3 keV is dominated by non-thermal emission from relativistic electrons. The fact that the NuSTAR detected synchrotron emission is not confined to the apparent location of the forward shock of SNR, but instead towards the inside of the thermal emission detected with XMM and Chandra, plays an important role in understanding the puzzle of this region. Here, we report on our observations and interpretation of these.

**Author(s):** Jorge R. Padial, Daniel Castro

**Institution(s):** Fisk University, Harvard-Smithsonian Center for Astrophysics

#### **150.11 - The X-ray Resolved Supernova Remnant S8 in the Nearby Dwarf Irregular Galaxy IC 1613 (Eric Schlegel)**

We describe a Chandra observation of the supernova remnant (SNR) S8 in the nearby irregular galaxy IC 1613 (distance 725 kpc). Chandra resolves the only known SNR in IC 1613, revealing a nearly circular morphology. We compare the X-ray morphology with H $\alpha$  and radio images. The SNR is approximately 5.5 arc seconds in diameter which corresponds to 19.3 pc at the distance of the host galaxy. A hardness map suggests a soft, brighter center within a harder, circular shell, but the statistics are limited. Using standard expressions that link the shock radius, shock temperature, explosion energy, and

time from the supernova, we infer an explosion energy of 2-7 foe and an age of 3800-6500 years. An upper limit to the presence of an X-ray pulsar in the 0.3-5 keV band is  $\sim 3.6 \times 10^{35}$  erg/sec; this compares to a Cas A-like central object of a few  $10^{33}$  erg/sec in the same band. However, a Crab-like pulsar would be detected as its luminosity in the defined energy band is 10-100 times above our X-ray upper limit. We compare S8 with other SNRs in Local Group galaxies.

**Author(s):** Thomas Pannuti, Tatiana Lozinskaya, Alexei Moiseev, Christina Lacey, Eric Schlegel

**Institution(s):** The University of Texas at San Antonio, Sternberg Astronomical Institute, Morehead State University, Hofstra University, Special Astrophysical Observatory

**150.12 - A 10 year proper motion measurement using the Hubble Space Telescope of the forward shock of 0509-67.5, a supernova remnant in the Large Magellanic Cloud (Prasiddha Arunachalam)**

SNR 0509-67.5 is a young and unique Balmer-dominated supernova remnant in the Large Magellanic Cloud, whose light echo measurements show it to be of Type-Ia origin (Rest et al. 2008). Using narrow-band multi-epoch HST observations of this remnant, we determine the proper motion measurements of its expanding forward shock. The two images we use for our analysis were observed with the Advanced Camera for Surveys and are spread  $\sim 10$  years apart, which allows us to measure shock speeds to significantly better accuracy than the previous results from Hovey et al. (2015). We also improve upon the dynamical offset of the explosion site from the geometric center, by measuring for the first time, the offsets resulting from expansion in the North-South direction. This, along with the improved results from the East-West direction, allow us to place strong constraints on the search radius for a possible surviving companion star. In addition to this, we employ 1-D hydrodynamic simulations, and consider different initial ejecta density profiles and equation of state for the shocked interstellar medium (ISM) to constrain the density of the ambient medium and the age of the remnant. Our improved results provide tight measurements on the blast-wave shock speeds and examine the physical conditions of the surrounding ambient medium. We consider the different interpretations of an asymmetric expansion, and ultimately provide a strong avenue to test for a surviving progenitor companion star, shedding light into the nature of Type Ia progenitor systems. Funding for program: This work was partially supported by grant HST-GO-14733.001-A from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555.

**Author(s):** John Patrick Hughes, Kristoffer Eriksen, Luke Hovey, Prasiddha Arunachalam,

**Institution(s):** Rutgers- The State University of New Jersey, Los Alamos National Laboratory

**150.13 - The Slowly Fading Light Echo Around Type Ia Supernova 2009ig (Charlotte Wood)**

The light echo around Supernova 2009ig (SN2009ig) is the sixth known and most luminous around a type Ia supernova. Light echoes can provide information on the local environment around supernovae, which is particularly important for type Ias since they are used as standard candles. The presence of gas and dust in the local environment of a type Ia can affect the observed luminosity and could impact measurements of the Hubble constant. Using photometric data from the Large Binocular Telescope between 2010 and 2018, we present new observations of the SN2009ig light echo that confirm a slow fading of the echo over the past 6 years since its discovery in 2013. The fading is similar to that seen in the light echo of SN1991T and suggests that some of dust producing the echo may be local to the event.

**Author(s):** Peter Milne, Charlotte Wood, Dina Drozdov, Peter Garnavich

**Institution(s):** University of Notre Dame, Clemson University, University of Arizona

**150.14 - Expansion and Age of the X-ray Synchrotron-Dominated Supernova Remnant G330.2+1.0 (Stephen Reynolds)**

We report new Chandra observations of one of the few Galactic supernova remnants whose X-ray spectrum is dominated by nonthermal synchrotron radiation, G330.2+1.0. We find that between 2006 and 2017, some parts of the shell have expanded by about 1%, giving a free-expansion (undecelerated) age of about 1000 years, and implying shock velocities there of 9000 km s<sup>-1</sup> for a distance of 5 kpc. Somewhat slower expansion is seen elsewhere around the remnant periphery, in particular in compact knots. Since some deceleration must have taken place, we infer that G330.2+1.0 is less than about 1000 years old. Thus G330.2+1.0 is one of only four Galactic core-collapse remnants of the last millennium. The large size, low brightness, and young age require a very low ambient density, suggesting expansion in a stellar-wind bubble. We suggest that in the east, where some thermal emission is seen and expansion velocities are much slower, the shock has reached the edge of the cavity. The high shock velocities can easily accelerate relativistic electrons to X-ray-emitting energies. A few small regions show highly significant brightness changes by 10% -- 20%, both brightening and fading, a phenomenon previously observed in only two supernova remnants, indicating strong and/or turbulent magnetic fields.

**Author(s):** Brian J Williams, Stephen Reynolds, Robert Petre, Kazimierz Borkowski

**Institution(s):** North Carolina State University, NASA/GSFC

**150.15 - Identifying Binary Central Stars of Planetary Nebulae with PSF Fitting (Josh Dey)**

Ground-based observations find that about 15% of central stars of PNe are close binaries. Kepler light curves were successful in finding periodic variation in four out of six PNe targets in the original Kepler mission (De Marco et al. 2015), suggesting that 67% of the central stars are binaries. The 140 PNe in the K2 campaign 11 field provide an excellent sample size and suggest a binary fraction of about 20-25%, but these targets are in very crowded fields. Consequently, the K2 measuring aperture of 8-10 arcsec obscures the source of the variations since they could come from the PNe central star or from neighboring unrelated stars. We used point spread function (PSF) fitting photometry on the K2 data to try to improve the light curves beyond those from the Kepler pipeline, and to separate the light curves on a star-by-star basis. Use of the PSF fitting method yielded results consistent with the central star being the variable for 5/45 targets and inconclusive findings for the other 40 targets. PSF photometry successfully separated nearby stars, however, hard-to-remove systematic trends were exacerbated, hampering our effort to improve over the Kepler pipeline's original light curves. **Author(s):** George H Jacoby, Josh Dey, Alison Crocker **Institution(s):** Reed College, Lowell Observatory

## **151 - Relativistic Astrophysics, Gravitational Lenses & Waves Posters**

### **151.01 - Gravitational Waves from Core Collapse Supernovae(Sinead Humphrey)**

The detection of gravitational waves (GWs) from core collapse supernovae (CCSNe) could provide astrophysical properties such as a likely explosion mechanism. Due to their relatively small GW emission, any improvement in recovering more energy from a generic supernova signal could be critical to discovering a GW from a CCSNe occurring in our galaxy. Here we start to evaluate possible techniques for recovering more information from CCSNe GW signals using X-Pipeline, an algorithm designed to search for gravitational wave bursts (GWBs). X-Pipeline uses data from multiple interferometers, clusters of "loud" time-frequency pixels, and statistical properties of these pixels to differentiate GWBs from other sources of loud noise transients in the LIGO data. The pixels on the final time-frequency map are grouped using the "nearest neighbor" method. With this method, the loudest pixels are grouped with their "neighbors", other loud pixels adjacent to them, in order to form an event. Because of the time-frequency distribution of CCSNe, the default settings or the clustering method of "nearest neighbor" itself may not be the best clustering model for finding GW signals from CCSNe. We varied the connectivity of the clustering method to find the method best suited to recovering a CCSNe. The default connectivity is 8, which corresponds to a 3x3 grid with the center pixel omitted. If the connectivity is increased, then there can be a greater distance between "neighboring" pixels. We injected 3 GW signals from simulated CCSNe at a distance of 10kpc into realistic aLIGO noise and calculated how much energy was recovered at grid sizes of 3x3, 5x5, 7x7, and 9x9. This same procedure was done to 10 examples of 3 noise transients found in real LIGO data. It was found that the 3

CCSN signals all show similar increases in energy recovered. Therefore similar signals are more likely to be detected when using larger connectivity. However the three types of noise transience also increase in energy recovery, especially at larger grid sizes. We are exploring if the increase in recovered energy from the noise transience, corresponds to them being more likely to fail coherent consistency tests.

**Author(s):** Sinead Humphrey, Scott Coughlin,

**Institution(s):** DePaul University, Cardiff University, Northwestern University

### **151.02 - Probing Additional Gravitational Lensing Effects of Supernova iPTF16geu(David Wassie Zegeye)**

Gravitational lensing is an effect of General Relativity, where massive objects, such as galaxies, are able to bend the light path of background sources, making the position of the observed image differ from where the source would be seen in the absence of lensing. If the lens is massive enough, it can produce multiple images of the source, each with a different magnification. However, there may be discrepancies in the predicted and observed magnifications of the images. This difference can be resolved by accounting for additional microlensing due to stars in the lensing galaxy. Supernova iPTF16geu, discovered in 2016 by the Intermediate Palomar Transient Factory, is a lensed source that still has a discrepancy between the predicted and observed image magnifications, even after accounting for microlensing due to stars. We present a more detailed gravitational lensing model that attempts to account for the discrepancy observed in the magnifications of iPTF16geu. We find that our more realistic model is an improvement from simpler lensing models, with still the possibility of ongoing millilensing caused by additional objects, such as dark matter substructures, in the lensing galaxy.

**Author(s):** David Wassie Zegeye, Liliya Williams

**Institution(s):** Haverford College, University of Minnesota-Twin Cities

### **151.03 - Gravitational Waves from Cosmic String Cusps and Kinks(Andrew Clark)**

On September 14, 2015 the Laser Interferometer Gravitational wave Observatory (LIGO) made the first observation of gravitational waves. Gravitational waves had previously been predicted by general relativity and inferred from their effects on binary pulsar systems. With a network of gravitational wave detectors we can begin looking for evidence of theoretical astrophysical phenomena that may produce gravitational waves such as cosmic strings. A network of cosmic strings is predicted to form cusps and kinks that may produce gravitational radiation detectable by Advanced LIGO. Large cosmic string loops with relatively high string tension,  $G\mu$ , will have decayed via gravitational radiation quickly after their formation during the cooling of the CMB (Cosmic Microwave Background). This means we are looking for evidence of small cosmic loops with

shorter decay rates. Current estimates place the upper constraints at  $G\mu < 10^{-8}$  for cosmic strings we can detect from cosmic microwave background measurements. To validate our technique we have injected simulated gravitational wave signals from cosmic strings into LIGO data. Recovery of this simulated waveform shows we have a valid search technique that is capable of identifying cosmic string signatures from gravitational wave measurements.

**Author(s):** Andrew Clark, Joey Shapiro Key

**Institution(s):** University of Washington Bothell

**Contributing Team(s):** LIGO Scientific Collaboration, Virgo Collaboration

#### **151.04 - Gravitational Wave Radiation from Primordial Black Hole Clusters(Rahul Rao)**

Arising from inhomogeneities during inflation, primordial black holes (PBH) have long been proposed as a dark matter candidate. There has been a renewed interest in PBHs after the LIGO detections of binary black hole mergers, with claims that these were primordial in nature. Gravitational wave observations hold promise for future scrutiny of these theories: PBH binaries produce gravitational waves detectable by LISA. We evolve PBH clusters using a direct n-body simulation, including post-Newtonian physics and gravitational wave recoil, to capture the evolution of dense PBH substructures. We present preliminary results on the predicted gravitational wave strain and evolution of the PBH mass function.

**Author(s):** Rahul Rao, Kelly Holley-Bockelmann

**Institution(s):** Vanderbilt University

#### **151.05 - Relativistic and non-relativistic astrophysics: unified formalism for fluid dynamics and nuclear energy generation(Christian Cardall)**

In contemplating astrophysical fluid dynamics and nucleosynthesis-whether purely for deeper theoretical understanding and appreciation, or for the practical purpose of developing an extensible simulation code-it may be useful to abstract certain notions that are common to both the relativistic and non-relativistic cases. A kinetic theory of classical particles serves as a unified basis for developing a geometric 3+1 spacetime perspective on fluid dynamics capable of embracing both Minkowski and Galilei/Newton spacetimes. In dealing with both fiducial and comoving frames as fluid dynamics requires, tensor decompositions in terms of the four-velocities of observers associated with these frames render use of coordinate-free geometric notation not only fully viable, but conceptually simplifying. A particle number four-vector  $N$ , three-momentum (1,1) tensor  $M$ , and kinetic energy four-vector  $E$  characterize a simple fluid and satisfy balance equations involving spacetime divergences on both Minkowski and Galilei/Newton spacetimes. Reduced to a fully 3+1 form, these equations yield the familiar conservative formulations of special relativistic and non-relativistic hydrodynamics as partial

differential equations in inertial coordinates, and in geometric form will provide a useful conceptual bridge to arbitrary-Lagrange-Euler and general relativistic formulations. Historically, energy generation due to nuclear composition changes has generally been handled as a separate source term in the energy equation in Newtonian fluid dynamics simulations. A relativistic equation in conservative form for total fluid energy, obtained from the spacetime divergence of the stress-energy tensor, in principle encompasses such energy generation; but it is not explicitly manifest. An alternative relativistic energy equation in conservative form-in which the nuclear energy generation appears explicitly, and that reduces directly to the Newtonian internal + kinetic energy in the appropriate limit-emerges through definition of a mutable average baryon mass  $m$  expressed in terms of contributions from the nuclear species in the fluid.

**Author(s):** Christian Cardall

**Institution(s):** Oak Ridge National Laboratory

#### **151.06 - Modeling the Relativistic Jet of GW170817(Brian Morsony)**

We model GW170817 as the emission of an off-axis relativistic jet. The jet used for our model was produced by a single hydrodynamics simulation of a Short GRB, producing a structured jet that is energetic in the center and falls off at larger angles. We find that the prompt gamma-ray emission, late-time X-ray and radio afterglow, and observed superluminal motion of the radio source are all consistent with GW170817 being a typical Short GRB seen off-axis.

**Author(s):** Riccardo Ciolfi, Brian Morsony, Jared Workman, Bruno Giacomazzo, Matteo Cantiello, Davide Lazzati, Rosalba Perna, Diego Lopez-Camara

**Institution(s):** California State University Stanislaus, Stony Brook University, Oregon State University, CCA, Flatiron Institute, UNAM, University of Trento, National Institute for Astrophysics INAF-OAPd, Padova, Colorado Mesa University

### **152 - RFI, Light Pollution, Etc. Posters**

#### **152.01 - RFI Mitigation with Spectral Kurtosis(Aman Kar)**

Spectral Kurtosis is a statistical tool that measures the randomness of a data set. As a result, this tool can identify signals that deviate from Gaussian statistics, making it sensitive to man-made signals such as cellphones and radar. The Green Bank Ultimate Pulsar Processing Instrument (GUPPI) raw files from the Green Bank Telescope (GBT) was used for this project. The Spectral Kurtosis Estimator was proposed by Nita et al. (2007) as a real-time RFI mitigation technique. We discuss our attempts of implementing this technique with archival data from the GBT and show our preliminary results from this project.

**Author(s):** Anastasia Kuske, Richard Prestage, Evan Smith, Luke Hawkins, Aman Kar



**Institution(s):** University of Wyoming, Green Bank Observatory, Franklin & Marshall College, West Virginia University

### **152.02 - Using CCD Imagery for the Study of Night Sky Brightness in a Small College Setting(Nicole Rodriguez)**

The National Park Service (NPS) Night Skies Team has utilized charge-coupled device (CCD) imagery to create all-sky mosaics of the night sky-brightness at various sites within U.S. National Parks. This data, publicly available on the Night Sky Monitoring Database, applies the imaging and analysis techniques commonly used in the undergraduate astronomy curriculum, but in a new context. We sought to reproduce the methods of Duriscoe, Luginbuhl, & Moore (2007) in the context of a burgeoning astronomy research program at a small liberal arts college. Our goals are to make datasets that can be utilized by policy makers and advocates of dark sky preservation in the Salt Lake Valley, and to create publicly available code for similar projects to be reproduced by other astronomy students, at a fraction of the cost of the NPS methods. We have used a CCD camera to image the night sky from locations near Salt Lake City, using typical equipment available to a small college astronomy program. After calibrating and aligning all of the images, we created a panoramic view of the night sky in Python. This map of sky brightness in magnitudes per square arcsecond can be used to determine a number of indices of sky quality: surface brightness at notable locations (zenith, brightest, darkest portions of the sky), total integrated sky background, and total integrated brightness of a nearby city's light dome. Our procedures and Python scripts are publicly available on GitHub [<https://github.com/jrka/slclight/>] for other small college or amateur researchers to use. By investigating the challenges of applying this technique in a small college setting, we have aimed to make the study of night sky brightness easily accessible to other researchers. We encourage other undergraduate astronomy programs to utilize this procedure in their advanced laboratory courses or independent research in order to help teach CCD imaging techniques. The resulting datasets have personal significance for the students and interdisciplinary applications to policy, ecology, and human health.

**Author(s):** Nicole Rodriguez, Julia Kamenetzky  
**Institution(s):** Westminster College

### **152.03 - Use of Live Sky Quality Meters for Outreach and Public Awareness(Julia Kamenetzky)**

Increased exposure to artificial light at night is a factor in increased health risks, energy waste, and damage to wildlife ecosystems. We have set up identical sky quality meters (SQMs) in two locations in Utah for comparison of one bright and one dark night sky locations. One SQM is at the rooftop observatory on the South Physics Building on the University of

Utah's urban campus; the other is located at Dead Horse Point State Park in eastern Utah. In both cases, a Unihedron SQM-LU was mounted on a tripod and attached to an Internet connected computer housed in a utility box. The measurement of zenith sky quality, in magnitudes per square arcsecond, is recorded every five minutes and updates a file in a shared OneDrive folder. Monthly data will be added to the Globe at Night Monitoring Network (GaN-MN) for public availability to allow researchers to understand trends in the sky brightness over extended periods of time as Salt Lake City continues to grow. We present designs for a web widget which would include a live reading of the night sky quality using easy to understand visuals. Interacting with the widget would direct the user to additional information about night sky preservation. Such a widget could increase public awareness of night sky conditions and be included on the websites of local weather stations or community groups involved in night sky preservation. In addition to this widget, we will present possible uses of the simple SQM data reports for incorporation into secondary science and introductory college classrooms, including some preliminary lab activities. The goal of these activities is for students to practice data science skills in Excel or Python with real sky quality data that is relevant to their personal lives.

**Author(s):** Janet Wong, Julia Kamenetzky, Anil Seth  
**Institution(s):** Westminster College, University of Utah

## **153 - White Dwarfs, Pulsars, Neutron StarsÂ -- Posters**

### **153.01 - Pulsating and Eclipsing White Dwarfs Discovered from Time-Series GALEX Observations(Dominick Rowan)**

We search for photometric variability in more than 23,000 known and candidate white dwarfs, the largest ultraviolet survey compiled for a single study of white dwarfs. We use gPhoton, a publicly available pipeline, to generate calibrated time-series photometry of white dwarfs observed by GALEX. By implementing a system of weighted metrics, we select sources with variability due to pulsations and eclipses. Although GALEX observations have short baselines ( $\sim 30$  min), we identify intrinsic variability in sources as faint as  $G = 20$  mag. With our ranking algorithm, we identify 49 new variable white dwarfs (WDs) in archival GALEX observations. We detect 41 new pulsators: 37 have hydrogen-dominated atmospheres (DAVs) and four are helium-dominated pulsators (DBVs). We also discover eight new eclipsing systems; four are new discoveries, and four were previously known spectroscopic binaries. We perform synthetic injections of the light curve of WD 1145+017, a system with known disintegrating planets, to test our ability to recover similar systems.

**Author(s):** Dominick Rowan, Benjamin Shappee, Michael Tucker, JJ Hermes

**Institution(s):** Haverford College, University of North Carolina, Chapel Hill, Institute for Astronomy, University of Hawaii

### **153.02 - An Exploration of Detecting the Periods of ZZ Ceti Stars with a 0.4 Meter Telescope(Ian Clark)**

White dwarfs are the end result of stellar evolution for most stars. Many of these white dwarfs will pulsate at some point in their lifetime. These pulsations are generally low amplitude, so the telescope used to detect these pulsations must be fairly large in order to detect them. Just how large the mirror must be is a topic worthy of exploration; this project aims to determine if a 0.4 meter telescope is large enough to adequately detect these white dwarf pulsations. Various exposure times (120 s, 90 s, 60 s) and different period analysis softwares are also tested to find which combination are most likely to produce the expected periodicity of three white dwarfs, DN Dra (109 s), ZZ Psc (110-116 s), and PY Vul (142-652 s).

**Author(s):** Ian Clark, Denise Stephens, Jarrod Hansen, Trevor Martin, Alex D Spencer, John Michael Eberhard, Jacob Gehrett  
**Institution(s):** Brigham Young University

### **153.03 - The Search for Disintegrating Planets Orbiting White Dwarfs(Gerlinder Difo Cheri)**

White dwarfs are the end state for low to medium mass stars like our sun and are essentially the exposed cores of such stars. Once a star exhausts its hydrogen and leaves the main sequence, mass loss occurs which can disturb the orbital path of objects within its gravitational influence. In some cases, the star's planets will fall into a much closer orbit and begin to disintegrate which can occur either through destructive gravitational forces or through the vaporization of rocky surface material. This material is then accreted onto the surface of the white dwarf where it can be analysed to gain a better understanding of the composition of the objects which were destroyed. Recently, transits of disrupted planetary material have been detected around the white dwarf WD 1145+017, giving researchers a new way to study this phenomenon. Here we present a search for new WD 1145+017-like transiting systems through optical observational data conducted by both ground and space-based surveys. Our search utilizes white dwarf databases which have identified thousands of white dwarfs. The NASA Exoplanet Archive was used for the retrieval of light curve data for targets which were observed by the SuperWasp, KELT, and K2 exoplanet surveys. The light curve data was then processed using a Fourier Transform which can reveal periodic dips in stellar flux. So far we have not detected any new WD 1145+017-like systems, but if we are successful in the future, observation of such events provide researchers with a better understanding of the way planets are disrupted around white dwarfs and the planets' exact inner compositions.

**Author(s):** Gerlinder Difo Cheri,  
**Institution(s):** University of the Virgin Islands, University of Texas

### **153.04 - An Isolated Neutron Star Discovered in the Chandra Data?(Hang Gong)**

We discovered a persistent X-ray source in Chandra/ACIS data with an extreme X-ray to optical (X/O) flux ratio,  $f_x = f_{opt} > 1400$ . We estimate an X-ray flux  $4.5 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$  assuming a power-law spectrum. An R-band observation taken by the VLT gives  $R > 25 \text{ mag}$ . We propose that it is a strong new candidate of isolated neutron stars (NSs). We need a deeper and multi-band optical/infrared observation to obtain a deeper limit on its optical counterpart and definitively rule out the possibility of a high-redshift, optically dim AGN.

**Author(s):** Roberto Soria, Jifeng Liu, Hang Gong  
**Institution(s):** NAOC, UCAS

### **153.05 - Arecibo Multifrequency Polarimetric Single-Pulse Emission Survey(Timothy Olszanski)**

High frequency radio emission has long been believed to arise deep within the magnetosphere and thus serves as a useful probe of the primordial conditions that give rise to pulsar radio emission. Historically, most observatories have only been capable of high frequency single-pulse observations for less than a handful of the brightest pulsars, making a large scale survey of emission dynamics an elusive pursuit. The current necessity of quality high frequency single-pulse observations cannot be understated. Using the unmatched sensitivity of Arecibo observatory, we have conducted a number of observations on more than three dozen of the brightest "Classic" Arecibo pulsars at 4.5 GHz, in addition to previously collected companion observations at 327 MHz, and 1.5 GHz in an effort to study frequency changes in the emission dynamics. I will present the initial findings of this survey.

**Author(s):** Joanna Rankin, Timothy Olszanski, Dipanjan Mitra  
**Institution(s):** University of Vermont, National Centre for Radio Astrophysics

### **153.06 - Finding Compact Sources in the VLA Sky Survey(Cameron Riley)**

The VLA Sky Survey (VLASS) is a three epoch radio wavelength survey which covers over 33,000 deg<sup>2</sup> of the sky as visible from the Very Large Array in New Mexico, USA. At a resolution of 2.5 arcseconds and 120 microJansky RMS sensitivity per epoch, the VLASS is expected to locate around five million sources. We have initiated a project to identify candidate radio pulsars from the VLASS images for targeted follow up observations. To do so, we require a compact source catalog with minimal false positive detections that simultaneously does not miss out on real sources. We are testing the performance of various source finding tools to optimize such a catalog. In particular, Aegean Source Finder and PyBDSF were used to create catalogs for sample VLASS Quicklook images, which were analyzed for accuracy and completeness. Although more testing is required,

our preliminary analysis shows that PyBDSF has a lower false positive detection rate and excels in differentiating sources within clusters, while Aegean has better performance in locating point sources. After further testing of other tools, we will construct a compact source catalog and use multiwavelength matches to rank pulsar candidates for follow up.

**Author(s):** James Cordes, Cameron Riley, Shami Chatterjee

**Institution(s):** Cornell University Contributing Team(s): National Radio Astronomy Observatory

### **153.07 - Clocking Stars with Radio Telescopes: Timing Four Pulsars from the GBNCC Survey (Robert Aloisi)**

We present the timing solutions for four pulsars discovered in the Green Bank Northern Celestial Cap (GBNCC) survey. Timing observations were processed and timing solutions were obtained by undergraduate students participating in course-based research at the University of Wisconsin - Milwaukee. Both discovery and timing observations were conducted at a center frequency of 350 MHz using the 100-m Robert C. Byrd Green Bank Telescope. All four pulsars are isolated with spin periods between 0.26 s and 1.84 s. PSR J0038-2501 has a 0.26 s period and a period derivative of  $7.6 \times 10^{-19} \text{ s s}^{-1}$ , which is unusually low for isolated, longer period pulsars. This low period derivative may be simply an extreme value for an isolated pulsar or it could indicate an unusual evolution path for PSR J0038-2501, such as a disrupted recycled pulsar (DRP) from a binary system or an orphaned central compact object (CCO). Correcting the observed spin-down rate for the Shklovskii effect suggests that this pulsar may have an unusually low space velocity, which is consistent with expectations for DRPs since they come from disrupted binaries. There is no X-ray emission detected from PSR J0038-2501 in an archival Neil Gehrels Swift Observatory observation, which suggests that it is not a young orphaned CCO. A second pulsar, PSR J1949+3426 has a high dispersion measure suggesting that it is one of the most distant pulsars discovered in the GBNCC survey at an estimated distance of 12.3 kpc. Among the pulsars discovered in the GBNCC survey that makes it one of the brightest pulsars discovered in the GBNCC survey with a pseudo-luminosity of 570 mJy kpc<sup>2</sup>.

**Author(s):** Renee Spiewak, Shawn Banaszak, Lina S. Levin, Xavier Siemens, Jason Boyles, Chen Karako-Argamano, Luke Daniels, Bingyi Cui, Joe Swiggum, Scott M. Ransom, Emmanuel Fonsecao, Maura McLaughlin, Mallory Roberts, Ryan S Lynch, Megan E. DeCesar, Natalie Meyer

**Institution(s):** New York University, oDepartment of Physics, McGill Space Institute for Radio Astronomy, Department of Physics and Astronomy, Western Kentucky University, Center for Gravitation, Cosmology, and Astrophysics, Department of Physics, University of Wisconsin

### **153.08 - Green Bank Northern Celestial Cap (GBNCC) Survey Census and Flux Density Analysis (Alexander McEwen)**

We have created and implemented a pipeline to search through data taken as a part of the GBNCC survey for known pulsars, returning well over 500 redetected pulsars. From these redetections, we present the measured S/N and flux density of the pulsars as well as new measurements for pulse widths and profiles. The central frequency of the GBNCC survey is 350 MHz, which is low enough for markedly increased sensitivity for measurements of dispersion measure. Using the PRESTO search software, we provide new measurements of this parameter for all redetections. We utilize the measured S/Ns along with a radio frequency interference (RFI) analysis to provide a sensitivity curve and sky map for the survey, improving the precision of the expectations of the survey. Utilizing measured parameters of pulsars detected in other surveys that overlap with the GBNCC, we also shed light on the observation frequency dependence of pulsar duty cycles.

**Author(s):** Joe Swiggum, Alexander McEwen, Renee Spiewak, David Kaplan

**Institution(s):** University of Wisconsin-Milwaukee, Swinburne University of Technology Contributing Team(s): NANOGrav Physics Frontier Center

### **153.09 - Probing the Injected Particle Spectrum of the Mouse Pulsar Wind Nebula (Y.-Y. Chan)**

A pulsar wind nebula (PWN) is a synchrotron bubble formed when the relativistic outflow from a pulsar is shocked in the ambient medium. PWNe are relatively nearby objects, offering ideal laboratories for studying relativistic shocks. In particular, it could help understand the particle acceleration mechanism, which remains an open question. For a pulsar moving supersonically in the interstellar medium, the wind is confined by the ram pressure, resulting in a bow-shock PWN. These systems can be considered as in a steady state, thus, making the modeling much simpler than younger PWNe. We present a multi-wavelength study of the Mouse, which is a bright bow-shock PWN near the Galactic center. We compile its spectral energy distribution using observations from the Very Large Array (VLA), the Giant Metrewave Radio Telescope (GMRT), the Molonglo Observatory Synthesis Telescope (MOST), and Chandra X-ray Observatory. We then performed a detailed comparison with various injected particle distributions, including a single power law, a broken power law, and a Maxwellian distribution with a high-energy power law tail, by taking into account synchrotron loss, synchrotron cooling as well as inverse Compton scattering. We will discuss the result and its implications. This work is supported by a GRF grant from the Hong Kong Government under HKU17305416P.

**Author(s):** C.-Y. Ng, Y.-Y. Chan

**Institution(s):** The University of Hong Kong

### **153.10 - The Broadband Spectral Behaviour of Crab Giant Pulses(Bradley Meyers)**

Pulsars provide unparalleled Galactic laboratories to study astrophysical coherent emission processes. The Crab pulsar (PSR J0534+2200) is a young ( $\sim 1260$  yr), energetic pulsar that sporadically emits intense (brightness temperatures  $> 10^{12}$  K), intrinsically short-duration ( $\sim 1$  ns) giant pulses, that can be detected with a high signal-to-noise ratio across a range of observing frequencies. The frequency dependence of giant pulse emission provides vital information about the emission processes involved, but has not been examined in detail, especially at low frequencies. To study the spectral behaviour of Crab giant pulses, we conducted simultaneous wideband observations of the Crab pulsar with the Parkes radio telescope and the Murchison Widefield Array (MWA), spanning a frequency range of 120-3100 MHz. We found that the mean spectral index of Crab giant pulses flattens at low frequencies, from  $-2.6 \pm 0.5$  between the Parkes bands ( $\sim 700$ -3100 MHz), to  $-0.7 \pm 1.4$  between the lowest MWA subbands ( $\sim 120$ -210 MHz). This intriguing result motivated a recent coordinated simultaneous observing campaign that involved multiple radio telescopes, from Australia, India, China and the USA, spanning 20-8000 MHz, and was complimented by simultaneous high-energy observations from NASA's Neutron star Interior Composition Explorer (NICER). Data from this campaign will allow an in-depth investigation of giant pulse emission characteristics including the spectral behaviour and will prompt further development of theoretical models pertaining to the emission of giant pulses.

**Author(s):** Bradley Meyers, Ryan Shannon, Steven Tremblay, Ramesh Bhat

**Institution(s):** ICRAR-Curtin University, Swinburne University of Technology, CSIRO Astronomy and Space Science

### **153.11 - Modeling Stability of Magnetic Fields in Magnetars with Applications to Continuous Gravitational Wave Detection(Samuel Frederick)**

Possessing the strongest magnetic fields ( $\sim 10^{15}$  gauss) in the Universe, a group of pulsars known as magnetars represent an extremum of our understanding of physical phenomena. Recent research has sought to explain the structure of these magnetic fields, their evolution, and their stability. In theory, the strength of such fields induces topological deformations which give way to a time-varying quadrupole, leading to the formation of gravitational waves. With the advent of gravitational wave astronomy following the detection of multiple black hole and neutron star mergers, magnetars represent a source of continuous gravitational waves (GWs); a promising but undetected subset of GWs differing from those resulting from sources such as binary mergers detected by LIGO. Although recent work regarding the study of magnetars has sought to improve the accuracy of magnetic field models interior and exterior to the stellar surface by taking into consideration the various structural zones of the star, little work has been

completed towards estimating the wave strain, or intensity, of GWs resulting from such magnetars. Here, we present a study of wave strain modeling for sources in the McGill Magnetar Catalog. Furthermore, in modeling the field structure and strain, we test the stability of recent magnetar magnetic field models under long term evolution by using computational simulations to guide their implementation. This work seeks to inform the magnetar and GW communities of the relative signal strength for such continuous GWs, pointing to future requirements for GW detector sensitivity.

**Author(s):** Samuel Frederick, Kristen Thompson, Michelle Kuchera

**Institution(s):** Davidson College

### **153.12 - Pipe it up: How NICER Data Filtration Methods Affect Time-of-Arrival Accuracy(Elizabeth Teng)**

NASA's NICER telescope (Neutron star Interior Composition Explorer) is an X-ray instrument with 56 X-ray detectors, mounted on the outside of the International Space Station (ISS). Haverford College's NICER research team is concerned with increasing the precision in timing the arrival of photons from a collection of millisecond pulsars, which may have significant implications for gravitational radiation detection. NICER has provided us with the ability to time pulsars with astounding accuracy by collecting X-ray frequency photons, rather than radio frequency, as has been customary in pulsar timing. While NICER has advanced our ability to time pulsars, there is a significant amount of high energy background radiation present in the ISS environment. Thus, our project's main goal is to find the best method for filtering out this radiation while retaining the data necessary to create residual plots, which grant us further insight into the precision of these filtering modes and thereby pulsar timing as a whole.

**Author(s):** Sadie Austin Kenyon-Dean, Elizabeth Teng

**Institution(s):** Haverford College

### **153.13 - NICER Observations of the Massive Millisecond Pulsar PSR J1614-2230(Michael Wolff)**

We report on observations of the millisecond pulsar PSR J1614-2230 with the Neutron star Interior Composition Explorer (NICER) experiment on the International Space Station. PSR J1614-2230 is detected from radio wavelengths to gamma-rays, is in a binary system, and relativistic Shapiro delay has been detected at superior conjunction of the neutron star, indicating the neutron star mass is near 1.9 solar masses. Previous X-ray observations found that PSR J1614-2230 has a thermal spectrum with 0.2-10 keV flux  $\sim 4 \times 10^{-14}$  erg/cm<sup>2</sup>/s. We report on our attempt to detect the X-ray pulsations with NICER. This pulsar is faint and the field close by to the pulsar position has enough X-ray sources and diffuse counts so that the pulsar is approximately 16% of the total flux in the non-imaging field of view of NICER. As of September 21, 2018, NICER has

accumulated 232 ks of good time on PSR J1614-2230. Millisecond pulsations have been detected above the 5 sigma level in the 0.71 - 2.0 keV energy range. Recently Miller (2016) argued that the fractional oscillation amplitude observed in the X-ray band may rule out some equations of state that are currently being considered for neutron star matter. We discuss the details of our observations undertaken so far and the prospects for improving the detection fractional oscillation amplitude. NICER is a 0.2-12 keV X-ray telescope operating on the International Space Station. The NICER mission and portions of the NICER science team activities are funded by NASA.

**Author(s):** Michael Wolff, Wynn C.G. Ho, Paul S Ray, Sebastien Guillot

**Institution(s):** Naval Research Laboratory, Haverford College, IRAP-CNRS  
**Contributing Team(s):** NICER Working Groups on Pulsation Searches and Light Curve Modeling

### **153.14 - The Soyuz Effect : Searching for Sources of Noise in NICER Data(Reilly Parker Milburn)**

The NICER telescope on board the International Space Station records X-ray pulsar data. While X-rays prove to be resilient in their travel through interstellar medium, our project searches for potential sources of noise within our signal. One potential source being investigated is the effect of the Soyuz Spacecraft. These spacecraft are equipped with a Cobalt 60 altimeter that emits gamma rays. It is hypothesized that when docking or undocking from the ISS, these gamma rays could interact with NICER's detectors. By comparing filtered and unfiltered data near Soyuz docking and undocking events, it is determined that a Soyuz Effect is a rare occurrence, and is removed with standard filtering procedure.

**Author(s):** Reilly Parker Milburn, Lamiaa Dakir, Andrea Lommen

**Institution(s):** Haverford College, Bryn Mawr College

### **153.15 - Distinguishing Bright Pulses from RFI via Machine Learning Using Single-Pulse Data from PSR J1713+0747(David Forman)**

Using data from the 24-hr global campaign on the millisecond pulsar (MSP) J1713+0747, we have developed a machine learning classifier that helps find bright pulses and distinguish them from bursts of Radio Frequency Interference (RFI). Due to its high timing precision, PSR J1713+0747 is a critical component of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) pulsar timing array and thus of NANOGrav's search for supermassive black hole binaries. The brightest single pulses of this pulsar, in their temporal and polarimetric properties, may be a significant component of its noise budget, producing measurable perturbations in the integrated pulse profile. Our machine learning tool is useful to inspect the properties of the brightest pulses, distinguishing them from RFI. An understanding of rare and bright single

pulses, beyond refining the NANOGrav pulsar timing array, also provides information about Fast Radio Bursts (FRBs). One way to theorize the origin of FRBs is via giant pulses emitted by extragalactic pulsars. A better physical understanding of the giant pulse emission mechanism, provided by more detections of giant pulses from other pulsars, results in a better informed evaluation of this hypothesis. Toward this aim, our algorithm has successfully detected bright pulses from 10 to 12 sigma emitted by PSR J1713+0747 during the Arecibo Observatory portion of the 24-hr global campaign. This method will be useful for single-pulse searches in other many-hours observations of individual pulsars, datasets that will be frequently obtainable on more MSPs with new radio telescopes such as MeerKAT, the Square Kilometer Array (SKA), and the ngVLA (Next Generation Very Large Array).

**Author(s):** David Forman, Kathryn Crowter, Shami Chatterjee, Paul Demorest, Timothy Dolch, Dan Richard Stinebring, Natalia Lewandowska, Michael T Lam, Kevin Stovall, James Cordes

**Institution(s):** Hillsdale College, Oberlin College, West Virginia University, Cornell University, National Radio Astronomy Observatory, University of British Columbia  
**Contributing Team(s):** NANOGrav PFC

### **153.16 -**

### **Upgrading Receivers at the Green Bank Observatory to Improve Pulsar Capabilities(Joy Skipper)**

The Green Bank Telescope (GBT) is one of the world's premier pulsar instruments, due in large part to its flexible suite of receivers in the 0.3-8 GHz range. The Green Bank Observatory is pursuing two new projects that will further enhance these capabilities. The first project is an ultra-wideband receiver that will instantaneously cover ~0.7-4 GHz. The primary science driver is the detection of nanohertz-frequency gravitational waves via pulsar timing. Radio pulses from pulsars are dispersed by their passage through ionized gas in the interstellar medium. Measurement of pulses at widely-spaced frequencies is necessary to characterize and remove dispersive effects. This currently requires use of two separate GBT receivers, often on different days. The new receiver will allow these measurements to be made simultaneously with a single instrument, improving the signal-to-noise for pulsar observations, and improving observing efficiency for high-precision pulsar timing programs. The receiver will also enable wideband spectroscopic studies of fast radio bursts and other transients, as well as regions rich in molecular lines at these frequencies. Additionally, the Green Bank Observatory is investigating an upgrade to the GBT's current L-band receiver. This receiver (1.15-1.73 GHz) is in high demand for observations of pulsars and the 21cm line in Galactic and extragalactic sources. A straightforward upgrade using modern components will reduce the zenith system temperature from the current 18 K to 14 K or less. This will improve the receiver's reliability and performance for all projects, and can reduce the time needed for many observations by as much as a factor of 0.6. This

upgrade uses known technology and takes advantage of the GBT's clean optics to achieve new records in receiver sensitivity.  
**Author(s):** Ryan S Lynch, Joy Skipper, Scott M. Ransom, Steve White

**Institution(s):** Green Bank Observatory, University of Virginia, NRAO

## **154 - YSOs & Friends I -- Posters**

### **154.01 - New X-ray Detections of Young Exoplanet Host Stars and FU Orionis Stars(Steve Skinner)**

Several thousand exoplanets have now been discovered but almost all orbit relatively old central stars. These systems provide little information about physical conditions in the protoplanetary disk at ages of a few Myr when planets begin to form. I will summarize recent X-ray observations of two young exoplanet host stars. The Herbig Be star HD 100546 (age ~5 - 10 Myr) has dramatic disk structure and evidence for multiple protoplanets has been reported. XMM-Newton reveals soft X-ray emission which will be strongly absorbed and heat the disk gas surface layers. The T Tauri star HL Tau (age ~1 Myr) drives a high-velocity jet and ALMA observations resolve a spectacular ringed disk that has likely been sculpted by protoplanets. Chandra observations show hard and variable X-ray emission. In addition, a recent Chandra observation detecting X-ray emission from the rare FU Orionis-type binary system RNO 1B/C will be summarized.

**Author(s):** Steve Skinner

**Institution(s):** Univ of Colorado

### **154.02 - Mining Big Data Over the Entire IR Sky: Improved Photometric Classification of YSOs, AGB and Post-AGB Stars, Mira Variables, and Biogenic Ice Candidates through Machine Learning(Jacqueline Blaum)**

Knowledge of the IR sky is crucial for understanding a wide array of astrophysical phenomena including star formation and the late stages in the evolution of intermediate- to high-mass stars. It also provides a large potential for discovery because many sources detected in IR surveys such as protostars, evolved dusty stars, and young stars bearing biogenic ices in their circumstellar environments have not yet been fully characterized. To maximize the scientific potential of large IR surveys, we must be able to classify sources that often overlap in color-color diagrams. Here we aim to produce an improved census of IR sources in the galactic plane by employing machine learning (ML) techniques rather than traditional color cuts to source classification, which allows us to assign probabilistic rather than deterministic labels. Specifically, we aim to increase the number of classified YSOs, AGB and post-AGB stars, Mira variables, and biogenic ice candidates. The latter are particularly important to the study of planet formation and constitute excellent targets for follow-up with missions such as the proposed NASA Medium Explorer mission SPHEREx. We have constructed a robust training set of spectroscopically

confirmed sources and used their AllWISE and 2MASS photometry to train three ML classifiers: Support Vector Machine, Random Forest, and Multi-layer Perceptron. When classifying a test set, all three optimal classifiers perform with scores >0.97. We apply the optimal RF algorithm to a science target set of WISE- and Gaia-selected sources in the galactic plane. As a preliminary result, we have classified over 60,000 of these sources, among which we find over 1,000 likely biogenic ice candidates. We will continue to expand our training set so that we can apply these techniques to even larger sets of unclassified sources in the future. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1659473, and by the Smithsonian Institution.

**Author(s):** Matthew L. N. Ashby, Rafael Martnez-Galarza, Jeremy Atkins, Jacqueline Blaum,

**Institution(s):** Iowa State University, University of Rochester, Harvard-Smithsonian Center for Astrophysics

### **154.03 - A WISE GLIMPSE of Star Formation in the Outer Milky Way(Osase Omoruyi)**

Star formation in the outer Galaxy has not been as extensively studied as it has in the inner Galaxy. Due to lower gas density, lower metallicity levels, and more sparsely distributed molecular clouds, the outer Galaxy's environment is markedly different to the gas-rich and high metallicity environment present in the inner Galaxy. The outer Galaxy thus serves as an excellent laboratory to understand the ways in which the process depends on environmental factors, and obtain a more complete understanding of star formation in the Milky Way. In this project, we use mid-infrared observations from Spitzer and WISE to examine young star clusters (YSC) in a region of the outer Galaxy centered at  $(l, b) = (92.37, 1.97)$ . The kinematic distances obtained from the WISE Catalog of Galactic H II Regions estimate that the YSCs in this field lie a range of distances of 8.8 - 13.3 kpc from the center of the Galaxy. Using a combination of IRAC, ALLWISE, and 2MASS photometry, we identify a total of 293 Class I, 594 Class II, and 45 Class III young stellar objects (YSOs). Given the distance to the region, we are most sensitive to the most massive and luminous stars. Using the DBSCAN and minimum spanning tree methods, we analyzed the clustering properties of identified YSOs in the field. We identify 21 clusters in the region, mostly correlated with the locations of the H II regions in the field and in areas with apparent nebulosity in mid-IR images. The YSO masses modeled by SEDfitter indicate that these are mainly intermediate to massive star-forming regions and with protostellar/pre-main sequence ratios indicating cluster ages of a few Myrs. Our findings, while not representative of the entire outer Milky Way, are an important step in understanding star formation sites in the outer Galaxy, helping us to understand how the process of star formation depends on environmental factors. This research was made possible through participation in the SAO REU program. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-

1659473, and by the Smithsonian Institution.

**Author(s):** Osase Omoruyi, Joseph Hora, Elaine Winston

**Institution(s):** Yale University, Harvard-Smithsonian Center for Astrophysics

#### **154.04 - Studying YSOs Behind the Orion Nebula with High Resolution ALMA Data(Justin Atsushi Otter)**

We report findings from high resolution ALMA data of the Orion Nebula Cluster (ONC). This region is important for studying star-formation because it is the closest site of high-mass star-formation and has a high density of young stellar objects. Both qualities may cause truncated protoplanetary disks in the region through various mass loss processes. We detect 71 sources, of which 13 are newly detected. We also measure proper motions of sources in the region and place an upper limit of 1.2 mas/yr in right ascension and 2.1 mas/yr in declination for measured sources. Combining measured fluxes of these sources with upper limits from previous studies of the region we construct SEDs for each source and will fit these SEDs to derive physical properties of the disks such as luminosity and mass.

**Author(s):** Justin Atsushi Otter, Adam Ginsburg

**Institution(s):** Haverford College, National Radio Astronomy Observatory

#### **154.06 - Multi-Epoch Spectral Analysis of Accretion and Outflow Signatures in Young Binary Stellar Systems: DQ Tau, V826 Tau, and UZ Tau E.(Alina Sabyr)**

Over half of all stars in the Galaxy are found in binary or higher order multiple star systems. The Kepler mission has revealed that planets can form and remain in stable orbits despite the dynamical complexity of these systems. Examining how circumstellar and circumbinary disks evolve in these environments is essential for understanding planet formation. The connection between accreting material and outflowing material (i.e., stellar and disk winds, collimated jets) in singular systems may not apply to the star-disk or star-disk-disk interactions in multiple star systems. To further probe the mass accretion and outflow relationship in binary systems, we are conducting a long-term optical and infrared spectroscopic monitoring program of three nearby binary systems in the Taurus-Auriga star-forming region: DQ Tau, V826 Tau, and UZ Tau E. With nearly simultaneous optical and near-IR spectra, we can probe the standard optical and infrared tracers of accretion and outflow in these systems, taking advantage of the predictability of accretion flares in systems like DQ Tau. Here we present preliminary results of accretion and outflow spectral signatures and compare them to existing single-epoch studies of accreting, solitary young stars.

**Author(s):** Jeffrey S Bary, Alina Sabyr, Jocelyne Andrade, Allison Quintana, Rhys Kurtz Manley, Nicole Jieyi Tan

**Institution(s):** Colgate University, Wesleyan University,

Swarthmore College, Wellesley College

#### **154.07 - Misaligned Circumbinary Keplerian Disks around the Protobinary BHB11(Kazuya Saigo)**

We present the kinematic structure of a peculiar protostellar disk system around the protobinary BHB11, in Barnard 59. BHB11 is embedded in a mini-cluster forming clump, Barnard 59, that is located at the top of the Pipe Nebula. Using ALMA observations, Alves et al. (2017; 2018) show that molecular outflows are launched at the edge of a sharp compact disk with a radius of  $\sim 100$  au. Extended spiral structures of  $\sim 400$  au scales are connected to the compact disk. These extended spiral-like structures are interpreted as infalling gas flows from the envelope onto the compact disk. However, by model fittings of C18O (2-1) using the ALMA Archive data (2013.1.00291.S PI=F. Alves), we propose that BHB11 is a new type of protobinary system that was formed by an encounter of previously unbound protostellar disks. Our fitting results show that the circumbinary disk consists of two misaligned circumbinary Keplerian disks (CBDs). The inclination of the inner CBD with  $R < 90$  au and the outer CBD with  $90 \text{ au} < R < 400$  au are  $i = 35$  deg and  $i = 70$  deg, respectively. Thus, the spiral structures, previously interpreted as inflowing gas, are indeed part of the outer Keplerian disk. We suggest that the outflows are launched from the transition region between both misaligned Keplerian disks. Recent numerical simulations show that such a peculiar disk kinematic around protobinaries can be formed in a binary formation process by a protostellar capture (see Bate 2018). In this poster, we show detailed model fitting and discuss about the impact of such a disk misalignment on star formation scenarios.

**Author(s):** Kengo Tachihara, Masao Saito, Shigehisa Takakuwa, Tomoaki Matsumoto, Kazuya Saigo, Ryohei Kawabe, Patricio Sanhueza, Toshikazu Onishi, Kazuki Tokuda

**Institution(s):** National Astronomical Observatory of Japan, Kagoshima University, Hosei University, Nagoya University, Osaka Prefecture University

#### **154.08 - Accretion, Winds, and Rotation in the Transition Disk System V410 X-ray 6(Olena Komarova)**

The formation pathways of low-mass stars and brown dwarfs, and the mechanisms of their angular momentum evolution during the T Tauri phase, remain outstanding questions in star formation. However, recent observational evidence has shown that wind processes and braking due to disk interaction are less efficient for lower-mass stars than their higher-mass counterparts. This implies that the physical processes governing the rotational evolution of young stellar objects are mass-dependent. We present results from a multi-wavelength case study of the transition disk system V410 X-ray 6 ( $M_{5.5\text{\AA}\pm 1.0}$ ) in Taurus, which falls near the stellar/substellar boundary with an estimated mass of  $0.06 - 0.1 M_{\text{J}}^{\text{TM}}$ . We use WIYN 0.9 m/HDI

VRI + H $\beta$  8-night time series photometry and VLT/X-shooter 200-2500 nm spectra to study stellar rotation and disk environment and explore potential mechanisms of angular momentum loss. The optical lightcurves allow us to estimate a rotation period of the host object, and from multicomponent fits to spectral lines (including H $\beta$ , Pa $\beta$ , Pa $\gamma$ , CaII, NaI) enabled by 0.8 Å... (36 km/s) resolution, we calculate accretion rates and constrain winds. We assess the relative contributions of accretion and wind properties to explore their relationship to rotation period for V410 X-ray 6 and other young objects of similar mass. The combined analyses provide insight into how spin-down mechanisms operate at the stellar/substellar boundary in a transitional disk system. In turn, studying the angular momentum and disk evolution of the lowest-mass stellar and substellar objects improves our understanding of these environments as planet formation sites.

**Author(s):** Kimberly Ward-Duong, Michael Petersen, Miranda Eiben, François Ménard, James D. Lowenthal, Joanna Bulger, Katherine Follette, Suzan Edwards, Gerrit van der Plas, Jennifer Patience, Olena Komarova

**Institution(s):** Smith College, UMass Amherst, Amherst College, Arizona State University, Institut de Planétologie et d'Astrophysique de Grenoble, Université Grenoble Alpes, University of Hawaii

#### **154.09 - The Extinction Curve of AA Tau's 2011 Dimming Event(Kristen Larson)**

AA Tau is a classical T Tauri star with a highly inclined, warped circumstellar disk. For decades prior to 2011, AA Tau exhibited photometric and spectroscopic variability that were successfully modelled as occultations of the primary star by circumstellar material. In 2011, AA Tau entered an extended faint state, presumably due to enhanced levels of circumstellar dust. Optical color-magnitude measurements of the dimming seem consistent with an increase of 2 magnitudes of visual extinction. Color-color diagrams with near-infrared photometry, however, are more indicative of four magnitudes of extinction. To investigate this discrepancy, we obtained two sets of contemporaneous optical-near infrared spectra of AA Tau, one from before the dimming event in December 2008 and one from after the dimming event in 2014. Analysis of the spectra allows us to measure directly the wavelength-dependent extinction curve of the 2011 dimming event. We show that most of the extinction curve is consistent with two magnitudes of visual extinction, and use synthetic photometry of the spectra to explain the previously-reported discrepancy between estimates of visual extinction from optical and near-infrared reddening. We also use veiling measurements to account for the presence of non-photospheric emission in the spectrum, and demonstrate how inferring the extinction curve from the veiling-corrected spectrum affects the agreement with commonly-used extinction laws, particularly in the near infrared. Our study of AA Tau's 2011 dimming event shows the value of obtaining spectra to study the extinction due to dust around young stars.

**Author(s):** Gregory Herczeg, Kristen Larson, Kevin Covey,

Carlo Manara

**Institution(s):** Western Washington University, European Southern Observatory, Kavli Institute for Astronomy and Astrophysics, Peking University

#### **154.10 - Outflows and star-formation feedback from young stellar objects in NGC1333(Natalie Allen)**

NGC1333 is a nearby star-forming region in Perseus which is particularly rich in Class 0/I protostars and associated outflows. We have mapped the entire NGC 1333 complex (~400 arcmin<sup>2</sup>) in near- and mid- infrared spectral lines which trace the supersonic interaction of these outflows with their surroundings. Here we present new Hubble Space Telescope Wide Field Camera 3 spectral images in two [Fe II] lines and H I Pa beta, and earlier Spitzer Space Telescope Infrared Spectrograph images of many more molecular and atomic emission lines. We use these data along with detailed shock models to make accurate rate measurements of the mass, momentum, and kinetic energy deposited into the surrounding cloud by the protostellar outflows. We also determine accurately the extinction toward the shocks, which enables us to determine the location of the energy/momentum deposition in quasi-3D.

**Author(s):** Edwin Bergin, S. Thomas Megeath, Gary Melnick, Joel Green, Thomas Nick Gautier, Dan Watson, Karl Stapelfeldt, David Neufeld, Natalie Allen, Adam Frank

**Institution(s):** University of Rochester, University of Michigan, University of Toledo, Space Telescope Science Institute, Jet Propulsion Lab, Johns Hopkins University, Harvard-Smithsonian Center for Astrophysics

#### **154.11 - Distribution of Serpens South protostars revealed with ALMA(Adele Plunkett)**

Clusters are common sites of star formation, and their members display varying degrees of mass segregation. The cause may be primordial or dynamical, or a combination both. If mass segregation were to be observed in a very young protostellar cluster, then the primordial case can be assumed more likely for that region. We investigated the masses and spatial distributions of pre-stellar and protostellar candidates in the young, low-mass star forming region Serpens South, where active star formation is known to occur along a predominant filamentary structure. In Plunkett et al. (2018) we presented ALMA observations of 1 mm (Band 6) continuum in a 3 x 2 arcmin region at the center of Serpens South. Our angular resolution of 1 arcsec is equivalent to 400 au, corresponding to scales of envelopes and/or disks of protostellar sources. We detected 52 sources with 1 mm continuum, and we measured disk/envelope masses of 0.002-0.9 solar masses. For the deeply embedded (youngest) sources with no IR counterparts, we find evidence of mass segregation and clustering according to: the minimum spanning tree method, distribution of projected separations between unique sources, and concentration of



higher-mass sources near to the dense gas at the cluster center. We conclude that the mass segregation of the mm sources is likely primordial rather than dynamical given the young age of this cluster, compared with segregation time. In this poster we also present an overview of statistical methods currently being used in the literature in order to quantify clustering, which previously had been used for stellar clusters and now can be used along with recent high-resolution/sensitivity mm-wave observations for the earlier cases of protostellar clusters.

**Author(s):** Diego Mardones, Hector Arce, Manuel Fern andez-L  pez, Michael Dunham, Gemma Busquet, Adele Plunkett

**Institution(s):** National Radio Astronomy Observatory, Instituto Argentino de Radioastronom  a, CCT-La Plata (CONICET), Institut de Ci  ncies de l'Espai (IEEC-CSIC), Universidad de Chile, Yale University, State University of New York at Fredonia

#### **154.12 - Different Observational Properties of the Leading and Trailing Edges of the KH 15D Circumbinary Ring(Aylin Garcia Soto)**

Since the discovery of its unique photometric behavior at Wesleyan University's Van Vleck Observatory in 1998, V582 Mon (KH 15D) has been closely monitored at optical and, more recently, near-infrared wavelengths. Photographic plates from the 1950s have helped provide a longer-scale timeline, detailing the complex photometric behavior of a binary system of two weak-lined T Tauri stars embedded within a circumbinary (CB) ring. Detailed modeling has clarified the precession-driven movement of a warped CB ring, whose stellar occultations periodically cause the system to dim by up to 3.5 magnitudes in the V-band. As time has progressed, the CB ring, essentially acting as an opaque screen, has moved across the system and blocked varying parts of the binary orbit. The Leading Edge of this screen moved across the orbit of star B prior to the beginning of intensive monitoring and then began, in the mid-1990's, occulting increasingly more of the orbit of star A, until we only saw star A "rising" and "setting" behind the ring. It is not until more recently (~2012) that the Trailing Edge has caused a similar phenomenon with star B in place of star A. Optical and infrared observations from the SMARTS/ANDICAM instrument at the Cerro-Tololo Inter-American Observatory (CTIO) have revealed details of a clumpy and semi-transparent Trailing Edge. The photometric behavior is different from the previously observed properties of the Leading Edge, which showed little to no reddening caused by dust clumps, but a behavior characteristic of a knife-edge. In this paper, we present observational evidence that the two edges differ in their clumpiness and transparency. These properties of the Trailing Edge enhance the need to continue monitoring the system. The CB ring in KH 15D, with a radius of about 3 AU, is one of the innermost pre-planetary rings known and the only one in which clumpiness on stellar scales can be observed.

**Author(s):** Aleezah Ali, William Herbst, Amanda Newmark, Joshua Winn, Aylin Garcia Soto, Diana Windemuth

**Institution(s):** Wesleyan University, University of Washington, MIT, Princeton University

### **155 - YSOs & Friends II -- Posters**

#### **155.01 - Orbits of Low Mass Binary Stars in the Taurus Star-forming Region(Kathryn Chandra)**

We present new astrometry and orbital solutions for a set of binary stars in the Taurus star-forming region. These binaries, some of which have been monitored for over two decades, were observed by our team using speckle interferometry and adaptive optics at Keck Observatory between 1997 - 2015. We combine our new data with astrometric points from the literature in order to fit orbits to those binaries with sufficient measurements. We will present new and/or updated mass estimates for these binaries, which are aided by new parallax estimates from Gaia. Our masses will be compared to predictions from theoretical evolutionary models, with a focus on the M-type binaries that have the fewest empirical constraints at the age of Taurus. Our results will aid in understanding the early evolution of low mass stars

**Author(s):** Russel White, Kathryn Chandra, Andrea Ghez, Quinn Konopacky, Gaspard Duchene

**Institution(s):** University of California, San Diego, Georgia State University, University of California Los Angeles, University of California Berkeley

#### **155.02 - Probing the Hot, Dense Gas near Massive Protostars via Water Absorption(Nick Indriolo)**

The regions surrounding massive protostars are complex in terms of structure, dynamics, and chemistry. Warm conditions drive a significant fraction of the oxygen into water, increasing H<sub>2</sub>O abundances such that water is ubiquitous in these environments. As a result, water is a sensitive tracer of the various physical components (e.g., envelope, outflow, jet, disk) associated with massive protostars. While Herschel/HIFI has revealed abundant emission from warm water around massive protostars, those observations predominantly probe the large scale structures of the envelope and outflows. To probe the hot, dense gas in the innermost regions surrounding massive protostars requires complementary observations of ro-vibrational H<sub>2</sub>O transitions in the near- to mid-infrared. We have observed select spectral windows in the 5-7 micron range at about 4 km/s resolution with SOFIA/EXES toward a small sample of massive protostars, targeting ro-vibrational transitions of water arising from states with energies ranging from 0 to 4000 K above the ground state. I will present findings from our analysis of these data, and include comparisons to previous observations of water in these objects made at THz frequencies with Herschel/HIFI, at far-IR wavelengths with Herschel/PACS, and in the mid-IR at low spectral resolution with ISO-SWS.

**Author(s):** M. J. Richter, Nick Indriolo, A. Karska, Edward J Montiel, Curtis DeWitt, A. C. A. Boogert, David Neufeld

**Institution(s):** Space Telescope Science Institute, Institute

for Astronomy, University of Hawaii at Manoa, Johns Hopkins University, University of California Davis, USRA, SOFIA, NASA Ames Research Center, Center for Astronomy, Nicolaus Copernicus University

#### **155.03 - The Importance of Luminosity Outbursts in Building Low-Mass Stars(William J. Fischer)**

During the formation of a low-mass star, gas accretes from the protoplanetary disk onto the star both in episodic bursts and in steady, slowly varying flows. We investigate what fraction of a typical star's ultimate main-sequence mass is attributable to each mode. This has implications for the evolution of accretion onto protostars, the properties of stars as they transition from protostars to pre-main-sequence stars, and the evolution of disks being heated by the bursts. We update our ongoing study of outbursts among 319 Orion protostars with new data on the known events in HOPS 223 (V2775 Ori) and HOPS 383 and with the discovery of two additional outburst candidates via the Spitzer program "Orion: The Final Epoch." Our previously reported estimate of about 1000 yr between outbursts in each protostar remains unchanged with the addition of two new outbursts over a longer time baseline. Under a range of assumptions, we estimate that more than 25% of a star's main-sequence mass is attributable to outbursts. We discuss a strategy for refining these estimates further with a campaign by the proposed Origins Space Telescope.

**Author(s):** Wafa Zakri, William J. Fischer, S. Thomas Megeath, Robert Gutermuth, Emily Safron

**Institution(s):** Space Telescope Science Institute, University of Toledo, Louisiana State University, University of Massachusetts

#### **155.04 - Characterization of Phosphorus-Bearing Molecules within the B1-a Protostar(Salma Cynthia Walker)**

The element phosphorus is imperative to life on Earth and even more considered an important ingredient for the origins of life. However, little is known about the inheritance of phosphorus-bearing molecules during the early stages of star and planet formation. Low-mass protostars are analogs to the young sun and offer a window into the history of our solar system. We recently detected phosphorus-bearing molecules in the vicinity of one such protostar, B1-a, using the IRAM 30m telescope. We have quantified the amount of phosphorus nitride and phosphorus monoxide present in the gas phase and determined the temperatures these molecules are emitted. To derive further information on the emission origin of these phosphorus molecules, we have observed additional tracer molecules: SiO, C<sub>18</sub>O, <sup>13</sup>CO, CH<sub>3</sub>OH, and H<sub>2</sub>CO. Comparisons of tracer molecules with phosphorus nitride and phosphorus monoxide will reveal whether the phosphorus emission comes from the cold outer envelope, warm inner envelope/hot corino, or shocked outflow, leading to an understanding of how

phosphorus might be inherited in later evolutionary stages.

**Author(s):** Salma Cynthia Walker, Jennifer Bergner, Karin I Åberg

**Institution(s):** California State University, Northridge, Harvard-Smithsonian Center for Astrophysics

#### **155.05 - H Band Observations of the Candidate Young Spectroscopic Binary UY Auriga B and its Disk(Sean Graham)**

Binaries dominate the stellar census; understanding disk evolution in these complex environments is crucial in order to form a complete and accurate model for planet formation. UY Auriga is a ~2 Myr old classical T Tauri binary with a separation of ~0.9". The system contains a number of complex gas-dust interactions between the circumbinary and circumstellar disks. Multiple epochs of high-resolution H-band spectroscopy show that UY Aur B exhibits extreme spectral variability over a period of 13 years or more; it is also known to be highly photometrically variable. We explore whether UY Aur B might itself be a close, short-period binary and provide estimates of accretion properties and possible orbital solutions and component mass ratios.

**Author(s):** Kendall Sullivan, Gail Schaefer, Sean Graham, Lisa Prato, Matthew Michael Wittal, Larissa Nofi

**Institution(s):** Northern Arizona University, GSU/CHARA, Lowell Observatory, JPL, UT Austin

#### **155.06 - High Resolution Mid-IR Observations of the Molecular Universe with EXES on SOFIA(Curtis N DeWitt)**

The Echelon Cross Echelle Spectrograph (EXES) is a high-resolution (R~100,000) spectrograph operating in the 4.5-28.3um region onboard NASA/DLR's SOFIA observatory. The combination of high-resolution spectroscopy and spectral windows previously unavailable from the ground has made EXES a powerful and productive tool particularly in the study of molecules around protostars, evolved stars and in solar system objects. We highlight results from the 2016-2017 campaigns including studies of sulfur chemistry in two massive protostellar envelopes (Mon R2 IRS 3 and AFGL 2591), water in the atmosphere of the cool supergiant, VY CMa, and a search for water vapor plumes from Jupiter's moon Europa.

**Author(s):** Matthew Richter, Edward J Montiel, Curtis N DeWitt

**Institution(s):** USRA SOFIA, University of California Davis

#### **155.07 - Stellar Photometry of Cepheus-C Using PSF-Fitting(John B Taylor)**

As part of the 2017 NASA/IPAC Teacher Archive Research Program (NITARP), potential young stellar objects (YSOs) were examined in the Cepheus-C star-forming region of the Cepheus

OB3 molecular cloud. Aperture photometry was performed on archival Herschel data to construct spectral energy distribution diagrams (SEDs) along with color-color and color-magnitude diagrams. In Evans, et. al (2018), 54 YSO candidates were identified; 11 of which had not been previously detected. As Ceph-C is a crowded field, using aperture photometry is not the best method of determining the flux of close stars. In the current project, PSF-fitting is used to improve the photometry in this crowded region. The Astropy implementations of DAOPhot (Photutils) were used to do PSF-fitting photometry at PACS (70 and 160  $\mu\text{m}$ ) and SPIRE (250, 350 and 500  $\mu\text{m}$ ) wavelengths. This study shows that aperture photometry from last year's work was probably sufficient for isolated sources, while PSF-fitting photometry is necessary for the crowded regions.

**Author(s):** Dakota Powers, Luisa Rebull, John B Taylor, Thomas Rutherford, Olivia K. Stalnaker

**Institution(s):** Elkhart Memorial High School, Sullivan South High School, Caltech-IPAC/IRSA, Lake Dallas Middle School

### **155.08 - Fast and Furious: Constraints on Runaway Ejection Mechanisms for Massive Stars in the Small Magellanic Cloud(John Dorigo Jones)**

We study the kinematics of runaway stars using GAIA DR2 proper motions (PMs) of 304 field OB stars in the Small Magellanic Cloud (SMC) from the RIOTS4 survey. To identify runaways, we remove the SMC systemic motion from, and apply geometric corrections to, the PMs to obtain the residual peculiar velocities. We find that the SMC Wing has a systemic transverse velocity relative to the SMC Bar of  $(v_{\perp}^{\text{SMC}}, v_{\perp}^{\text{Bar}}) = (62 \pm 7, 18 \pm 5) \text{ km/s}$ . After removing this offset from our 68 Wing stars, we obtain  $43 \pm 6 \text{ km/s}$  as the median total transverse velocity of all 304 stars. We find this implies that on the order of half of our massive field stars are runaways, as opposed to having formed in situ. We explore the two mechanisms that produce runaway stars: dynamical binary-binary interactions and supernova “slingshot” ejections. We confirm that both processes have a similar contribution to our runaway population, with the former inferred from the number of eclipsing binaries and double-lined spectroscopic binaries, and the latter inferred from the number of high-mass X-ray binaries. Moreover, our finding that the SMC Wing has a relative motion away from the Bar and toward the Large Magellanic Cloud supports models of a recent collision between the Clouds.

**Author(s):** Danny Lennon, M. Oey, Maxwell Moe, Nitya Kallivayalil, Gurtina Besla, Helen Januszewski, John Dorigo Jones, Norberto Castro, Paul Zivick

**Institution(s):** University of Michigan, University of Arizona, University of Virginia, Instituto de Astrofísica de Canarias, European Space Astronomy Centre

### **155.09 - The Duration of Star Formation in Galactic Massive Star-Forming Regions from X-ray and Infrared Observations(Matthew Samuel Povich)**

We present two new techniques for constraining the evolutionary ages of intermediate-mass ( $2-8 M_{\odot}$ ), pre-main-sequence stars (IMPS) in obscured, massive Galactic star-forming regions using combined infrared (IR) and X-ray point-source photometry catalogs containing thousands of objects. High-spatial-resolution X-ray images identify IMPS with or without IR excess emission from circumstellar disk disks. IMPS complete their evolution across the Henyey tracks to reach the ZAMS as AB stars in  $<10 \text{ Myr}$ , hence placing them on the HR diagram by modeling IR SEDs gives a more robust constraint on (model-dependent) evolutionary age than is possible for lower-mass stars that slowly descend the Hayashi tracks. Very young IMPS with GK spectral types produce intrinsic, strong coronal X-ray emission that rapidly decays with time following the development of a radiative zone. We hence observe an age-dependent dearth of intermediate-mass stars in an X-ray-selected stellar mass function compared to a standard stellar initial mass function. In the process we identify candidate unresolved binary star systems in which the IR-detected primaries are A or late B-type stars (including Herbig Ae/Be stars), but the observed X-ray emission must originate from lower-mass, T Tauri companions. These techniques will be applied to calibrate star formation rates in a sample of luminous Galactic H II regions. This work has been supported by the NSF via awards CAREER-1454224 and DUE-1356133 (Cal-Bridge) and by NASA through Chandra Award Go7-18003B.

**Author(s):** Jessica T Maldonado, Matthew Samuel Povich, Thomas Robitaille, Evan Haze Nunez

**Institution(s):** Cal Poly Pomona, Max Planck Institute for Astronomy, Michigan State University, Headingley Enterprise and Arts Centre

### **155.10 - Star Formation Near Cometary Globules in the Gum Nebula(Alexandra Christine Yep)**

The Gum Nebula is a complex, blustery region home to at least 32 cometary globules, evaporated into comet-like shapes by O-type stars  $\hat{\Gamma}^{32} \text{ Vel}$  and  $\hat{\Gamma}^{\eta} \text{ Pup}$ . Our spectroscopic study of 21 low-mass young stars reveals 14 may be dynamically related to cometary globule CG 30. Gaia DR2 distances to a subset of 6 stars yield a distance of  $361.8 \pm 5.4 \pm 5.2 \text{ pc}$  to CG 30. We also spectroscopically confirm that the infrared source CG 30 IRS 4, the first spectroscopically confirmed star embedded inside a cometary globule, has T Tauri-like properties. The related young stars' strong lithium absorption, broad  $\text{H}\beta$  emission, spectral veiling (a filling-in of absorption lines caused by accretion), and placement on an HR diagram suggest they are  $\sim 1 \text{ Myr}$  old. We calculate an accretor fraction of 21-36%, roughly half that of similarly aged Taurus-Auriga and  $\hat{\Gamma}^{\eta} \text{ Ophiuchus}$  clusters, implying a high-radiation environment may shorten circumstellar disk lifetimes. To investigate this more completely, we use Gaia DR2 parallaxes and proper motions to identify new clusters associated with other cometary

globules in the Gum Nebula. We highlight 4 potentially young clusters near CG 1, 3, 4, and 22, as well as six more potentially young stars near CG 30. We observe the brighter stars ( $V < 13$ ) with CHIRON on the 1.5 m SMARTS telescope to confirm cluster membership and measure youth and other stellar properties. This assessment of stellar populations in the Gum Nebula could help us understand star and potentially planet formation under intense radiation.

**Author(s):** Alexandra Christine Yep

**Institution(s):** Georgia State University

#### **155.11 - A High-Resolution Optical Spectroscopic Survey of Herbig AeBe Stars(Alicia Aarnio)**

We present an atlas of high-resolution optical spectra of Herbig AeBe stars, pre-main sequence objects bridging the gap between high- and low- to intermediate-mass star formation. Our data are from the Magellan Inamori Kyocera Echelle (MIKE) double echelle spectrograph and span a range of  $\sim 3200\text{--}9000\text{\AA}$ .... We analyze and categorize spectral line morphologies and comment on their relationship with stellar parameters derived from the spectra and the literature. A preliminary discussion of coordinated interferometric measurements, part of a broader Michigan Young Stellar Object program, is also presented.

**Author(s):** Alicia Aarnio, John Monnier

**Institution(s):** University of North Carolina Greensboro, University of Michigan

#### **155.12 - Resolving Protostars in L1251A: A Look into a Small Young Group with SOFIA/FORCAST(Tracy L. Huard)**

The Spitzer Space Telescope and Herschel Space Observatory have surveyed nearby star-forming regions, resulting in an enormous census of protostars in a wide variety of environments, from those forming a single star to those forming large clusters. Much of the detailed modeling of core collapse and the formation process has focused on the former, while most stars form in clusters. A natural next step is to focus on modeling of small young groups, such as L1251A, which includes several protostars blended in previous mid-infrared observations. We recently obtained SOFIA/FORCAST observations of L1251A to deblend these protostars and construct reliable spectral energy distributions. We present these observations, estimate the luminosities of the protostars, infer their evolutionary stages, and discuss their formation in L1251A. Such observations of small young groups may inform and constrain models extended to handle multiple star formation in a common envelope.

**Author(s):** Tracy L. Huard, Susan Terebey

**Institution(s):** University of Maryland, California State University at Los Angeles

#### **156 - The Role of Magnetic Fields and Filaments in Star Formation -- Posters**

##### **156.01 - HAWC+/SOFIA Observations of OMC-1: Spectral Energy Distributions(Joseph M. Michail)**

The Orion Molecular Cloud-1, OMC-1, has been well-studied as an example of a region that is actively forming massive stars. The High-resolution Airborne Wideband Camera+, HAWC+, on the SOFIA telescope has observed this region polarimetrically and photometrically at wavelengths of 53, 89, 154, and 214 microns. These new data will help determine the role of magnetic fields in the dynamics of the region. Combining the photometry from HAWC+ with other far-infrared, submillimeter and radio maps, we produce new spectral energy distributions across a  $\sim 5$ -arcminute region from  $\sim 50$  microns to 3.5 cm. We fit the intensity with a single-temperature modified blackbody and a free-free component that contributes at long wavelengths. We present the resulting maps of temperature, column density and dust emissivity index at 19-arcsecond resolution.

**Author(s):** Michael Werner, John Vaillancourt, Javad Siah, David Chuss, Joseph M. Michail, Doyal Harper, C. Darren Dowell, Jordan Guerra Aguilera

**Institution(s):** Villanova University, Jet Propulsion Lab, MIT Lincoln Lab, University of Chicago Contributing Team(s): HAWC+ Science Team

##### **156.02 - Infrared Studies of Mass Loss from Evolved Stars in the Galactic Bulge(Allyssa Riley)**

To investigate the relationship between mass loss from evolved stars and host galaxy metallicity, we aim to determine the total mass loss rate and average mass loss rates due to various classes of evolved stars - asymptotic giant branch (AGB) stars and red supergiant stars - in the Galactic Bulge and compare this result to that previously obtained for the Magellanic Clouds, with special attention to the dust production rates. We construct spectral energy distributions (SEDs) for our candidate RSG and AGB stars using observations from various infrared surveys, including the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE). Because Robitaille et al (2008, AJ, 136, 2413) have already identified Intrinsically Red Objects from the GLIMPSE I and II surveys, we use their method as a starting point and expand the study by using the GLIMPSE 3D survey. AGB stars can be variable, so we match the GLIMPSE I, II, and 3D sources to other surveys, such as DEEP GLIMPSE, WISE, VVV, and DENIS, in order to characterize the variability across the spectral energy distribution (SED) of each source. This allows us to determine the source's average SED over multiple epochs. Then, we use extinction curves derived from Spitzer studies of extinction in the Galaxy to determine the extinction corrections for our sample. To establish dust-production rates of evolved stars in the Bulge, we use the Grid of Red supergiant and Asymptotic giant branch Models (GRAMS) of dust-enshrouded evolved stars (2011, A&A, 532, A54; 2011, ApJ, 728, 93). Before determining total dust return to the Bulge from these stars, we

must separate and distinguish Young Stellar Objects (YSOs) from AGB stars by comparing the GRAMS fit to fits using Robitaille, et al 2017 YSO models. In the end, we present a final catalog and archive containing AGB stars found in this analysis. This work has been supported by NASA ADAP grant 80NSSC17K0057.

**Author(s):** Benjamin Sargent, Allyssa Riley, Sundar Srinivasan

**Institution(s):** Space Telescope Science Institute, IRyA/UNAM

### **156.03 - SOFIA-EXES and Spitzer-IRS Studies of Gases in the Circumstellar Environments of Young Stellar Objects(Allyssa Riley)**

The building blocks of planets in planet-forming ("protoplanetary") disks assemble early in the lifetime of a young star. The gas disks are relatively short-lived, with a half-life of several (about 3-5) million years, as chemical reactions modify the reservoir of material from the natal molecular cloud. We present 5-7.5 micron Spitzer Space Telescope Infrared Spectrograph (IRS) spectra of about a dozen T Tauri stars in the Taurus-Auriga star-forming region with emission from water vapor and absorption from other gases in these stars' protoplanetary disks. Some of these stars' spectra show a strong emission feature at 6.6 microns due to the  $\nu_2 = 1-0$  bending mode of water vapor, with the shape of the spectrum suggesting water vapor temperatures  $>500$  K. Other stars' spectra show a strong absorption band, peaking in strength at 5.6-5.7 microns, which appears consistent in some cases with gaseous formaldehyde ( $H_2CO$ ) and in other cases with formic acid ( $HCOOH$ ). Modeling of these stars' spectra suggests these gases are present in the inner few AU -- i.e., in the planet-forming regions -- of their disks. Spitzer-IRS spectra at these wavelengths are of low resolution ( $R \sim 100$ ), so higher resolution spectra are needed to confirm the presence of these molecules. As such, we obtained SOFIA-EXES spectra of YSOs to follow up on these Spitzer-IRS studies. The medium resolution EXES spectrum is of good quality and shows interesting absorption structure. The low resolution EXES spectra suffer strong fringing, and we present our attempts to de fringe the data. These data are evaluated in light of the analysis of the Spitzer-IRS data. Future directions for this research are also discussed. This work suggests that water and organic molecules, which are crucial for life as we know it, are present in the habitable zones of stars at a very early age [of 1-3 million years]. We would like to acknowledge SOFIA funding from subcontract SOF 04-0180 Sargent and subcontract SOF 04-0188 Sargent of prime contract NAS2-97001.

**Author(s):** Benjamin Sargent, Nuria Calvet, Allyssa Riley, William J. Forrest

**Institution(s):** Space Telescope Science Institute, University of Michigan, University of Rochester

### **156.04 - First Look at Orion-KL with FIFI-LS onboard SOFIA(Robert Minchin)**

As the closest region of high-mass star formation the Kleinmann-Low (KL) Nebula in Orion has been well studied. The young massive Trapezium cluster emits copious UV radiation that created a blister HII region bounded by the molecular cloud. In addition, this radiation creates a photon-dominated region (PDR) that includes the well-known Orion Bar. As our nearest region of massive star formation and as a bright and interesting region by itself, every new instrument will always observe Orion. It is our prototype region with which we can compare to other star forming regions farther away where limited spatial resolution requires more assumptions about morphology and use as a template when observing star forming regions in galaxies. In this presentation, we present the first look at the Orion-KL region in the far-infrared obtained with the Far Infrared Field Imaging-Line Spectrometer (FIFI-LS) instrument onboard SOFIA. We observe six fine structure lines and several CO high-J transitions to illustrate the mapping ability of FIFI-LS and to probe the physical conditions in the Orion-KL region. We present large maps in these transitions of the Orion Nebula. We used the ratio of the two  $[OIII]$  lines at 52 and 88  $\mu m$  to map the electron density over the HII region. It ranges from 103 to 104  $cm^{-3}$ . We can also present first results of the analysis of the PDR cooling lines and molecular lines leading to maps of physical conditions

**Author(s):** Randolph Klein, Leslie Looney, Dario Fadda, Chrisitan Fischer, Robert Minchin

**Institution(s):** SOFIA/USRA, SOFIA/DSI, University of Illinois  
Contributing Team(s): FIFI-LS

### **157 - Space Mission Instrumentation I -- Posters**

#### **157.01 - Thermal Blocking Filters for Infrared Applications(Sophia Singh)**

Thermal blocking filters find wide-spread application in cryogenic astronomical imaging systems. Representative examples can be found in far-infrared radiometers, photometers, spectrometers, and polarimeters where high in-band throughput and out-of-band rejection are important design considerations. A goal of this project is to investigate the ability of Frequency Selective Surfaces (FSS) to meet these needs. Numerical and analytical modeling techniques are explored as tools for the prediction of the electromagnetic response of these structures. Expressions were evaluated in MATLAB to simulate the interaction of electromagnetic waves with an infinite 2D metallic array of structures on a dielectric substrate. This analysis approach assumes that the metal lattice was infinitely thin and resides at the interface of a dielectric half-space. The results obtained with this analytical model were then compared to the numerical simulations. COMSOL - a multi-physics package widely used for different applications, including electromagnetic applications, was used to implement a 3D model of the structure and verify the accuracy of the analytical expressions.

**Author(s):** Edward Wollack, Sophia Singh, Karwan Rostem  
**Institution(s):** University of Southern California, NASA  
Goddard Space Flight Center

#### **157.02 - HabEx: Architecture A Telescope Design and Performance Prediction(H. Philip Stahl)**

The Habitable Exoplanet Observatory Mission (HabEx) is one of four missions under study for the 2020 Astrophysics Decadal Survey. Its goal is to directly image and spectroscopically characterize planetary systems in the habitable zone around nearby sun-like stars. Additionally, HabEx will perform a broad range of general astrophysics science enabled by 100 to 2500 nm spectral range and 3 x 3 arc-minute FOV. Critical to achieving the HabEx science goals is a large, ultra-stable UV/Optical/Near-IR (UVOIR) telescope. The baseline HabEx telescope is a 4-meter off-axis unobscured three-mirror-anastigmatic, diffraction limited at 400 nm with wavefront stability on the order of a few 10s of picometers. The telescope's opto-mechanical design enables it to meet its error budget allocated thermal-structural-optical performance tolerances.

**Author(s):** H. Philip Stahl

**Institution(s):** NASA Contributing Team(s): MSFC HabEx Telescope Study Team, JPL HabEx Telescope Study Team

#### **157.03 - The James Webb Space Telescope: Observatory Status and Plans(Randy Kimble)**

The James Webb Space Telescope (JWST) is a large (6.5 m), segmented-aperture telescope, equipped with near- and mid-infrared instruments (0.6-28 microns), all of which are passively cooled to ~40 K in the shade of a 5-layer sunshield, while the mid-infrared instrument is actively cooled to 7 K. The integration of the observatory has funneled down to two major components: 1) the telescope and its associated integrated instrument suite - this assembly was delivered to Northrop Grumman in early 2018, after a successful cryo-vacuum test program at NASA's Johnson Space Center in 2017; and 2) the spacecraft element, consisting of the sunshield and the warm spacecraft bus on the sunward side of the observatory - this assembly is currently undergoing environmental testing. We describe the current status of the observatory, its path toward completion, and the planning for commissioning of the observatory after launch.

**Author(s):** Randy Kimble, Erin C. Smith, Charles W. Bowers, Malcolm B. Niedner, Michael McElwain

**Institution(s):** NASA's Goddard Space Flight Center  
Contributing Team(s): The JWST Project Team

#### **157.04 - The Nimble Time Domain Explorer Mission Concept: Ancillary Science Opportunities(Thomas Barclay)**

Nimble is a NASA Explorer class mission concept that couples a very wide-field gamma ray monitor with a multiwavelength telescope and rapid response spacecraft. The primary mission science is focused on detection and characterization of binary neutron star (BNS) mergers by observing their short gamma-ray bursts and kilonovae. The transient BNS science is estimated to account for around 50% of available science time, and therefore, a significant portion of Nimble on-sky time will be made available to the general astronomical community. Nimble's workhorse instrument is a Small UV-Optical-IR camera (SUVOIR) that provides high-precision, multiwavelength photometry and low-resolution spectroscopy. The orbital design will enable multi-day observing baselines, providing a highly capable follow-up resource for photometric facilities such as Kepler, TESS, and LSST. One exciting opportunity is for Nimble to perform transmission spectroscopy of transiting exoplanets at wavelengths from 300-2300 nm, which will enable a survey of super-Earth and mini-Neptune atmospheric compositions. Beyond planets, Nimble's flexible platform will enable for a wide range of time domain science spanning distance scales measured in AU to Mpc.

**Author(s):** Sarah E. Logsdon, Maxime Rizzo, S. Bradley Cenko, Joshua Schlieder, Eric D. Lopez, Jeremy S Perkins, Thomas Barclay, Julie McEnery, Kimberly Weaver, Stephen Rinehart, Judith Racusin, Qian Gong, Patricia Boyd, Regina Caputo, Michael McElwain

**Institution(s):** NASA Goddard Space Flight Center

#### **157.05 - Constructing a User Interface for the Alignment of CAT Gratings(Paula Moraga Baez)**

The objective of this project is to integrate existing software programs into a single software interface that will allow a user to align Arcus critical angle transmission (CAT) gratings before they are bonded to their frames, making grating facets. CAT gratings allow x-ray photons to pass through at an angle that matches the grazing incidence angle, hence the name critical angle transmission gratings. Arcus, an x-ray spectrometer, will require 704 aligned grating facets. Because these gratings are produced with a small amount of error, they must be aligned in 6 axes (translation and rotation) before they are bonded to a facet frame. This is done so that any two of the resulting grating facets can be interchangeable with each other. The current process used to align these gratings requires two people to exchange measurements and to manually input corrections to alignment: one to control the movement of the Hexapod, a six-legged stage on which the grating will be placed, and the other to perform the data analysis used to calculate the required adjustments. This is impractical for the large scale operation that will be required for the flight-build, causing a need for a simplified alignment process that is completely and comprehensively planned out and that eliminates the possibility of operator error. This project specifically focuses on rewriting the existing C# and Matlab programs used to record alignment data and demonstrate when alignment has been achieved. The code written in Python will take data, indicate which Hexapod axes to move to achieve alignment and determine that the

misalignment has been completely removed. There are future plans to finish building the GUI by including code that will aid in the movement of the Hexapod, and building the user interface around it. This work was supported through the NSF-REU Solar Physics program at SAO, grant number AGS-1560313. Keywords: Astronomical optics, Interdisciplinary astronomy, Spectrometers

**Author(s):** Paula Moraga Baez, Peter Cheimets, Edward Hertz  
**Institution(s):** Northern Illinois University, Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics  
**Contributing Team(s):** Arcus Team

#### **157.06 - Updates on the Performance and Calibration of HST/STIS(Matthew Maclay)**

The Space Telescope Imaging Spectrograph (STIS) has been on board the Hubble Space Telescope for 21 years and continues to produce high quality results. The instrument's diverse capabilities include spatially resolved spectroscopy in the UV and optical, high spatial resolution echelle spectroscopy in the UV, and solar-blind imaging in the UV. STIS also supports unique visible-light coronagraphic modes that keep the instrument at the forefront of exoplanet and debris-disk research. The instrument's characteristics evolve over time, and the STIS branch at the Space Telescope Science Institute monitors its performance and continually works to optimize its data products. We present updates on the performance of the STIS CCD and FUV & NUV MAMA detectors, improvements to the calibrated science products delivered by CalSTIS, and other recent user-relevant updates. We discuss the effects of the new HST gyroscope configuration on STIS performance and highlight improvements to the calibration of echelle observations, including echelle blaze function shift updates and a calibration program to derive new sensitivity curves for the E140M grating.

**Author(s):** Tala Wanda R. Monroe, Paule G. Sonnentrucker, Charles Proffitt, Sean Lockwood, Daniel Welty, John Debes, Allyssa Riley, Doug Branton, S. Tony Tony Sohn, Matthew Maclay, Joleen K Carlberg

**Institution(s):** Space Telescope Science Institute

#### **157.07 - The Mid-Infrared Transit Spectrometer Instrument (MISC) for the Origins Space Telescope Baseline Mission Concept(Thomas Roellig)**

The Origins Space Telescope (OST) is one of four potential flagship missions that have been funded by NASA for study for consideration in the upcoming Astrophysics Decadal Review expected in 2020. In order to fit inside the NASA cost guidelines, a OST Baseline Mission Concept has been developed that consists of a 5.9m diameter telescope that is cooled to 4.5K and a mission that will be optimized for efficient mid and far-infrared astronomical observations. An initial suite of three focal plane instruments was chosen for the Baseline version of this observatory, although an up-scaled version of this mission

will also be presented to the Decadal Review that will include an additional instrument and expanded capabilities within the base-lined instruments. The Mid-Infrared Transit Spectrometer (MISC) instrument will observe at the shortest wavelengths of any of these instruments, ranging from 2 to 20 microns and is optimized for measurements of bio-signatures in the atmospheres of transiting exoplanets. This wavelength range allows measurements of the surface temperatures of the exoplanets as well as detections of the bio-signature molecules O<sub>3</sub>, CH<sub>4</sub>, H<sub>2</sub>O, CO<sub>2</sub>, and N<sub>2</sub>O at Earth-levels, should they exist in an exoplanet atmosphere. The MISC instrument has a densified pupil spectrometer design with R~50-100 and is capable of exoplanet transit and emission spectroscopy with very high spectro-photometric stability from 2.8 to 20.0 microns. A dichroic beam-splitter picks off 2.0-2.8 micron light from the host star and sends it to a small detector array that is used to provide fine pointing correction signals to a tip-tilt mirror in the telescope optics. This presentation covers the design and expected performance of both the current Baseline version of this instrument as well as the capabilities of the up-scaled design that will also be provided to the Decadal Review.

**Author(s):** Taro Matsuo, Itsuki Sakon, Kimberly Ennico, Thomas Roellig, Tomoyasu Yamamuro, Yuji Ikeda

**Institution(s):** NASA Ames Research Center, University of Osaka, University of Tokyo, Photocoding Corp., Optocraft Corp  
**Contributing Team(s):** The MISC Instrument Study Team

#### **157.08 - JWST/NIRSpec Pipeline Data Processing(Glenn M Wahlgren)**

We present the methodology and current status of James Webb Space Telescope (JWST)/NIRSpec instrument pipeline data processing, highlighted by spectral data products generated from ground test data and simulations. NIRSpec pipeline data processing is part of a comprehensive calibration pipeline that will provide science-ready data products for the JWST instruments. The NIRSpec spectrograph will enable spectroscopy from 0.6-5.3 microns for a wide variety of celestial sources and science use cases. The instrument offers three different modes that provide unique and complementary capabilities. Simultaneous spectroscopy of dozens to hundreds of objects in a single exposure will be possible using the multi-object spectroscopy mode, accomplished using a microshutter array (MSA) that contains a quarter-million independently operable microshutters and covers a 3.6'x3.4' field of view. The integral field spectroscopy mode will allow spatially-resolved spectroscopy with spatial elements of 0.1" over a field of view of 3"x3" using an integral field unit (IFU). Finally, high-contrast spectroscopy of individual sources, including time series observations such as planet transits, will be possible using the fixed slit mode.

**Author(s):** Benjamin Sargent, James Muzerolle, Graham Kanarek, Cheryl Pavlovsky, Glenn M Wahlgren

**Institution(s):** GDIT/STScI, STScI  
**Contributing Team(s):** The NIRSpec Team

#### **157.09 - History of the ACS/WFC Bias Properties after Servicing Mission 4(Tyler Desjardins)**

We present an analysis of the Hubble Space Telescope (HST) Advanced Camera for Surveys Wide Field Channel (ACS/WFC) bias properties since its repair during Servicing Mission 4 (SM4) in May 2009. The bias levels in all four readout amplifiers have shown an asymptotic decline of  $\sim 45$  electrons since SM4, with additional periodic behavior in the bias level corresponding to several timescales ranging from one month to one year. An examination of the read noise history since SM4 reveals that the post-SM4 WFC subarrays experienced slightly elevated read noise compared to the full-frame readout with the increase in read noise inversely proportional to the size of the subarray. The subarray patterns implemented in HST Cycle 24 brought the subarray read noise values back into agreement with the full-frame. Furthermore, we find that the read noise levels have steadily increased by 0.005 electrons per year, infrequently punctuated by rapid and mostly low-amplitude jumps in those levels. A total of five read noise anomalies are observed in readout amplifiers A and D, while the read noise of amplifiers B and C has been more well-behaved.

**Author(s):** Norman Grogin, Tyler Desjardins

**Institution(s):** Space Telescope Science Institute

#### **157.10 - Photon Counting EMCCD Developments for the WFIRST Coronagraph(Patrick Morrissey)**

A photon counting camera based on the Teledyne-e2v CCD201-20 electron multiplying CCD (EMCCD) is being developed for the NASA WFIRST coronagraph, an exoplanet imaging technology development of the Jet Propulsion Laboratory (Pasadena, CA). The coronagraph is designed to demonstrate technologies necessary to directly image planets around nearby stars, and to characterize their spectra. The planets are exceedingly faint, providing signals similar to the detector dark current, and require the use of photon counting detectors. Red sensitivity (600-980nm) is preferred to capture spectral features of interest. EMCCDs are baselined both as science and wavefront sensors in the coronagraph in order to simplify the system architecture. We are engaged in a test program to characterize the performance of the EMCCD in the required modes, as well as in a technology development program with Teledyne-e2v to ruggedize the sensors for use in space. In this poster we will summarize our progress, program status, and plans for flight development.

**Author(s):** Ross Burgon, Michael Bottom, Nathan Bush, Patrick Morrissey, Andrew Holland, Leon Harding, David Hall

**Institution(s):** Jet Propulsion Laboratory/Caltech, Centre for Electronic Imaging, Open University

#### **157.11 - Carbon Monoxide Surveyor using Monolithic Millimeter-wave Integrated Circuits (COSMMIC): A CubeSat Concept for a High Resolution All-Sky Survey of CO in the Milky Way(Lorene Samoska)**

We describe a mission concept to carry out a high spectral resolution all-sky survey of carbon monoxide in the Milky Way, using a CubeSat or small satellite in low earth orbit. The instrument employs a state-of-the-art low noise amplifier and digital spectrometer. Recent developments in CubeSats enable low cost missions for carrying out surveys of millimeter wavelength lines and in the future could enable submillimeter observations as well. The COSMMIC instrument will consist of Monolithic Millimeter-wave Integrated Circuit Low Noise Amplifiers (MMIC LNAs) integrated with ultra-low-mass and power CMOS spectrometers. We will target the CO 2-1 transition at 230 GHz. A modest aperture, high spectral resolution mission is required to determine the location and kinematics of the out-of-plane CO emission in the Milky Way. Observations carried out by the Planck satellite revealed the presence of large amounts of CO at high Galactic latitudes. These data had no velocity information so could not measure kinematics, mass motions or locate the gas. The COSMMIC observations will test the hypothesis that the Milky Way is accumulating significant mass from its environment. We will describe the key instrument-enabling technology, namely the high performance low noise amplifiers and mixers with Northrop Grumman Corporation (NGC) state-of-the-art 35 nm gate length InP HEMT MMIC process technology and the high resolution CMOS spectrometer chip. We will discuss the angular and velocity resolution possible given the constraints of a typical CubeSat size, as well as what could be obtained with a small satellite platform. We will discuss tradeoffs in satellite size with angular resolution, sensitivity, and spectrometer performance, as well as the time required for a CubeSat mission.

**Author(s):** Lorene Samoska, Paul Goldsmith, Maria Alonso, Joshua Gundersen, Adrian Tang, Pekka Kangaslahti, Sharmila Padmanabhan

**Institution(s):** Jet Propulsion Laboratory, University of Miami Dept of Physics

#### **157.12 - Preparing for JWST Commissioning, Calibration, and Science with the Multi-Instrument Ramp Generator (MIRAGE)(Lauren Chambers)**

The accurate simulation of James Webb Space Telescope (JWST) data, for use by both JWST engineers and by future observers, is an imperative part of successful preparation for launch. The Multi-Instrument Ramp Generator (MIRAGE) is an open-source Python package developed at Space Telescope Science Institute that generates high-fidelity data simulations for three JWST instruments: FGS, NIRCams, and NIRISS. It can be used to generate imaging data and wide-field slit-less spectroscopic data, with modeling of time series data in development. MIRAGE products include Poisson noise, cosmic rays, and other realistic detector effects, and thus are used for



comprehensive testing of JWST data reduction pipelines and algorithms. New modifications to MIRAGE enable simulation of data from the commissioning of the Optical Telescope Element (OTE). Such simulations incorporate models of non-nominal mirror states and are necessary to design procedures for the early steps of commissioning, to develop analysis software, and to plan for contingencies. MIRAGE is a flexible tool which will be used to prepare for commissioning, calibration, and science observations with JWST.

**Author(s):** Marshall Perrin, Kevin Volk, Shannon Osborne, Lauren Chambers, Johannes Sahlmann, Bryan Hilbert

**Institution(s):** Space Telescope Science Institute

### **157.13 - Origins Space Telescope: Architecture (Jonathan Arenberg)**

This poster is a discussion of how to modify the James Webb Space Telescope for application in the far infra-red, as an architectural option for OST. This poster examines the architectural considerations for JWST reuse as one of the designs being considered for the Origins Space Telescope (OST) a future far infra-red (~6-600  $\mu\text{m}$ ) space-based observatory. OST requires the temperature of the instruments and optics to operate at temperatures about 4 Kelvin. Achieving these very low temperatures throughout the optical train in an executable and verifiable design is the defining architectural challenge for any design. This paper will discuss the main elements of OST's thermal design, cooling, parasitics and thermal verification.

**Author(s):** John Pohner, Michael DiPirro, Jonathan Arenberg, Paul Lightsey, Matthew East, Micheal Petach

**Institution(s):** Northrop Grumman Aerospace Systems, Harris Corporation, Ball Aerospace, NASA

### **157.14 - The UV Space Telescope Concept, CETUS(Sara Heap)**

The Astro-2010 Panel on Electromagnetic Observations from Space called for a "more capable UV-optical telescope to follow Hubble", and that is the plan for the Probe-class UV space telescope mission concept, CETUS. With its far-UV and near-UV cameras having a 300 sq. arcmin field of view - more than 40 times larger than any UV camera on Hubble - CETUS will be a full, contributing partner to multi-wavelength surveys planned for the 2020's. \* How common is extended star formation in E and S0 galaxies? \* What does the UV tell us about when and where within a galaxy quenching takes place? \* Can we distinguish between the effects of stellar age and dust extinction? With its unprecedented sensitivity in the Lyman UV (100-122 nm), CETUS will make a major survey of galaxies in the local universe and their circumgalactic medium (CGM). \* Are the missing baryons in the warm-hot phase of the CGM? \* How do the flows of mass and energy in the CGM of galaxies change with stellar mass and environment? \* How are the properties a galaxy and its CGM and nearby IGM connected? \* Does the CGM promote/suppress star formation? \* What does

the CGM of local dwarf galaxies tell us about high-redshift dwarf galaxies thought to be responsible for the reionization of the early universe? With its multi-object spectrograph and wide-field camera, CETUS will undertake a massive survey of  $z \sim 1$  galaxies in the rest-frame far-UV. \* What are the signs of quenching in  $z \sim 1-2$  galaxies? \* How do galaxies of the same stellar mass differ in properties of their stellar population, interstellar medium, ionized nebulae? With its rapid response and high sensitivity, CETUS far-UV and near-UV cameras will follow up on transients discovered by other telescopes. \* How are accretion disks regenerated upon the tidal disruption of a star? \* How do massive stars die? \* What are the UV properties and light curves of LIGO sources? \* How do flares in M-dwarfs affect the habitability of planets? With its  $R=40,000$  near-UV spectrograph, CETUS will study very primitive stars in the galaxy to infer the properties of the first stars.

**Author(s):** Sara Heap

**Institution(s):** Emerita scientist, NASA's GSFC Contributing Team(s): and the CETUS Science Team

### **157.15 - The Origins Survey Spectrometer (OSS) for the Origins Space Telescope: Enabling Unbiased Spectral Surveys of Galaxies through Cosmic Time(Charles Matt Bradford)**

The Origins Survey Spectrometer (OSS) is a multi-purpose wideband spectrograph for the Origins Space Telescope. The sensitivity possible with the combination of the actively-cooled 5.6-meter OST telescope and new far-IR direct detector arrays is outstanding; potentially offering a 10,000x improvement in speed over Herschel and SOFIA for point-source measurements, and factor of more than 1,000,000 for spatial-spectral mapping. Massive galaxy detection rates are possible via the rest-frame mid- and far-IR spectral features, overcoming continuum confusion and reaching back to the epoch of reionization. The OSS has been optimized for scientific return over the course of the OST study. It covers the full 25 to 585 micron band instantaneously at a resolving power (R) of 300 using 6 logarithmically-spaced grating modules. Each module couples at least 30 and up to 100 spatial beams simultaneously, enabling true 3-D spectral mapping, both for the blind extragalactic surveys and for mapping interstellar matter in the Milky Way and nearby galaxies. Furthermore, two high-resolution modes are provided. The first inserts a long-path Fourier-transform interferometer into the light path in advance of the grating backends, enabling R up to  $38,000 \times [100 \text{ microns} / \lambda]$ , while preserving the grating-based sensitivity for line detection. The second incorporates a scanning etalon to provide R up to 300,000 for the 100-200 micron range for velocity-resolved tomography in protoplanetary disks using the ground-state transitions HD and H<sub>2</sub>O. OSS requires large arrays of direct detectors with the per-pixel sensitivity meeting or exceeding the photon background limit due to zodiacal and Galactic dust:  $\text{NEP} \sim 3e-20 \text{ W/sqrt(Hz)}$ . The total pixel count for all 6 bands is  $\sim 100,000$  pixels. These sensitive far-IR detector arrays are not provided by the kind of industrial efforts producing the the optical and

near-IR detectors, but they are being developed by NASA scientists, including OST team members. We review the rapid progress in this area, and outline milestones for demonstrating flight readiness (TRL 6).

**Author(s):** Charles Matt Bradford

**Institution(s):** JPL / Caltech Contributing Team(s): The Origins Space Telescope Study Team

#### **157.16 - The Origins Space Telescope Baseline Concept: The architecture and cryogenic system for a large Mid to Far IR 4 Kelvin Observatory(Michael DiPirro)**

For the far and mid infrared wavelengths, colder is better. 4-5 Kelvin optics allows sky-background-limited performance. 4.5 K is also a good temperature from which to start other stages on the way to 50 mK at the detectors to take advantage of that low background. To be successful in the design, build, verification, and operation of a low-temperature observatory and sub-Kelvin focal planes, one must be cognizant of good cryogenic practices in all phases. This results in a design that works at all levels:

quick trade-offs can be performed with hand calculations; detailed modeling can be done with fewer uncertainties; and testing can be performed with better assurance of full performance while assuming lower cost risk. This paper will show the results of trades and the cooling technologies required for the observatory and instruments.

**Author(s):** Ruth Carter, Michael DiPirro

**Institution(s):** NASA GSFC Contributing Team(s): Origins Space Telescope mission concept study team

#### **157.17 - Application of Helmholtz Coils in X-ray Instrumentation(Taylor Spoo)**

Good spectral resolution is difficult to achieve in x-ray wavelengths. When an x-ray is absorbed by a superconducting Transition Edge Sensor (TES), the device measures a small temperature change. Measuring the photon energy accurately requires very low operating temperatures: around 0.05 K. These sensors are sensitive to small magnetic fields and must be surrounded by superconducting shielding. As the shielding is cooled to its superconducting state, magnetic fields can be trapped around the TES. To prevent this from happening, Helmholtz coils are placed around a cooling apparatus. Coils were created, mounted in place, and their fields were characterized in three dimensions so they can be used to provide a field-free zone in which to cool the TESs. This presentation will focus on the design, construction, and testing of the Helmholtz coil apparatus.

**Author(s):** Casey Melton, Rachel Gruenke, Dan McCammon, Taylor Spoo,

**Institution(s):** Angelo State University, University of Wisconsin - Madison

#### **157.18 - Photonic crystal fibers improve light collection in plastic scintillation detectors(Austin Stover)**

We investigate photonic crystals to increase light piping down wavelength shifting and scintillating optical fibers. We determine the frequency bandgaps for a variety of crystal geometries with the plane wave expansion method and discuss the effects of modified total internal reflection and photonic bandgaps on light capture. We also derive the fraction of light piped down the end of our scintillating photonic crystal fiber and compare the results to those for conventional scintillating fibers. We find that our proposed fiber outperforms classical fibers in light collection almost twofold, even with a conservative geometry.

**Author(s):** Austin Stover, James H. Buckley

**Institution(s):** Washington University in StLouis

#### **157.19 - Telescope Design for the LISA Mission(Jeffrey Livas)**

The Laser Interferometer Space Antenna (LISA) Mission Proposal has been selected for L3 Launch Opportunity for ESA's Cosmic Visions Program. A space-based gravitational wave observatory is expected to see a rich array of astrophysical sources in a frequency band from 0.1 mHz to 0.1 Hz. The instrument operates by ranging between free-flying test masses as demonstrated by the LISA Pathfinder Mission. The ranging system requires an optical telescope to efficiently transfer light between the test masses, spaced 2.5 Gm apart. The requirements and current design for this optical telescope are described.

**Author(s):** Jeffrey Livas

**Institution(s):** NASA Goddard Space Flight Center  
Contributing Team(s): LISA Telescope Team

#### **157.20 - Navigation and Orbit Phasing of Modular Spacecraft for Segmented Telescope Assembly about Sun-Earth L2(Gabriel Soto)**

Future space telescopes require larger primary mirrors to image fainter objects in our universe with higher resolution.

Manufacturing and launch costs prevent scaling up the size of monolithic mirrors fabricated on Earth; a segmented mirror design is therefore needed to produce a large diameter primary mirror when assembled in space. We propose a novel mission concept for a segmented space telescope where each mirror segment is designed identically and placed individually on modular spacecraft. Individual modules are launched as payloads of opportunity that self-assemble about the Sun-Earth L2 point. They use a solar sail as a means of continuous thrust propulsion; after docking, the solar sails are steered to overlap and create a planar sun shield for the telescope. We model trajectories from Earth to L2 as two-point boundary value problems solved through collocation. Each module begins on GTOs or other Earth orbits simulated by sampling the

distribution of potential launch orbits. Modules then target insertion onto a quasi-periodic Lissajous orbit, found through integration of the circular restricted three-body problem (CR3BP) equations of motion. The path traced by a Lissajous trajectory nearly intersects itself multiple times as it revolves around L<sub>2</sub>; modules inserted at different locations on the Lissajous are likely to encounter one another and clump together to form the final primary mirror. The transfer orbit from Earth to L<sub>2</sub> is found by integrating the CR3BP equations perturbed by the solar radiation pressure force from the Sun and combined with the optimal control law for the sail clock and pitch angles. In this work, we outline the framework for transferring modules from Earth orbit to the Sun-Earth L<sub>2</sub> with a solar sail onto a Lissajous orbit. We explore the relationship between staggering module launches and the likelihood and frequency with which modules will come into proximity for docking.

**Author(s):** Dean Keithly, Gabriel Soto, Jacob Shapiro, Dmitry Savransky, Erik Gustafson, Christopher Della Santina

**Institution(s):** Cornell University, Carl Sagan Institute

#### **157.21 - Extending multi-aperture geometric alignment with ELASTICS to an 18 sub-aperture system(Iva Laginja)**

Large diffraction-limited telescopes are required to combine high-angular resolution and large collecting aperture, enabling the observation of distant galaxies, exoplanets or even our own solar system. Given the need for these increasingly large telescope diameters, segmented apertures are a possible solution to overcome manufacturing limitations as well as launch constraints for space-based telescopes. In consequence, the individual segments of such telescopes must be aligned and phased to a fraction of the observed wavelength to enable diffraction-limited imaging. The first step in such an alignment process is typically to stack all sub-point spread functions (sub-PSFs) stemming from each individual segment on top of each other, a problem which can be reduced to the correction of large amplitude tip and tilt aberrations. This adjustment must be precise enough to bring the residual tip/tilt aberrations within the capture range of fine phasing algorithms, which can in consequence correct for small amplitude piston/tip/tilt and higher order aberrations. The Estimation of Large Amplitude Sub-aperture Tip/tilt from Image Correlation and projections on orthogonal Subspace (ELASTICS) algorithm was developed to perform the PSF stacking (geometric alignment) using only two near-focus images and a low cost computing calculation. Its performance has been demonstrated on numerical simulations and with a closed-loop alignment of a six sub-aperture system in a laboratory setting. The residuals were shown to be within the capture range of the Linearized Analytic Phase Diversity (LAPD) algorithm, a real-time algorithm for fine- phasing of the sub-apertures. We present the results of simulation and implementation of these geometric and fine alignments on the James Webb Space Telescope Optical Simulation Testbed (JOST), extending the used-case of ELASTICS to 18 sub-apertures.

**Author(s):** Remi Soummer, Iva Laginja, Sylvain Egron, Sébastien Vievard, Laurent Mugnier, Frédéric Cassaing, Aurélie Bonnefois

**Institution(s):** Space Telescope Science Institute, ONERA/DOTA, Office National d'Etudes et de Recherches Aérospatiales, National Astronomical Observatory of Japan, Subaru Telescope, Iridescence S.A.R.L

#### **157.22 - The Off-plane Grating Rocket Experiment: LSF Error Budget & Expected Performance(Benjamin Donovan)**

The Off-plane Grating Rocket Experiment (OGRE) is a soft X-ray spectroscopy suborbital rocket payload which hopes to achieve the highest resolution astronomical spectrum when it launches in late 2020. To achieve this resolution goal, the payload will utilize high spatial resolution monocrystalline silicon X-ray optics, high spectral resolution X-ray reflection gratings, and an array of electron-multiplying CCDs at the focal plane. Paramount to the development of the payload is the detailed analysis of all factors which contribute to the shape of the line spread function (LSF) on the spectral CCDs. Here, we present a detailed LSF error budget for the OGRE spectrometer and comment on its expected performance.

**Author(s):** Benjamin Donovan

**Institution(s):** The Pennsylvania State University

Contributing Team(s): OGRE Instrument Team

#### **157.23 - Optical Design of a Large Segmented Space Telescope(Jacob Shapiro)**

Space observatories have many advantages over ground-based telescopes. However, constructing and launching large space telescopes remains a significant challenge. A solution to this problem lies in autonomous, in-space assembly. To gain benefits from efficiencies of scale and mass production, a modular telescope assembled in space should be constructed from identical mirror segments. This work examines the optical feasibility of such a project, using a thirty-one meter Ritchey-Chrétien telescope composed of about 1,000 one-meter mirrors as a case study. In particular, this work examines the shape of the telescope optics through Zernike decomposition, determines a realistic actuator design to achieve the desired shape, and computes the physical optics propagation of such a system to analyze the resultant PSF with simulation in Zemax OpticStudio.

**Author(s):** Dean Keithly, Gabriel Soto, Jacob Shapiro, Dmitry Savransky, Erik Gustafson, Christopher Della Santina

**Institution(s):** Cornell University, Carl Sagan Institute

#### **157.24 - HaloSat: Observation Scheduling and the Cygnus Superbubble(William Fuelberth)**

HaloSat is a NASA-funded CubeSat that will measure X-rays from hot gas surrounding the Milky Way and address the question: is there a massive, extended, hot halo around the Milky Way? HaloSat was deployed on July 13, 2018, from the International Space Station. As of this writing, we are currently commissioning the science instrument which has soft X-ray detectors with a 10 degree diameter field of view. HaloSat will survey a large fraction of the sky by patterning the sky with targets. HaloSat observes only during the night side of each spacecraft orbit and the targets must be at Sun angles larger than 110 degrees to limit the foreground emission from the heliosphere. This causes us to have a limited visibility window for each target, which is also constrained by the limb angle of the Earth and the Moon's position. We will describe how our software schedules observations for each target such that they satisfy our requirements. For my senior thesis at the University of Iowa, I will also be using HaloSat to observe the Cygnus Superbubble. Preliminary results will be presented.

**Author(s):** William Fuelberth

**Institution(s):** University of Iowa Contributing Team(s): Department of Physics and Astronomy, University of Iowa - WFuelberth, PKaaret, DLaRocca, AZajczyk, D.LKirchner, W.TRobison, H.CGulick, J.KBluem, ESilich, RMcCurdy; NASA Goddard Space Flight Center - KJahoda, T.EJohnson

#### **157.25 - Summary of JWST NIRCам Latent Image Behavior(Marcia Rieke)**

Latent images, also called persistence, are an unavoidable feature of near-infrared detector arrays comprised of photodiodes. Test data collected while characterizing the detector arrays for NIRCам have been used to understand the latent image behavior. These data have suggested possible calibration schemes that could be added to data processing pipelines. The impact of latent images on likely operations scenarios for JWST are also considered to help users understand whether persistence is an issue for their observing programs, and how users may be able to mitigate the impact of persistence on their data.

**Author(s):** Karl Misselt, Marcia Rieke, Jarron Leisenring

**Institution(s):** University of Arizona

#### **157.26 - Gravitational Wave Counterparts with the Nimble Mission Concept(Judith Racusin)**

Nimble is a NASA Explorer class mission concept that couples a very wide-field gamma ray monitor with a multiwavelength telescope and rapid response spacecraft. The primary mission science is focused on detection and characterization of compact binary mergers (most likely binary neutron star or neutron star/black hole) through characterizing short gamma-ray bursts and kilonovae. Nimble's High-energy All-sky Monitor (HAM) and Small UV-Optical-IR (SUVOIR) instruments together will

detect, localize, and characterize gravitational wave counterparts, and disseminate that information to the ground for additional rapid follow-up observations. In addition to detecting short gamma-ray bursts followed by their afterglow/kilonova counterparts, Nimble will be able to quickly respond to external triggers from the ground-based gravitational wave network or other triggering instruments. The broad gamma-ray and UVOIR observations will trace the evolution of these events and their cosmic chemical enrichment, explore the structure and origin of their emission mechanisms, and be probes of fundamental physics and cosmology.

**Author(s):** Judith Racusin

**Institution(s):** NASA Goddard Space Flight Center

Contributing Team(s): Nimble Team

#### **157.27 - An update on X-ray reflection gratings for space missions(Drew Miles)**

Astronomical X-ray diffraction gratings are a key technology under development for current and future NASA missions. X-ray reflection gratings developed at Penn State University have recently demonstrated both leading diffraction efficiency and high spectral resolving power. However, recent yields are the results of different fabrication techniques and a single technique has not yet been developed to produce a grating that satisfies both the diffraction efficiency and resolving power required by future missions. Here we seek to leverage and improve on existing electron-beam lithographic techniques to produce a grating with a groove pattern capable of high resolving power. We then introduce several new techniques to create custom groove profiles capable of high diffraction efficiency over large areas using techniques and tools that are traditionally geared towards smaller-format products. We will discuss our work in optimizing electron beam lithography to produce high fidelity gratings with tight control of the critical dimension and line edge roughness over large areas. We also present initial measurements of ion milling custom groove profiles and discuss progress in various etch techniques. Finally, we provide updates on overall grating fabrication and results on recent experiments to verify grating performance, and provide an outline of future work.

**Author(s):** Fabien Grise, Jake McCoy, Ross McCurdy, Randall L McEntaffer, Drew Miles, Ningxiao Zhang

**Institution(s):** Penn State University

#### **157.28 - HST WFC3: Instrument Status and Advice for Proposers and Observers(Elena Sabbi)**

The Wide Field Camera 3 is UV, Visible and near Infrared Camera on board of the Hubble Space Telescope, that provides astronomers with powerful imaging and slitless spectroscopic capabilities from the near-ultraviolet (200 nm) to the near-infrared (1700 nm). We summarize the basic characteristics and performances of WFC3, including our analysis of its stable

and time variable calibrations, and summarize the calibration program for Cycle 26. Key recent improvements in our calibrations and instrument characterizations will be discussed including better models for the correction of the degrading Charge Transfer Efficiency, a new tool to derive focus-dependent libraries of Point Spread Function, new time-dependent dark files for the IR channel, and new IR flat-fields.

**Author(s):** Elena Sabbi

**Institution(s):** Space Telescope Science Institute

Contributing Team(s): WFC3 Team

#### **157.29 - Updates to HST's ACS/SBC: UV Imaging Performance and Calibration(Roberto J Avila)**

The ACS/SBC has now been in continual operation for 16.5 years. Recently, the ACS team has been conducting an ongoing campaign to characterize the changes in performance that have taken place in that time and to improve the calibration of the detector. Presented here are: updates to the long term changes in sensitivity, updated high and low frequency flat fields, a new aperture to be used to mitigate elevated dark rates, and a new study in the effects of source color on encircled energy curves.

**Author(s):** Roberto J Avila

**Institution(s):** Space Telescope Science Institute

#### **157.30 - The JWST-MAST Spectroscopic Initiative(Marc Rafelski)**

The James Webb Space Telescope (JWST) is a spectroscopic power-house in the near-infrared and covers wavelengths from 0.6 microns to 28.3 microns with resolution ranging from R~100 to R~3250. All instruments have spectroscopic modes, and together support standard single-object slit, multi-object micro-shutter, integral-field unit, and grism spectroscopy. The institute will deliver calibrated 1D and 2D spectra for all modes. The Barbara A. Mikulski Archive for Space Telescopes (MAST) is exploring a range of next-generation tools to support maximizing the use of archival data, including new search and delivery interfaces, APIs, and integration of the archive with science platforms. The goal is to provide an intuitive interface enabling astronomers from diverse fields to find spectra of interest, perform preliminary spectral analysis, and download the data. Additional hooks will enable seamless transitions between the exploratory visualizations and more advanced analysis interfaces (e.g. python data analysis tools). We present the initial plans for this initiative with the aim to collect suggestions and feedback from the community.

**Author(s):** Joshua Peek, Arfon M Smith, Marc Rafelski, Jonathan Hargis, Brian Cherinka

**Institution(s):** Space Telescope Science Institute

#### **157.31 - HabEx UVS Design Update and Exemplar Science(Paul Scowen)**

We present an update to the design and performance of the HabEx ultraviolet spectrograph (UVS) that includes an exposure time calculator (ETC). As part of this update we present a series of exemplar science cases that the instrument was designed, in part, to address. These cases are used to illustrate some of the capabilities of the instrument and the facility for non-exoplanet General Observatory science. Science cases such as these were used to shape the Science Traceability Matrix (STM) that the instrument was designed to enable, and that features in the HabEx Final Report to NASA, which will be submitted in 2019.

**Author(s):** Jessica Werk, Paul Scowen, Miriam Garcia Garcia, Aida Wofford, Chris Evans, Stefan Martin, Stephan McCandliss, Ian Roederer

**Institution(s):** Arizona State University, UKATC, Jet Propulsion Laboratory, Johns Hopkins University, CSIC-INTA, University of Washington, University of Michigan, UNAM

#### **157.32 - The Origins Space Telescope: Development of a Scientifically Compelling, Low-Risk, Executable Mission Concept(David Leisawitz)**

The Origins Space Telescope (OST) will trace the history of our origins from the time dust and heavy elements permanently altered the cosmic landscape to present-day life. How did the universe evolve in response to its changing ingredients? Why is the Earth wet? How common are life-bearing planets? To enable the community to answer these and other important questions, OST will operate at mid and far-infrared wavelengths and offer sensitivity and spectroscopic capabilities vastly exceeding those found in any preceding far-IR observatory. During the past two years, the OST study team prioritized scientific objectives, explored many facets of the mission concept solution space, evaluated two alternative mission architectures - one inspired by JWST and another by Spitzer - developed designs for and assessed the performance of several science instruments, and took steps to reduce cost and risk while retaining the measurement capabilities needed to answer definitively the driving science questions. We report on the overall study approach, the studied architectures, and the key decisions that led to a scientifically compelling, low-risk, executable mission concept. This "baseline" mission concept will be presented to the National Academies' 2020 Decadal Survey in Astrophysics.

**Author(s):** David Leisawitz

**Institution(s):** NASA Goddard Space Flight Center  
Contributing Team(s): the Origins Space Telescope Mission Concept Study Team

**157.33 - From First Stars to Life: Scientific Capabilities of the Origins Space Telescope(Asantha Cooray)**

This poster will outline the science program of the Origins Space Telescope (OST), a 2020 Decadal observatory concept under study by NASA. OST operates from 3 to 600 microns, covering the key wavelength regime in the infrared. The scientific instruments of OST will be capable of carrying out a wide range of astronomical programs focussed on the distant universe during the epoch of first star/first galaxy formation to the Solar system. We will highlight the key science themes - in extragalactic, Galactic, and extra-solar planetary sciences, including main objectives of the OST. We will also outline general observing science programs that can be achieved with order 100 hours of observing with OST. All science programs are designed to be led by the community, through competitive proposals, similar to the past and existing NASA flagship observatories.

**Author(s):** Asantha Cooray

**Institution(s):** University of California Irvine Contributing Team(s): The Origins Space Telescope Science and Technology Definition Team

**157.34 - Measuring Galactic Evolution and Feedback with the Origins Space Telescope(Lee Armus)**

A significant fraction of star formation and black hole growth in galaxies occurs behind a veil of dust. Our understanding of how galaxies evolve will remain incomplete until deep, wide area spectroscopic surveys in the infrared can be carried out from space. The Origins Space Telescope (OST), a mission concept being studied for presentation to the 2020 Decadal Survey, represents an enormous leap over the capabilities of any previous or planned infrared mission, and it will uniquely measure star formation and black hole growth in millions of individual galaxies over more than 95% of cosmic history, generating the first true 3D map of the extragalactic, infrared sky. With a wavelength coverage of 5-600 microns, a large primary mirror actively cooled to 4K, and a capable suite of imagers and spectrometers, OST will be an extremely sensitive probe of the energetics and dynamics of the multi-phase atomic and molecular ISM in galaxies. Energetic feedback from stars and AGN is required to regulate galaxy growth over a wide range in mass, and it is critical for the enrichment of the interstellar and circumgalactic medium, yet the existence and type of feedback as a function of redshift, luminosity, and environment is poorly constrained. With OST we can directly observe the role of feedback in quenching galaxies, derive the wind kinetic energy and mass outflow rates, and correlate these with key galaxy properties such as AGN or starburst power, environment, mass and age. We will explain how blind and targeted surveys with OST will have an enormous impact on our understanding of the duty cycle and basic physical properties of feedback in AGN and starburst galaxies over the last 12 Gyr of cosmic time.

**Author(s):** Alberto Bolatto, Alexandra Pope, Lee Armus, Charles Matt Bradford

**Institution(s):** Caltech/IPAC, JPL/Caltech, University of Massachusetts, University of Maryland Contributing Team(s): The Origins Science and Technology Definition Team

**157.35 - Origins Space Telescope: The Far Infrared Imager and Polarimeter FIP(Ruth Carter)**

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, one of the four science and technology definition studies of NASA Headquarters for the 2020 Astronomy and Astrophysics Decadal survey. The observatory consists of a cold (4.5 K) 5.9 m space telescope with 3 instruments, covering a wavelengths range from 2.8 um to 667 um. In the Far-Infrared, the achievable sensitivity of the observatory will provide up to three orders of magnitude of improvement in sensitivity over current observational capabilities, allowing to address a wide range of new and so far inaccessible scientific questions, ranging from bio-signatures on exo-planets to mapping primordial H<sub>2</sub> from the "dark ages" before the universe went through the phase of re-ionization. Here we present the Far Infrared Imager and Polarimeter (FIP) for OST. The camera will cover two bands, 50 um, and 250 um. If selected, it will allow for polarimetric observations in these bands. While the confusion limit in the total power mode will be reached in only a few milli-seconds in the 250 um band, at 50 um, where OST's angular resolution is about 2", the source density in the sky is so low, that it will take about 2 hours until the confusion limit will be reached. Science topics that can be addressed by FIP include, but are not limited to galactic and extragalactic magnetic field studies, deep galaxy surveys, and outer Solar System objects.

**Author(s):** Ruth Carter, David Leisawitz, David Chuss, Damon Bradley, Margaret Meixner, Edward G Amatucci, Joaquin Daniel Vieira, James Corsetti, S. Harvey Moseley, Edward Wollack, Johannes G Staguhn,

**Institution(s):** NASA GSFC, University of Illinois, Johns Hopkins University, Villanova University, Space telescope Science Institute Contributing Team(s): Origins Space Telescope Study Team

**157.36 - Origins Space Telescope: Science Traceability Matrix and Design Reference Mission(Margaret Meixner)**

The Origins Space Telescope (OST) is a science and technology definition study for NASA Headquarters for the 2020 Astronomy and Astrophysics Decadal survey. OST, operating from 3 to 600 microns, will have a factor of 1000 improved sensitivity over prior far-infrared missions, enabled by cold (4.5 K) optics and sensitive detectors. This poster will describe the science traceability matrix and design reference mission for the OST Baseline Mission Concept. Three science themes are featured. How does the Universe work?: How do galaxies form stars, make metals and dust, and grow their central supermassive black holes from reionization to today? How did

we get here?: How do the conditions for habitability develop during the process of planet formation? Are we alone?: OST will assess the habitability of nearby exoplanets and search for signs of life. Major new results in all three themes can be accomplished within one year of time. Moreover, these science themes have defined observatory capabilities that enable a broad range of general astronomical science. We welcome you to contact the OST Science and Technology Definition Team (STDT) with your science questions and ideas by emailing us at [ost\\_info@lists.ipac.caltech.edu](mailto:ost_info@lists.ipac.caltech.edu).

**Author(s):** Klaus Martin Pontoppidan, Martina C. Wiedner, Edwin Bergin, Stefanie N Milam, David Leisawitz, Johannes G Staguhn, Itsuki Sakon, Tiffany Kataria, Asantha Cooray, Kimberly Ennico, Margaret Meixner, Thomas Roelligo, Joaquin Daniel Vieira, Jonathan Fortne

**Institution(s):** Sorbonne Universite, Observatoire de Paris, oNASA Ames Research Center, University of California, Santa Cruz, University of Illinois, Space Telescope Science Institute, NASA/GSFC, Johns Hopkins University, University of Michigan, University of Massac

#### **157.37 - CETUS science capabilities enabled by the CETUS NUV multi-object spectrometer and NUV/FUV camera(Stephen E Kendrick)**

The Cosmic Evolution Through UV Spectroscopy (CETUS) concept has three ultraviolet instruments to achieve its science goals. This presentation highlights the features of the NUV multi-object spectrometer (MOS) and the NUV/FUV camera which operate simultaneously with their separate field of views. The NUV MOS can target up to 100 objects at a time without being confused by nearby sources or background zodiacal light. This multiplexing will allow over 100,000 galaxies to be observed over a typical mission lifetime. The MOS includes a next-generation micro-shutter array, an efficient aspheric Offner-like spectrometer design with a convex grating, and nanotube light traps for suppressing unwanted wavelengths. The UV Camera has the capability to image from the FUV to the NUV at the same time the MOS is operating at 180-350 nm. The UV Camera has a similar Offner-like relay, fixed filters, and two separate detectors to optimize observing in either the far-UV (>Lyman-alpha filter) or the near-UV (LF256W filter centered at 256.4 nm with FWHM 40.6 nm) utilizing a sealed CsI solar blind micro-channel plate (MCP) and a 4Kx4K CCD respectively. Both instruments have a tip/tilt/focus mechanism on one of their optics allowing independent focus correction and dithering of the image at the focal plane.

**Author(s):** Anthony Hull, Robert Woodruff, Sara Heap, Stephen E Kendrick, Lloyd Purves, William Danchi, Alexander Kutrev

**Institution(s):** Kendrick Aerospace Consulting LLC, University of New Mexico, NASA GSFC emerita, NASA GSFC, Woodruff Consulting, University of Maryland

#### **157.38 - The search for life with the Origins Space Telescope(Tiffany Kataria)**

As we look up at the skies, humankind has always wondered, "Are we alone?" Only now are scientists and engineers designing instruments purpose-built to answer this question. Our quest in the search for life on planets around other stars rests on our ability to measure the chemical composition of their atmospheres and understand this data in the context of planet formation and evolution. The Origins Space Telescope (OST) concept, one of the large mission concepts for the Astronomy and Astrophysics 2020 Decadal Survey, will seek to answer this question with a mid-IR instrument specifically designed for characterization of Earth-sized transiting exoplanets.

**Author(s):** Kevin Stevenson, Tiffany Kataria, Jonathan Fortney

**Institution(s):** JPL/Caltech, UC Santa Cruz, Space Telescope Science Institute  
Contributing Team(s): OST Science and Technology Definition Team, OST Exoplanets Science Working Group

#### **157.39 - Coronagraphy for segmented aperture space telescopes: results on the HiCAT testbed(Rémi Soummer)**

The Large Ultra-Violet Optical InfraRed (LUVOIR) is a mission concept for a large, segmented-aperture space telescope that will enable the direct imaging and spectroscopy of habitable worlds and search for life. Demonstrating coronagraphy on such challenging aperture geometries - segmented and on-axis - is the goal of the High-contrast imager for Complex Aperture Telescopes (HiCAT) testbed. In the past year, HiCAT has increased the Technology Readiness Level (TRL) of coronagraphy for segmented apertures, by producing the first ever demonstration of a high-contrast dark zone for a truly segmented aperture with central obstruction and support structure, an optimized coronagraph, and wavefront control using deformable mirrors. The Apodized Pupil Lyot Coronagraph (APLC) is optimized for the HiCAT aperture and uses carbon nanotube technology for the apodizer mask. The software infrastructure enables 24/7 automated experiments that include routine both calibration tasks and high-contrast experiments. An extensive metrology suite allows for rapid reconfiguration and hardware flexibility to accommodate multiple experiments. In this poster we present the latest updates and performance results from the testbed.

**Author(s):** Roser Juanola-Parramon, A J Eldorado Riggs, Scott Willo, Scott Pourshalchi, Alexander Doran, Kathryn St. Laurent, John Hagopian, Ana-Maria Valenzuela, Peter Petrone, Marshall Perrin, Evelyn McChesney, Sylvain Egrou, Rob Gontrum, Thomas Tiberghien Alvare

**Institution(s):** ONERA, oUniversity of Rochester, Space Telescope Science Institute, Iridescence, Caltech, Laboratoire d'Astrophysique de Marseille, Advanced Nanophotonics Inc., Observatoire de la Cote d'Azur, Johns Hopkins University,

**157.40 - Apodized Pupil Lyot Coronagraphs designs for future segmented space telescopes II(Kathryn St. Laurent)**

A coronagraphic starlight suppression system situated on a future flagship space observatory offers a promising avenue to image Earth-like exoplanets and search for biomarkers in their atmospheric spectra. One NASA mission concept that could serve as the platform to realize this scientific breakthrough is the Large UV/Optical/IR Surveyor (LUVOIR). Such a mission would also address a broad range of topics in astrophysics with a multi-wavelength suite of instruments. The apodized pupil Lyot coronagraph (APLC) is one of several coronagraph design families that the community is assessing as part of NASA's Exoplanet Exploration Program Segmented aperture coronagraph design and analysis (SCDA) team. The APLC is a Lyot-style coronagraph that suppresses starlight through a series of amplitude operations on the on-axis field. We have developed an optimization and analysis toolkit in Python to automate the exploration of APLC design parameter combinations. Using this toolkit, we have produced APLC designs for the LUVOIR-A pupil at  $1E-10$  contrast and studied their sensitivity to fabrication and alignment error, low-order wavefront error, and potential scientific yield. Our work indicates the APLC is a very competitive concept for surveying the local exoEarth population with a mission like LUVOIR.

**Author(s):** Roser Juanola-Parramon, Christopher Stark, Anand Sivaramakrishnan, Scott Will, Mamadou N'Diaye, Kathryn St. Laurent, Laurent Pueyo, Johan Mazoyer, Rémi Soummer, Brendan Crill, Stuart Shaklan, Kevin Fogarty, Neil T. Zimmerman

**Institution(s):** Space Telescope Science Institute, California Institute of Technology, Observatoire de Nice C te d'Azur, University of Rochester, NASA Goddard Space Flight Center, John Hopkins University, Jet Propulsion Laboratory

**157.41 - Updated Technology Roadmap for the Habitable-zone Exoplanet Imaging Observatory (HabEx) Concept(Keith Warfield)**

The HabEx Concept telescope is optimized for direct imaging and spectroscopy of potentially habitable exoplanets, and also enables a wide range of general astrophysics science. The design strategy chose mature technologies and leveraged in-development technologies to minimize risk and possibly reach Technology Readiness Level 5 by 2026 for Architecture A. We update the technology maturity roadmap with technology advances in the past year and expand it to include an Architecture option which is a 3.2 m diameter on-axis segmented aperture with a starshade only. The starshade suppresses starlight before it enters the telescope, allowing the telescope optical performance and stability to be significantly looser than for a coronagraph, thus enabling a segmented

primary mirror design that can meet stability requirements with minimal advancement from the state of the art. In this poster we assess the exoplanet-driven technologies, including elements of coronagraphs, starshades, mirrors, jitter mitigation, segment stability, wavefront control, and detectors.   California Institute of Technology 2018. All rights reserved. Government sponsorship acknowledged.

**Author(s):** Kunjithapatham Balasubramanian, Shouleh Nikzad, Keith Warfield, Karl Stapelfeldt, H. Philip Stahl, Eugene Serabyn, Gary M Kuan, Rhonda Morgan, Steven Wwarwick, David Redding, Stuart Shaklan, Bertrand Mennesson, Joel Nissen, Dimitri Mawet

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology, Marshall Space Flight Center, Northrop Grumman Corporation Contributing Team(s): HabEx Design Team

**158 - Space Mission Instrumentation II -- Posters**

**158.01 - ZERODUR   Solutions for Spaceborne and Earth-based Telescopes(Anthony Hull)**

**Abstract:** ZERODUR   was developed by SCHOTT 51 years ago as a thermally stable material for astronomical telescope mirrors, yet has found diverse applications since where ultra dimensional stability is required. While the formulation of ZERODUR   has remained stable, recent studies, techniques and facility investments have positioned ZERODUR   for selection for most of the mirror substrates of E-ELT. Highly lightweighted mirror blanks are now available through 4-meter diameter, and lightweighted ZERODUR   is the current mirror baseline for NASA's studies toward HabEx and CETUS Missions. We will summarize recent advances in technology for ZERODUR  , and give a directory of recent papers in the literature defining optimum engineering for ZERODUR   based mirror substrates.

**Author(s):** Anthony Hull, Thomas Westerhoff

**Institution(s):** University of New Mexico, Schott AG

**158.02 - HaloSat: X-Ray Calibration and Spectral Analysis for a NASA CubeSat(Hannah Gulick)**

HaloSat is a NASA funded 6U CubeSat designed to measure the mass of baryonic matter in the Milky Way's hot Galactic halo. Currently in low Earth orbit, HaloSat uses three X-ray silicon-drift detectors sensitive in the 0.4 - 2 keV band. HaloSat will map the geometry of the Galactic halo through detection of X-rays from O VII and O VIII at ~600 eV. We present on the laboratory measurements of the HaloSat flight detectors, including: alignment, energy calibration, and performance optimization. We show analysis of in-lab and initial on-orbit data.

**Author(s):** Hannah Gulick

**Institution(s):** University of Iowa Contributing Team(s): PKaaret, AZajczyk, DLaRocca, D.LKirchner, W.TRobison, WFuelberth, J.KBluem, ESilich, RMcCurdy Department of



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#### **158.03 - Principal Component Analysis of Up-the-ramp Sampled IR Array Observations(Bernard Rauscher)**

Using Principal Component Analysis (PCA) of HST WFC3 IR observations, we find that nearly all of the meaningful information in prototypical astronomical scenes can be condensed down to six parameters per pixel. The six parameters are essentially the incomplete Legendre transform of the up-the-ramp sampled pixel data. Compared to the polynomial fitting that is widely used in IR calibration pipelines today, the Legendre polynomials are superior in that they provide an orthonormal basis that diagonalizes the covariance matrix. As such, the Legendre polynomials provide a linearly uncorrelated representation of the information. For space missions, the PCA quantitatively informs how much data, and what kind of data, must be sent to the ground. We are optimistic that these insights have the potential to lead to improved calibration techniques for HST, JWST, and WFIRST.

**Author(s):** Dale Fixsen, Richard Arendt, Dani Eleanor Atkinson, Bernard Rauscher, Gregory Mosby, S. Harvey Moseley, Alexander Kuttyrev

**Institution(s):** NASA/GSFC

#### **158.04 - Cosmic Dawn Intensity Mapper (CDIM): Instrument and Mission Design(Stephen C Unwin)**

The Cosmic Dawn Intensity Mapper (CDIM) is a probe-class mission currently under study for NASA, as part of preparations for the 2020 Astrophysics Decadal Survey. A detailed Report from the study will be completed by end of 2018 for consideration as part of the Survey. We present the initial concept for the instrument and mission design. The flight system will comprise a wide-field passively-cooled cryogenic telescope, and a large focal plane array with complete coverage from optical through mid-IR. The system will be deployed to Sun-Earth L2 orbit, to provide a stable thermal environment, and allow extended observations of fields selected to be cross-correlated with deep surveys in other wavebands. Spectra will be measured for every point in each target field, using linear variable filters (LVFs). These filters allow us to do spectroscopy using simple imaging, and eliminating the need for a spectrometer instrument in the focal plane. Spectra are built up through simple imaging of a series of telescope pointings separated by small angular offsets. The resulting huge data cube will help us understand star formation during the epoch of reionization, the production of metals at that epoch, and to search for the earliest quasars in the universe.

**Author(s):** Stephen C Unwin

**Institution(s):** JPL Contributing Team(s): CDIM Science Team, CDIM Design Team

#### **158.05 - Revolutionary Astrophysics using an Incoherent Synthetic Optical Aperture(Gerard L Rafanelli)**

We are updating our exploration of a paradigm shift for astronomical observatories that would replace circular apertures with rotating synthetic apertures. Rotating Synthetic Aperture (RSA) observatories can enable high value science measurements for the lowest mass to orbit, has superior performance relative to all sparse apertures, can provide the resolution of 20m to 30m aperture with the collecting area of an 8m to 12 m telescope with much less mass, risk, schedule, & cost. RSA is based on current, or near term technology and can be launched on a single, current launch vehicle to L2 (with much larger apertures possible using SLS)

**Author(s):** Arthur M Newman, Susan B Spencer, Douglas Wolfe, Supriya Chakrabarti, Gerard L Rafanelli, Kushal Mehta, Christopher Mendillo, Ronald Polidan

**Institution(s):** Raytheon Space and Airborne Systems, University of Massachusetts-Lowell, Polidan Science System and Technology

#### **158.06 - Origins Space Telescope: Little Heterodyne Receiver for OST (Little HERO)(Gary Melnick)**

The (Little) Heterodyne Receiver for OST (HERO) is a very high spectral resolution ( $\Delta \nu / \nu = 10^{-7}$ , or  $\Delta v = 0.03$  km/s) instrument for the Origins Space Telescope (OST) and complements OST's incoherent mid- to far-IR spectrometers. HERO is designed as a large focal plane array for OST Concept 1, while Little HERO has been optimized for best performance with the more modest resources available in OST Concept 2 and is an up-scope to the OST Concept 2 baseline design to enhance its capabilities. One of the three main science drivers for the OST, as well as (Little) HERO, is to trace the trail of water from the ISM via the different stages of star and planet formation to habitable worlds. Other science topics currently identified for the heterodyne receivers are the study of turbulence and shocks in the ISM and their role in star formation, the determination of the cosmic ray ionization rate in the Milky Way and nearby galaxies, and the discovery of the earliest stages of dust formation around evolved stars. Little HERO has an unprecedented frequency range of 486 GHz to 2.7 THz, covering a large number of water transitions, including the dominant water cooling lines, as well as other important cooling lines. Little HERO extends the heterodyne receiver heritage of such successful observatories as the Herschel Space Observatory and ALMA by incorporating the latest technologies. In particular, for the first time, close to quantum limited mixers combined with new, extremely low power components make it possible to fly heterodyne focal plane arrays on a space observatory. Little HERO has four receiver bands, each possessing two polarizations and nine pixels, while placing very modest requirements on the spacecraft. Little HERO can carry out pointed observations as well as make on-the-fly maps and can operate in dual frequency, dual

polarization modes. HERO is the product of a detailed design study of a new generation of heterodyne receivers for the OST and will enable a host of unique science objectives requiring the highest spectral resolving powers.

**Author(s):** Martina C. Wiedner, Gary Melnick, Maryvonne Gerin, André Laurens

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, CNES, LERMA, Sorbonne Université, Observatoire de Paris, Université PSL, CNRS Contributing Team(s): HERO Science and Technical Team, OST Science and Technology Definition Team

#### **158.07 - Cosmic Dawn Intensity Mapper (CDIM): a New Probe of Cosmic Dawn and Reionization (Tzu-Ching Chang)**

The Cosmic Dawn Intensity Mapper, CDIM, is a NASA Probe-class Mission Study. CDIM is designed to be a near-IR survey instrument optimized for Cosmic Dawn and reionization sciences, answering critical questions on how and when galaxies and quasars first formed, the history of metal build-up, and the tomography of reionization, among other questions. CDIM will provide  $R=300$  spectroscopic imaging over 7 sq. degree instantaneous field of view at 2 arcsecond resolution, over the wavelength range of 0.75 to 7.5  $\mu\text{m}$ . A three-tiered wedding-cake survey will consist of a shallow tier spanning close to 300 deg<sup>2</sup>, a medium tier of 30 deg<sup>2</sup>, and a deep tier of 15 deg<sup>2</sup>. CDIM survey data will allow us to (i) establish the metal abundance of first-light galaxies during reionization by spectrally separating NII from H $\beta$ , and detecting both H $\beta$  and [OIII]; (ii) detect quasars at redshifts greater than 6 and infer blackhole masses down to 106 solar masses ; (iii) establish the environmental dependence of star-formation during reionization through clustering and other environmental measurements; (iv) measure 3D tomographic intensity fluctuations during reionization in both Ly $\alpha$  at  $z > 6$  and H $\beta$  at  $0 < z < 9$ ; and (v) cross-correlating intensity fluctuations with 21-cm data to establish the topology of reionization bubbles.

**Author(s):** Tzu-Ching Chang

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology Contributing Team(s): CDIM Science Team, CDIM Design Team

#### **158.08 - High Precision Photometry with Spatial Scans - WFC3 UVIS(Clare Shanahan)**

We provide results on a high precision photometry study with HST/WFC3 using spatial scans. The goal of this study is both to demonstrate the maximum photometric repeatability that can be obtained with WFC3/UVIS, as well as to better characterize the time-dependent trends in photometric throughput. Calibration programs 14878 and 15398 have obtained spatial scans of bright, isolated white dwarf standard stars GD153 and GRW70. The photometric stability of UVIS has historically been continually monitored with staring mode observations of white

dwarf standard stars GD153 and GRW70. Based on the excellent results of the first spatial scan program 14878, which achieved  $\sim 0.1\%$  repeatability between visits, this monitoring program now incorporates spatial scans for better signal-to-noise measurements to characterize any throughput changes with time. We also present analysis tools in Python that will be available to the public for analyzing spatial scan data.

**Author(s):** Clare Shanahan, Sylvia Baggett, Peter McCullough  
**Institution(s):** Space Telescope Science Institute

#### **158.09 - WFIRST Coronagraph Technology Development Testbed: Status and Recent Testbed Results(Fang Shi)**

WFIRST technology development testbed provides critical support for the WFIRST Coronagraph Instrument (CGI). The testbed has been a platform and tool to mature the coronagraph technologies, support the CGI system engineering requirement development, and retire or mitigate the technology risks. With its configuration similar to the WFIRST flight coronagraph instrument the Occulting Mask Coronagraph (OMC) testbed consists of two coronagraph modes, Shaped Pupil Coronagraph (SPC) and Hybrid Lyot Coronagraph (HLC), a low order wavefront sensor (LOWFS), and an optical telescope assembly (OTA) simulator which can generate realistic LoS drift and jitter as well as low order wavefront error that would be induced by the WFIRST telescope's vibration and thermal changes. During past year we have carried many tests on the testbed including demonstration of the coronagraph and LOWFS performance under flight like photon flux and closing LOWFS loops on the line-of-sight disturbances simulating actions from six reaction wheels in a typical CGI observation. The Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies (PISCES) is an integral field spectrograph (IFS) developed for the testbed and it has been demonstrated 18% contrast of  $1e-8$  on our static SPC/IFS testbed. Currently we are integrating the PISCES on to the OMC testbed. In this presentation we will show case some of our recent testbed results and describe plans for future tests.

**Author(s):** A J Eldorado Riggs, David Marx, John Terry Trauger, Maxime Rizzo, Victor White, Joel Shields, Eric Cady, Tuan Truong, Daniel Wilson, Brian Kern, Qian Gong, Fang Shi, Erkin Sidick, Kunjithapatham Balasubramanian, Karl Yee, Hanying Zhou, Camilo Mejia Prada,

**Institution(s):** Jet Propulsion Laboratory, NASA Goddard Space Flight Center, Princeton University

#### **158.10 - HabEx: A Starshade-Only Alternative(David Redding)**

The HabEx mission concept is intended to directly image planetary systems around nearby stars, and to perform a wide range of general astrophysics and solar system observations. Its main goal is the discovery and characterization of Earth-like exoplanets through high-contrast imaging and spectroscopy. The baseline HabEx concept would use both a coronagraph and

a starshade for exoplanet science. We describe an alternative mission design concept, which would use a starshade (only) for exoplanet science. The benefit is lower cost: by deleting the complex coronagraph instrument; by use of a compact on-axis telescope design; by lowering observatory mass; by relaxing tolerances and stability requirements; by use of a smaller launch vehicle. The starshade would provide excellent exoplanet science performance, but for a smaller number of detected exoplanets of all types, including exoEarth candidates, and a smaller fraction of exoplanets with measured orbits. The full suite of HabEx observatory science is supported. Our approach uses a non-deployed segmented primary mirror, whose manufacture is within current capabilities.

**Author(s):** Christopher Stark, Eric Cady, Howard Tseng, Claudia Pineda, Kevin Schulz, Keith Coste, Stefan Martin, Michael Rodgers Rodgers, David Redding, Matthew East, Kevin Hurd, Otto Polanco

**Institution(s):** JPL, Synopsys, Cal Poly Pomona, Harris, ST Sci

#### **158.11 - STROBE-X: X-ray Timing & Spectroscopy on Dynamical Timescales from Microseconds to Years(Colleen A. Wilson-Hodge)**

We describe a probe-class mission concept that provides an unprecedented view of the X-ray sky, performing timing and 0.2-30 keV spectroscopy over timescales from microseconds to years. The Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X) has three key science drivers: (1) measuring the spin distribution of accreting black holes, (2) understanding the equation of state of dense matter, and (3) exploring the properties of the precursors and electromagnetic counterparts of gravitational wave sources. To perform these science investigations, STROBE-X comprises three primary instruments. The first uses an array of lightweight optics (3-m focal length) that concentrate incident photons onto solid state detectors with CCD-level (85-130 eV) energy resolution, 100 ns time resolution, and low background rates to cover the 0.2-12 keV band. This technology is scaled up from NICER, with enhanced optics to take advantage of the longer focal length of STROBE-X. The second uses large-area collimated silicon drift detectors, developed for ESA's LOFT, to cover the 2-30 keV band. These two instruments, with effective areas of 2 m<sup>2</sup> at 1.5 keV and 5 m<sup>2</sup> at 10 keV, respectively, each provide an order of magnitude improvement in effective area compared with its predecessor (NICER and RXTE, respectively). Finally, a sensitive sky monitor triggers pointed observations, provides high duty cycle, high time resolution, high spectral resolution monitoring of the X-ray sky with ~20 times the sensitivity of the RXTE ASM, and enables multi-wavelength and multi-messenger studies on a continuous, rather than scanning basis. The STROBE-X mission concept is a rapidly repointable observatory in low-Earth orbit, similar to RXTE or Swift, and will be presented to the 2020 Astrophysics Decadal Survey for consideration as a probe-class mission.

**Author(s):** Michael McDonald, Ronald Remillard, Deepto Chakrabarty, Colleen A. Wilson-Hodge, Michael Nowak, Soren

Brandt, Abigail L. Stevens, Marco Feroci, Silvia Zane, Bernard F. Philips, Paul S Ray, Laura Brenneman, Dieter Hartmann, Alessandra DeRosa, Zaven Arzouma

**Institution(s):** IAPS/INAF, oSAO, Clemson University, USRA, Michigan State University, Institute of Space Sciences, CSIC-IEEC, University of Amsterdam, UC Berkeley, MSSL/UCL, Praxis Inc(resident at NRL), NASA MSFC, Texas Tech, NRL, NASA GSFC, MIT, Georgia Tec

#### **158.12 - Reducing the Athena WFI Background with the Science Products Module: Results from Geant4 Simulations(Eric D. Miller)**

The Wide Field Imager (WFI) on ESA's Athena X-ray observatory will include the Science Products Module, a secondary CPU that can perform special processing on the science data stream. Our goal is to identify on-board processing algorithms that can reduce WFI charged particle background and improve knowledge of the background to reduce systematics. Telemetry limitations require discarding most pixels on-board, keeping just candidate X-ray events, but information in the discarded data may be helpful in identifying background events masquerading as X-ray events. We present an analysis of Geant4 simulations of cosmic ray protons interacting with the structures aboard Athena, producing signal in the WFI from a variety of secondary particles with various types of particle tracks. We search for phenomenological correlations between these particle tracks and detected events that would otherwise be categorized as X-rays, and explore ways to exploit these correlations with efficient algorithms to flag or reject such events on-board. In addition to possibly reducing the Athena instrumental background, these results are applicable to understanding the particle component in any X-ray silicon-based detector in space. We gratefully acknowledge support from NASA grant NNX17AB07G, administered by Penn State, and from NASA contracts NAS 8-37716 and NAS 8-38252 to MIT.

**Author(s):** Eric D. Miller, David Burrows, Jonathan Keelan, Marshall Bautz, Esra Bulbul, Steven Allen, Ralph Kraft, Andrew Holland, Catherine Grant, Paul Nulsen, David Hall

**Institution(s):** Massachusetts Institute of Technology, Harvard-Smithsonian Center for Astrophysics, Open University, Stanford University, The Pennsylvania State University

#### **158.13 - Twenty years of the Advanced CCD Imaging Spectrometer on the Chandra X-ray Observatory(Catherine E. Grant)**

As the Advanced CCD Imaging Spectrometer (ACIS) on the Chandra X-ray Observatory enters its twentieth year of operation on orbit, it continues to perform well and produce spectacular scientific results. The response of ACIS has evolved over the lifetime of the observatory due to radiation damage, molecular contamination and aging of the spacecraft in general.

Here we present highlights from the instrument team's monitoring program and our expectations for the future of ACIS. Performance changes on ACIS continue to be manageable, and do not indicate any limitations on ACIS lifetime.

**Author(s):** Catherine E. Grant

**Institution(s):** MIT Contributing Team(s): ACIS Instrument Team

#### **158.14 - Probe Extreme Particle Acceleration and Neutrinos in Relativistic Jets with AMEGO Gamma-ray Polarimetry(Haocheng Zhang)**

The All-sky Medium Energy Gamma-ray Observatory (AMEGO) is a next-generation Compton and pair-production telescope. It can perform gamma-ray polarimetry in the MeV band. Relativistic jets are the most extreme particle accelerators in the universe. In particular, blazars show strongly variable multi-wavelength radiation, where its gamma-ray emission may be either Compton scattering by energetic electrons or synchrotron of very high energy protons and hadronic cascading products. A byproduct of hadronic process is high-energy neutrinos. We perform self-consistent multi-physics simulations of blazar jets including fluid dynamics, particle transport, and polarized radiation transfer. We find that the hadronic model gives consistent higher polarization degree than the leptonic model, and time-dependent multi-wavelength polarimetry can diagnose the particle acceleration and leptonic/hadronic processes in blazar jets. Based on detailed simulations of AMEGO polarization sensitivity, we illustrate that AMEGO gamma-ray polarization can clearly identify hadronic processes in bright blazars complementary to neutrino observations, and we present predictions for possible AMEGO polarization detections for various blazar parameters. These predictions demonstrate the AMEGO's capability to lead the next breakthrough in ultra-high-energy cosmic rays and neutrino astronomy.

**Author(s):** Haocheng Zhang

**Institution(s):** Purdue University Contributing Team(s): AMEGO collaboration

#### **158.15 - Diffuse gamma-ray line astronomy with AMEGO(Carolyn Kierans)**

Gamma-ray line astronomy began in the 1970s, but the field is still in its infancy due to limitations in current telescope technologies. The signature of positron annihilation at 511 keV was the first gamma-ray emission line to be detected as originating outside of our solar system. After 40 years of observations, the Galactic sources of positrons, which annihilate predominately in the Galactic Center region, are still unconfirmed and remains one of the pioneering topics in gamma-ray astronomy. The next Galactic gamma-ray line to be detected was the 1.8 MeV diffuse emission from the radioactive decay of Al-26, which was the first confirmation of active

nucleosynthesis in our Galaxy. Nuclear emission lines from isotopes created in massive stars and their supernovae, such as Fe-60 and Ti-44, in addition to Al-26, allow for fingerprint-like probes into stellar structure and evolution, a tool which has yet to be fully realized. The All-sky Medium Energy Gamma-ray Observatory (AMEGO), is an Astrophysics Probe concept design that can make significant progress in our understanding of cosmic nucleosynthesis and the source of Galactic positrons. AMEGO will have a wide field-of-view, direct imaging capabilities, high spectral resolution, and sensitivity orders of magnitude better than previous telescopes: all characteristics necessary to advance gamma-ray astronomy. In this presentation we will focus on the topics that can be addressed with long-lived stellar nucleosynthesis products and discuss the intriguing open questions associated with Galactic positrons. We will present predictions for AMEGO performance and expected results.

**Author(s):** Dieter Hartmann, Andreas Zoglauer, Chris Fryer, Carolyn Kierans, Chris Shrader

**Institution(s):** UC Berkeley, LANL, NASA/GSFC, Clemson University Contributing Team(s): AMEGO Team

#### **158.16 - Gravitational Waves and gamma-rays with AMEGO(Eric Burns)**

On August 17th, 2017 the merging of two neutron stars was independently detected in gravitational waves and gamma rays. These detections and the ensuing follow-up observations measured the speed of gravity, gave an independent measure of  $H_0$ , confined the equation of state of supranuclear matter, confirmed binary neutron stars as a progenitor of both short gamma-ray bursts and kilonova, informed our understanding of relativistic jets, and ruled out modified theories of gravity that attempted to explain dark matter and dark energy. The first multimessenger detection with gravitational waves met its lofty expectations. It also exposed that we are already in the era when gravitational wave detected mergers may have gamma-ray signals below our current sensitivity. A decade from now this problem will only be exacerbated. We discuss the future science that will be done with neutron star mergers, and how AMEGO can play a key role as the greatest gamma-ray burst detector ever.

**Author(s):** Eric Burns

**Institution(s):** NASA/GSFC Contributing Team(s): AMEGO Collaboration

#### **158.17 - Exploring the particle nature of dark matter with the All-sky Medium Energy Gamma-ray Observatory (AMEGO)(Regina Caputo)**

The era of precision cosmology has revealed that ~85% of the matter in the universe is dark matter. Two leading candidates, motivated by both particle and astrophysics, are weakly interacting massive particles (WIMPs) and weakly interacting sub-eV particles (WISPs) like axions and axionlike particles.

Both WIMPs and WISPs have distinct gamma-ray signatures. Data from the Fermi Large Area Telescope (Fermi-LAT) continues to be an integral part of the search for these dark matter signatures spanning the 50 MeV to >300 GeV energy range in a variety of astrophysical targets. Thus far, there are no conclusive detections; however, there is an intriguing excess of gamma rays associated with Galactic center (GCE) that could be explained with WIMP annihilation. The angular resolution of the LAT at lower energies makes source selection challenging and the true nature of the detected signal remains unknown. WISP searches using, e.g. supernova explosions, spectra of blazars, or strongly magnetized environments, would also greatly benefit from increased angular and energy resolution, as well as from polarization measurements. To address these, we are developing AMEGO, the All-sky Medium Energy Gamma-ray Observatory. This instrument has a projected energy and angular resolution that will increase sensitivity by a factor of 20-50 over previous instruments. This will allow us to explore new areas of dark matter parameter space and provide unprecedented access to its particle nature.

**Author(s):** Manuel Meyer, Miguel SÁnchez-Conde, Tim Linden, Regina Caputo

**Institution(s):** NASA/GSFC, IFT UAM-CSIC, SLAC/Stanford, The Ohio State University  
**Contributing Team(s):** AMEGO Team

#### **158.18 - Development of the AMEGO Prototype(Sean Griffin)**

The study of gamma rays from a few hundred keV to hundreds of MeV is challenging due to high gamma-ray backgrounds, multiple scattering within the detector, and the fact that there are two competing interactions in this regime, Compton scattering and pair production, with cross-sections which crossover at  $\sim 15$  MeV. As such, this regime, known as the MeV gap, has been largely unexplored since the pioneering measurements made by COMPTEL aboard CGRO (1991-2000). The All-sky Medium Energy Gamma-ray Observatory (AMEGO) is a Probe-class mission concept designed to operate at energies from  $\sim 200$  keV to  $> 10$  GeV. AMEGO comprises four subsystems: a silicon tracker for measuring the energy and track of Compton recoil electrons and electron/positron pairs, a CZT calorimeter for measuring the energy and interaction location of Compton scattered photons, a CsI calorimeter for measuring the energy of the electron/positron pair-production products at high energies, and a plastic anticoincidence detector for rejecting cosmic-ray events. Prototypes of the subsystems are under development at the NASA Goddard Space Flight Center and the Naval Research Laboratory; in this contribution we provide details on the development of the various subsystems in preparation for beam tests and a balloon flight of the AMEGO prototype.

**Author(s):** Sean Griffin

**Institution(s):** UMCP / CRESST / NASA GSFC  
**Contributing Team(s):** AMEGO Team

#### **158.19 - Advances seeded by Gamma-ray Observations of Magnetars with AMEGO(George Younes)**

Magnetars are young, isolated neutron stars possessing the largest magnetic fields ever measured in the universe. The decay of these fields power their bright X-ray emission. Current hard X-ray observations of persistent magnetars with INTEGRAL, Fermi-GBM, and NuSTAR reveal the existence of a very hard non-thermal component extending up to few hundred keV, and dominating the energy budget of these sources. Historic soft gamma-ray limits from COMPTEL place the peak of magnetar spectra between few hundred keV to few MeV. The most efficient mechanism for the production of such spectra is resonant inverse Compton scattering of soft thermal photons by relativistic electrons in the magnetosphere. B-field strength, particle Lorentz factor, and QED scattering kinematics and attenuation will dictate the exact shape of these spectra and their cutoff energies. Energy-dependent pulse profiles and phase-resolved spectroscopy in the MeV range are powerful tools to infer the magnetic inclination, viewing geometry, and emission locale in these sources. Finally, such spectra are expected to be highly polarized. Spectropolarimetric studies may reveal the signature of exotic QED effects thought to be present in super strong B-fields, e.g., photon splitting. Here, we make the case that AMEGO, the All-sky Medium-energy Gamma-ray Observatory, would be the prime mission to unlock the mysteries governing magnetar high energy emission.

**Author(s):** Alice K Harding, George Younes, Matthew Baring, Zorawar Wadiasingh

**Institution(s):** The George Washington University, Rice University, NASA Goddard Space Flight Center  
**Contributing Team(s):** on behalf of the AMEGO team

#### **158.20 - The most powerful blazars with AMEGO(Marco Ajello)**

MeV blazars, the most luminous, persistent, sources in the Universe, are best observed in the MeV band where they release most of their radiative output. These blazars, which are typically found at high redshift, tend to host black holes with a mass in excess of 1 billion solar masses and as such are powerful probes of the formation mechanisms of massive black holes in the early Universe. The All-sky Medium Energy Gamma-ray Observatory (AMEGO) is poised to be the best instrument to detect and study MeV blazars. Here, we discuss the prospects for a survey of powerful MeV blazars with AMEGO.

**Author(s):** Vaidehi Paliya, Marco Ajello

**Institution(s):** Clemson University  
**Contributing Team(s):** on behalf of the AMEGO Collaboration

### **158.21 - Neutrino Astrophysics and AMEGO(Roopesh Ojha)**

The possible association of the blazar TXS 0506+056 with a PeV neutrino detected by IceCube holds the tantalizing potential to answer three astrophysical questions: the sites where Cosmic Rays are produced and accelerated, the origins of PeV neutrinos, and the physical mechanisms producing the high energy gamma-ray emission from blazars. AMEGO is the perfect instrument to look for neutrino counterparts because MeV neutrinos are an excellent proxy for neutrino emission if photo-hadronic processes play a dominant role. Hadronic models also predict a high level of polarization in the MeV band. In addition, AMEGO's wide field of view and sensitivity guarantee it a central role in neutrino astrophysics. We will elaborate on AMEGO's capabilities in the context of multi-messenger astronomy.

**Author(s):** Roopesh Ojha

**Institution(s):** NASA/GSFC/UMBC Contributing Team(s): on behalf of the AMEGO Team

### **158.22 - The All Sky Medium Energy Gamma-ray Observatory (AMEGO) - A Discovery Mission for the MeV Band(Julie McEnery)**

The MeV domain is one of the most underexplored windows on the Universe. From astrophysical jets and extreme physics of compact objects to a large population of unidentified objects, fundamental astrophysics questions can be addressed by a mission that opens a window into the MeV range. AMEGO is a wide-field gamma-ray telescope with sensitivity from ~200 keV to >10 GeV. AMEGO provides three new capabilities in MeV astrophysics: sensitive continuum spectral studies, polarization measurements, and nuclear line spectroscopy. AMEGO will consist of four hardware subsystems: a double-sided silicon strip tracker with analog readout, a segmented CZT calorimeter, a segmented CsI calorimeter and a plastic scintillator anticoincidence detector, and will operate primarily in an all-sky survey mode. In this presentation we will describe the AMEGO mission concept and scientific performance.

**Author(s):** Julie McEnery

**Institution(s):** NASA/GSFC Contributing Team(s): On behalf of the AMEGO team

### **158.23 - Resolving Mysteries of Rotation-Powered Pulsars with AMEGO(Matthew Kerr)**

Thanks to the Fermi Large Area Telescope, we now know young and recycled pulsars fill the gamma-ray sky, and we are beginning to understand their emission mechanism and their distribution throughout the Galaxy. However, key questions remain open: Is there a large population of pulsars near the Galactic center? Why do the most energetic pulsars shine so brightly in MeV gamma rays? What is the source and nature of the pair plasma in pulsar magnetospheres, and what role does the polar cap accelerator play? Addressing these questions calls

for a sensitive, wide-field MeV telescope, which can detect the population of MeV-peaked pulsars hinted at by Fermi and hard X-ray telescopes and characterize their spectral shape and polarization. We discuss these and other topics in the context of AMEGO, the All-sky Medium Energy Gamma-ray Observatory, a Probe-class mission concept.

**Author(s):** Alice K Harding, Matthew Kerr, Zorawar Wadiasingh

**Institution(s):** Naval Research Laboratory, Goddard Space Flight Center Contributing Team(s): AMEGO Team

### **158.24 - Stability error budget for exo-earth imaging with a large segmented telescope in space.(Laurent Pueyo)**

The brightness ratio between the sun and earth is  $10^{10}$ - $10^{11}$ . Coronagraphs can be designed to reach such levels of starlight suppression while keeping the planet flux relatively pristine. However, such extinctions also translate into controlling the deformations and misalignments in the optical train of a space-based coronagraph at tens of picometer levels. In this poster we present a semi-analytic method that relates wavefront stability to the ultimate starlight extinction of a coronagraph instrument in large segmented telescope in space over a broad range of spatial and temporal scales. We consider a few possible observation scenarios and study their impact on the stability budget. We present a series of end to end simulation that validate our approach. We conclude that robust coronagraph designs do yield a significant relaxation of the stability requirements. We apply this method to the NASA's Large UV-Optical-IR flagship (LUVOR) mission concept.

**Author(s):** Laura Coyle, Laurent Pueyo, Remi Soummer, J. Scott Knight

**Institution(s):** STScI, Ball Aerospace Contributing Team(s): ULTRA team

### **158.25 - Optimast Structurally Connected Interferometry Enabled by In-Space Robotic Manufacturing and Assembly(Gerard van Belle)**

Future goals for astrophysics at the frontiers of high spatial resolution drive the need for large effective apertures beyond what the current generation of space observatories provides. Space-based interferometry delivers on this promise and enables cost-effective observation of faint objects at unprecedented levels of angular resolution. Using the Made In Space (MIS) Optimast capability, a simple, two aperture Structurally Connected Interferometer (SCI) is produced via in-space Additive Manufacturing (AM) technology. This capability allows the two modest apertures to be packaged efficiently for launch and then placed at a large separation, coherently, in order to achieve a greater effective angular resolution. Optimast enables the manufacturing and deployment of large primary trusses unconstrained by launch loads or volume restrictions that meet science requirements for the high angular

resolutions (in the milliarcsecond regime) necessary for applications such as characterization of planets near bright stars, and measurement individual objects in dense star clusters. Space-based deployment of an interferometer unfettered by the turbulent atmosphere will markedly increase the sensitivity reach of such an instrument relative to its ground-based counterparts. Adapting the MIS Optimast technology to produce long baseline structures with low thermal expansion materials enables simultaneous structural fabrication and positioning of the optical subsystems to the required static, thermal deflection, and oscillation tolerances. An Optimast-SCI baseline structure eliminates parasitic mass and provides superior absolute position control over traditional deployable structures at much lower cost, mass, and integration complexity.

**Author(s):** Jack Schomer, Max Fagin, Mike Snyder, Simon Patané, Gerard van Belle, Noah Paul-Gin, Daniel Riley

**Institution(s):** Lowell Observatory, Made In Space

#### **158.26 - A position-sensitive high-resolution CdZnTe calorimeter for AMEGO(Elizabeth Hays)**

We will present a concept for a calorimeter based on a novel approach using 3D position-sensitive virtual Frisch-grid CdZnTe (CZT) detectors. This calorimeter aims to measure photons with energies from ~100 keV to 20-50 MeV. The energy resolution at 662 keV is expected to exceed 1% FWHM. The measured position accuracy for the photon interaction is expected to exceed 1 mm in all 3 dimensions. Each CZT element is a rectangular prism with a cross-section of 6x6 mm<sup>2</sup> and a length of 20-40 mm. The individual elements are arranged into 4x4 modules that can be assembled into larger arrays. The 3D virtual voxel approach solves a long-standing problem with CZT detectors associated with material imperfections that limit the performance and usefulness of relatively thick detectors (> 10 mm). This approach also allows relaxed requirements on the quality of the CZT crystals, while maintaining similar energy resolution and significantly reducing the cost of a calorimeter system. Such a calorimeter is an excellent candidate for use in a space telescope employing Compton scattering to detect gamma rays, such as AMEGO, serving as part of a multilayer calorimeter and providing the necessary position and energy measurement for Compton-scattered photons. Intriguingly, this technique could provide suitable energy resolution for spectroscopic measurements of gamma-ray lines from nuclear decays.

**Author(s):** Aleksey Bolotnikov, Alexander Moiseev, David J. Thompson, Carolyn Kierans, Elizabeth Hays

**Institution(s):** NASA GSFC, University of Maryland, CRESST, NASA GSFC, Brookhaven National Laboratory  
Contributing Team(s): AMEGO team

#### **158.27 - The SPRITE CubeSat: Far-Ultraviolet Imaging Spectroscopy of Galaxies and Nebulae in a Small Technology Demonstration Package(Brian Fleming)**

We present an overview of the Supernova remnants/Proxies for Reionization/ and Integrated Testbed Experiment (SPRITE) CubeSat. SPRITE is a 6U CubeSat designed to carry out two science objectives while simultaneously flight testing two LUVOIR-LUMOS enabling technologies: protected eLiF mirror coatings and low-background borosilicate microchannel plate detectors. These advanced technologies allow SPRITE to reach projected far-ultraviolet sensitivities on par with previous larger NASA missions while maintaining imaging spectroscopic capability. SPRITE will spend roughly half of the projected two-year baseline mission mapping shock emission in supernova remnants in the Milky Way and Magellanic Clouds, and the other half determining the escape fraction of hydrogen ionizing radiation from 100 low-redshift starforming galaxies. In parallel with the science operations, SPRITE will execute a calibration program that will track the stability of the mirror coatings and detector over the mission lifetime. SPRITE is currently in the late design phase with an anticipated launch in 2022.

**Author(s):** Anne Jaskot, John O'Meara, Manuel Quijada, Stephan R McCandliss, Sanchayeeta Borthakur, Kevin France, John Hennessy, Ravi sankrit, Brian Fleming, Jason Tumlinson, Michael Rutkowski

**Institution(s):** University of Colorado, NASA Goddard Space Flight Center, NASA Jet Propulsion Laboratory, Minnesota State University, Saint Michael's College, University of Massachusetts, Arizona State University, Johns Hopkins University, Space Telescope Science

#### **158.28 - Telescope Testing for the LISA Mission(Ada A Uminska)**

The Laser Interferometer Space Antenna (LISA) Mission will listen to the universal sub-Hz gravitational wave concert played by massive black hole mergers, compact galactic binaries and many other expected and unexpected sources. LISA will measure these waves by exchanging laser beams between three spacecraft separated by 2.5Gm. The required 30cm, F#~1 transmit/receive telescopes are part of the interferometer arms. They have to meet several unusual requirements such as pm/Å<sup>2</sup> length stability and sub-ppm back scatter of the transmit laser power. We will discuss the telescope test plan and the development and testing of the ground testing equipment.

**Author(s):** Paul Fulda, Ada A Uminska, Harold Hollis, Joseph Gleason, Soham Kulkarni, Reid Ferguson, Guido Mueller

**Institution(s):** University of Florida

## **159 - HAD IV: History Posters**

### **159.01 - The Astronomy Genealogy Project(Joseph S. Tenn)**

The Astronomy Genealogy Project (AstroGen) has been underway since 2013. We are creating a database of all astronomy-related doctoral dissertations. Each entry contains the name(s) of the author, awarding institution, year, title, advisor(s), other important mentors, and links to the thesis if it is online and to a page about the author's professional life (obituary if deceased). Included in the database are names, locations, and other information about universities. An important goal of this project is to enable tracing the academic lineage of all who have ever held a doctorate in an astronomy-related field, through the relation between advisor (academic parent) and doctoral student (academic child). The project is sponsored by the AAS Historical Astronomy Division (HAD). It was conceived and is led by Joseph S. Tenn. AstroGen is modeled after the Mathematics Genealogy Project (<http://www.genealogy.ams.org/>), directed by Mitchell Keller. The AstroGen team has had to make a series of decisions regarding the scope and contents of the database, such as what constitutes an eligible dissertation, how to handle the different degrees awarded in different countries, criteria for accepting co-advisors and mentors, dealing with universities that change their names, merge or split, and distinguishing between individuals with the same name. All information is provided in the native language and in English. Most information is obtained from online sources, though some libraries have been visited as well. As of September 2018 we have recorded about 27,000 theses, with Argentina, Australia, Canada, Chile, Denmark, Estonia, Ethiopia, Finland, Greece, Iceland, Iran, Ireland, Mauritius, Netherlands, New Zealand, Norway, Pakistan, South Africa, Spain, Sweden, the United Kingdom, and the United States fairly complete, and we have started work on France, India, and Russia. We need volunteers familiar with the languages and, if possible, the academic cultures of other nations. The emphasis is still on data collection, but the AAS, which is currently undergoing major changes in how it handles IT, has promised to assist in getting the project onto the AAS website in the not-too-distant future.

**Author(s):** Arnold H Rots, Peter Broughton, Joseph S. Tenn  
**Institution(s):** Sonoma State University, Retired, Cfa/SAO

### **159.02 - Analysis of Montanari's Observations of Algol(Jason E. Ybarra)**

The first recorded mention of the variability of Algol ( $\beta^2$  Persei) was by the 17th-century astronomer Geminiano Montanari. He observed the star from 1667-1670, during which he noted a change in magnitude on three separate occasions, separated by a year or more. Algol's variability is known to be 2.867 days, which might suggest Montanari should have observed the variability more often, and more frequently. Montanari however had little reason to continuously observe Algol night after night, given that the only other known variable at the time had a period of 332 days. We present a statistical analysis of

observing Algol's dimming given various parameters and discuss our results with respect to Montanari's observations.

**Author(s):** Jason E. Ybarra, Stephen Pincus, Andrealluna Pizzetti,

**Institution(s):** Bridgewater College, Alma Mater Studiorum Università di Bologna, Associazione Astronomica "Geminiano Montanari"

### **159.03 - Urania in the Marketplace: Radio Telescopes(Kenneth S. Rumstay)**

For over a century the iconic image of the astronomical telescope has been exploited in commercial advertisements for a variety of consumer goods. Astronomy is widely regarded as an exact and precise science, and manufacturers of all manner of mechanical devices, from watches to automobiles, have featured images of telescopes or of astronomers at work to suggest that their products meet these same standards of quality. At the same time, the heavens induce a sense of wonder and many advertisers have located their products in a celestial setting to give them an otherworldly flavor. With the rapid development of radio astronomy in the post-war years, radio telescopes began to appear in magazines published for the general public. But their use was for the most part restricted to ads for industrial manufacturers. These enormous dishes appear to have been less appealing to the average person, many of whom undoubtedly labored under the assumption that astronomers used them to "listen" to the stars, rather than to watch them. Radio telescopes were used to sell alloys, lubricants and electronics, rather than consumer goods. But at least the Commonwealth of Puerto Rico recognized the Arecibo antenna's potential to attract tourists! This work was supported by a faculty development grant from Valdosta State University.

**Author(s):** Kenneth S. Rumstay,

**Institution(s):** Valdosta State University, SARA

## **160 - Societal Matters Poster Session**

### **160.01 - The Working Group on Accessibility and Disability: meeting access and recommendations for writing accessible publications(Alicia Aarnio)**

The AAS Working Group on Accessibility and Disability (WGAD) has been working in the 2018-2019 year on recommendations for practices to make professional meetings more accessible. We present here a summary of those recommendations. The WGAD has also maintained a living, ever-improving document of recommendations for publication accessibility; here, we highlight inclusive practices authors can adopt to make their publications accessible to all astronomers.

**Author(s):** Nicholas Murphy, Karen Knierman, Sarah Tuttle, Jacqueline Monkiewicz, Alicia Aarnio, Wanda Liz Diaz-Merced

**Institution(s):** University of North Carolina Greensboro, Arizona State University, Office of Astronomy for Development, Harvard Smithsonian Center for Astronomy, University of Washington



## **161 - Astronomy Research -- Posters**

### **161.02 - Femtosecond Laser Pulses and their Applications(Nathan Daniel Magno)**

Physical processes at the atomic and molecular level, such as the vibration of atoms, the formation of chemical bonds, and the motion of charge in materials, occur on a timescale of femtoseconds ( $10^{-15}$  seconds). At facilities like the LCLS at Stanford University, ultrafast X-ray lasers and ultrafast optical lasers can produce femtosecond pulses that can be used to probe these dynamic processes. As ultrafast laser pulses propagate through materials like windows, lenses, and even air, the pulses undergo dispersion, a process that increases the pulse duration, and reduces the time resolution in these experiments. In my Cal-Bridge/CAMPARE research project, I wrote a code with a graphical interface that predicts the dispersion and pulse duration changes of femtosecond laser pulses through specific materials.

**Author(s):** Nathan Daniel Magno

**Institution(s):** California State University East Bay  
Contributing Team(s): DrAlan Fry, Karl Gummerlock

### **161.03 - Measurement of trace gases using direct Sun observations at the Smithsonian Astrophysical Observatory(Malcolm Gyagenda)**

Malcolm J Gyagenda<sup>1,2</sup>, Gonzalo Gonzalez Abad<sup>1</sup>, Caroline Nowlan<sup>1</sup>, Kelly Chance<sup>1</sup>. Smithsonian Astrophysical Observatory, Cambridge, MA, USA<sup>2</sup>. University of Massachusetts, Francis College of Engineering, Lowell, MA, USA  
Traces gases in the Earth's atmosphere have important implications for atmospheric chemistry, linking them to air quality and climate. Accurate measurements of atmospheric trace gas concentrations are crucial for supporting studies aimed at understanding the processes that govern the distribution of atmospheric pollutants. One of the methods that can be used to obtain information about gas concentrations is ground-based remote sensing, through which measurements of air quality related species (ozone, nitrogen dioxide, and formaldehyde) can be collected using spectroscopic measurements of direct Sun light. These observations are not only useful for performing local scientific studies but also for validating satellite products. The upcoming NASA mission "Tropospheric Emissions: Monitoring of Pollution (TEMPO)" aims to characterize U.S. air quality with unprecedented spatial and temporal resolution. In preparation for its launch in 2021, we present here efforts to establish ground-based remote sensing capabilities at the Smithsonian Astrophysical Observatory (SAO) to be used to validate TEMPO measurements. The SAO site is equipped with a Pandora spectrometer. Pandoras are TEMPO validation baseline instruments. They can measure total column levels of ozone, nitrogen dioxide, and formaldehyde using direct Sun observations. The goal is to create a long-term data record of these trace gas species suitable for TEMPO validation by 2021. Description of the TEMPO mission, Pandora spectrometer, site setup at SAO, preliminary results and future plans are

presented.

**Author(s):** Malcolm Gyagenda,

**Institution(s):** Harvard Smithsonian Center for Astrophysics  
, Harvard Smithsonian Center for Astrophysics  
Contributing Team(s): Gonzalo Gonzalez Abad, Caroline Nowlan, Kelly Chance

## **162 - Catalogs -- Posters**

### **162.01 - The Sloan Digital Sky Survey Quasar Catalog: Sixteenth Data Release(Brad W Lyke)**

The Sloan Digital Sky Survey (SDSS) has a rich history of releasing value-added catalogs for objects of interest to researchers, especially quasars. In that vein, we present the sixteenth quasar catalog for SDSS and the last quasar catalog for the extended Baryon Oscillation Spectroscopic Survey (eBOSS). This new catalog of quasars, the largest to date, will include all previously identified and inspected quasars from past catalog releases and should add ~100,000 newly observed quasars detected over an area larger than 9300 deg<sup>2</sup>. Overall the catalog will contain about 750,000 unique quasars, of which ~400,000 will have been visually confirmed and inspected. In addition to presenting redshift and spectroscopic data obtained from SDSS and eBOSS, we will include multiwavelength data for many quasars from 2MASS, GALEX, UKIDSS, ROSAT, XMM, and WISE. "This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics program under Award Number DE-SC0019022. This material is also based upon work supported by the National Science Foundation under Grant No. 1616168."

**Author(s):** Alexandra N Higley, H  lion du Mas des Bourboux, Jacob McLane, Danielle P Schurhammer, Alina Streblyanska, Brad W Lyke, Adam D Myers

**Institution(s):** University of Wyoming, Instituto de Astrof  sica de Canarias (IAC), University of Utah  
Contributing Team(s): SDSS-IV/eBOSS collaboration

### **162.02 - A Search for Faint Sources of Infrared Excess in the Spitzer Enhanced Imaging Products Catalog(Nicholas K Goeldi)**

This research focuses on faint sources (magnitude  $\approx 8$  at 24  $\mu$ m) in the Spitzer Enhanced Imaging Products (SEIP) Catalog. The SEIP is a unique repository of high resolution infrared data for 42 million point sources acquired during the Spitzer Space Telescope's 5-year cryogenic mission. Due to the large field of view of Spitzer's Infrared Array Camera (IRAC) and the Multiband Imager and Photometer for Spitzer (MIPS) camera, many of these objects were imaged serendipitously in the field of view of the intended targets and have never been analyzed. These sources should reveal new objects which show infrared excess not detected by other infrared surveys. The presence of an infrared excess can be used to find a wide range of phenomena, such as young stellar objects, planet-forming regions around main sequence stars, and active galactic nuclei. Filtering of the SEIP database at SNR > 5 in the 3.6, 4.5, and 24

micron channels yielded 459,748 sources. That was then filtered further by comparison with the GAIA DR 2 catalog yielding 3086 targets in common, of which 181 targets had SNR > 3 parallax data and 53 sources that passed a visual inspection of the Spitzer images. This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program.

**Author(s):** Kealohalani Gustavus, David Friedlander-holm, Jialin Xin, Oona Woodbury, Dylan Schattschneider, Matt Nowinski, Thomas Rutherford, Ross Barnett, Nicholas K Goeldi, Mallory Muse, Luca Angeleri, Kara Kniezewski, Stella Seats, Connor Schueller, Alissa Sperl

**Institution(s):** Ripon Area School District, The Bay School of San Francisco, Caltech/Jet Propulsion Laboratory, The Boeing Company, Loudoun County Public Schools, Springside Chestnut Hill Academy, Sullivan South High School

### **162.03 - I Spy With My Little Eye: Building a Catalog of Ghostly Ultra-Diffuse Galaxies in the Coma Cluster(Amy Griffin)**

Ultra-diffuse galaxies (UDGs) are a class of low surface brightness dwarf galaxies that are still poorly understood. Although the existence of UDGs was first recognized several decades ago, their low surface brightnesses and large effective radii make them difficult to detect, and current catalogs are therefore highly incomplete. The overall goal of this project was to determine the number and location of UDGs located in the Coma Galaxy Cluster. To do so, we also needed to identify the parameters that define a UDG. Starting from Subaru HyperSuprimeCam optical images in the R band, we found close to 3 million extended sources. Using a combination of size and brightness selections, followed by two-dimensional model fitting using galfit, we downselected this number to a final catalog of ~5000 UDG galaxy candidates, increasing the previously known sample of UDGs in Coma by a factor of ~20x. This large sample now allows us to better study the nature and formation processes of, as well as the stellar populations within, these galaxies.

**Author(s):** Ralf Kotulla, Amy Griffin,

**Institution(s):** University of Oklahoma, University of Wisconsin-Madison

### **162.04 - The Starchive(Angelle Tanner)**

The Starchive (starchive.org) is an open access, open source stellar database and web application like no other. We have designed an interface which is intuitive, comprehensive and adaptable. Currently, the database contains multiple stellar samples including all stars within 30pc, all known brown dwarfs and white dwarfs, stars with planets and circumstellar disks and stars in young stellar associations. We have plans to incorporate the WDS, Gaia and TESS catalogs. The web app allows users to search the database using coordinates, names or an ADS reference code. A search can include a single star or

multiple stars (batch mode). If users search for information on a single star, the result page contains all published measurements and derived physical parameters on that star, a VizieR image as well as any available high contrast images via js9. If the star is in a multiple system, there is a clear hierarchical tree with live links to the other members of the system. If available, users will have access to wavelength calibrated spectra and time series of that star. If a user submits a list of stars or utilizes the rank list search option, the web app provides a dynamic table of multiple stars with links to each individual star page. Users are able to download a text, .csv or latex file of that table. Directly from the multi-star web page application users will be able to use adaptable plotting tools to visualize the resulting data set. It is the goal of the Starchive that the plots be publication quality thus eliminating the need to download and then replot data for presentations and papers. Registered users will be able to upload data into the database. To ensure the fidelity of the data, we will highly regulate and constantly validate any uploaded data sets. There will be an API available for users to access the database directly from their own code. The front-end scripts will be placed on github and users will be encouraged to contribute new plotting tools. This poster is intended to introduce the community to the Starchive including its contents, functionality and potential and we look forward to gathering community input on how to improve this evolving, new astronomical resource.

**Author(s):** Claire Geneser, Christopher Gelino, Demitri Muna, Angelle Tanner, Farzaneh Zohrabi, Brett Addison

**Institution(s):** Mississippi State University, Eureka Scientific, University of Southern Queensland, IPAC

### **162.05 - Systematic Differences in the Calculation of Stellar Mass for ALFALFA Galaxies(Clare Burhenne)**

To create a Baryonic Tully-Fisher Relationship (BTFR) for the ALFALFA galaxies, we require a corresponding catalog of optical photometry to produce reliable stellar masses to complement their HI masses. Different methods of calculating stellar mass have been used in derivations of the BTFR depending on the sky distribution, prior redshift information or multiwavelength photometry of the sample galaxies. In order to obtain stellar masses for all of the ALFALFA galaxies in the SDSS photometric footprint, we use a crossmatch file between the  $\hat{I}\pm 100$  catalog and the SDSS DR14 database to produce a reliable catalog of optical photometric properties for use in the stellar mass calculation and inclination-dependent corrections. For the stellar masses, we use the methodology set forth in Taylor et al. (2011), specifically, the modeled mass to light ratio estimated from the g-i color index. In order to compare stellar masses derived in this way with results obtained by other authors in the literature who used Petrosian and Sersic masses available in the NASA Sloan Atlas (NSA) to derive stellar masses, we investigate the differences in stellar mass and the corrections for inclination and extinction between values compiled in the NSA and ones obtained using our  $\hat{I}\pm 100$ -SDSS cross-match. We investigate systematic differences in stellar mass estimates based on photometric properties such as color,

surface brightness and concentration and on others such as distance, velocity width and HI richness. This research is supported by the Brinson Foundation for the Arecibo Pieces-Perseus Supercluster Survey (APPSS) and NSF grant NSF/AST-1714828 to M.P. Haynes.

**Author(s):** Clare Burhenne

**Institution(s):** Cornell University Contributing Team(s): Arecibo-Pieces-Perseus Supercluster Survey (APPSS)

#### **162.06 - A New Method to Improve Radial Velocity Coverage in the USNO Bright Star List in the Astronomical Almanac(Christopher Rura)**

Radial velocities of bright stars are important parameters to assist in determining astrometric parameters of bright stars in the sky for navigational purposes. The USNO list of bright stars gives designations, positions, magnitudes, spectral types, radial velocities, and other important astrometric parameters for ~1500 visually bright stars in an even spread around the sky. The current USNO bright star list has radial velocity measurements for only 22% of the stars in the current catalog. Given that navigators and astronomers rely on this list for accurate astrometric parameters of bright stars, this raised a concern. This research project gives a possible consideration for a new method to improve the coverage of radial velocity measurements in the catalog using data from GAIA DR2, released in April 2018, as well as other catalogs with low-error radial velocity measurements. The initial results of this new method are discussed, including discussion of how much it improves coverage of radial velocity values in the USNO bright star list, and the implications of these improvements.

**Author(s):** Christopher Rura, Susan G Stewart

**Institution(s):** Villanova University, United States Naval Observatory

#### **162.07 - CatWISE: A Full Sky WISE-Selected Catalog from WISE & NEOWISE Data(Peter Eisenhardt)**

CatWISE is combining data from NASA's WISE and NEOWISE surveys to generate a full sky catalog for the community. The CatWISE catalog will include motion estimates based on the ensemble of WISE and NEOWISE data, covering a time baseline of 6 years, as compared to the 6 month baseline used for AllWISE. The CatWISE catalog contains approximately one billion sources with W1 (3.4 microns), W2 (4.6 microns) photometry, and will be released in 2019. Initial tests indicate SNR=5 limits for CatWISE of W1=17.5 mag and W2=16.5 mag (Vega), about 0.5 mag deeper than AllWISE, and an order of magnitude improvement over AllWISE in measuring motions with respect to Gaia.

**Author(s):** Peter Eisenhardt

**Institution(s):** JPL/Caltech Contributing Team(s): CatWISE Team

### **163 - Circumstellar Disks -- Posters**

#### **163.01 - Characterizing the Debris Disk around HD 170773 with Resolved Millimeter Observations(Aldo Sepulveda)**

Debris disks are extra-solar analogs to our own Kuiper belt and found around at least 17% of nearby sun-like stars. The morphology and dynamics of a disk encode information about its history, as well as that of any exoplanets within the system. We used the Atacama Large Millimeter Array (ALMA) to obtain 1.3 mm observations of the debris disk around the nearby F5V star HD 170773 as part of the REASONS (RESolved ALMA and SMA Observations of Nearby Stars) Survey. We image the face-on ring and accurately determine its fundamental parameters, such as its radius and width, using a forward-modeling Markov Chain Monte Carlo approach. We find the belt to lie at much larger distances from the star compared to most belts around other late A / early F type stars. This makes HD 170773 part of a small group of 4 potential outliers, 2 of which host directly imaged giant planets, which may point to a connection between large belts and the presence of long-period giant planets. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1659473, and by the Smithsonian Institution.

**Author(s):** Luca Matr , Aldo Sepulveda, David Wilner, Karin I  berg

**Institution(s):** The University of Texas at San Antonio, Harvard-Smithsonian Center for Astrophysics Contributing Team(s): REASONS Team

#### **163.02 - Determining the Evolutionary Status of the Disk Surrounding HD 166191(Diego Enrique Garcia)**

The evolution of circumstellar disks is closely tied to our understanding of the formation of planetary systems. The transition from gas-rich planet-forming disks to tenuous debris disks like our own Solar System's Kuiper belt is a particularly important phase because giant planets can no longer form once the primordial gas has dispersed. HD166191 is a Sun-like (F8) star located at a distance of 119 pc from our Sun. The circumstellar disk of this star exists in an ambiguous state between a protoplanetary and a debris disk, as it has traits that would independently classify it for either type. The proper classification of individual systems matter because of the insights it provides about the relationship and transitional period between circumstellar disk types. An important indicator of the evolutionary state of a transition disk is the presence or absence of molecular gas. We present observations from the Sub-Millimeter Array (SMA) that search for CO(2-1) molecular line emission, as well as optically thin continuum emission from dust, at an angular resolution of 1.3 arcseconds (155 au) and wavelength of 1.3 mm. We detect a spatially unresolved continuum flux density of  $5.3 \pm 1.0$  mJy/beam, corresponding to  $0.65 M_{\oplus}$  of dust, and measure a  $3\sigma$  upper limit on the integrated CO(2-1) flux of  $1.1$  Jy km/s, corresponding to  $5.7 \times 10^{-2}$

$M_{\text{CO}}$  of CO gas (assuming optically thin emission and local thermodynamic equilibrium). Both the low gas mass and the low gas-to-dust mass ratio are characteristic of a debris disk and inconsistent with ongoing planet formation.

**Author(s):** Diego Enrique Garcia, A. Meredith Hughes

**Institution(s):** Middlebury College, Wesleyan University

### **163.03 - Walking the water trail with the Origins Space Telescope(Klaus Martin Pontoppidan)**

Water is critical for the emergence and evolution of life as we know it. The mass of Earth's life forms is dominated by water, with the addition of carbon, nitrogen, phosphorus, and other elements in minor quantities. During the process of star- and planet formation, water traces the flow of volatile elements toward their ultimate incorporation into potential biospheres. Understanding how the ingredients for life emerge from the interstellar medium requires an understanding of the trail of the water. The Origins Space Telescope (OST) concept, to be submitted to the 2020 decadal survey, aims to reveal the entire trail of water by measuring water gas and ice at all temperatures as it emerges from the interstellar medium, is transported into planet-forming disks, and added to planetary surfaces during the debris disk phase. Through the study of Solar System comets, OST will also determine the delivery mechanism of water to the Earth.

**Author(s):** Edwin Bergin, Kate Su, Stefanie N Milam,

Maryvonne Gerin, Gary Melnick, Klaus Martin Pontoppidan

**Institution(s):** Space Telescope Science Institute, Harvard Smithsonian Center for Astrophysics, University of Michigan, Observatoire de Paris, Steward Observatory, NASA Goddard Space Flight Center Contributing Team(s): Origins Space Telescope Science and Technology Defin

### **163.04 - Unveiling the Circumstellar Regions of Thermally Pulsing Asymptotic Giant Branch Stars with the Gemini Planet Imager(Nina Shirman)**

The Thermally-Pulsating (TP-) period of Asymptotic Giant Branch (AGB) stars is one of the least understood phases of stellar evolution. Understanding the TP-AGB phase mass-loss and molecule formation (in the stars' stellar winds) provides crucial insights into the composition of the interstellar medium and stellar populations of galaxies. We have commenced a high-contrast imaging program of TP-AGB stars to study morphologies and dust and gas properties of their circumstellar envelopes (CSEs). High-contrast polarimetric observations at 14 mas angular resolution were performed using the Gemini Planet Imager to study the inner regions of CSEs (~50-800 AU) around five TP-AGB stars. We resolved polarimetric H-band ( $\lambda_{\text{cen}} = 1.65 \mu\text{m}$ ) images of the inner CSE around the AGB star W Pic. We apply radiative transfer RADMC simulations to determine W Pic's stellar mass-loss rate, dust formation rates, wind speeds, and asymmetries.

**Author(s):** Max Millar-Blanchaer, Tuan Do, Quinn

Konopacky, Jérôme Maire, Nina Shirman, Shelley Wright

**Institution(s):** University of California, San Diego, University of California, Los Angeles, Jet Propulsion Laboratory

### **163.05 - Investigating the Asymmetric Features of the Protoplanetary Disk of MWC 758 due to a Warped Inner Disk(Ammar Bayyari)**

The protoplanetary disk of MWC 758 (HD 36112) contains noticeable differences in brightness along its outer disk based on the images taken from multiple instruments. This could be the result of the inner disk being midly warped, thus casting shadows and creating bright spots in certain regions. We modeled its spectral energy distribution (SED) using the Monte-Carlo Radiative Transfer code (MCRT) HOCHUNK3D utilizing an inner disk warp structure, and produced images viewed at multiple wavelengths based on the modeled SED. Using near-infrared (NIR) spectra obtained with the SpeX spectrograph on NASA's Infrared Telescope Facility (IRTF), we derived the mass accretion rates of MWC 758 to learn more about the inner regions of the disk.

**Author(s):** Ammar Bayyari

**Institution(s):** University of Cincinnati Contributing Team(s): Rachel B Fernandes, Zachary C Long, Michael L Sitko, Korash D Assani, Dakotah B Tyler, Carol A Grady, Ray W Russel, William Danchi, John P Wisniewski

### **163.06 - Bent out of Shape: A Theory on Stellar Interactions with Protoplanetary Disks(Isaiah Tristan)**

In recent years, asymmetrical protoplanetary disks have been discovered through observations with the Atacama Large Millimeter/submillimeter Array and the Submillimeter Array, but there are no clear reasons for their unusual development. We theorize that these asymmetries are instigated by gravitational interactions with neighboring stars. To explore this, we selected a sample of 37 targets with disks (symmetric and asymmetric) and searched for nearby stars that may have passed within 1,000 AU in the past million years using Gaia DR2 astrometry for 2D proper motion analysis, followed by 3D kinematic analysis for stars with radial velocities. From 378 final 3D-candidates, we detect 27 potential interactions within error (with many involving symmetric disks), indicating that passing neighbors can play an under-examined role in protoplanetary disk evolution and warranting further study of this theory.

**Author(s):** Isaiah Tristan, Andrea Isella

**Institution(s):** Rice University

### **163.07 - Efficient Monte Carlo Radiative Transfer in Optically-Thick Protoplanetary Disks(John DeVries)**

Protoplanetary disks are the birthplaces of planets in our universe. Observations of these disks with radio telescopes like

the Atacama Large Millimeter Array (ALMA) offer great insight into the star and planet formation process. Comparing theories of formation with observations requires tracing energy transfer via electromagnetic radiation using radiative transfer. monte, an existing simulation code which employs a Monte Carlo (MC) approach, can be used to determine the temperature structure of these disks. In regions of high optical depth, such as regions close to the disk midplane where planet formation takes place, this approach quickly becomes computationally expensive and statistically noisy. A diffusion approximation can replace many MC interactions with a single interaction. This method speeds up calculation of the radiation field and temperature structure in the planet-forming zones by an order of magnitude or more. This procedure is known as the Modified Random Walk (MRW) [1, 2] algorithm and will be the subject of the talk. I will discuss implementing the algorithm in monte, preliminary results, and future work. References [1] Min et al. 2009, A&A, 497, 155 [2] Robitaille, T. P. 2010, A&A, 520, A70

**Author(s):** John DeVries, Susan Terebey, Neal Turner

**Institution(s):** California State University Los Angeles, Jet Propulsion Laboratory

### **163.08 - Overcoming the Meter-size Barrier in Planet Formation Models(Elizabeth Yunerman)**

The meter-size barrier is a persistent problem in current planet formation models, where particles on the order of a meter in size fail to grow because they either fragment or drift into the star. Planetesimal formation at this size can be summarized in three characteristic timescales: growth, drift, and fragmentation. Accurate models of these timescales that resolve the meter-size barrier will improve our understanding of how planets form in a protoplanetary disk. Recent observations of protoplanetary disks indicate that they may be more massive than previously assumed. Decreasing the dust-to-gas ratio from typically assumed ISM values, and increasing the total disk mass, causes the growth timescale to be longer. According to our analytical model, the drift timescale is initially shorter than the growth timescale, allowing a particle to drift past the fragmentation limit of the meter-size barrier. Once beyond the barrier, the growth timescale becomes faster which permits the particle to grow quickly such that it is less susceptible to radial drift into the star. These preliminary results show that through increasing the total disk mass, the particle can potentially grow beyond the meter-size barrier. We adapt the two-population dust evolution numerical model from Birnstiel et al. (2012;15) to verify that, with a smaller dust-to-gas ratio and a smaller turbulence parameter, particles can survive the meter-size drift and fragmentation barriers and continue to grow.

**Author(s):** Elizabeth Yunerman, Jake Gerhardt, Diana Powell, Ruth Murray-Clay, Alejandro Gomez

**Institution(s):** University of California, Santa Cruz

### **163.09 - Modeling circumstellar gas around white dwarfs(Amy Steele)**

At least 30% of white dwarfs (WDs) show heavy elements in their atmospheres. This "pollution" likely arises from the accretion of planetesimals that were perturbed by outer planet(s) into the white dwarf's tidal radius. A small fraction of these WDs show either emission or absorption from circumstellar (CS) gas. For example, high resolution spectroscopic observations of WD1145+017 reveal photospheric and CS absorption lines of elements heavier than helium in multiple transitions. The photospheric abundances have been measured and are similar to the bulk composition of the Earth. However, models (to date) have not yet been able to link the CS species to the total atomic abundance in gas. The CS component arises from a gas disk produced through the sublimation of a transiting, disintegrating planetesimal. Here we present self-consistent models of CS gas in orbit around various types of WDs and demonstrate how we can determine the abundances of CS lines arising from planetesimals. We build a grid of models and place constraints on the gas masses needed for detection with current observatories, which can be used to constrain the frequency of CS gas around statistical samples of WDs. These models of CS gas around polluted white dwarfs will provide a key to understanding the instantaneous composition of the material flowing from the planetesimals, will guide modeling of the transits and of the dust in these polluted systems, and will help constrain the radial locations of different gas components.

**Author(s):** Siyi Xu, John Debes, Amy Steele

**Institution(s):** University of Maryland, Gemini Observatory, STScI

### **163.10 - Characterizing Changes in the Be Star Population of NGC 663(Erick Powell)**

Characterizing the amplitude and wavelength dependence of variations in the intrinsic polarization of classical Be stars can help inform how these circumstellar disks change over time. Since the observed polarization is a superposition of a component arising from the interstellar medium (ISP) and a component intrinsic to the Be star itself, robustly determining the ISP component is critical to isolating the intrinsic component. We present our analysis of multi-epoch, multi-wavelength photometric and polarimetric imaging of NGC 663. NGC 663 is an open cluster that is known to host a large population of Be stars. We use GAIA Data Release 2 to refine the distance and membership of NGC 663, and use these results to construct a refined field star polarization map towards the cluster, thereby enabling us to better quantify the ISP along the line of sight. This program is supported by NSF-AST 1411563, 1412110, and 1412135, along with the NSF REU program at the University of Oklahoma.

**Author(s):** Jamie L Lomax, John Wisniewski, Karen Bjorkman, Anthony Burrow, Rochelle Horanzy, Maria Schutte, Jon E Bjorkman, Brennan Kerkstra, Kevin Covey, Noel Richardson, Erick Powell, S. Drew Chojnowski, Brian Skiff

**Institution(s):** Western Washington University, University of Oklahoma, University of Connecticut, New Mexico State University, University of Toledo, Lowell Observatory, US Naval Academy

### **163.11 - Tracing Inner Disk H<sub>2</sub> and CO in Protoplanetary Systems with HST-COS(Nicole Arulanantham)**

As the two most abundant molecules in protoplanetary disks around young stars, H<sub>2</sub> and CO are critical tracers of the planet formation environment. We use these two hot gas populations to map the radial distribution of material in the inner disks around a sample of 15 T Tauri stars. Each system was observed with the Cosmic Origins Spectrograph onboard the Hubble Space Telescope (HST-COS), which detected a suite of ultraviolet emission lines from electronic transitions of both molecules. We fit a 2-D radiative transfer model to these spectra and derive the gas disk structure that reproduces the UV-CO and UV-H<sub>2</sub> emission lines, assuming that Keplerian rotation is the dominant source of line broadening. We find that the population of CO has a cooler temperature than the H<sub>2</sub>, indicating that the molecules are probing distributions of material at different radial locations in the gas disk. By combining kinematic information from these two inner disk tracers for the first time, we provide a more complete census of molecular structure in the planet forming regions of our sample of young disks.

**Author(s):** Kevin France, Nicole Arulanantham

**Institution(s):** University of Colorado Boulder

### **163.12 - A Deep Search for Five Molecules in the Debris Disk around 49 Ceti(Jessica Klusmeyer)**

The surprising presence of molecular gas in some circumstellar debris disks promises to provide insight into the evolution and composition of distant planetary systems. While most systems can be explained in the context of a second-generation scenario where the gas is produced by collisions between planetesimals and exocomets, several systems are anomalously gas-rich and may instead indicate a long-lived protoplanetary gas phase. With CO as the only detected gas-phase molecule in debris disks to date, a key unexplored avenue for understanding the origin and evolution of these systems lies in characterizing their molecular chemistry. We present a molecular survey of the debris disk around the nearby A star 49 Ceti at 1.3 mm wavelength with 0.9" angular resolution, which targets five molecules (HCN, CN, HCO<sup>+</sup>, SiO, and CH<sub>3</sub>OH) over the course of a 5-hour observation with the Atacama Large Millimeter/submillimeter Array (ALMA). To increase sensitivity to faint line emission, we employ the spectral shifting and spatial averaging method pioneered by Matra et al. (2017), utilizing previous spatially resolved observations of CO emission that revealed axisymmetric gas consistent with Keplerian rotation. Our survey will provide an order of

magnitude better sensitivity than previous searches for molecular lines other than CO in nearby debris disks.

**Author(s):** Luca Matr , Angeles Kospal, David Wilner, Attila Moor, Aki Roberge, Karin I  berg, Aaron Boley, Jessica Klusmeyer, A. Meredith Hughes, Kevin Flaherty, Peter Abraham

**Institution(s):** Wesleyan University, Konkoly Observatory, Harvard-Smithsonian Center for Astrophysics, The University of British Columbia, Williams College, NASA Goddard Space Flight Center

### **163.13 - Characterizing the Debris Disk of Substellar Companion Host HR 2562 with ALMA(Yimiao Zhang)**

We present our results on determining the properties of the debris disk surrounding star HR 2562 based on the first ALMA detection of the system. HR 2562 and its brown dwarf companion, HR 2562B, were the first discovered system where a substellar companion resided in a cleared inner hole of a debris disk, and hence they provide invaluable opportunities to study the direct interaction between the companion and the disk (Konopacky et al. 2016). The disk is observed to be nearly edge-on and well resolved with a signal to noise ratio of 36.2 and ~9 resolution elements across the disk. The observed disk is consistent with the previously marginally resolved Herschel image. We determine the disk properties by fitting the ALMA image with an MCMC routine that uses the MCFOST radiative transfer code. We find that the full extent of the disk is ~200 AU, and investigate a range of possibilities for the true size of the inner hole, which remains unresolved in our ALMA data. An inner radius comparable to the distance between HR 2562B and its host star may be an evidence for dynamical sculpting. We also use the derived disk properties to shed light on both the formation history and the true mass of HR 2562B.

**Author(s):** Thomas Esposito, Megan Ansdell, Yimiao Zhang, Gaspard Duch ne, Quinn Konopacky, Robert De Rosa, Brenda Matthews

**Institution(s):** University of California, San Diego, University of California, Berkeley, NRC Herzberg, Stanford University  
**Contributing Team(s):** The GPIES Team

### **163.14 - Dust properties of the HIP 79977 Debris Disk(Schuyler Wolff)**

We present spectroscopic and polarimetric high contrast images of the HIP 79977 debris disk (F star in Upper Scorpius SFR) obtained in J, H and K bands with the Gemini Planet Imager (GPI). The disk is resolved in all observing modes and is highly inclined (~85 degrees) with polarized disk signal extending to the edge of the GPI field of view. We construct color dependent polarization fraction scattering phase functions for intermediate scattering angles (20 - 90 degrees) to constrain the dust grain properties of the disk. Preliminary radiative transfer modelling (using MCFOST) probes the particle size distribution, minimum grain size, porosity and composition of

the debris belt.

**Author(s):** Paul Kalas, Max Millar-Blanchaer, Justin Hom, Christine Chen, Stanimir Metchev, Marshall Perrin, Kimberly Ward-Duong, Schuyler Wolff, Gaspard Duchene, Mike Fitzgerald, Brenda Matthewso, Christopher Stark, Glenn Schneider, Alycia Weinberger, Thomas Esposit

**Institution(s):** University of Western Ontario, oNational Research Council of Canada Herzberg Astronomy and Astrophysics Programs, Gemini Observatory, Jet Propulsion Laboratory, Department of Terrestrial Magnetism, University of Arizona, Harvard-Smithsonian Center for

### **163.15 - A Gas Inventory of the Edge-On Debris Disk Around HD 32297, A Beta-Pic Analog(Allison Quintana)**

We present the first comprehensive gas inventory of the edge-on debris disk system HD 32297. UV and optical spectra of the system were obtained using the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope (HST). Debris disks offer an important opportunity to study the evolution from early star and planet formation in dusty, gas-rich protoplanetary disks, to mature systems, such as our own, that are nearly all cleared of primordial material (Hughes et al. 2018). In particular, edge-on debris disk systems, such as HD 32297, afford astronomers the opportunity to study the dust and gas abundances within the disk, as was done for the well-known beta Pictoris system, whose spectrum revealed an astonishing overabundance of carbon (Roberge et al. 2006). Together with absorption features associated with the Local Interstellar Medium (LISM), Redfield (2007) detected a strong Na I gas absorption feature in the stellar rest frame of HD 32297, indicating gas in its disk. The previously mentioned observations permit a comparative gas study of the disks of HD 32297 and beta Pictoris. We fit absorption features to the spectra of HD 32297 to identify circumstellar absorption and distinguish it from interstellar absorption. We will simultaneously model the circumstellar and interstellar spectral features of two neighboring stars to HD 32297 in order to compare and, therefore, distinguish between the two absorption sources. We acknowledge support for this project through NASA HST Grant Go-11569 awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS 5-26555.

**Author(s):** Allison Quintana, Seth Redfield

**Institution(s):** Wesleyan University

### **163.16 - Semi-Lagrangian Dust Transport in Protoplanetary Disks and it's Role in Planetesimal Formation(Nicole Marie Rider)**

It is a remarkable fact that planets start out as microscopic grains within protoplanetary disks of gas and dust in orbit around newly-formed protostars, somehow growing by a factor

of  $10^{40}$  in mass in a period no more than  $10^7$  years. One of the least understood stages of planet formation is how millimeter-sized dust grains coalesce into kilometer-sized planetesimals. We have developed a numerical algorithm to investigate the advection of dust grains in protoplanetary disks. The algorithm consists of a two-fluid, semi-Lagrangian approach to dust dynamics. In purely Lagrangian advection, the equations of motion are integrated for a fixed set of particles. In semi-Lagrangian advection, the particles that are followed are different for each timestep; more specifically, the set of particles that are chosen are ones that land exactly at the grid points of an Eulerian grid at the end of a timestep. In other words, to determine the density of some tracer at a particular grid point, one determines the departure point of a particle that would have advected to that grid point. The departure point is almost certainly not on the grid, and so the density must be evaluated via interpolation, most often cubic spline interpolation. Instead of cubic spline interpolation, we use a spectrally accurate interpolation scheme developed by Suli & Ware. Like purely Lagrangian advection, semi-Lagrangian advection is not limited by the CFL condition, and can accurately capture very steep density gradients (because the derivative of the density never enters into the algorithm). Yet, semi-Lagrangian advection also has the advantages of an Eulerian grid method, especially when coupled with Eulerian hydrodynamics. Two methods of concentrating dust will be explored: the streaming instability and dust trapping vortices.

**Author(s):** Joseph Andrew Barranco, Nicole Marie Rider

**Institution(s):** San Francisco State University

### **163.17 - Variability of Ten Silhouette Disks in the Orion Nebula Cluster in Ten Years(Mackenzie James)**

There is evidence that our solar system formed in a high radiation environment, similar to the current environment of the Orion Nebula around young massive O stars. These stars emit strong UV radiation, which evaporates the gas and dust surrounding protoplanetary disks. Dust in protoplanetary disks is essential in the formation of planetary bodies, which makes the study of the evolution of these disks critical. We selected ten previously identified silhouette disks in the Orion Nebula Cluster, and analyzed the images from Hubble Space Telescope in two epochs, 2005 and 2015 in 435w, 555w, 656n, 658n, 775w, and 850lp filters. We measured the semi-major and semi-minor axis of ten disks for different filters in two epochs, and compared the background intensity levels near the disks. Preliminary results show that the dust disks are not visible in longer wavelengths (775w and 850lp), which imply that many of the disks in this region are composed of smaller dust grains. Variability in the sizes of the disks was different for each individual object, but overall most changes were greater than our margin of error. Each disk showed different amplitude in variability of the background intensity. There is no significant variation of physical sizes or morphology except for one large dust disk, 114-426. Silhouette disk 114-426 was of special interest, due to its much larger size and visible change in the morphology and size of the disk between the two epochs of

2005 and 2015. We noticed a change specifically in the northeastern edge of the disk, where it appears to have extended in the 2015 epoch. Future work will show any changes over time in the flux of the silhouette disk or the central star.

**Author(s):** Mackenzie James, Jinyoung Kim, John Bally

**Institution(s):** University of Arizona, University of Colorado

**163.18 - Time-variability in the mid-infrared spectra of pre-transitional disk sources AB Aur and MWC 758: preliminary results from SOFIA-FORCAST observations(Ralph Shuping)**

We present new infrared observations of the Herbig Ae stars AB Aur and MWC 758 (HD 36112) from 5 to 38 micron using the FORCAST instrument on SOFIA. We compare the resulting low resolution spectra ( $R = 200$ ) to previous observations using ISO and Spitzer, as well as archival photometry from WISE and 2MASS (where available). Even though both objects are of similar type and age, and possess pre-transitional (“gapped”) disks with spiral arms, the observed changes in the SED are somewhat different in each case. AB Aur displays significant variations in IR flux and spectral shape from 15 - 40 micron on decade-long timescales as well as small variations in the strength and shape of the silicate feature at 10 micron. AB Aur is known to be variable in the near-IR (JHK bands) as well which is likely due to changes in the structure of the inner disk. MWC758, on the other hand, displays a significant increase at near-IR wavelengths (5 - 8 mic) and relatively little change in the silicate emission feature or longer wavelengths since the mid-IR observations carried out in 2004 with Spitzer/IRS. We obtained observations of MWC 758 at two epochs with SOFIA-FORCAST within 7 days; the resulting mid-IR spectra at each epoch are nearly identical (within systematic uncertainties), indicating little or no short-term variability for this source. We discuss the underlying models for mid-IR variability in HAeBe pre-transition disks (including the “see-saw” effect) and their applicability to these two sources.

**Author(s):** William Vacca, Luke Keller, Catherine Espaillat, Ralph Shuping, Michael Sitko

**Institution(s):** Space Science Inst., Ithaca College, USRA-SOFIA, Boston Univ

**163.19 - Modeling the Circumstellar Disc of HD 166191(Korash Assani)**

Using a radiative transfer code developed by Barbara Whitney called HOCHUNK3D, we investigate the spectral energy distribution (SED) of HD 166191, revealing the parameters of its circumstellar disc. We produce a model with two coplanar disks. One representing smaller grains originating at approximately 1.1 AU from the star and the other representing a large grained settled disc beginning at 6 AU. We estimate an outer radius of 25 AU for both discs. Based on data from NASA's Infrared Telescope Facility (IRTF) on top of Mauna Kea, Hawaii, we classify HD 166191 with a F8V Stellar

classification and an effective temperature of  $6170 \pm 50$  K. We also explore Brackett Gamma and Paschen Beta line emissions in order to calculate the mass accretion rate of HD 166191. We find that there is no accretion taking place in HD 166191. Due to HD 166191's large infrared excess and young stellar age of approximately 15 Million years old, it is a potentially important object for understanding the protoplanetary to debris disc transition.

**Author(s):** Korash Assani

**Institution(s):** University of Cincinnati Contributing Team(s): University of Cincinnati Planet-Building Disc Research Group

**163.20 - Markov-Chain Monte Carlo Modeling of Protoplanetary Disks with and without Disk Winds(William Duffy)**

We observed 2 binary and 3 single protoplanetary disk systems using the Atacama Large Millimeter Array (ALMA) in band 7. Transitions from CO,  $^{13}\text{CO}$ , C $_{18}\text{O}$ , HCO $^+$ , HCN, and CN are detected in most of the disks. While some of the disk observations are well-fit with Keplerian models, others exhibit evidence for non-Keplerian motion - perhaps due to a disk wind. The latter sample includes AS 205 N, which showed signs of non-Keplerian motion when observed at lower resolution (Salyk et al. 2014). Using Markov Chain Monte Carlo (MCMC) modeling, we first investigate the properties of the Keplerian disks and demonstrate the need for more complex models for some disks. Then, we devise a model incorporating a parameterized disk wind to fit the data of the irregularly rotating disks, following a framework similar to that of Pontoppidan et al. 2011.

**Author(s):** Geoffrey Blake, Colette Salyk, William Duffy

**Institution(s):** Vassar College, California Institute of Technology

**163.21 - Going with the Grain: Using Bayesian Modeling to Uncover Physical Properties of Debris Disks(Mara Zimmerman)**

It is impossible to overestimate the importance of knowing the physical properties of dust in debris disks. Planetary formation, composition, and structure can all be inferred from the nature of the surrounding material in the circumstellar debris disk. We select nine debris disks targets to study in detail; we create debris disk models to fit the Spitzer IRS data for these targets. We use Mie Theory, which assumes dust grains are spherical, to determine the physical properties of the grains. We then allow the grain size, temperature, olivine fraction, and number of grains to vary as we implement MCMC processes to find the best fit model. From the results, we can then use the temperature to find the distance of the dust from the star. The grain size also gives us clues about the formation and evolution of these disk targets. By interpreting our models, we can uncover more about the physical processes and evolution of



these disks.

**Author(s):** Christopher Stark, Glenn Schneider, David Kasper, Mara Zimmerman, Hannah Jang-Condell, Christine Chen

**Institution(s):** University of Wyoming, Space Telescope Science Institute, University of Arizona

### 163.22 -

#### **From scattered-light to millimeter emission: A global view of the Gyr-old system of HD 202628 and its eccentric debris ring(Virginie Faramaz)**

We present a collection of new observations of the cold eccentric debris ring surrounding the Gyr-old solar-type star HD 202628 in scattered light with HST/STIS, at far-infrared wavelengths with Herschel/PACS and SPIRE, and at millimeter wavelengths with ALMA. Similar to the debris disk of Fomalhaut, the ring appears much narrower at millimeter wavelengths than at optical wavelengths, while its inner edge is found to be consistent between ALMA and HST data. Best fit to the dust parent ring seen with ALMA is found to have inner and outer edges  $143.8 \pm 2.3$  AU and  $165.3 \pm 2.2$  AU, respectively, an inclination of  $57.5^\circ \pm 0.6$  from face-on, and a position angle of  $129.8^\circ \pm 0.7$ . The offset of the ring centre of symmetry from the star allows us to quantify its eccentricity to be  $e = 0.08 \pm 0.03$ . This eccentric feature reveals itself as well in low resolution Herschel/PACS observations, under the form of a pericenter-glow. Upper limits on the gas mass provided by ALMA data allow us to exclude this narrow eccentric ring results from gas-solid interactions, hence confirming the presence of a distant belt-shaping eccentric perturber in this system. From the combination of the ALMA and the Herschel photometry, we retrieve a disk grain size distribution index of  $\alpha^{1/4} = 3.5$ , and therefore exclude in-situ formation of the inferred perturber, for which we provide new dynamical constraints. Another feature consistent across both ALMA and HST datasets is an emission enhancement in the SE direction, which cannot be explained by the overdensity expected at apocenter in eccentric debris disks, as the apocenter lies in NE direction. Finally, ALMA images show a source just interior to the ring, although we can not exclude it to be a background object at that stage. We cannot exclude either that this source is circumplanetary material surrounding the eccentric belt-shaper, in which case degeneracies between its mass and orbital parameters could be lifted, allowing us to characterize the mass and orbital properties of a mature planet on a wide orbit for the very first time.

**Author(s):** John Krist, Karl Stapelfeldt, Geoffrey Bryden, Virginie Faramaz

**Institution(s):** Jet Propulsion Laboratory

#### **163.23 - An ALMA Study of Disk and Wind Kinematics Using Hydrogen Recombination Masers in MWC 349A(Deanna Lily Emery)**

The kinematics of circumstellar disks and disk winds are poorly understood due to the difficulty of obtaining well-resolved observational data. However, the bright hydrogen recombination-line maser emission originating from the circumstellar disk of MWC 349A, offers a unique opportunity to study the disk at milli-arcsecond precision. We carried out observations of MWC 349A in hydrogen recombination line  $H_{30}\alpha$  and 1.3 mm continuum in Band 6 of ALMA using its most extended array configuration of  $\sim 16$  km baseline. With a beam size of  $80 \text{ mas} \times 30 \text{ mas}$  at a position angle of  $2^\circ$ , the high angular resolution observations resolved the disk in the east-west direction (along the plane of the disk) in both continuum and the line emission for the first time. With spatially resolved images of the maser emission, we are able to produce and analyze rotation curves for the  $H_{30}\alpha$  transition with greater precision than before. We will report the new constraint on the stellar mass and the spatial distributions of the hydrogen masers, as well as a study of the kinematics of the circumstellar disk.

**Author(s):** Deanna Lily Emery, Alejandro Baez-Rubio, James Moran, Qizhou Zhang, Izaskun Jimenez-Serra, Jesus Martin-Pintado

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Centro de Astrobiologia

#### **163.24 - Exploring Debris Disks across Spectral Types with Hubble STIS Coronagraphic Imaging(Marshall Perrin)**

Coronagraphic imaging with Hubble is one of the most effective tools for studying debris disks in scattered light; the STIS coronagraph achieves high contrast at shorter visible-light wavelengths and with deeper sensitivity to faint extended disks than any of the AO coronagraphs. We present new STIS coronagraphy of 4 debris disks, resolving these systems for the first time at optical wavelengths. This is the first portion of data from an ongoing HST/STIS program following up initial images from HST/NICMOS. The STIS images surpass the NICMOS discovery images in resolution and sensitivity to better reveal disk geometry and structure. One of these targets, TWA 25, is a rare example of an M dwarf with a resolved debris disk. Another, HD 377, is a young solar twin. 49 Ceti is an important example of the subset of relatively gas-rich debris disks around A stars. HD 192758 is a young F star now seen to host a close-to-face-on ring. Our eventual full sample of 13 targets (9 from this program plus 4 from an earlier one by our team) will span the full range of stellar spectral types and will allow us to explore how disk properties and dust distributions vary with host star masses.

**Author(s):** Marshall Perrin, Brendan Hagan, David Golimowski, Elodie Choquet, Rémi Soummer, Christopher Stark, J. Milli, John Debes, Glenn Schneider, Eugene Serabyn, Karl Stapelfeldt, Bin Ren, Laurent Pueyo, Aki Roberge, Schuyler Wolff, Christine Chen, Dimitri Mawet

**Institution(s):** STScI, Johns Hopkins University, Caltech, NASA Goddard Space Flight Center, European Southern Observatory, NASA Jet Propulsion Laboratory, University of

Arizona, Leiden Observatory

## **164 - Extrasolar Planets: Detection -- iPosters**

### **164.01 - Observing Two-Component Debris Disks with SCEXAO+CHARIS(Benjamin Gerard)**

Only six exoplanetary systems harboring planets within 100 AU of their host stars and beyond 10 Myrs old have been directly imaged. Three of these six systems have two component debris disks based on SED fits to their IR excess with spatially unresolved components modelled interior and exterior to the known planets, suggesting that other similar systems may contain gas giants detectable with direct imaging. We present results from a mini survey of two temperature component debris disk targets using the new Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) instrument on the Subaru Coronagraphic Extreme Adaptive Optics (SCEXAO) system, including an analysis of instrument sensitivity and implications for future instruments.

**Author(s):** Benjamin Gerard, Thayne Currie, Julien Lozi, Nemanja Jovanovic, Tyler Groff, Christian Marois, Olivier Guyon,

**Institution(s):** University of Victoria, NASA Ames, National Research Council of Canada, Herzberg Astronomy and Astrophysics, NASA Goddard, University of Arizona, Subaru Observatory, Caltech Contributing Team(s): SCEXAO

### **164.02 - A Maximum Likelihood Approach to Extracting Photon-Starved Spectra of Directly Imaged Exoplanets(Neil T. Zimmerman)**

Spectroscopic characterization of exoplanet atmospheres is a core objective of space-based coronagraph instruments. The data characteristics of integral field spectrograph (IFS) designs for the WFIRST Coronagraph Instrument and for future exoEarth-imaging mission concepts -- a tightly-packed grid of interlaced, spectrally dispersed spatial samples, each with low-to-moderate spectral resolution ( $50 < R < 200$ ) -- bear a natural resemblance to ground-based analogs in current use with adaptive-optics-fed coronagraphs. However, at the extreme contrast levels targeted by space-based exoplanet imagers (planet-to-star flux ratios  $< 1E-8$ ), the source count rates incident on the detector array are correspondingly low. Therefore, photon counting statistics will be a dominant noise contribution in each IFS detector pixel, motivating us to re-examine the data cube extraction strategy for this operating regime. We present a new model-based formalism to extract IFS data that is statistically optimal for Poisson noise-dominated spectra. Further, we derive a prescription for the error in the extracted source spectrum that takes into account the instrument-specific intensity profiles of the coronagraph PSF and IFS response.

**Author(s):** Timothy Brandt, Maxime Rizzo, Michael McElwain, Qian Gong, Avi M Mandell, Aki Roberge, Tyler Groff, Neil T. Zimmerman

**Institution(s):** Goddard Space Flight Center, UC Santa Barbara

### **164.03 - A new deformable mirror architecture and low-order wavefront sensing for coronagraphs(Hari Subedi)**

Ideally, the high contrast required to directly image exoplanets can be achieved by coronagraphs. However, coronagraphs are highly sensitive to optical aberrations. Therefore, all coronagraphic missions need a wavefront control system to cancel out these aberrations. High stroke, high actuator density deformable mirrors (DMs) are used to control the electric field at the required high spatial frequencies. All current DMs in use are manufactured with flat nominal surfaces. We are designing a testbed to verify a different deformable architecture, where the powered optic in the optical train are controllable and have lower actuator count. In addition to simplifying the packaging issue for space missions, this reduces both cost and risk of having the entire coronagraph instrument's performance depending on one or two high-actuator count DMs. Unlike the high-actuator count DMs, these powered low-actuator DMs can approximate low-order shapes such as focus or tip-tilt without introducing mid-spatial frequencies. The testbed would also be capable of testing different low-order wavefront sensing algorithms.

**Author(s):** Roser Juanola-Parramon, Hari Subedi, Tyler Groff

**Institution(s):** NASA GSFC

### **164.04 - Exoplanet Science Using University of Wyoming Observatories(Hannah Jang-Condell)**

The University of Wyoming is home to the 2.3-m Wyoming Infrared Observatory (WIRO) and the 0.6-m Red Buttes Observatory (RBO). These facilities enable research in exoplanet detection and characterization. Transit observations at RBO have led to the discoveries of KELT-9b and KELT-21b. Multi-band photometry of HD 189733b at WIRO has helped to characterize its atmosphere. New instruments under construction at WIRO include a speckle imaging camera (SPARC: SPeckle Advanced Resolution Camera) and an echelle spectrograph (FHiRE: Fiber-fed High Resolution Echelle). FHiRE is poised to become a precision radial velocity measurement instrument for long-term RV monitoring of candidate exoplanet host stars. As TESS identifies new planet candidates, our facilities will make significant contributions toward exoplanet discovery and characterization.

**Author(s):** Michael J Pierce, Cristilyn N. Gardner, David Kasper, Henry Kobulnicky, Hannah Jang-Condell, Catherine Pilachowski

**Institution(s):** University of Wyoming, Indiana University

#### **164.05 - Advancing Exoplanet Science with the WFIRST Coronagraph Instrument(John Terry Trauger)**

The Coronagraph Instrument (CGI) is one of two instruments on the Wide Field Infrared Survey Telescope (WFIRST), a NASA project now in the design (Phase B) stage and scheduled for launch in 2025. The CGI will demonstrate in space, for the first time, key technologies necessary for future Earth imaging missions, including precision optical wavefront control with deformable mirrors, sensitive photon-counting imaging detectors, selectable coronagraph observing modes, low-resolution integral field spectroscopy, advanced algorithms for wavefront sensing and control, high-fidelity integrated spacecraft and coronagraph modeling, and post-processing methods to extract images and spectra. Following the recommendations of the Astro2010 decadal survey, the CGI is intended to demonstrate new technologies that are key enablers for the next generation of Earth-observing exoplanet observatories in space. CGI is designed to demonstrate space coronagraphy at sensitivity levels of Jovian-mass planets and faint debris disks in reflected starlight. Following initial commissioning and formal technology demonstrations in the first year of operations, NASA envisions a Participating Science Program that engages the general exoplanet community in high-contrast direct imaging astronomy. Here, we describe the science that CGI may achieve, how this science will advance community goals in exoplanet astronomy, and how it can validate key technologies for future exoplanet missions, now envisioned as HabEx and LUVOIR.

**Author(s):** John Terry Trauger

**Institution(s):** Jet Propulsion Laboratory Contributing Team(s): On behalf of the WFIRST CGI science and engineering project

#### **164.06 - TESS Follow-up Observing Program Working Group (TFOP WG) Sub Group 4 (SG4): Precise Radial Velocities(David W Latham)**

The Transiting Exoplanet Survey Satellite (TESS) will observe most of the sky over a period of two years, divided into 26 sectors that are each observed for ~27 days. TESS data are expected to produce hundreds of transiting planet candidates (PCs) per month and thousands over the two-year nominal mission. The TFOP WG is a mission-led effort to organize and coordinate follow-up observations to confirm and characterize transiting planet candidates identified by TESS. The primary goal of the TFOP WG is to facilitate achievement of the Level One Science Requirement to measure masses for 50 transiting planets smaller than 4 Earth radii. Secondary goals are to serve any science coming out of TESS and to foster communication and coordination both within the TESS Science Team and with the community at large. This poster presents TFOP Sub Group 4: Precise Radial Velocities. SG4 is responsible for coordinating the observations needed to derive orbital solutions and determine masses for small transiting planets identified by TESS. The organization of SG4 and examples of recent results for planets found in Sectors 1-4 will be reported.

**Author(s):** David W Latham

**Institution(s):** Harvard-Smithsonian Center for Astrophysics  
**Contributing Team(s):** The TESS Follow-Up Observing Program Working Group (TFOPWG) and the TESS Team

#### **164.07 - K2-138 g: Spitzer Spots a Sixth Sub-Neptune for the Citizen Science System(Kevin Hardegree-Ullman)**

K2-138 is a moderately bright ( $V=12.2$ ) early-type K dwarf observed in Campaign 12 of the NASA K2 mission. Citizen scientists participating in the Exoplanet Explorers project on the Zooniverse platform helped discover five sub-Neptune planets orbiting K2-138 which form a near 3:2 mean motion resonance chain. A potential sixth planet with a 42 day period was identified in the K2 data, but the 80 day observing campaign only showed two transit events. We confirm the presence and refine the ephemeris of K2-138 g with follow-up observations from the Spitzer Space Telescope. This planet continues the near 3:2 resonant chain with two gaps between the fifth and sixth planets, suggesting K2-138 might host additional smaller or non-transiting planets. The near resonance of this system makes it amenable to TTV measurements, and if combined with precision radial velocity measurements, could make K2-138 a benchmark system for TTV mass calculations.

**Author(s):** Jessie Christiansen, Kevin Hardegree-Ullman

**Institution(s):** Caltech/IPAC-NExSci Contributing Team(s): K Spitzer Follow-Up Team

#### **165 - White Dwarfs, Pulsars, Neutron Stars -- Â iPosters**

##### **165.01 - Simulation of TOA Residuals of a Pulsar in a Planetary System(Joseph Vazquez)**

The time of arrival (TOA) time series of a pulsar can be used to measure the existence of a planetary system surrounding the neutron star. Using PyAstronomy, a Keplerian orbit simulator, one can create a simulation for the time series with N bodies orbiting the pulsar. The planetary system is modeled after a power law probability distribution for the masses of the orbiting bodies. Likewise, the angles of inclination of the orbits are modeled using a Gaussian distribution. Using models created by this simulation, the position of pulsars can be modeled in a time series, which introduces the possibility of using pulsars to detect gravitational waves.

**Author(s):** James Cordes, Shami Chatterjee, Joseph Vazquez,

**Institution(s):** Randolph College, Cornell University

#### **166 - Planetary Nebulae and SNRs -- iPosters**

##### **166.01 - Spatially Resolved X-ray Spectroscopy of the Large Magellanic Cloud Supernova Remnant N132D(Paul Plucinsky)**

We perform detailed X-ray spectroscopy of the brightest Supernova Remnant (SNR), N132D, in the Large Magellanic Cloud (LMC) using observations taken by the Advanced CCD Imaging Spectrometer (ACIS) on the Chandra X-ray Observatory (Chandra). By studying the spectra of regions on the well-defined rim running from NW to NE, we determine an average abundance set for O, Ne, Mg, Si, S and Fe for the local LMC environment. We note that the elements other than Fe and Ne show significant trends across this region, implying they cannot be approximated by a single, constant value. We characterize the blast wave properties and find a simple plane parallel shock model is sufficient to explain the X-ray spectrum of the forward shock moving into ambient LMC material, with a shock velocity near 800 km/s and a shock age of 800-1200 years. We find evidence of enhanced O and Si near the western blast wave and enhanced S near the western as well as the north-eastern rims, both of which imply an asymmetric explosion. We fit a region near the central, optical O-rich knots which exhibits enhanced abundances of O, Ne, Mg, Si, and Fe. Comparison to nucleosynthesis models of the ratios of these elements indicates a progenitor mass of 18-20 solar masses, consistent with most previous estimates. Lastly, we find an intriguing presence of a very hot plasma with a temperature of  $>3.0$  keV (assuming a non-equilibrium ionization model) to explain the Fe-K emission which is centrally concentrated in the lower half of the remnant.

**Author(s):** Paul Plucinsky, Terrance Gaetz, Piyush Sharda, Vinay Kashyap

**Institution(s):** Harvard-Smithsonian CfA, Department of Physics, Birla Institute of Technology

#### **166.02 - Smoothed Particle Inference Analysis of SNR DEM L71(Kari A. Frank)**

Supernova remnants (SNRs) are complex, three-dimensional objects; properly accounting for this complexity when modeling the resulting X-ray emission presents quite a challenge and makes it difficult to accurately characterize the properties of the full SNR volume. We apply for the first time a novel analysis method, Smoothed Particle Inference, that can be used to study and characterize the structure, dynamics, morphology, and abundances of the entire remnant with a single analysis. We apply the method to the Type Ia supernova remnant DEM L71. We present histograms and maps showing global properties of the remnant, including temperature, abundances of various elements, abundance ratios, and ionization age. Our analysis confirms the high abundance of Fe within the ejecta of the supernova, which has led to it being typed as a Ia. We demonstrate that the results obtained via this method are consistent with results derived from numerical simulations carried out by us, as well as with previous analyses in the literature. At the same time, we show that despite its regular appearance, the temperature and other parameter maps exhibit highly irregular substructure which is not captured with typical X-ray analysis methods.

**Author(s):** Ryan Matthew Crum, David Burrows, Vikram Dwarkadas, Kari A. Frank, Aldo Panfichi

**Institution(s):** Northwestern University, Pennsylvania State University, University of Chicago

#### **167 - Dust -- iPosters**

##### **167.01 - ALMA Insight Into CK Vulpeculae: The Aftermath of a White Dwarf - Brown Dwarf Merger?(Charles E. Woodward)**

In July 1670, observers witnessed a nova in the constellation Cygnus, cited as Nova sub Capite Cygni - "a new star below the head of the swan" (Hevelius, Phil. Trans. 1670, 5, 2087). Modern astronomers studying the remains of Nova Vulpeculae 1670 = CK Vul, initially thought this cosmic event was triggered by the merging of two main-sequence stars. However, our new Atacama Large Millimeter/Sub-millimeter Array (ALMA) observations of the remnant suggest a more intriguing picture. These data (Band 6, in 4 spectral windows 1.875 GHz in width, centered on 224, 226, 240, and 242 GHz) trace obscuring dust in the inner regions of the associated nebulosity. The dust forms two cocoons, each extending approximately 5" N and S of the presumed location of the central stellar remnant. Line emission from organic molecules methanamide ( $\text{NH}_2\text{CHO}$ ), methanol ( $\text{CH}_3\text{OH}$ ), formaldehyde ( $\text{H}_2\text{CO}$ ), and CN and  $\text{C}^{17}\text{O}$  is detected. CN lines trace bubbles within the dusty cocoons; methanol a N-S "S-shaped" jet; and other molecules a central cloud with a structure aligned with the innermost dust structure. The dust emission has approximate point symmetry about the radio source position (Hajduk et al. 2007, MNRAS, 378, 1298), the latter taken to be the putative location of stellar remnant. The inner 2" of the dust distribution is extended E-W with a sub-structure (2" x 1") that includes N-S extension around the peak, suggestive of a warped disk. After examining several possibly scenarios, we suggest 1670 "nova" was due to the merger of a white dwarf primary and a brown dwarf secondary. We argue the brown dwarf impact generated the unusual abundances and isotopic ratios seen in this object via nucleosynthesis (including Lithium). The ejected material formed the extended ejecta and disk observed with ALMA and that in turn drives the jets shaping the inner 6" of the nebulosity N and S of the center of the jet and disk. We find a total dust mass of  $\sim 2.04 \times 10^{-4} M_{\odot}$  of which  $\sim 1.56 \times 10^{-4} M_{\odot}$  is in the diffuse extended emission and  $\sim 4.81 \times 10^{-5} M_{\odot}$  is in the central disk.

**Author(s):** Sumner Starrfield, Albert Zijlstra, Stewart P.S. Eyres, Robert Gehr, Marcin Hajduk, Adam Avison, R. Mark Wagner, Charles E. Woodward, Nye Evans, Shazrene Mohamed

**Institution(s):** University of Minnesota, Arizona State Univ., Keele Univ., Univ of Warmia and Mazury, UnivManchester, UnivSouth Wales, SAAO, Large Binocular Telescope Observatory

##### **167.02 - Modeling circumstellar dust around low-mass-loss rate carbon-rich AGB stars(Angela Speck)**

Evolved intermediate-mass stars with carbon-to-oxygen ratios (C/O) above unity are known as carbon stars. Carbon stars are surrounded by dust shells dominated by carbon (C) and silicon

carbide (SiC) grains. These SiC grains have a diagnostic spectral feature at  $\sim 11$  microns. We have selected a sample of 9 carbon stars with low mass-loss rates such that their dust shells are sufficiently optically thin to allow abundance analysis of the stars' photospheres. This allows the study of how atomic abundances affect dust formation around carbon stars. We present the result of radiative transfer modeling for these stars, and compare the resulting dust shell parameters to published abundance measurements. To constrain model parameters, we use published mass-loss rates, expansion velocities, and theoretical dust condensation models to estimate the dust condensation temperature, and spectral types to constrain stellar effective temperatures. We then sought correlations between the model-derived parameters, and parameters collated from the literature in order to study why such similar stars show very different spectral features.

**Author(s):** Hannah Groom, Angela Speck

**Institution(s):** University of Missouri

#### **167.03 - Grain alignment and polarization hole in a starless core L183(Kristin Rose Kulas)**

Interstellar polarization is caused by elongated grains, aligned with the magnetic field, and can provide invaluable tools for probing magnetic fields, dust grains, and their environment, if the alignment physics can be fully understood. Radiative Alignment Torque (RAT) theory has now been refined to a predictive theory, and tested in several experiments. RAT predicts that the alignment should cease in star-less clouds when the light has been reddened to wavelengths longer than the grain diameters. Combining optical/NIR ( $A_V < 15$  mag.) and sub-mm wave data ( $A_V > 20$  mag.) appears to support this theory. However, these techniques do not probe the same material, leading to uncertainty in the results. We present our work on rectifying this inconsistency by mapping the star-less cloud L183 over an area where densely sampled H-band polarimetry exists.

**Author(s):** Miranda Caputo, Archana Soam, Kristin Rose Kulas, B-G Andersson,

**Institution(s):** Santa Clara University, SOFIA Science Center, USRA

#### **167.04 - The response of optical Fe II emission in AGNs to changes in the ionizing continuum, I: photoionization modelling(Betsy Tian)**

The line widths of optical Fe II emission in AGNs imply that it is coming from approximately twice as far from the center as H-beta emission. Reverberation mapping, on the other hand, indicates that Fe II emission comes from closer to the H-beta emitting region. We explore whether this discrepancy could be because line width size estimates indicate the emissivity-weighted radial distribution of Fe II emission, while reverberation mapping is measuring the radial distribution weighted by the responsivity to changes in the continuum. We

have used the photoionization code, Cloudy, to investigate which continuum spectral regions dominate the emissivity and responsivity. For Fe II the responsivity is dominated by gas in regions slightly beyond the mean Strömgren length in the cloud system, but there is also significant Fe II emission from a more extended region that is heated by optical and hard X-ray photons. We show how variability in different spectral regions affects the Fe II emission.

**Author(s):** Neha Thakur, Betsy Tian, Anjana Saravanan, C. Martin Gaskell

**Institution(s):** The Harker School, Crescenta Valley High School, UC Santa Cruz, Notre Dame High School

### **168 - YSO's & Friends -- iPosters**

#### **168.01 - Abundance Systematics in Herbig Ae/Be Stars(Charles Cowley)**

We review the systematics of abundance work on Herbig Ae/Be stars drawing largely on the work of Folsom, et al. (MNRAS, 442, 2072, 2012), but including 3 newly analyzed stars: HD 142527, V346 Ori, and the magnetic variable HD 95881 (Jarvinen, et al. ApJ, 858, L18, 2018). This star also shows prominent diffuse interstellar bands (DIBs). We also analyze HD 157869, which has been reported as an emission-line star and possible Herbig. We see no indication of emission; our model is in good agreement with the spectra type A1 III/IV (Houk, Co3, MSS, 1982). Roughly half of the Herbig Ae/Be stars show the Lambda Bootes pattern, where refractory elements are depleted relative to volatiles. The depletions are correlated with condensation temperature. Similar patterns are found in post AGB stars, in the interstellar medium, and in solar twins. Among the Herbig stars, the refractory element abundances are very highly correlated with one another. However, the volatiles carbon and oxygen are not closely correlated, nor are they closely anticorrelated with the refractory elements. The intermediate volatiles sodium (e.g. HD 190073) and zinc (e.g. HD 169142) can show anomalies unrelated to condensation temperature, suggesting the influence of additional differentiation mechanisms in the complex processes of star formation.

**Author(s):** Svetlana Hubrig, Silvie Jarvenin, Richard Monier, Charles Cowley

**Institution(s):** University of Michigan, Leibnitz-Institut für Astrophys(AIP), Leibnitz-Institut für Astrophys(AIP), Université Sorbonne, LESIA, UMR 809, Observatoire de Paris

#### **168.02 - High Resolution ALMA Images of Young Stellar Objects in Lupus(Masao Saito)**

We carried out an unbiased study with ALMA to investigate the binary properties at the Class 0/I stage in Lupus I, III, and IV at a spatial resolution of 20 - 30 au ( $\sim 0.15''$ ) and binary formation, a major mode of star formation in most nearby star forming regions. Surprisingly, tentative results indicate that the binary population in the Class 0/I stages identified in submillimeter continuum emission in Lupus is very low and

only two protobinary candidates are identified; J160708-391408 with its separation of 98 au and Sz-95 with 83 au separation. Later, J160708-391408 turned out to be a single star with an edge-on disk configuration. It is still puzzling why binary fraction is low in the Lupus Clouds. Further, we present imaging results of other interesting objects. Among 7 detected sources, an unresolved continuum emission was detected toward Class 0/I source IRAS 15398-3359 and a compact emission toward Class 0 Lupus III MMS clearly resolved perpendicular to the CO outflow. In addition, J160115-415235 shows extended emission in continuum and the emission distribution appears to show two arms or spiral structure similar to those identified in L1551 NE or Elias 2-27, but its size of 100 au is smaller than those of L1551 NE or Elias 2-27. In addition, Sz102 shows a compact continuum source while Merin 28, as reported in the last ASJ meeting, is associated with an E-W extended feature; possible binary. In addition, we also detected CO(J=3-2) and HCO+(J=4-3) emission toward some of our sample in Lupus. In case of J160115-415235, a velocity gradient is roughly along the major axis of the continuum disk presumably suggestive of a rotating disk. Its kinematics is not simple Keplerian and infall or outflowing motion is suggested.

**Author(s):** Masao Saito

**Institution(s):** National Astronomical Observatory of Japan  
Contributing Team(s): SOLA

## 169 - Starburst Galaxies -- iPosters

### 169.01 - Ionized and Molecular ISM study of the strongly lensed AGN/SMG hybrid, 'The Red Radio Ring' at $z = 2.5$ (Kevin Harrington)

An important coolant of the ISM, the far-IR fine-structure lines of singly ionized nitrogen trace purely ionized gas associated with massive OB stars. Here we present the first detection of the collisionally excited ground-state singly ionized nitrogen emission line, [NII]205 $\mu$ m, between redshift  $0.04 < z < 3.9$  (using the APEX 12m). In addition, we report low and mid-J CO line detections (using the GBT and IRAM 30m) with comparable line profiles, suggesting co-spatial kinematics on global scales for the ionized and molecular gas. We derive a lower limit to the SFR via the [NII]205 $\mu$ m emission line, and provide an estimate of the minimum HII gas mass of  $M(\text{HII}) \sim 3 \times 10^{10} M_{\odot}$ . Our CO(1-0) line measurements provide a direct detection of the well calibrated CO(1-0) line luminosity to molecular hydrogen gas mass, yielding apparent  $M_{\text{gas}} \sim 50 \times 10^{10} M_{\odot}$ , not factoring in the previously derived magnification factor of about 10. These findings suggest a significant starburst phase in this system, as the  $L(\text{NII}205)/\text{LIR}$  is 1-2x higher than the average value for local (U)LIRGs.

**Author(s):** Kevin Harrington

**Institution(s):** Max Planck Institut für Radioastronomie/Argander Institut für Astronomie

## 170 - Instrumentation: Ground Based or Airborne -- iPosters

### 170.01 - Past, Present, and Future Gemini/GSAOI zeropoint calibrations (Joy Chavez)

We present a consistent reduction and calibration of nearly all observations of Persson photometric standards (Persson et al. 1998) with the Gemini South Adaptive Optics Imager (GSAOI) from 2013 to present. Building upon the Python/Pyraf pipeline created by Stevenson et al., 2017, we add 10 more nights, spanning 2017 and 2018 in the J, H, Kshort, and K infrared bandpasses. We also launch the automation of the pipeline to continue to monitor and publish the current photometric zeropoint. Within a day of photometric standard observations, the script downloads the calibration images from the archive, runs a standard reduction with the IRAF gemini/gsaoi tasks, and performs aperture photometry with IRAF/DAOPHOT tasks. The zeropoints are added to the tables and plots to monitor the throughput performance of GSAOI through time. These will be published on the Gemini website as part of the Gemini Instrument Monitoring efforts. Based on observations obtained at the Gemini Observatory acquired through the Gemini Observatory Archive and processed using the Gemini IRAF package, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina), Ministério da Ciência, Tecnologia e Inovação (Brazil) and the Korea Astronomy and Space Institute (KASI). Stevenson, S. A., et al. 2017AAS...22915511SPersson, S. E., et al. 1998AJ....116.2475P  
**Author(s):** Eleazar Rodrigo Carrasco Damele, Joy Chavez, Joanna Thomas-Osip

**Institution(s):** Gemini Observatory

### 170.02 - Visiting Instruments at Gemini (Alison Peck)

The Gemini Observatory has a strong commitment to meeting the user community's scientific needs. This means providing a strong suite of instruments with broad applicability: those that can handle the largest share of science return as well as more unique instruments, some of which might have narrow scope but potentially high impact. Recognizing that building a new Facility Instrument is expensive and typically takes more than 5 years, we have developed the Visiting Instrument Program, which allows investigators to bring their own innovative instruments to either Gemini telescope. To be accepted, all visiting instruments must demonstrate their competitiveness via the regular time allocation process. The majority of successful instruments are made available to our broader user community within one semester of being commissioned at the telescope. Here we provide an update on the program, and information on how you can use these exciting new capabilities.  
**Author(s):** Stephen Goodsell, Alison Peck, Scot Kleinman, Andrew J Adamson

**Institution(s):** Gemini Observatory

### **170.03 - Community Access Time at the CHARA Array(Gail Schaefer)**

The CHARA Array is a long-baseline optical/infrared interferometer with milli-arcsecond resolution. In 2017 we began offering 50 nights per year of open access time to the astronomical community through the NOAO call for proposals. The CHARA Array can be used to measure stellar radii, image stellar surfaces, resolve close binary companions, and study circumstellar environments. We have held a number of workshops across the country to expand interest in using the Array. In this poster we report on the status of the program and discuss opportunities available through the community access time.

**Author(s):** Christopher Farrington, Jeremy Jones, Douglas Gies, Theo ten Brummelaar, Gail Schaefer

**Institution(s):** CHARA - Georgia State University, Georgia State University

### **170.04 - It's Alive! Building a Robot at the Thacher Observatory(George Cleveland Lawrence)**

We present an outline of our continued work on the automation software for the Thacher Observatory-a research and educational facility located in Ojai, CA. A new server configuration allows for seamless functionality between the various software drivers, and we demonstrate the performance of our code with a full night of observations as well as engineering observations which demand a highly specialized observing sequence. Additionally, our code architecture allows for a high level of versatility allowing for the possibility of this code being adapted to other observatories.

**Author(s):** George Cleveland Lawrence, Jon Swift, John Johnson, Julien Andrew Luebbers, Jason Eastman

**Institution(s):** The Thacher School, Harvard Center for Astrophysics Contributing Team(s): MINERVA

### **170.05 - The Green Bank Array - An Overview(Anthony Minter)**

The Green Bank Array (GBA) is a proposed array of radio telescopes located at the Green Bank Observatory in the National Radio Quiet Zone which will operate as a stand-alone instrument or in combination with the Green Bank Telescope (GBT). The array will consist of ten 18-m antennas (based on the ngVLA design) and will operate over 1.2 - 116 GHz. By itself, the GBA will have the collecting area of the Parkes telescope and will operate with good sensitivity at all of its operational frequencies. In the configuration that is currently being studied, most of the GBA will be within ~1 km of the GBT. The GBA alone will be capable of imaging spectral lines with an angular resolution from 42" in the 21cm HI line, to 0.7" in the lines of CO. The GBA+GBT will offer exceptional sensitivity from 1.2 - 50 GHz and will match or exceed the sensitivity of ALMA over most of their overlapping frequency coverage. The GBA's low

frequency capabilities will be ideal for monitoring pulsars and other transient phenomena, while its location and sensitivity will contribute greatly to long baseline interferometry, especially at 3mm. At higher frequencies it will make significant advances in our understanding of star formation in the Milky Way and nearby galaxies. The Green Bank Observatory is a facility of the National Science Foundation operated under a cooperative agreement by Associated Universities, Inc.

**Author(s):** Tapasi Ghosh, Joy Skipper, Natalie Butterfield, Ryan S Lynch, Anthony Minter, Ronald Maddalena, David Frayer, Felix Lockman, Andrew Seymour, Amber Bonsall, Frank Ghigo, William Armentrout, Karen O'Neil

**Institution(s):** Green Bank Observatory

### **170.06 - SCORPIO Instrument Design and Operational Modes(Todd Veach)**

SCORPIO (Spectrograph and Camera for the Observation of Rapid Phenomena in the Infrared and Optical) is a new multiband imager and spectrograph currently under development for the Gemini Observatories. The instrument is intended to be deployed at Gemini South but is designed for operation at both sites. SCORPIO covers 0.385um to 2.35um in spectroscopy and .400um to 2.35um in imaging; corresponding to the g, r, i, z, Y, J, H, and Ks wavebands. The band edges have been chosen to overlap as much as possible with LSST wavebands in order to facilitate the rapid follow-up of LSST alert phenomena. The instrument is designed for simultaneous high time resolution spectroscopic and imaging observations covering the aforementioned wavebands.

**Author(s):** Jeffrey Radwick, Tom Hayward, Brian Chinn, Stephen Goodsell, Todd Veach, Scot Kleinman, Peter Roming, Robert Barkhouser, Kathleen Labrie, Marisa Garcia Vargas, Ruben Diaz, Amanda Jo Bayless, Morten Andersen, Rebecca Thibodeaux, Kristian Persson, Alexander

**Institution(s):** Southwest Research Institute, FRAC TAL S.L.N.E., Gemini Observatory, Space Telescope Science Institute, The George Washington University, Johns Hopkins University

## **171 - Space Mission Instrumentation -- iPosters**

### **171.01 - The Observing Modes of NIRISS: The Hidden Gem of JWST(Michael A Wolfe)**

The Near Infrared Imager and Slitless Spectrograph (NIRISS) is a contribution of the Canadian Space Agency to the James Webb Space Telescope (JWST). NIRISS complements the other near-infrared science instruments onboard JWST by providing capabilities for (a) low-resolution grism spectroscopy between 0.8 and 2.2  $\mu\text{m}$  over a 2.2'—2.2 arcminute field of view, with the possibility of observing the same scene with orthogonal dispersion directions to disentangle blended objects; (b) medium-resolution grism spectroscopy between 0.6 and 2.8  $\mu\text{m}$  that is optimized to provide high spectrophotometric

stability for time-series observations of transiting exoplanets;(c) aperture masking interferometry that provides high angular resolution of 70 - 400 mas at wavelengths between 2.8 and 4.8 Åµm; and(d) imaging through a set of filters that are closely matched to those available with NIRCcam. In this poster, we discuss each of these modes and present simulations of how they might typically be used to address specific scientific questions.

**Author(s):** Michael A Wolfe

**Institution(s):** Space Telescope Science Institute  
Contributing Team(s): NIRISS Team

#### **171.02 - The History of Ionizing Light from Observations Shortwards of Rest-frame 900 Å... with LUVOIR(John O'Meara)**

To fully characterize the emergence of structure in the early universe, we must characterize the influence that ionizing radiation has on early galaxies. Directly observing ionizing photons at the epoch of reionization is severely hampered by the opacity of the intergalactic medium to the ionizing photons of that epoch. LUVOIR will leverage its FUV and UV sensitivity and resolution to directly detect weak Lyman continuum radiation escaping from  $z < 1$  galaxies in a spatially resolved manner for multiple objects per pointing, revealing the environmental factors that favor the escape of radiation, and thus providing crucial clues to how light escaped galaxies during the epoch of reionization at  $z \sim 7$ .

**Author(s):** John O'Meara, Stephen McCandliss

**Institution(s):** Saint Michael's College, Johns Hopkins University, WMKeck Observatory  
Contributing Team(s): The LUVOIR team

#### **171.03 - The State of Software Tools for the Space Telescope Imaging Spectrograph(Doug Branton)**

As in any technical/scientific field, the supporting landscape of applicable tools and technologies is ever-changing. While astronomy progresses forward, we require the continual rebuilding, expansion, and development of our supporting software, as this allow us to directly benefit from the continual advancements in complementary fields such as data science and computer science. The Space Telescope Science Institute (STScI) has experienced this firsthand with the evolution of the software ecosystem supporting the Hubble Space Telescope (HST) and its user community, transitioning from the venerable IRAF/PyRAF software package to a more modern and accessible Python-based environment. In line with this, the Space Telescope Imaging Spectrograph (STIS) instrument team has been rebuilding and developing the suite of data analysis tools available to the STIS user community. In this poster, we provide an overview of the current state of the available software tools for STIS, detailing recently developed and upcoming tools as well as discussing current progress on efforts such as documentation and testing.

**Author(s):** TalaWanda R. Monroe, Paule G. Sonnentrucker, Sean Lockwood, Daniel Welty, John Debes, Allyssa Riley, Doug Branton, S. Tony Tony Sohn, Matthew Maclay, Joleen K Carlberg

**Institution(s):** Space Telescope Science Institute  
Contributing Team(s): STIS Team

#### **171.04 - Updated Status and Performance of the Cosmic Origins Spectrograph(Rachel Plesha)**

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope (HST) in 2009. Now, after almost a decade of operations, both the FUV and NUV channels remain scientifically productive and continue to provide high quality spectroscopic capabilities, with the COS/FUV channel operating at its fourth lifetime position on the detector (LP4). Here we present updates on the current status of COS and summarize recent calibration work of interest to HST Cycle 27 proposers and all COS users.

**Author(s):** Dzhuliya Dashtamirova, Thomas Ake, Robert Jedrzejewski, David J. Sahnou, Nick Indriolo, Andrew J Fox, Rachel Plesha, Ravi sankrit, Cristina Oliveira, James White, Bethan James, Camellia Magness, Julia Roman-Duval, William J. Fischer, Gisella De Rosa, Elai

**Institution(s):** Space Telescope Science Institute

#### **171.05 - Building the Future: Progress in Designing Large Space Observatories to be Assembled in Space(Harley Thronson)**

With continuing advances in robotics, rendezvous and proximity operations, relatively cheaper commercial launch systems, and autonomy, the prospect of assembling and servicing future large-aperture telescopes in space seems increasingly feasible. As scientific productivity often depends upon a high power of the aperture, without a paradigm change in how large optical systems are deployed, major advances in future space astronomy will be severely limited within a very few decades by the limited sizes of launch vehicle fairings. Some even smaller-aperture concepts are constrained by the lift capacity even the most powerful launch vehicles under consideration. However, advances in the capabilities of telerobotics and autonomous systems, the availability potential robot systems and astronauts on site at the NASA Gateway habitat, and lower-cost medium-lift launch vehicles offer the opportunity for assembly of very large-aperture observatories. We will present a recent design for a 20-meter UVOIR space observatory to be assembled in space and the capabilities necessary to realize such a mission, including robotic systems now under development and proposed technology development priorities.

**Author(s):** Bradley Peterson, Nicholas Siegler, Howard MacEwen, John Grunsfeld, Harley Thronson, Lynn Bowman, Rudranarayan Mukherjee, Matthew Greenhouse, Ronald Polidan



**Institution(s):** NASA Goddard Space Flight Center, PSST, LLC, Jet Propulsion Laboratory, Ohio State University, Reverisco, NASA Langley Research Center

#### **171.06 - The Potential for Unique and Transformative Astrophysics Measurements from the Interstellar Probe(Michael Zemcov)**

Astronomical observations from vantage points significantly away from the Earth can give us important and unique insights into a variety of astrophysical questions. A potential future mission to directly sample the interstellar medium (ISM) for launch around 2030 is currently being studied. This mission would offer an outstanding opportunity to perform astrophysical observations throughout and well beyond the solar system. Using new technologies and detectors, an astrophysics instrument for this Interstellar Probe could be made extremely compact and lightweight. The science cases that are unique for such an instrument require only a small, 10 cm-class aperture and passively cooled, off-the-shelf detectors. For studies of the Edgeworth-Kuiper Belt dust disk of our solar system, a low spatial resolution FIR camera that shares the telescope focal plane would also be desirable. Recent studies of a CubeSat-class astrophysical mission designed to image interplanetary dust to the asteroid belt provide a good template for a workable low size, weight and power system. Since a mission to the ISM spanning 50 years would require generations of scientists and engineers to realize, astrophysical measurements during its cruise phase would offer a critical opportunity to generate both high-impact science during the long quiescent periods en route to the ISM, as well as to build and maintain technical expertise in the spacecraft and instruments. Such a mission could be a true flagship of space science, offering an opportunity to demonstrate that different space science disciplines really can collaborate to make a generational vision become a reality.

**Author(s):** Ralph McNutt, Kirby Runyon, Carey Michael Lisse, Christian Pape, Pontus Brandt, Abigail Rymer, Kathleen Mandt, Andrew Poppe, Michael Zemcov,

**Institution(s):** Rochester Institute of Technology, Johns Hopkins University Applied Physics Laboratory, Jet Propulsion Laboratory, UC Berkeley Space Sciences Laboratory  
**Contributing Team(s):** The Interstellar Probe Concept Study Team

#### **171.07 - WFIRST: Project Overview and Status(Jeffrey Kruk)**

The Wide-Field InfraRed Survey Telescope (WFIRST) will be the next Astrophysics strategic mission to follow JWST. The observatory payload consists of a Hubble-size telescope aperture with a wide-field NIR instrument and a coronagraph operating at visible wavelengths that employs state-of-the-art wavefront sensing and control. The Wide-field instrument is optimized for large area NIR imaging and spectroscopic

surveys, with performance requirements driven by programs to study cosmology and exoplanet detection via gravitational microlensing. All data will be public immediately, and substantial general observer and archival research programs will be supported. The WFIRST Project is presently in Phase B, with the confirmation review expected in late 2019 or early 2020. Candidate observing programs are under detailed study in order to inform the mission design, but the actual science investigations will not be selected until much closer to launch. We will present an overview of the present mission design and expected performance, a summary of Project status, and plans for selecting the observing programs.

**Author(s):** Jeffrey Kruk

**Institution(s):** NASA/GSFC  
**Contributing Team(s):** WFIRST Project Team, WFIRST Formulation Science Working Group

#### **171.08 - Selecting the Near-IR Detectors for the Euclid Mission(Michael Seiffert)**

We present the process and results for the selection of the near-infrared detectors for the Euclid mission. We introduce a Figure of Merit (FoM) approach that characterizes the performance of the detectors in the context of the planned Euclid survey. Several alternative FoMs were considered; the one selected allows a straightforward implementation and captures key factors that drive survey efficiency. The FoM may be useful in prioritizing further detector testing, decisions regarding detector characterization on orbit, and other project decisions. This approach may also find use in other survey projects involving large numbers of detectors.

**Author(s):** Michael Seiffert,

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology  
**Contributing Team(s):** on behalf of the Euclid Near-Infrared Detector Working Group

#### **171.09 - Revealing the Multiscale Nature of Turbulence with a Spacecraft Swarm(Jay Bookbinder)**

Turbulence plays a critical role in controlling the physics of the collisionless, magnetized plasmas that pervade our solar system as well as astrophysical systems throughout the cosmos. The pristine solar wind near Earth offers a natural laboratory for the in situ observation of turbulent fields and particle distributions that are representative of those throughout the universe. Understanding the transport of mass, momentum, and energy, and associated dissipation in such systems is important and compelling, but its exact nature remains a mystery owing primarily to our past, present, and planned future approaches to reveal it. To date, all in situ observations of solar wind plasmas have single point measurements (i.e., ACE, WIND), or have focused on a single scale through the use of carefully controlled clusters of four spacecraft (i.e., Cluster, MMS). Turbulence is fundamentally a multi-scale, three-dimensional, time-evolving phenomenon and therefore neither single point measurements nor even a cluster of four spacecraft provide

insight into the full nature of the turbulent medium. To reveal the full temporal and spatial structure of turbulence requires observations at an array of points that far exceeds the tetrahedral configurations flown to date. With the advent of low resource sensors and small satellites, such arrays of spacecraft are now possible and promise to transform our knowledge of turbulence. Rather than flying in formation, a swarm of small spacecraft (nodes) will enable direct measurement of a wide range of spatial and temporal scales that span physical ranges of interest. In this presentation, we describe a newly-feasible, innovate mission concept employing such a swarm of many small spacecraft. The cost-effective mission will reveal and quantify key unknown aspects of turbulence, allowing us to understand the cascade of energy from longer scale and time sizes toward and into smaller scales and shorter times.

**Author(s):** Jay Bookbinder, Kristopher Gregory Klein, Harlan Spence

**Institution(s):** NASA/Ames, UNH, UArizona Contributing Team(s): Helioswarm Mission Team

## **172 - HAD IV: History -- iPosters**

### **172.01 - Lyman's Telescope is Alive and Well!(David Leaphart)**

The year was 1882. The lenses for the new Great Refractor were poured by the Feil Brothers in France and ground by Alvan Clark in Massachusetts. The new telescope was installed in the Halsted Observatory on the Princeton University campus. The telescope was revitalized and moved to the new Princeton FitzRandolph Observatory in 1932. While many used the telescope, the Director of the observatory was Dr. Lyman Spitzer from 1947 to 1979. (I now refer to the Great Refractor affectionately as "Lyman's telescope.") When Princeton sold the telescope to the Navy in 1964, it was put out of operation and stored in a warehouse. That could easily have been the end of the great instrument. However, in 1978, the Greenville (S.C.) county school district purchased the telescope from the the Navy. With successful fund raising, the Great Refractor once again saw light in 1987. For many years, the telescope was used in manual pointing mode. Later, a homegrown system was used to guide the telescope and dome. In 2018, all new electronics and software were installed using current industrial strength systems. So, Lyman's telescope is alive and well, scanning the skies in a completely modern observatory. The history of this wonderful instrument and a review of the new instrumentation is the subject of this submission.

**Author(s):** David Leaphart

**Institution(s):** Roper Mountain Science Center

### **172.02 - Movies on the Early History of KPNO and CTIO(John Glaspey)**

We will present video format versions of several movies covering some of the early history of Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO). The oldest movie is from 1956 by Aden

Meinel and documents the first ascent to the summit of Kitt Peak during the site survey. Another, Journey into Light, was produced by AURA in the 1970s and describes astronomy in general, making extensive use of the telescopes and staff of KPNO as examples. These movies have recently been recovered from the plate vault in what is now NOAO headquarters in Tucson and converted to video. Each video has been uploaded to YouTube for viewing via the channel "NOAO Library & Archives". Documentation of the videos are available on the NOAO Library website at

<https://www.noao.edu/noao/library/Digital-Archives.html>.

**Author(s):** Sharon Hunt, John Glaspey

**Institution(s):** NOAO

### **172.03 - This Month in Astronomical History: Providing Context for the Advancement of Astronomy(Teresa Wilson)**

This Month in Astronomical History is a short (~500 word) illustrated column hosted on the AAS website (<https://had.aas.org/resources/astro-history>). Its mission is to highlight people and events that have shaped the development of astronomy to convey a historical context to current researchers, to provide a resource for education and public outreach programs seeking to incorporate a historical perspective, and to share the excitement of astronomy with the public. Knowing how the astronomical journey has proceeded thus far allows current professionals to map where to go next and how to get there. The column charts the first part of this journey by celebrating anniversaries of births, discoveries, and deaths, and the technological advances that made discoveries possible. A "Further Reading" section encourages readers to pursue subjects in greater depth and strengthens the articles as classroom resources. The column has evolved over the last year to include works by a number of volunteer authors. This not only adds variety in the writing style, but also allows authors to contribute articles in line with their area of expertise. Topics this year ranged from the life of Benjamin Banneker, to Da Vinci's discussion of Earthshine, to the mysterious Wow! Signal. Volunteer authors, as well as suggestions for additional topics, are always welcome.

**Author(s):** Teresa Wilson,

**Institution(s):** Michigan Technological University, US Naval Observatory

## **173 - Evolution of Galaxies iPosters**

### **173.01 - The UVJ Diagram of Star-Forming Galaxies in CANDELS(Jerome Fang)**

This work examines the demographics of star-forming (SF) galaxies at  $0.2 < z < 2.5$  in CANDELS, focusing on systematic trends embedded within the UVJ diagram. We study 9100 galaxies from GOODS-S and UDS, having published values of redshifts, masses, star formation rates (SFRs), and dust attenuation (AV) derived from UV-optical spectral energy distribution fitting. In agreement with previous works, we find

that the UVJ colors of a galaxy are closely correlated with its specific star formation rate (SSFR) and AV. We define rotated UVJ coordinate axes, termed SSED and CSED, that are parallel and perpendicular to the SF sequence and derive a quantitative calibration that predicts SSFR from CSED with an accuracy of ~0.2 dex. SFRs from UV-optical fitting and from UV+IR values based on Spitzer/MIPS 24  $\mu$ m agree well overall, but systematic differences of order 0.2 dex exist at high and low redshifts. A novel plotting scheme conveys the evolution of multiple galaxy properties simultaneously, and dust growth, as well as star formation decline and quenching, exhibit “mass-accelerated evolution” (“downsizing”). A population of transition galaxies below the SF main sequence is identified. These objects are located between SF and quiescent galaxies in UVJ space and have lower AV and smaller radii than galaxies on the main sequence. Their properties are consistent with their being in transit between the two regions.

**Author(s):** Jerome Fang, Sandra Faber

**Institution(s):** Orange Coast College, University of California, Santa Cruz  
**Contributing Team(s):** CANDELS

### **173.02 - A Study of the Nuclear Regions of the Triple Merging System Arp 195(Stephanie Fiorenza)**

The evolutionary connection between nuclear starbursts and active galactic nuclei (AGNs) in luminous infrared galaxies (LIRGs) and ultraluminous infrared galaxies (ULIRGs), which often result from galaxy interactions and mergers and produce the bulk of their radiation as infrared (IR) emission, is not well understood. To this effort, we examine spectroscopic data extracted for sections at various galactocentric distances within each of the three galaxy components of Arp 195, a LIRG with  $\log[\text{LIR}(\text{L}\lambda\text{S}^{\text{TM}})] = 11.81$  and  $z = 0.0559$ . We then classify the sections of each galaxy component as exhibiting characteristics of a HII-region-like, LINER, or Seyfert spectral type galaxy using the BPT diagrams. By observing how the position on the BPT diagram for a particular galaxy section changes as a function of galactocentric distance, we see how the individual galaxy components of Arp 195 appear less HII-region-like and more like AGNs as one makes observations closer to the centers of the galaxy components. Finally, we examine how properties that describe the galaxy components’ nuclear starbursts and AGNs (e.g., star formation rate,  $\text{L}[\text{O III}]$ , optical D parameter,  $\text{D}_{4000}$ , and  $\text{EW}(\text{H}\beta)$ ) vary as a function of galactocentric distance. This study can further our understanding of the link between nuclear starbursts and AGN.

**Author(s):** Stephanie Fiorenza, Raphael Uzan

**Institution(s):** College of Southern Nevada

### **173.03 - Machine Learning from Cosmological Simulations to Identify Distant Galaxy Mergers(Gregory Snyder)**

We apply ensemble learning to high-redshift galaxy mergers from the Illustris cosmological simulation to improve image-

based merger selection criteria. To do so, we created synthetic deep HST and JWST images and measured common morphology diagnostics. Using the simulation merger tree, we assess methods to select hard-to-identify distant galaxy mergers from these image statistics. We confirm that common methods select mergers with low purity and completeness. As an alternative, we train random forests to classify mergers across a wide range of redshifts based on 10 image diagnostics from input HST surveys. Cross-validation shows that the random forests yield superior measurements of the simulated late-stage merger fraction because they identify more true mergers that occur in bulge-dominated galaxies that are less likely to display image asymmetries and disturbances. We apply these classifiers to CANDELS morphology catalogs, estimating a merger rate increasing to at least  $z = 3$  and with improved statistical errors, albeit with rates a factor of two higher than expected by theory. This points to possible differences in the feedback-determined morphology distributions, but confirms our basic understanding of the evolution of galaxy mergers. By linking complex galaxy assembly histories and astrophysics to observational datasets, machine learning techniques offer a promising opportunity to more effectively blend surveys and simulations to learn how galaxies formed.

**Author(s):** Gregory Snyder

**Institution(s):** Space Telescope Science Institute

### **173.04 - Toward Robust Merging History of Massive Galaxies Since $z \sim 3$ : Pair Observability Timescales using Mock CANDELS Observations(Kameswara Mantha)**

Theory predicts that the merger rate for massive galaxies ( $M_{\text{stellar}} > 10^{10} M_{\odot}$ ) should rise strongly from  $z \sim 1$  to 3. Many empirical merger rates are based on galaxy-galaxy pairs in plausible “close” physical proximity (projected distance and redshift). The close-pair observability timescale is critical to constraining the merger rates. Recent studies find that constant timescale-based merger rates do not evolve with redshift during  $1 < z < 3$ , suggesting that a redshift-dependent observability timescale may be necessary to explain the rising theoretical merger rate predictions. We use a large suite of mock lightcones from four state-of-the-art semi-analytical and semi-empirical models: SantaCruz, Carnegie, SAGE, and UniverseMachine (UM) to quantify the close-pair fractions for massive galaxies at  $0.5 < z < 3$  for a wide variety of pair selection criteria. Our preliminary comparisons of kinematic ( $< 500 \text{ km/s}$ ) major pair ( $< 4:1$  stellar-mass ratio) fractions for  $M_{\text{stellar}} > 10^{10} M_{\odot}$  galaxies show that the UM pair fractions do not evolve with redshift and the Carnegie fractions evolve weakly with redshift, both of which are consistent with previous findings. Motivated by Snyder et al., we infer a close-pair timescale evolution as the ratio between our mock pair fractions and the instantaneous merger rates from the Illustris simulation. Our preliminary results suggest that the observability timescale for our pair selection should evolve as  $2.2 (+/- 0.2) (1+z)^{-1.6 +/- 0.1} \text{ Gyr}$ . In the future, we will extend our analysis to a large set of pair-fraction selection functions to infer the timescale evolution as a

function of stellar mass, mass ratio, projected separation, and physical proximity conditions.

**Author(s):** Rachel Somerville, Daniel H. McIntosh, Darren Croton, Gregory Snyder, Kameswara Mantha, Peter Behroozi, Vicente Rodriguez-Gomez, Yu Lu

**Institution(s):** University of Missouri-Kansas City, Center for Astrophysics and Supercomputing, Swinburne University of Technology., Department of Astronomy, University of Arizona, Department of Physics & Astronomy, Johns Hopkins University, Carnegie Observatories,

### **173.05 - Toward Robust Identification and Quantification of Galaxy Merging: Analyzing Rest-frame Optical Residual Substructure from Real and Mock CANDELS Images(Daniel H. McIntosh)**

The role of major merging in galaxy evolution remains a key open question. Existing empirical merger identifications typically rely on non-parametric automated metrics or subjective visual classifications which can pose systematic challenges in terms of purity, completeness, and observability timescales. To robustly identify and catalog hallmark identifiers of galaxy merging (e.g., tidal tails, bridges, and fans), we develop a new analysis tool to extract flux and area wise significant substructures within the model-subtracted “residual” images produced by popular parametric image profile fitting tools (e.g., GALFIT). We apply our tool on the single-Sersic residual HST/WFC3 F160W images (from van der Wel et al. 2012) of 16 CANDELS galaxies that host a wide variety of residual features (e.g., disk, spiral arms, and plausible tidal features). We also employ our method on synthetic HST mock observations of a galaxy merger (at  $z=1.44$ ) from the VELA zoom-in hydrodynamical simulations, and we extract tidal features that are similar to those from the CANDELS examples during different merger stages, viewing orientations, and observational depths. This novel tool holds promise for improving constraints on the major merger rate evolution with CANDELS and future JWST imaging. At low redshift, we further study key physical properties of the residual tidal signatures found in a sample of 100 SDSS mergers from Weston et al., 2017. We generate ugriz residual images by systematically fitting the central light component within a physically motivated circular aperture defined by a stellar mass-size relationship for SDSS spheroid-dominated galaxies. We quantify the urz color-color diagnostics and stellar masses of the merging features to shed new light on the plausible progenitors (gas-rich vs. gas-poor merger) of these low-redshift systems.

**Author(s):** Anton Koekemoer, Daniel H. McIntosh, Daniel Ceverino, Nimish Hathi, Elizabeth McGrath, Gregory Snyder, Logan B Fries, Kameswara Mantha, Henry Ferguson, Vicente Rodriguez-Gomez, Raymond C. Simons, Yicheng Guo, Joel Primack, Eric Bell, Camilla Pacifici

**Institution(s):** UMissouri-Kansas City, Zentrum für Astronomie, Universität Heidelberg, University of Michigan, Colby College, STScI, Johns Hopkins University, UC Santa

Cruz, UMissouri-Columbia

### **173.06 - Keck DEIMOS Spectroscopy of Compact Stellar Systems in the Next Generation Virgo Cluster Survey(Kadri Bin Mohamad Nizam)**

We present an analysis of the stellar populations of compact stellar systems in the Virgo cluster of galaxies. We analyze Keck/DEIMOS spectra of five flavors of objects: nuclei of dwarf elliptical galaxies (dEs), globular cluster (GC) satellites of dEs, GC satellites of ultra-diffuse galaxies (UDGs), GCs in the remote halo of M87 (the massive elliptical galaxy at the center of the Virgo cluster), and intracluster GCs. These categories have been established based on multi-wavelength photometry, image morphology, sky position, and line-of-sight velocities from the Next Generation Virgo Cluster Survey (NGVS, Ferrarese et al. 2012) and follow-up Keck/DEIMOS spectroscopy (Toloba et al. 2016, 2018). All of these compact stellar systems show a narrow range of photometric colors and are classified as ‘blue’ in comparison to the inner GCs found around massive elliptical galaxies. We use coaddition to enhance the spectral signal-to-noise ratio of the average spectrum of each category of compact objects and use these coadded spectra to measure metallicity and alpha-enhanced abundances from absorption lines. The goal of this research is to test the following questions: (1) are the dE nuclei formed from dry mergers of GC satellites that spiraled to the center of the galaxy via dynamical friction? (2) do the GC satellites of dEs resemble those of the UDGs? (3) are the GC satellites of dEs similar to those in the remote halo of M87 suggesting that a significant number of contributors to this halo are disrupted dEs, and (4) are the galaxies cannibalized by M87 statistically similar to those disrupted by the cluster gravitational potential itself? This research was funded in part by NASA/STScI.

**Author(s):** Elisa Toloba, Puragra Guhathakurta, Laura Ferrarese, Patrick Côté, Eric W. Peng, Kadri Bin Mohamad Nizam

**Institution(s):** University of the Pacific, National Research Council of Canada, University of California Santa Cruz, Peking University

### **173.07 - Galaxy Kinematics at $z\sim 1$ from the Keck HALO7D Spectroscopic Survey(Jack Loneragan)**

Galaxy kinematics determined from spectroscopy of emission lines and stellar absorption lines provide a direct insight into the dynamical properties as well as the dark and stellar mass content of galaxies. However, due to the intrinsic faintness of distant galaxies, such measurements are often limited to close, relatively galaxies. Here we present preliminary results on the kinematic properties of massive galaxies at  $z\sim 1$ , based on extremely deep, up to 8 hours, integrations taken with the DEIMOS spectrograph on Keck telescope as part of the HALO7D survey (Cunningham et al. 2018). These galaxies are selected from the deepest HST CANDELS cosmological fields,

which provides a wealth of supplementary information, such as structural parameters and multi-band photometry. These spectra are analyzed using full spectral fitting techniques which provide information about the galaxies' specific stellar age, chemical compositions, and dynamical masses. Ultimately, we will compare these properties to those of well-known nearby galaxies to determine how a galaxy's chemistry and dark matter content evolve over cosmic time.

**Author(s):** Elisa Toloba, Guillermo Barro, Puragra Guhathakurta, Emily Cunningham, Sandra Faber, David Koo, Yicheng Guo, Jack Loneragan

**Institution(s):** University of the Pacific, University of Missouri, UC Santa Cruz

### **173.08 - Characterizing Residual Substructures of Massive CANDELS Galaxies(Luther Landry)**

Constraining the specific physical processes at play in the assembly of massive galaxies during the peak epoch of galaxy development ( $1 < z < 3$ ) remains difficult. Hierarchical processes like merging and rapid gas accretion are predicted to transform the appearance of galaxies, and different evolutionary processes may produce unique but faint and transient signatures in the morphological substructure of galaxies. To facilitate the identification and further analysis of plausible hallmark indicators, we visually inspect single Sersic, model-subtracted "residual" images of high-redshift objects. We characterize the H-band (WFC3/F160W) residual images of 10,000 galaxies with  $\log(M_{\text{stellar}}/M_{\text{sun}}) > 9.7$  and spanning  $1 < z < 3$  in the five CANDELS fields from van der Wel et al. 2012. We classify these residual images according to two criteria: (1) the quality of the model fit to the galaxy; and (2) the qualitative nature of the residual flux, both objective (e.g., underfit centers, clumpy or patchy substructure), and subjective (e.g., plausible tidal features, spiral arms, disks). We find that 30% of these objects have no residual substructure; 5% have fit quality problems; 31% have minimal residual structure present (e.g., low surface brightness features); and, 34% have strong residual structure present. We detect plausible signs of merging for  $3 \pm 2\%$  of high-mass CANDELS galaxies at  $1 < z < 2$ , but less at  $z > 2$ . Future observations with JWST will resolve whether imaging depth is at play here. We plan to publish a value-added catalog of fit-quality and residual-substructure flags to accompany the van der Wel et al. GALFIT-derived data on MAST.

**Author(s):** Elizabeth McGrath, Daniel H. McIntosh, Daniel Ceverino, Henry Ferguson, Joel Primack, Gregory Snyder, Cody Ciaschi, Osiris Hines, Kameswara Mantha, Andrew Pepper, Luther Landry, Scott Thompson, Derrick Jennings, Jack Connors, Coleman Gliddon, Rubyet Evan,

**Institution(s):** University of Missouri, Kansas City, Zentrum für Astronomie, Institut für Theoretische Astrophysik, Universität Heidelberg, University of Michigan, University of Missouri, Columbia, Space Telescope Science Institute, University of California, Santa C

### **173.09 - Dwarf galaxy formation and enrichment during reionization(John Wise)**

JWST will uncover a vast population of low-luminosity galaxies at Cosmic Dawn that is responsible for most of reionization. We present predictions for this high-redshift population, using two suites of high-resolution cosmological simulations -- the Renaissance Simulations and the Tempest Simulations -- that sample different large-scale environments. The Tempest Simulations specifically focus on the progenitors of a Milky Way like galaxy. Using a sample of over 3,000 resolved galaxies along with the formation of 10,000 massive Population III stars, we show that the luminosity function flattens above a UV magnitude of -14, and the faintest galaxies may be the ancestors of ultra-faint dwarfs. Metals from Population III supernova are the primary source of metals in a fraction of the most metal-poor galaxies. Star formation in low-luminosity galaxies is extremely bursty as the gas reservoir is easily disrupted by internal feedback, resulting in a large spread in galaxy relationships, such as the mass-metallicity, SFR-stellar mass, and stellar mass-halo mass relations. This inefficient star formation ultimately leads to high mass-to-light ratios, similar to local ultra-faint dwarfs, even at high redshifts.

**Author(s):** Britton D. Smith, John Wise, Brian W. O'Shea

**Institution(s):** Georgia Institute of Technology, San Diego Supercomputer Center, Michigan State University

### **173.10 - Implications for Reionization of a Search for Local Group Dwarfs with HI and Optical: Is There a Missing dIrr Problem?(Erik Tollerud)**

While optical survey-based searches have proven extraordinarily effective at identifying dwarf galaxies in the Local Group, they have a unique set of limits and systematics. This begs the question: what can be learned by combining these surveys with other wavelengths? To address this, I will describe an approach for comparing HI (21 cm) surveys cross-matched with optical observations to LCDM simulations combined with a basic model for galaxy formation and gas content. When applied to the GALFA-HI survey and the ELVIS simulations, this technique reveals a strong apparent dearth of gas-rich dwarf galaxies. While it is far from certain that this is the cause, reionization provides a plausible explanation for these observations. Under that assumption, these observations provide strong constraints on the mass scales at which reionization must impact Local Group dwarf galaxies. While broadly consistent with theoretical models of inflation, this measurement also suggest a possible tension between those models and the very \*existence\* of the faintest known gas bearing galaxies (e.g., Leo T).

**Author(s):** Joshua E. G. Peek, Erik Tollerud

**Institution(s):** Space Telescope Science Institute

## **175 - Graduates & Majors: Education, Retention, Persistence, & Advancement**

### **175.01 - Inclusive Graduate Education Network: Increasing Diversity in Doctoral Degrees in Astronomy(Theodore Hodapp)**

The fraction of doctoral degrees earned by underrepresented racial and ethnic minorities falls dramatically between bachelor's and PhDs in every field in the physical sciences including astronomy. Physics is witnessing a dramatic national solution to this problem through the American Physical Society's (APS) Bridge Program. A recent NSF INCLUDES Alliance award, the Inclusive Graduate Education Network (IGEN), has enabled this strategy to be replicated in Astronomy, Chemistry, Earth and Space Sciences, and Materials Science and Engineering. The AAS, APS, and the other central professional societies are joining together to champion these efforts at the national level. We will briefly discuss the project and how astronomy and astrophysics departments can recruit and retain underrepresented racial and ethnic minority students into their graduate programs.

**Author(s):** Theodore Hodapp

**Institution(s):** American Physical Society

### **175.02 - Empowering Women in STEM at the University Level(Madalyn Elizabeth Weston)**

Though women make up roughly half of the work force, they only account for one-quarter of STEM (science, technology, engineering, mathematics) workers. Issues that women face in STEM include sexual discrimination, sexual harassment, unequal pay, and a lack of role models. The University of Missouri - Kansas City Women in Science (Wi-Sci) student group was created in Fall 2016 to encourage and empower women undergraduate and graduate students pursuing a degree in a STEM-related field. Wi-Sci acts as a support network for students at the university by encouraging female members to persist in their career pursuits, and showing male members how to be advocates for women in STEM curricular and co-curricular activities. Faculty members get involved by helping make connections in the community, attending meetings to show support and provide expertise, organizing female faculty panels for professional development, and inviting female speakers for colloquia so that Wi-Sci members can network with women working in their fields. To increase awareness of the variety of women STEM role models, Wi-Sci publishes a regular column in the student newspaper. To date, 26 published "Celebrating Women in STEM" columns by Weston have featured a diversity of women in STEM by discipline, race, and geography. These women's biographies can be incorporated into STEM classrooms, similar to how famous male scientists like Albert Einstein and Edwin Hubble are included. In astronomy, many women have made a significant impact to the field and should be recognized. Besides Annie Jump Cannon, Henrietta Leavitt, Vera Rubin, and Jocelyn Bell Burnell, in-class references to less well-known past and present astronomers spanning a range of backgrounds and expertise

can have a powerful impact on retention of the next generation of women in Astronomy.

**Author(s):** Daniel H. McIntosh, Madalyn Elizabeth Weston

**Institution(s):** University of Missouri - Kansas City

### **175.03 - Improving Undergraduate Physics Major Retention Rates through an Early Introduction to Research Methods with an On-Campus Observatory(Noel Richardson)**

With a 1-m telescope on the University of Toledo (OH) main campus, we have initiated a grad student-undergraduate partnership to help teach the undergraduates observational methods and introduce them to research through peer mentorship. During the last 5 years, we have trained 70 undergraduates for observing, with up to 21 undergraduates participating in a given semester. We recruit students from a recommended introductory physics class, while other students have approached us directly. The students observe once a week with either upperclassmen or graduate students, and have found that these students have remained in the physics major at a higher rate than the traditional program that our students have pursued. This year, we began having our students use the telescope to obtain multi-filter data to make their own color images in addition to the normal use of fiber-fed spectrographs and a spectropolarimeter. The students have helped collect data for four refereed papers since 2015, with an additional four papers in preparation. Preliminary discussions with students show a positive impact on student enthusiasm for observing and for the department's programs. We will discuss possible reasons for the increased retention rates and the impact our observing team has on undergraduate involvement and academic success.

**Author(s):** Scott Lee, Karen Bjorkman, Kevin Hardegree-Ullman, Jesica Trucks, Jon E Bjorkman, Noel Richardson, Allison Gullingsrud

**Institution(s):** University of Toledo, California Institute of Technology Contributing Team(s): Ritter Observing Team

### **175.04 - Actively Encouraging Learning and Degree Persistence in Advanced Astrophysics Courses(Daniel H. McIntosh)**

Major stakeholders from all STEM disciplines agree that interactive-engagement ("active learning") is a best practice for addressing the persistent and critical challenge to grow and diversify the U.S. high-tech workforce. Less than 40% of all STEM majors achieve a bachelor's degree in their desired field; worse, the odds are dire for students belonging to underrepresented groups based on gender, race, and socioeconomic status. These statistics represent a national crisis regarding our ability to remain competitive in science and tech. A major factor is persistent performance gaps in rigorous 'gateway' and advanced science courses for majors from diverse backgrounds leading to discouragement, a sense of exclusion,

and high dropout rates. Education research has clearly demonstrated that active learning increases student outcomes, boosts confidence, and helps build positive 'identity' in STEM. Likewise, the evidence shows that traditional science education practices do not help most students gain a genuine understanding of concepts nor the necessary skill set to succeed in their disciplines. I share insights and simple guidelines for implementing this high-impact pedagogy in existing lecture-format science courses to facilitate inclusive, encouraging, and collaborative learning that helps students from all backgrounds synthesize complex ideas, build bedrock conceptual frameworks, gain technical communication skills, and achieve mastery learning outcomes in advanced subjects - all necessary to successfully complete rigorous degrees like astrophysics. Providing a student success-centered counter to traditional STEM education practices, that are effectively 'weeding out' capable students from all backgrounds, is crucial to improving persistence and degree completion rates. By providing faculty an easy road map to adopting active learning as the curricular norm, astronomy departments can be powerful pipelines for increasing and diversifying the STEM workforce.

**Author(s):** Daniel H. McIntosh

**Institution(s):** UMissouri-Kansas City

#### **175.05 - Research, Education, and Outreach in the NASA MIRO FIELDS Program(Xinnan Du)**

Fellowships and Internships in Extremely Large Data Sets (FIELDS), a five-year NASA program, aims to train underrepresented minority students in STEM fields to prepare the workforce essential for future NASA missions. Based at University of California, Riverside (UCR), the FIELDS program develops research, education, training, and collaborative opportunities in big data and visualization for students and scholars ranging from high school to postdoctoral levels. These include supporting high-school students to attend summer-session STEM courses at UCR, providing undergraduates with summer internship opportunities at JPL/IPAC, implementing an online Master-level Data Science course at UCR, offering fellowships to graduate students to conduct research involving large data sets, and recruiting postdoctoral scholars to work between UCR and JPL/IPAC to strengthen collaborations. The collaboration among undergraduates, graduate students, and postdoctoral scholars has led to the development of the latest technology, including Virtual Reality, Machine Learning, and computer simulations, which could be beneficial for both education and research purposes. The FIELDS program also actively engages in public outreach, with multiple programs specifically designed to target Spanish-speaking audience. By organizing classroom visits, telescope viewings, science talks, and public exhibitions, the FIELDS program hopes to foster interest and improve science literacy of the public in the Riverside County.

**Author(s):** Xinnan Du, Mario De Leo-Winkler, Bahram Mobasher

**Institution(s):** University of California, Riverside

#### **175.06 - Python, Unix, Observing, and LaTeX: Introducing First Year Undergraduates to Astronomical Research(Ana Matkovic)**

We have developed a course at Penn State for first year-undergraduate Astronomy majors with the primary goal of introducing students to programming and some of the necessary tools and techniques for astronomical research. Throughout the course, students develop a firm foundation in visualizing and manipulating data, basic astronomical data reduction techniques, statistical methods, and hands-on observing at a telescope. Along with basic Unix commands, students learn Python programming with specific applications to astronomical data sets and images, plotting, and fundamental statistics. Students are also trained on how to use the telescopes on campus in order to complete a semester project, which entails acquiring images or spectra (depending on the chosen project) and writing Python scripts to analyze those data. The results of the project are then written in the format of a short scientific paper in LaTeX. Students finish the course ready to start substantial scientific research projects after just their first year of college. We will present examples of the types of activities, assignments, and how these prepare students with the skills they need as they start their formal research experience.

**Author(s):** Brian D Davis, Ana Matkovic

**Institution(s):** Pennsylvania State University

#### **175.07 - Principles and Models for Workforce, Education, Public Outreach and Communications (WEPOC) in Large Science Projects(Gordon K. Squires)**

It is noteworthy and that while many science projects engage Communication and Outreach specialists as part of their team, their experience, access to leadership, specific roles and functions can be quite different. Each of these skilled professionals is finding solutions to project-specific problems. However there are principles and models that are universal to cutting-edge science projects. In this presentation we discuss:- Models for education and public communications/outreach in large-scale research infrastructure projects- What is the value of WEPOC to the projects and their communities?- How, when and where should WEPOC be defined, developed and implemented?- What are the barriers and challenges in developing strategic plans and programs?- How do you make the case of the value of WEPOC to the leadership in these projects?In particular, conclusions will be drawn from the "proclamation" endorsed by WEPOC leaders from large-international science projects from across the world in the 2017 "Making the Case" workshop:

<https://conference.ipac.caltech.edu/wepoc2017>

**Author(s):** Sandra Dawson, Janesse Brewer, Gordon K. Squires

**Institution(s):** Caltech/IPAC - TMT, 4 Degrees, TMT

**175.08 - Diversity and inclusion in observatory operations: Advocating for and implementing positive change(Alysha Brooke Shugart)**

Strong diversity and inclusion initiatives within scientific organizations are trending towards standard practice. The merits of these programs are quantifiable, and these data are positively correlated with a program's overall success. These programs demonstrate direct benefits to individuals and working groups in the organization, as well as overall workplace culture improvement. The goals of this paper are: 1) Report the findings of recent studies that research outcomes of diversity and inclusion programs implemented in academic environments or scientific organizations; 2) Emphasize the importance of inclusion in the workplace; 3) Provide examples of diversity and inclusion initiatives already in place at multi-national astronomy organizations. The first goal of this paper is to review recent studies that employ metrics designed to quantify the impact of diversity and inclusion programs on various working groups or organizations. This is critically important to the illustration of the effectiveness of diversity and inclusion programs. Diversity has historically received more attention than the subject of inclusion, but initiatives that focus only on diversity improvement are incomplete. Organizations must aim to have low employee-turnover rates that maintain diverse staff. Employee retention and contentment are shown to directly correlate with an inclusive workplace environment, so the second goal is to generate awareness of the importance of an inclusive workplace and explain what that means. The third goal is to present existing models of diversity and inclusion activities in observatories. Both indirect and direct impacts of these programs are presented. Examples of recruitment routines used to generate a diverse staff are highlighted, as well as techniques to create and maintain an inclusive workplace environment. Groups within different organizations can combine these models, individual worker experiences, and diversity metrics to design a plan of action to improve their working communities. Resources for information are offered for those who want to create a new diversity and inclusion program from the ground up, as well as for those who wish to improve an existing program within their organizations.

**Author(s):** Chris Yamasaki, Alysha Brooke Shugart, Stephen Ridgway, Claire Raftery, Stacey R. Sueoka, Dara Norman

**Institution(s):** Gemini South Observatory, National Optical Astronomy Observatory, National Solar Observatory, Gemini North Observatory

**176 - Galaxy Formation and Evolution II**

**176.02 - Spitzer catalog of Herschel-selected ultrared dusty star-forming galaxies at  $z \sim 3-6$ (Jingzhe Ma)**

The largest Herschel extragalactic surveys, HerMES and HATLAS, have selected a large number of luminous infrared galaxies. While most of them are dusty star-forming galaxies

(DSFGs) at  $z \sim 1-2$ , selecting those with “ultrared” colors (SPIRE S500 > S350 > S250) is extremely efficient for identifying a tail extending towards higher redshift ( $z > 4$ ). The space density and physical properties of the highest-redshift starbursts provide some of the most stringent constraints on galaxy-formation models. We will present a large Spitzer follow-up program of 300 Herschel ultrared DSFGs. We have obtained high-resolution ALMA and NOEMA data for a subset ( $\sim 60$ ), which allow us to securely identify the Spitzer/IRAC counterparts and determine whether these galaxies are gravitationally lensed or unlensed. For the rest of the sources, we identify the most probable Spitzer counterparts and their nature (lensed/unlensed) based on the SCUBA-2 positions and presence/absence of optical/near-IR low- $z$  foreground objects identified in SDSS and VIKING etc. surveys. With multi-wavelength ancillary data, we have performed spectral energy distribution (SED) modeling to derive their physical properties and compare with the more numerous  $z \sim 2$  DSFG population. Based on the subset with high-resolution interferometry data, a significant fraction ( $\sim 0.5$ ) of the ultrared sources are unlensed, intrinsically luminous DSFGs. The median values of the stellar mass, SFR, LIR,  $A_V$  and dust mass derived from the SED fitting are all higher than those of the  $z \sim 2$  DSFG population. We will also talk about the redshift distribution, SFR surface density, and contribution to cosmic SFR density and their implications on the formation and evolution of DSFGs. A photometric catalog of the Spitzer/IRAC data for the “ultrared” sources as well as the Spitzer-Herschel cross-matched sources in the IRAC fields will be made publicly available.

**Author(s):** Ivan Oteo, Seb Oliver, Hooshang Nayyeri, Steven Duivenvoorden, David Clements, Dominik A Riechers, Asantha Cooray, Julie Wardlow, Rob Ivison, Ismael Perez-Fournon, Jingzhe Ma, Arianna Brown

**Institution(s):** University of California, Irvine, ESO, Cornell University, University of Lancaster, University of Sussex, Imperial College, IAC

**176.04 - Novel observations of the optical nebulae in brightest cluster galaxies(Julie Hlavacek-Larrondo)**

Clusters of galaxies exhibit some of the most spectacular examples of optically bright, line emitting nebulae. These nebulae surround the central galaxies, are filamentary in nature and can extend over 100 kpc in size. Here, we present novel observations of the giant filamentary nebula surrounding NGC 1275, the brightest cluster galaxy in the Perseus cluster. We produce for the first time a H $\alpha$  and NII velocity map of the nebula in its entirety ( $\sim 100$  kpc; 4 arcmin) and reveal a previously unknown rich velocity structure. Rather surprisingly, the nebula appears to harbor an extremely complex and chaotic velocity structure although some trends are observed to correlate with X-ray structures (bubbles, shocks, trends with distance from the AGN). We also compare these measurements to recent Hitomi measurements of the X-ray gas, enabling us to better understand the heating and cooling mechanisms of the hot intracluster medium.

**Author(s):** Thomas Martin, Laurent Drissen, Marie-Lou



Gendron-Marsolais, Julie Hlavacek-Larrondo  
**Institution(s):** Université de Montréal, Université Laval

#### **176.06 - The Dust Mass Fraction Across Cosmic Time(Tommy Wiklind)**

We present an ALMA survey of dust continuum emission in a sample of 70 galaxies in the redshift range  $z=2-5$ . The galaxies are selected from the CANDELS GOODS-S field. Multi-Epoch Abundance Matching (MEAM) is used to define galaxies that are likely progenitors of a  $z=0$  galaxy of stellar mass  $1.5 \times 10^{11} M_{\odot}$ , seen at different epochs. Gas masses are derived from the 850  $\mu m$  luminosity. Ancillary data from the CANDELS GOODS-S survey are used to derive the gas mass fractions. The results at  $z < 3$  are mostly in accord with expectations: The detection rates are 75% for the  $z=2$  redshift bin and 50% for the  $z=3$  bin. The average gas mass fraction for the detected  $z=2$  galaxies is  $f_{\text{gas}} = 0.55 \pm 0.12$  and  $0.62 \pm 0.15$  for the  $z=3$  sample. These agree with expectations for galaxies on the star-forming main sequence, and indicate that gas fractions on the main sequence have decreased at a roughly constant rate from  $z=3$  to  $z=0$ . Stacked images of the galaxies not detected with ALMA give upper limits to  $f_{\text{gas}}$  of  $<0.08$  and  $<0.15$ , for the  $z=2$  and  $z=3$  redshift bins. Those that are undetected show lower values of specific star-formation rates and higher Sersic indices than the detected galaxies at the same redshift, but many would not be classified as passive galaxies. The results are more surprising at  $z > 4$ . None of our galaxies in the  $z=4$  and  $z=5$  sample are detected. The stacked upper limits are  $f_{\text{gas}} < 0.38$  and  $<0.37$ , for the  $z=4$  and  $z=5$  redshift bins. Based on several different estimates of the metallicities of these galaxies, we do not think that lower metallicities can entirely explain the lower dust luminosities. We briefly discuss the possibility of accretion of very low-metallicity gas to explain the absence of detectable dust emission.

**Author(s):** Tommy Wiklind

**Institution(s):** Catholic University of America

#### **176.01D - Star-Forming Galaxies in the Proto-Cluster Environment at $z=1.6$ and $2.1$ (Leo Yvonne Alcorn)**

As near-infrared instrumentation comes into widespread use in extragalactic astronomy, we can observe the rest-frame properties of galaxies in over-dense or proto-cluster environments. These observations provide valuable information on the early effects of environmental density on galaxy evolution. The ZFIRE survey has spectroscopically confirmed two such proto-clusters, at  $z=2.095$  in COSMOS, and at  $z=1.62$  in UDS, using the MOSFIRE instrument on Keck 1. Our analysis of galaxies associated with these proto-clusters conclusively shows the lack of environmental effects in developing proto-cluster member galaxies at these redshifts. Instead, results indicate that the mass of an individual galaxy is a greater factor in the observed properties than environment. We measure the  $H\beta$  kinematics of galaxies associated with the COSMOS proto-

cluster, finding no significant environmental effects in their integrated velocity dispersion and dynamical masses. By inferring gas masses using the Schmidt-Kennicutt Law, we also determine that the internal effective radii of these galaxies are baryon dominated. Kinematic modeling using the Heidelberg Emission Line Algorithm showed similar kinematic scaling relations (Tully-Fisher,  $So.5$ ) between irregular (clumpy) and regular (smooth) galaxies. Each population has similar levels of scatter around the relations ( $\sim 0.16$  dex). We estimate the specific angular momenta of these galaxies and find a slope of  $0.36 \pm 0.12$ , shallower than predicted without mass dependent growth. This is possibly caused by measurement uncertainty and high levels of scatter at  $\log(M^*) < 9.5$ . However, through a Kolmogorov-Smirnov test we determine that irregular galaxies have marginally higher values of specific angular momentum. We measure the interstellar medium properties of these proto-cluster galaxies by measuring fluxes from four emission lines,  $H\beta$  4861  $\text{\AA}$ ,  $[OIII]$  5007  $\text{\AA}$ ,  $H\alpha$  6563  $\text{\AA}$ , and  $[NII]$  6585  $\text{\AA}$ . Our results indicate no significant environmental effects on our galaxy populations, and instead show a stronger stellar mass-based effect on the  $[NII]/H\alpha$  ratio.

**Author(s):** Glenn G. Kacprzak, Tiantian Yuan, Anshu Gupta, Leo Yvonne Alcorn, Kim-Vy Tran, Karl Glazebrook

**Institution(s):** Texas A&M University, George Pand Cynthia Woods Mitchell Institute for Fundamental Physics and Astronomy, University of New South Wales, Swinburne University of Technology Contributing Team(s): ZFIRE, ZFOURGE

#### **176.03D - Rest-UV Spectroscopy of Galaxies in the Reionization Era(Ramesh Mainali)**

Recent studies have revealed detections of high ionization UV metal emission lines (CIII], OIII], CIV) in three of the first galaxies observed at  $z > 6$ , providing the first spectroscopic insight into the nature of early star forming galaxies. The equivalent widths (EWs) of these lines are more than an order of magnitude stronger than what is typical at lower redshifts, potentially indicating significant differences in the ionizing spectrum of galaxies in the reionization era. The origin of the high ionization lines remains unclear, likely requiring either a low metallicity stellar population or AGN. However owing to the limited number of  $z > 6$  sources with deep spectroscopy and limited number of analogs at lower redshifts, it has proven difficult to generalize and interpret the initial results. In my thesis work, I have undertaken a comprehensive Keck and Magellan spectroscopic campaign to both characterize the EW distribution of UV metal lines at  $z > 6$  and to identify analogs of the strong UV metal line emitters at lower redshift. I will present the latest results from this survey, describing new constraints on the fraction of strong CIII] and CIV emitting galaxies at  $z > 6$  and discussing the origin of intense UV metal line emission in a new sample of extreme CIII] emitters at lower redshift. My results indicate that galaxies with large equivalent width UV metal emission lines tend to be those with moderately low gas-phase oxygen abundance, low stellar metallicity, large ionization parameter, and very little dust extinction. Using

these results, I will summarize what we know about the nature of the galaxies in the reionization era and describe the prospects and science case for targeting UV metal lines in  $z > 6$  galaxies with JWST.

**Author(s):** Richard Ellis, Ramesh Mainali, Adi Zitrin, Daniel Stark

**Institution(s):** University of Arizona, Ben-Gurion University, University College London

### **176.05D - The Evolution of Brightest Cluster Galaxies And Their Progenitors In COSMOS(Kevin C. Cooke)**

The brightest and most massive galaxies in the universe, the Brightest Cluster Galaxies (BCGs), tell a unique story of galaxy evolution. Today, BCGs are quiescent ellipticals hosted in relaxed clusters, with pasts fraught with mergers and high star formation rates (SFRs). However, star-forming BCGs continue to be discovered at low redshifts. For my dissertation, I utilize BCGs to investigate the evolution of SFR with redshift and environment using two samples. First, I investigate the role of cluster mass on BCGs in the COSMOS field below  $z \sim 1$ . To approximate the stellar mass and SFRs of each BCG, we fit the far-ultraviolet (FUV) to far-infrared (FIR) spectral energy distributions (SEDs) using stellar and dust attenuation models. We find that low redshift BCGs are sensitive to their environment. Our sample exhibits a lower specific SFR than BCGs found in samples hosted by more massive clusters. Second, I investigate how this environmental dependence may evolve with redshift in the COSMOS field out to  $z \sim 3$ . To identify BCG progenitors, I invoke a stellar mass selection function using the number density evolution tracks derived from the Illustris cosmological simulation. By using an evolving number density method, we identify progenitors that inhabit the universe at a density consistent with their descendants at low redshift, corrected for mergers. Once identified, I utilize the FUV-FIR photometric data from the COSMOS survey to fit progenitor SEDs with stellar, dust, and AGN models. We find that BCG progenitors gain stellar mass in three eras; (1) In-situ star formation is dominant until  $z < 2.2$ ; (2) Star formation and stellar mass deposition through gas-rich and poor mergers are equally responsible until  $z \sim 1.3$ ; (3) Gas-poor mergers are the dominant mechanism from  $z \sim 1.3$  to today. We show that evidence for any environmental dependence is only weakly shown in our lowest redshift bin, and not observed beyond  $z > 1.3$ , corroborating other recent literature work finding a low dependence of SFR with the environment at high redshift. Finally, I will show preliminary results regarding the environmental dependence of the SFR-stellar mass correlation.

**Author(s):** Kevin C. Cooke, Christopher P. O'Dea, Krystal Tyler, Benham Darvish, Jeyhan Kartaltepe, Kevin Fogarty  
**Institution(s):** Rochester Institute of Technology, Space Telescope Science Institute, California Institute of Technology, University of Manitoba Contributing Team(s): COSMOS

### **201 - Plenary Prize Lecture: Beatrice M. Tinsley Prize: One Large Galaxy with One**

### **Small Telescope, Julianne Dalcanton, (University of Washington, Seattle) 201.01 - One Large Galaxy With One Small Telescope(Julianne Dalcanton)**

Beyond the Milky Way, the Andromeda Galaxy is the largest, most well-resolved massive spiral galaxy on the sky. Early this decade we began a multi-year campaign to map a large fraction of this important, nearby galaxy with the Hubble Space Telescope. HST's resolution and Andromeda's proximity combined to reveal over a hundred million stars, all at a common distance. The resulting Panchromatic Hubble Andromeda Treasury (PHAT) has led to a rich archive of UV, optical, and near-IR imaging and stellar photometry, further enhanced with a systematic program of stellar spectroscopy and mapping of the interstellar medium. In this talk I will discuss the scientific legacy of this survey, and its recent extension into the smaller spiral M33. These two surveys add M31 and M33 to the Milky Way and Magellanic Clouds as fundamental calibrators of stellar evolution and astrophysical processes on 10's of parsec scales.

**Author(s):** Julianne Dalcanton

**Institution(s):** University of Washington

### **202 - TESS: Early Results and Future Plans I 202.01 - The Transiting Exoplanet Survey Satellite (TESS): Mission Status and Early Results(Roland Vanderspek)**

The Transiting Exoplanet Survey Satellite (TESS) was launched on April 18, 2018, and began regular science operations on July 25, 2018. In this talk, I will discuss the status of the TESS mission and present results from the first few 27-day observation sectors.

**Author(s):** Roland Vanderspek

**Institution(s):** MIT Contributing Team(s): TESS Team

### **202.02 - Stellar Astrophysics with TESS(Jennifer Van Saders)**

Stellar astrophysics is experiencing a renaissance thanks to high cadence, high precision, space-based data, and TESS is the next chapter of the story. Its lightcurves will contain signatures of a zoo of stellar behaviors: rotation, activity, oscillations, convective granulation, and flares. With these data we can probe stellar evolution, the chemical enrichment of the galaxy, angular momentum evolution across the Hertzsprung-Russell diagram, and the magnetic lives of stars--- all at scales and sample sizes unrealized even with Kepler. I will give a brief overview of the stellar astrophysics enabled with TESS, and discuss a few case studies in detail.

**Author(s):** Jennifer Van Saders

**Institution(s):** University of Hawaii

### **202.03 - Confirmation and Characterization of TESS Planet Candidates(David W Latham)**

The TESS Follow-up Observing Program Working Group (TFOP WG) has members from both the community and the TESS team working together to coordinate efforts toward the common goal of confirming and characterizing transiting planet candidates identified by TESS. The TFOP WG is organized into five Sub Groups that use different techniques and facilities for pursuing this goal: Seeing-limited Photometry (SG1), Recon Spectroscopy (SG2), High-Resolution Imaging (SG3), Precise Radial Velocities (SG4), and Space Photometry (SG5).

ExoFOP-TESS is a web-based tool designed to archive results from follow-up observations of TESS Objects of Interest and to help coordinate the follow-up efforts. Details for the Sub Groups and ExoFOP-TESS, including information on how to join, are presented by half a dozen posters at this meeting.

**Author(s):** David W Latham

**Institution(s):** Harvard-Smithsonian Center for Astrophysics  
**Contributing Team(s):** The TESS Follow-Up Observing Program Working Group (TFOPWG) and the TESS Team

### **202.04 - A Complete Survey of the Southern Sky with TESS Full-Frame Images(Adina Feinstein)**

The Kepler/K2 Mission queued us in to how many transiting planets exist in the galaxy; however, we have yet to obtain a large sample of transiting planets across the remaining 85% of the sky. The identification and follow-up observations of transiting planets can inform us about planet characteristics, such as densities and atmospheric properties, as well as differing planet-system architectures which will allow us to better understand planet formation and evolution. Every 26 days, the Transiting Exoplanet Survey Satellite (TESS) observes a new  $96 \times 24^\circ$  sector of the sky at 30 minute cadence as Full-Frame Images, enabling the detection of thousands of previously undiscovered planets across the sky. We have created open-source software that will provide light curves for 25 million sources in the TESS Input Catalog brighter than  $I=16$  with expected 1% precision throughout the Southern Hemisphere. We will use both aperture and PSF photometry to identify and characterize transiting planets. Our techniques have been tested and optimized using the TESS End-To-End 6 simulated data. We will release a catalog of objects of interest (e.g. planet candidates, eclipsing binaries, stellar astrophysics) to the community through ExoFOP-TESS; the catalogs will also contain best-fit parameters for planet candidates and eclipsing binaries to enable rapid follow-up observations. Cadence stacked images, raw, and detrended light curves for each analyzed star will be hosted on MAST and ExoFOP-TESS for everybody in the community to access.

**Author(s):** Rodrigo Luger, Benjamin Montet, Megan Bedell, Jessie Christiansen, Nicholas Saunders, Christina L Hedges, Daniel Foreman-Mackey, Adina Feinstein, Jose Vinicius De Miranda Cardoso

**Institution(s):** University of Chicago, Flatiron Institute,

Caltech/IPAC-NExScI, Universidade Federal de Campina Grande, NASA Ames

### **202.05 - Exact model for phase curves, eclipses, and transits of stars and their planets for TESS(Eric Agol)**

Any spherical body may have its surface brightness expressed in terms of a sum of spherical harmonics,  $Y_{lm}$ . We have derived exact, analytic expressions for the eclipses, transits, occultations, and phase curves of spherical bodies comprised of any linear combination of spherical harmonics, of arbitrary  $l$  and  $m$ , with which we can rapidly compute light curves for fitting to various astrophysical objects, including transits of stars with arbitrary polynomial limb-darkening and transits/eclipses of stars with star spots observed with TESS. We have paid special care to numerical accuracy and computational speed, and have developed open-source software for this computation, dubbed *starry*, in Python and C++ (<https://github.com/rodluger/starry/>), and (partly) Julia (<https://github.com/rodluger/limbdark/>). In addition, we have computed the first derivatives of these light curves with respect to the model parameters using automatic differentiation, as well as analytic derivatives for the  $m = 0$  cases. The derivatives may be used to accelerate the optimization of model fits to TESS data and to utilize Hamiltonian Markov Chain Monte Carlo, which may enable fast computation of the posterior of light curve parameters, to efficiently "map" astronomical bodies. The code has been documented extensively with examples, and, in addition to TESS, may be used in fitting primary and secondary transit light curves from ground-based telescopes, as well as HST, Spitzer, Kepler, K2, Corot, PLATO and JWST light curves, and future direct-imaging missions including LUVOIR and HabEX, which may make maps of exo-Earths with phase-curves and planet-moon mutual events. Support for this work was provided by NASA, NSF and the Guggenheim Foundation.

**Author(s):** Russell Deitrick, Rodrigo Luger, Eric Agol, David Fleming, Daniel Foreman-Mackey, Jacob Lustig-Yeager,

**Institution(s):** University of Washington, The Virtual Planetary Laboratory, Flatiron Institute, Center for Space and Habitability, Universitat Bern

### **202.06 - Speckle Imaging of TESS Host Stars(Rachel Matson)**

TESS is conducting a two-year wide-field survey searching for transiting planets around nearby, bright stars that will be ideal for follow-up characterization. To facilitate studies of planet compositions and atmospheric properties, accurate and precise planetary radii are needed. However, since 40 - 50% of exoplanet host stars are part of multi-star systems, the observed transit depth may be diluted by a companion star, causing the radius of the planet to be underestimated. Speckle imaging can detect companion stars that are not resolved in the TESS Input Catalog, or by most other high-resolution imaging techniques, to validate exoplanet candidates and derive accurate planetary

radii. We examine the population of stellar companions that will be detectable around TESS planet candidate host stars, and those that will remain undetected, by applying the detection limits of speckle imaging to the simulated host star populations of Sullivan et al. 2015 and Barclay et al. 2018. By detecting stellar companions with delta magnitudes of 7 - 9 and separations of  $\sim 0.02 - 1.2''$ , speckle imaging will detect A - K star companions around A stars and all but the faintest companions around M stars, as well as up to 99% of the of the expected binary star distribution for systems located within a few hundred parsecs.

**Author(s):** Steve Howell, Rachel Matson, David Ciardi

**Institution(s):** NASA Ames, Caltech/IPAC-NExSci

### **202.07 - Extracting Asteroseismology from TESS FFIs: The TASOC Pipeline(Derek Buzasi)**

NASA's TESS mission is primarily designed to use the transit method to search for exoplanets around relatively bright, nearby stars over nearly the entire sky. As part of that process, the mission is expected to observe on the order of 20 million stars at 30-minute cadence in the full-frame images (FFIs) as well as a smaller but still substantial number as specific targets at 2-minute cadence. Such a data set is ideal for the study of stellar astrophysics, particularly through the use of asteroseismology. However, FFI data will be released to the public in pixel format only. Drawing on the Kepler experience, a TESS Asteroseismic Science Consortium (TASC) has been formed to enable collaborative efforts to use TESS data for asteroseismology, and a TESS Asteroseismic Science Operations Center (TASOC) to produce light curves and ancillary data which are useful for that purpose. In this talk, we will briefly discuss the process and algorithms used by the TASOC, including lightcurve extraction from the FFIs, lightcurve correction for instrumental effects, automated stellar variability classification, and calibration of absolute time for the resulting photometry, as well as outlining the nature of the data products the TASOC will provide to the community. In addition, we will show results from preliminary searches for seismic detections in the TESS alert data.

**Author(s):** Joel Zinn, Dennis Stello, Nada Jevtic, Derek Buzasi, Mikkel Lund, Lindsey Carboneau, Oliver Hall, Rasmus Handberg, Ashley Chontos, Jennifer Johnson

**Institution(s):** Florida Gulf Coast University, University of Birmingham, University of Hawaii, Bloomsburg University, Aarhus Universitet, University of New South Wales, Ohio State University

### **202.08 - Transient Science with TESS(Michael Fausnaugh)**

I will discuss uses of the Transiting Exoplanet Survey Satellite for transient and extragalactic science. With continuous monitoring of  $\sim 2300$  square degrees of the sky for a full month (and  $\sim 300$  square degrees for 1 full year), as well as  $< 1\%$

photometry at 16th mag, TESS provides a unique opportunity for transient science. We have built a pipeline to interface with the Transient Name Server API that will automatically extract early-time light curves for precovery of astrophysical transients (and in some cases, late-time light curves for follow-up). This has applications for identifying the progenitors of supernovae, and I will discuss potential for this measurement in 5 bright ( $< 18$ th mag) supernovae light curves from the first two sectors of TESS observations. We will also search bright galaxies for unknown transients (such as tidal disruption events) and low level variability (that might indicate the presence of Active Galactic Nuclei). Finally, I will describe our search for new kinds of variable objects based on pixel level data.

**Author(s):** Michael Fausnaugh

**Institution(s):** MIT Contributing Team(s): The TESS team

### **203 - Extrasolar Planets: Characterization & Theory Track 2: VI. Terrestrial Planets and Habitability**

#### **203.01 - Evryscope flares as probes of the space weather environments of Proxima b and the nearest rocky exoplanets(Ward S Howard)**

In March 2016, the Evryscope observed the first superflare from Proxima Centauri. The Evryscope array of small optical telescopes recorded the superflare as part of an ongoing survey of all bright southern stars, monitored simultaneously at 2 minute cadence since 2015. Evryscope flares act as probes of the space weather environment of nearby exoplanets in three ways: by constraining their UV surface environments, by looking for planetary magnetic fields via star-planet interaction and flares that phase up with planet orbits, and by monitoring optical counterparts to radio flare observations. We illustrate each of these probes for Proxima Centauri and discuss future work for other nearby planets. By modeling the photochemical effects of particle events accompanying large flares in a recently accepted letter, we find repeated flaring is sufficient to reduce the ozone column of an Earth-like atmosphere at the orbit of Proxima b by 90% within five years. Surface UV-C levels during the Evryscope superflare reach  $\sim 100\times$  the intensity required to kill simple UV-hardy microorganisms without ozone, suggesting that life would struggle to survive in the areas of Proxima b exposed to these flares. Next, we discuss a possible correlation between the times of energetic flaring and Proxima b's orbit. Finally, an approved program (PI: M. MacGregor) for 40 hours of simultaneous Evryscope and ALMA observations of large sub-mm flares on Proxima will be undertaken. We discuss constraints on blackbody emission supplied by optical counterparts to observed sub-mm flares. Flares seen by Evryscope give insight into the unknown emission mechanism and habitability impacts of large sub-mm events. With the launch of TESS, providing 27-day ultra-high-precision coverage for most bright stars, multi-year Evryscope monitoring of the TESS field constrains the occurrence of superflares impacting nearby planets. From TESS-discovered planets such as LHS 3844 to previous discoveries TRAPPIST-1, YZ Ceti, Ross 128, and others, we discuss how Evryscope flares probe each planet's

space weather environment.

**Author(s):** Allison Youngblood, Daniel del Ser, Octavi Fors, Joshua Haislip, Henry T Corbett, Nicholas Law, Carl Ziegler, Ward S Howard, R. O. Parke Loyd, Evgenya L. Shkolnik, Aaron Pietraallo, Robert Quimby, Meredith Ann MacGregor, Amy Glazier, Jeff Ratzloff,

**Institution(s):** The University of North Carolina at Chapel Hill, NASA Goddard Space Flight Center, University of Washington, Universitat de Barcelona ICCUB, Arizona State University School of Earth and Space Exploration, Carnegie

### **203.03 - The Origin of Heavy-element Content Trend in Giant Planets via Core Accretion(Yasuhiro Hasegawa)**

We explore the origin of the trend of heavy elements in observed massive exoplanets. Coupling of better measurements of mass ( $M_p$ ) and radius of exoplanets with planet structure models enables estimating the total heavy element mass ( $M_z$ ) in these planets. The corresponding relation is characterized by a power-law profile,  $M_z \propto M_p^{3/5}$ . We develop a simplified, but physically motivated analysis to investigate how the power-law profile can be produced under the current picture of planet formation. Making use of the existing semi-analytical formulae of accretion rates of pebbles and planetesimals, our analysis shows that the relation can be reproduced well if it traces the final stage of planet formation. In the stage, planets accrete solids from gapped planetesimal disks and gas accretion is limited by disk evolution. We find that dust accretion accompanying with gas accretion does not contribute to  $M_z$  for planets with  $M_p < 103 M_{\oplus}$ . Our findings are broadly consistent with those of previous studies, yet we explicitly demonstrate how planetesimal dynamics is crucial for better understanding the relation. While our approach is simple, we can reproduce the trend of a correlation between planet metallicity and  $M_p$  that is obtained by detailed population synthesis calculations, when the same assumption is adopted. Our analysis suggests that pebble accretion would not play a direct role at the final stage of planet formation, whereas radial drift of pebbles might be important indirectly for metal enrichment of planets. Detailed numerical simulations and more observational data are required for confirming our analysis.

**Author(s):** Yasuhiro Hasegawa

**Institution(s):** JPL/Caltech

### **203.05 - Atmosphere Retrieval of Planetary Mass Companions with the APOLLO Code: A Case Study of HD 106906b and Prospects for JWST(Alex Ryan Howe)**

We present retrieved atmospheric properties for the very low mass companion, HD 106906b, which is spatially resolved from its host star, using APOLLO, a spectral retrieval code designed for flexibility of atmosphere models. APOLLO allows retrieval

on both transit and emission spectra of planets to determine molecular abundances as well as comparison of different parameterizations of the thermal structure and cloud properties. We compare fits of our models to high signal-to-noise spectra of HD 106906b, a 10-20 Jupiter mass early L-type companion orbiting a 10-15 Myr old binary system at 730 AU projected separation, obtained with SINFONI on the ESO VLT (Daemgen et al. 2017). Using these models, we measure molecular abundances and present constraints on cloud properties. Comparing the retrieved abundances of volatile species (e.g. C/O) to those of the host star, we can speculate on whether this object may have formed much closer to its host star through a core accretion-like mechanism and was later dynamically ejected to larger orbital separation. Because HD 106906b is a prime target for JWST, we present a similar analysis of model JWST spectra for this object to demonstrate the performance of APOLLO with data obtained over a broader wavelength regime (e.g. 0.6 to 5 microns).

**Author(s):** Kamen Todorov, Marie Ygouf, Michael R. Meyer, Sascha P Quanz, Alex Ryan Howe

**Institution(s):** University of Michigan, IPAC-Caltech, University of Amsterdam, ETH Zurich

### **203.06 - O<sub>2</sub>-Dominated Atmospheres for Potentially Habitable Environments on TRAPPIST-1 Planets(Renyu Hu)**

Small exoplanets of nearby red dwarf stars present the possibility to find and characterize habitable worlds within the next decade. TRAPPIST-1, an ultracool red dwarf star, was recently found to have seven Earth-sized planets of predominantly rocky composition. The planets e, f, and g can have a liquid water ocean on their surface given appropriate atmospheres of N<sub>2</sub> and CO<sub>2</sub>. Particularly, climate models have shown that the planets e and f can sustain a global liquid water ocean, for  $\sim 0.2$  bar CO<sub>2</sub> plus 1 bar N<sub>2</sub>, and  $\sim 2$  bars CO<sub>2</sub>, respectively. These atmospheres are irradiated by ultraviolet emission from the star's moderately active chromosphere. Using an atmospheric photochemistry model, we investigate how the irradiation drives chemical reactions in the atmospheres of TRAPPIST-1 e and f, where we assume habitable compositions predicted from the climate models and include the effects of lightning and oxidation of the crust. Our models show that chemical reactions driven by the irradiation in the atmosphere produce and maintain more than 1 bar of O<sub>2</sub> and 0.1 bar of CO if the CO<sub>2</sub> is  $\sim 0.1$  bar. Because of this O<sub>2</sub> runaway, the habitable environments on the TRAPPIST-1 planets entail an O<sub>2</sub>-dominated atmosphere, with co-existing CO, CO<sub>2</sub>, and N<sub>2</sub>. The sole process that would prevent the O<sub>2</sub> runaway is a direct recombination of O<sub>2</sub> and CO in the ocean, a reaction not found on Earth but might be facilitated biologically. Our results indicate that O<sub>2</sub> and CO should be considered together with CO<sub>2</sub> as the primary molecules in the search for atmospheric signatures from potentially habitable planets of TRAPPIST-1 and other red dwarf stars.

**Author(s):** Luke Peterson, Eric T Wolf, Renyu Hu

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### **203.07 - Internal Structure and CO<sub>2</sub> Reservoirs of Habitable Water-Worlds(Leslie Anne Rogers)**

Water-worlds are water-rich (>1% water by mass) exoplanets. If located at an appropriate orbital separation from their host star (i.e. in the habitable zone) they may have the potential to host a global surface water ocean. Water-worlds likely accrete a comet-like mixture of volatiles, leading to CO<sub>2</sub>-rich compositions, with between ~3 mol% to ~30 mol% CO<sub>2</sub> relative to water. In this study, we constrain the hydrosphere structures, CO<sub>2</sub> contents and CO<sub>2</sub> reservoirs in the interiors of water-worlds. We couple a sophisticated equation of state that accurately reproduces experimental phase boundaries of CO<sub>2</sub>-H<sub>2</sub>O mixtures to models of planet interior structure and atmospheric radiative transfer. We determine that neither the atmosphere, ocean, nor clathrate layer (if present) can be the main CO<sub>2</sub> reservoir on habitable (liquid ocean-bearing) water-worlds that accreted more than 11 wt% volatiles. The largest potential reservoir of CO<sub>2</sub> inside of habitable water-world hydrospheres is likely to be CO<sub>2</sub> ice trapped in the high-pressure water ice mantle. Consequently, the atmospheric composition of a water-world does not necessarily reflect the total mass of volatiles accreted during the formation of the planet, nor the relative proportions of CO<sub>2</sub> and H<sub>2</sub>O in the hydrosphere. Instead, the CO<sub>2</sub> molar fraction in the atmosphere is determined by the post-accretional cooling history of the planet. Detailed modeling of the post-accretional cooling of water-worlds is needed to determine whether CO<sub>2</sub> ice burial could allow water-worlds to have liquid water oceans or whether the evolution of the planet would generically lead to too much atmospheric CO<sub>2</sub> for the planets to be habitable.  
**Author(s):** Nadejda Marounina, Leslie Anne Rogers  
**Institution(s):** University of Chicago

### **203.02D - The Impact of Stellar UV Activity on Habitable Moist Terrestrial Exoplanet Atmospheres Around M Dwarfs(Mahmuda Afrin Badhan)**

Transit spectroscopy of terrestrial planets around nearby M dwarf stars is a primary goal of space missions in the coming decades. 3D climate modeling has shown that slowly rotating terrestrial extrasolar planets, at the inner edge of their habitable zones (IHZ), may possess significantly enhanced stratospheric water vapor compared to a rapidly rotating planet like Earth. For host M-dwarfs with  $T_{\text{eff}} > 3000$  K, synchronously rotating IHZ planets have been shown to retain moist greenhouse conditions (stratospheric water mixing ratio >10-3) despite low Earth-like surface temperatures. In such slow rotators, strong vertical mixing is expected to loft the H<sub>2</sub>O high into the atmosphere. This is promising for H<sub>2</sub>O detection in the atmospheres of tidally-locked habitable planets with the

upcoming James Webb Space Telescope (JWST). The first HZ exoplanets to have their atmospheres characterized will likely be such tidally-locked planets orbiting nearby M dwarfs. However, M dwarfs also possess strong UV activity, which may effectively photolyze stratospheric H<sub>2</sub>O. Prior modeling efforts have not included the impact of high stellar UV activity on stratospheric H<sub>2</sub>O abundance. Here, we employ a 1-D photochemical model with varied stellar UV, to assess whether H<sub>2</sub>O destruction driven by high stellar UV would affect the detectability of H<sub>2</sub>O in transmission spectroscopy. Temperature and water vapor profiles are taken from published 3-D climate model simulations for an inner HZ Earth-sized planet around a 3300 K M dwarf with a pure N<sub>2</sub>-H<sub>2</sub>O atmosphere; they serve as self-consistent input profiles for the 1-D model. We find that as long as the atmosphere is well-mixed up to the 1 mbar pressure level, UV activity appears to not impact detectability of H<sub>2</sub>O in the transmission spectrum. The strongest H<sub>2</sub>O features occur in the JWST MIRI instrument wavelength range and are comparable to the estimated systematic noise floor of ~50 ppm for a cloudless atmosphere. We also explore additional chemical complexity within the 1-D model by introducing other species into the atmosphere and discuss their impact on the transmission spectrum.  
**Author(s):** Eliza Kempton, Mahmuda Afrin Badhan, Shawn David Domagal-Goldman, Eric T Wolf, Ravi Kopparapu, Giada Arney, Drake Deming  
**Institution(s):** University of Maryland College Park, University of Colorado, Boulder, NASA Goddard Space Flight Center

### **203.04D - Heavy Ion Escape from Terrestrial Exoplanets(Hilary Egan)**

The most potentially observable habitable zone planets are found around M-dwarfs, therefore characterizing their long term atmospheric stability is important. Ion loss in particular is critical to study because electric fields provide additional escape energy to heavy species that could make up volatile rich atmospheres. We used a global hybrid plasma model to systematically study how ion escape processes vary from solar system expectations due to the extreme conditions found at the habitable zone of a typical M-dwarf. To isolate the effects of different stellar influence properties we incrementally changed each parameter, allowing our interpretation to be more generalizable across systems. We found that while both the ion loss morphology and rates were dictated by the resultant plasma environment, there was not a straightforward relationship between energy input and ion outflow due to ion production limitations. It is thus important to consider under what conditions scaling laws derived by observations of solar system planets begin to break down when applied to more extreme environments. Additionally, the asymmetric plasma environment created by a nearly flow aligned interplanetary magnetic field lead to asymmetric ion outflow, possibly creating observable atmospheric asymmetry in tidally locked planets. We also investigated the influence of intrinsic planetary magnetic field on the ion escape. Although terrestrial planets around M-

Dwarfs are likely to be un- or weakly-magnetized, even a weak magnetic field is capable of changing the dynamics of the solar wind interaction. Our results reflect a balancing act between magnetic standoff pressure and polar outflow, where the presence of a magnetic field enhances escape to a certain point before beginning to inhibit it.

**Author(s):** David Brain, Riku Jarvinen, Hilary Egan

**Institution(s):** University of Colorado Boulder, Finnish Meteorological Institute

## **204 - M Dwarfs Magnetic Activities and Flares**

### **204.01 - Near-Ultraviolet Flares from M Dwarfs with Simultaneous X-ray and Optical Observations(Allison Youngblood)**

An essential task on the journey to finding life beyond the solar system is to determine which places are suitable for life. While terrestrial planets orbiting M dwarfs are highly sought after, their habitability is in question owing to high activity levels and close-in habitable zones. We are undertaking a large survey primarily with the Swift and TESS satellites of dozens of M dwarfs spanning all combinations of mass and age in order to understand their flare rates and spectral energy distributions. We have obtained Hubble Space Telescope time-resolved NUV spectroscopy with the STIS spectrograph of two M dwarfs, GJ 832 (M2 V) and GJ 1061 (M5.5 V) simultaneously with Swift and TESS. The NUV spectra were designed to illuminate the typical flare spectral response in Swift's broadband NUV filter (UVM2; 1600-3300 Å...), which is being used for the larger flare survey. We also present supporting Las Cumbres Observatory optical spectroscopy/photometry and Kilo-degree Extremely Little Telescope (KELT) photometry of the NUV flares. Multi-wavelength observations of flares are few, yet are critically important for understanding the effect of space weather on exoplanets, and NUV flares may provide potentially-critical missing energy for origin-of-life scenarios on M dwarf exoplanets.

**Author(s):** Allison Youngblood, Joshua Schlieder, Thomas Barclay, Elisa Quintana, James Davenport, Knicole Colon, R. Parke Loyd

**Institution(s):** NASA Goddard Space Flight Center, University of Washington, Arizona State University

### **204.03 - FUMES: Simultaneous Optical and UV Spectroscopy of an M-dwarf Flare(J. Sebastian Pineda)**

The strong high-energy emissions of M-dwarf systems can significantly affect the atmospheres of their close-in exoplanetary systems by driving mass-loss and defining the prevalent atmospheric photochemistry. Moreover, the strong and frequent flaring from these stars can contribute to the atmospheric erosion and remove important compounds in Earth-like atmospheres like ozone. Through the Far Ultraviolet M-dwarf Evolution Survey (FUMES) with the Hubble Space Telescope, we have been studying how the high-energy

emissions of early-to-mid M-dwarf systems change with rotation period and age, including observations of young active M-dwarfs to assess the high-energy radiative environment experienced by young exoplanetary systems. This survey included extensive concurrent ground-based spectroscopic support at optical and infrared wavelengths to supplement the FUV HST-STIS spectroscopy and connect the FUV features to more observationally accessible multi-wavelength magnetic emissions. We present early results of time-resolved observations spectroscopically capturing an M-dwarf flare, with a total FUV peak flux of ~70 times above quiescence, simultaneously in the UV with HST and at optical wavelengths from the Apache Point Observatory. We illustrate how the FUV emission lines behave during the flare in relation to the optical Balmer and continuum emission, with important implications for typical flares experienced by M-dwarf exoplanetary systems.

**Author(s):** Allison Youngblood, J. Sebastian Pineda, Kevin France

**Institution(s):** University of Colorado Boulder - LASP, NASA Goddard Space Flight Center

### **204.04 - HAZMAT. IV. Flares and Superflares on Young M Stars in the Far Ultraviolet(Parke Loyd)**

The many planets orbiting M stars are at the mercy of those stars' infamously high levels of activity. In order to study the range of activity levels that these planets are exposed to, the HAbitable Zones and M dwarf Activity across Time (HAZMAT) program is surveying M star ultraviolet (UV) activity with HST. The survey is providing a detailed look at the activity-driven UV emission of M stars at young (45 Myr), intermediate (650 Myr), and old (~several Gyr) ages. Here, we present a comprehensive look at the results of the youngest members of the HAZMAT sample, the 40 Myr Tuc-Hor moving group members, an age when terrestrial planets are actively forming. We present the time-resolved near-UV and far-UV spectra, including FUV flare rates and energies. Both the quiescent UV luminosity and the energies of far-UV flares display a decline around 2 orders of magnitude from 40 Myr to Gyr ages. The flares observed include a superflare ( $E_{\text{bol}} = 10^{33.6}$  erg), dubbed the "Hazflare," that displayed well-resolved continuum emission at 15,500 K. Besides being one of only two M-star superflares with time-resolved UV spectroscopy, this flare, captured in less than a day's worth of exposure, supports the possibility that flares contribute as much or more energy than quiescence to the overall UV emission of M stars, with superflares occurring daily on young M stars. These types of frequent superflares will have important implications for the atmospheres of planets forming around young M stars.

**Author(s):** Parke Loyd, Victoria Meadows, Adam Schneider, Evgenya L. Shkolnik, Travis Barman, Sarah Peacock, Isabella Pagano

**Institution(s):** Arizona State University, University of Washington, University of Arizona, Osservatorio Astrofisico di Catania

#### **204.05 - Resolved imaging of the quiet and flaring radio corona of active M dwarfs(Jacqueline Villadsen)**

Magnetically active M dwarfs produce non-thermal quiescent radio emission, along with coherent and incoherent flares. Very long baseline imaging (VLBI) has revealed that these luminous phenomena can occur on spatial scales significantly larger than the stellar photosphere, in processes which have no clear analog in the solar corona. This non-thermal radio emission originates directly from energetic electrons, making radio the only direct observational probe of accelerated particles in stellar coronae. I will present VLBI observations of the quiescent and flaring radio emission from two nearby active M dwarfs. These two stars with saturated coronal activity have distinctly different structure in their radio coronae, perhaps indicative of different underlying electron acceleration mechanisms responsible for the quiescent radio emission.

**Author(s):** Jacqueline Villadsen, Stephen Bourke, Gregg Hallinan, Timothy Bastian, Amy Mioduszewski

**Institution(s):** National Radio Astronomy Observatory, Chalmers University of Technology, California Institute of Technology

#### **204.06 - The Rotation-X-ray Activity Relation for Low-Mass Stars in the Hyades and Praesepe(Alejandro Nájera)**

The 650-Myr-old Hyades and Praesepe are the oldest open clusters within 250 pc, and thus the oldest easily accessible ensembles of low-mass stars with a definitive age. This makes them indispensable laboratories for studying both the relationship between stellar rotation and magnetic activity in a single-aged population and the evolution of activity over Gyr. We combine ground- and space-based measurements of periods with our Chandra, Swift, and XMM-Newton data to examine activity, as characterized by coronal X-ray emission, as a function of rotation for high-confidence members of both clusters. We also compare the results of this analysis to results derived from spectroscopic measurements of chromospheric activity in these same stars. These results provide essential insight into the relative efficiency of magnetic heating of the stars' atmospheres, thereby informing the development of robust age-rotation-activity relations.

**Author(s):** Stephanie T. Douglas, Marcel Agüeros, Kevin Covey, Alejandro Nájera

**Institution(s):** Columbia University, Harvard-Smithsonian Center for Astrophysics, Western Washington University

#### **204.07 - Magnetic activity and starspots as a cause of sub-subgiant stars(Natalie M. Gosnell)**

Sub-subgiant stars populate an area of the color-magnitude diagram below the subgiant branch, where stars are too faint to be subgiant stars and too cool to be main sequence stars. Although they are found in many open and globular clusters,

traditional evolutionary pathways do not predict sub-subgiants. Many sub-subgiant stars are found in short period binaries ( $P_{\text{orb}} < 20$  days) with moderate H-alpha and X-ray emission, indicative of chromospheric and coronal activity. Using a high-resolution near-infrared IGRINS spectrum of S1063, a sub-subgiant in open cluster M67, we present a spectral decomposition of the ambient photosphere and starspot spectra, resulting in estimates of the starspot filling factor and spot temperature. This spectral-based constraint, in conjunction with K2 light curves, provides observational evidence suggesting that the sub-luminous nature of sub-subgiants is consistent with high magnetic activity and moderate starspot filling factors of 30-40%. These spots inhibit convective energy transport in the star, resulting in a dramatic under-luminosity during this specific stage of stellar evolution, changing the location of the star in the H-R Diagram.

**Author(s):** Michael A. Gully-Santiago, Natalie M. Gosnell, Emily Leiner

**Institution(s):** Colorado College, Bay Area Environmental Research Institute, NASA Ames Research Center, CIERA/Northwestern University

#### **204.08 - Characterizing Magnetic Activity as a Function of Mass and Rotation Period of Fully Convective M-dwarfs(Amber Medina)**

Main-sequence stars with masses less than 30% that of the Sun are fully convective and are the most abundant stars in the galaxy. The question of how fully convective stars generate their magnetic field is of intrinsic interest and also bears upon the habitability of their orbiting planets. We are undertaking a multi-epoch high-resolution spectroscopic volume-limited survey of stars with masses between 0.1-0.3 the solar value and within 15 parsecs. The stars in the sample are well characterized with accurate masses, radii, and photometric rotation periods from the MEarth Project. We present preliminary results on the variability of several indicators of magnetic activity, including H alpha, and how they relate to stellar properties such as rotation. We will compare the variability of magnetic activity indicators as a function of stellar rotation period, which will tell us how the magnetic field evolves throughout the lifetime of these fully convective stars and what implications that has for potentially habitable planets. This project was made possible through the support of a grant from the John Templeton Foundation. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the John Templeton Foundation. This work was supported by grants from the National Science Foundation. A. M. is supported by an NSF Graduate Research Fellowship.

**Author(s):** Jonathan Irwin, Jennifer Winters, David Charbonneau, Amber Medina

**Institution(s):** Harvard Smithsonian Center for Astrophysics



## **204.02D - Photometric and Spectroscopic Perspectives Stellar Magnetic Activity and Its Effect on Exoplanet Characterization(Brett M. Morris)**

Exoplanets have been discovered principally via the transit method, which reveals planetary radii and orbital periods. Transits reveal the composition of exoplanet atmospheres via transmission spectroscopy. When the planet passes in front of the host star, the planet will appear largest at wavelengths where the planet's atmosphere is opaque, and smallest at wavelengths where the atmosphere is transparent. Thus by measuring the apparent radius of the planet as a function of wavelength, we attain a spectrum of an exoplanet's atmosphere. In transiting multi-planet systems, we can also measure the masses of exoplanets by using transit timing variations. The orbit of a single transiting planet around a single star would be perfectly periodic, but if there's more than one planet in the system the gravitational influence of each planet on each other pulls the planets slightly ahead or behind in their orbits. The apparent early or late arrival of an exoplanet transit transmits information about the mass of the perturbing planet. However, stellar magnetic activity injects confounding time- and wavelength-dependent signals into the spectrophotometry of exoplanet host stars which complicate all of these measurements. I used the transiting planet HAT-P-11 b to measure the sizes and latitude distribution of starspots on its active K4 dwarf host star, and find that its magnetic activity mirrors the Sun's. I measured the chromospheric activity of HAT-P-11 and compared it to similar stars, and find that it's the most active of its peers, perhaps suggestive of star-planet interaction. I measured starspot coverage on a sample of bright stars via TiO molecular band modeling. With ground-based photometry, I measured the transit times of TRAPPIST-1 b and c, and several Kepler host stars. I devised a technique for measuring robust exoplanet radii, even in the presence of significant starspot distributions. Finally, I devised a simulator for James Webb Space Telescope observations of transiting exoplanets, to explore the limits imposed by magnetic activity on transit timing and transmission spectroscopy measurements.

**Author(s):** Brett M. Morris

**Institution(s):** University of Washington

## **205 - Extrasolar Planets: Characterization & Theory Track 1: V. Measurements and Models of Giant Planet Atmospheres C**

### **205.01 - An Investigation of the Atmosphere of the Extremely Inflated Exoplanet KELT-11b with HST and Spitzer(Knicole Colon)**

KELT-11b is a hot, inflated, sub-Saturn mass planet transiting a bright star, making it one of the best known targets for atmospheric characterization. To that end, we recently obtained an ultra-precise transmission spectrum of KELT-11b using the Wide Field Camera 3 on the Hubble Space Telescope as well as eclipse photometry with Spitzer at 4.5 microns. We also previously collected a broadband transit of KELT-11b with

Spitzer at 3.6 microns. Here, we present new results from our Hubble and Spitzer observations, which we use to probe the metallicity of a hot, inflated planet with a metal-rich, evolved host star for the first time. We demonstrate that the KELT-11 system is becoming a benchmark in the study of extremely inflated exoplanets and their atmospheres.

**Author(s):** Thomas Beatty, Michael R. Line, Avi M Mandell, Nikku Madhusudhan, Joshua Pepper, Eric D. Lopez, Keivan G Stassun, Brett M. Morris, Daniel Angerhausen, Laura Kreidberg, Patrick Tamburo, Luis Welbanks, John Johnson, Jonathan Fortney, Knicole Colon, Kevin St

**Institution(s):** University of Washington, oSmithsonian

### **205.03 - An optical transmission spectrum for the ultra-hot Jupiter WASP-121b measured with the Hubble Space Telescope(Thomas Evans)**

I will present a new atmospheric transmission spectrum for the ultra-hot Jupiter WASP-121b, measured using the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope. The transmission spectrum is quite distinct from those published previously for other exoplanets. Across the 0.4-1 micron wavelength range, the inferred atmospheric opacity is comparable to - and in some spectroscopic channels, exceeds - that previously measured at near-infrared wavelengths. Wavelength-dependent variations in the opacity rule out a gray cloud deck at a confidence level of 3.7-sigma and may instead be explained by VO spectral bands. We find a cloud-free model assuming chemical equilibrium for a temperature of 1500K and metal enrichment of 10-30x solar matches these data well. We find no evidence for TiO, suggesting it may have condensed from the gas phase at the day-night limb. The opacity rises steeply at the shortest wavelengths, increasing by approximately four pressure scale heights from 0.4 to 0.28 micron in wavelength. If this feature is caused by Rayleigh scattering due to uniformly-distributed aerosols, it would imply an unphysically high temperature of 5000+/-1200K. One alternative explanation for the short-wavelength rise is absorption due to SH (mercapto radical), which has been predicted as an important product of non-equilibrium chemistry in hot Jupiter atmospheres. Irrespective of the identity of the NUV absorber, it likely captures a significant amount of incident stellar radiation at low pressures, thus playing a significant role in the overall energy budget, thermal structure, and circulation of the atmosphere.

**Author(s):** Kevin Zahnle, Munazza Alam, Michael Williamson, Eric Hebrard, Lars A. Buchhave, Mercedes Lopez-Morales, Nikolay Nikolov, Vincent Bourrier, Panayotis Lavvas, Lotfi Ben-Jaffel, David Ehrenreich, Jayesh Goyal, Pascal Tremblin, Jorge Sanz-Forcada, Benjamin Dr

**Institution(s):** Sorbonne Universites, oUniversity of Arizona, Universitat Berlin, Universite de Geneve, Space Telescope Science Institute, CEA Saclay, Technical University of Denmark, Massachusetts Institute of Technology, University of Exeter, Johns Hopkins Univer

### **205.05 - The Mega-MUSCLES HST Treasury Survey(David Wilson)**

Rocky planets around nearby M dwarfs have emerged as prime targets for atmospheric characterisation with JWST. A few such planets are already known (e.g. around GJ1132, Proxima Cen, and Trappist-1) and TESS is predicted to find many more, including ~9 habitable zone planets. To interpret observations of these exoplanets' atmospheres, we must understand the high-energy SED of their host stars: X-ray and EUV irradiation can erode a planet's gaseous envelope and FUV/NUV-driven photochemistry shapes an atmosphere's molecular abundances, including potential biomarkers like O<sub>2</sub>, O<sub>3</sub>, and CH<sub>4</sub>. The Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems (MUSCLES) Treasury Survey, carried out in Cycles 19 and 22, used Hubble/COS+STIS ultraviolet observations with contemporaneous X-ray and ground-based data to construct complete SEDs for 11 low-mass exoplanet hosts. MUSCLES is the most widely used database for early-M and K dwarf (>0.3 M<sub>sun</sub>) irradiance spectra and has supported a wide range of atmospheric stability and biomarker modeling work. However, TESS will find most of its habitable planets transiting stars less massive than this, and these will be the planets to characterize with JWST. Here, we provide an update on the Mega-MUSCLES project, a Cycle 25 HST Treasury program. Following on the successful MUSCLES survey, Mega-MUSCLES is expanding our target list to focus on: (a) new M dwarf exoplanet hosts with varying properties; (b) reference M dwarfs below 0.3 solar masses that may be used as proxies for M dwarf planet hosts discovered after HST's lifetime; and (c) more rapidly rotating stars of GJ1132's mass to probe XUV evolution over Gyr timescales. By the time of the AAS meeting, we will have observed 7/13 targets, including the first panchromatic SEDs of rocky planet hosts GJ1132 and Trappist-1. We will present an overview of the Mega-MUSCLES motivation and target list, discuss the observations already obtained, and show how it extends proven methods to a key new sample of stars, upon which critically depends the long-term goal of studying habitable planet atmospheres with JWST and beyond.

**Author(s):** Allison Youngblood, David Wilson, Zachory Berta-Thompson, Kevin France, R. O. Parke Loyd, Cynthia S. Froning, Christian Schneider, Alexander Brown

**Institution(s):** University of Texas at Austin, Arizona State University, University of Colorado, ESA/ESTEC, NASA/GSFC  
Contributing Team(s): Mega-MUSCLES

### **205.06 - Spitzer Phase Curves with Clouds: A New Population of Anomalous Infrared Phase Curves(Jonathan D Fraine)**

We here present phase curve observations of Qatar-2b (P = 1.337 days) with the Spitzer Space Telescope at 3.6 and 4.5  $\mu$ m. Qatar-2b has an equilibrium temperature  $T_{eq} \sim 1350$  K, which is similar to that of WASP-43b. Cloud-free general circulation models (GCM) predict that recirculation should

dominate over rapid re-radiation, which would reduce the day-to-night brightness contrast at longer wavelengths (i.e. increase the night side flux). Our observations show that Qatar-2b's night side flux is undetected at 4.5 microns, maximizing its day-to-night contrast; but the atmosphere has significant night side flux at 3.6 microns. Neither channel shows a significant offset in the peak emission. We will present our Qatar-2b observations along with a catalogue of anomalous Spitzer phase curve observations, and compare possible physical explanations; nominally that the night side is dominated by the formation of inhomogeneous, high-altitude aerosol layers that are forming near the terminator and absorbing thermal emission from the nightside.

**Author(s):** Eliza Kempton, Jonathan D Fraine, Brian Kilpatrick, Tiffany Kataria, Nikole K Lewis, Carlos Eduardo Munoz Romero, Kevin Stevenson

**Institution(s):** Space Telescope Science Institute, Grinnell College, Space Science Institute, Cornell University, NASA Jet Propulsion Laboratory, University of Maryland, Brown University  
Contributing Team(s): STARGATE: Space Telescope Advanced Research Group for the Atm

### **205.07 - Clear and Cloudy Exoplanet Forecasts for JWST: Maps, Retrieved Composition, and Constraints on Formation with MIRI and NIRCам(Everett Schlawin)**

The James Webb Space Telescope (JWST) will transform our understanding of planet structure, dynamics, chemistry, and formation by obtaining high quality near-infrared and mid-infrared transmission and eclipse spectra of transiting planets at unprecedented precisions. JWST characterization of sub-Jupiter mass planets with temperature below ~1000 K will be essential in the march toward biosignature searches on potentially habitable planets. We explore a range of exoplanet atmospheric conditions and forecast the expected results with JWST that will be part of the MIRI+NIRCам Guaranteed Time Observations for HD 189733 b, WASP-80 b, WASP-107 b, GJ 436 b, HAT-P-26 b and HAT-P-19 b. We take realistic CHIMERA models that match existing Spitzer and Hubble Space Telescope results and simulate the spectra achievable with the JWST MIRI slitless LRS and NIRCам grism time series modes. We then retrieve atmospheric parameters from these spectra to estimate the precision to which the planets' atmospheric compositions can be measured. We find that emission spectra have well-constrained unimodal solutions but transmission spectra near 10 $\mu$ m— solar abundance and solar C/O ratios can suffer from bimodal solutions. Broad wavelength coverage as well as higher-precision data can resolve bimodal solutions and provide dramatically better atmospheric parameter constraints. We find that metallicities can be measured to within 20%-170%, which approaches the precisions on solar system planets, and C/O ratios can be constrained to  $\sim 1/4$  10%-60%, assuming that observers can leverage short wavelength data to select the correct solution from the bimodal posteriors. These compositional precisions are sufficient to test some predictions from disk formation

models on final atmospheric abundances as long as their history is not erased by planet evolution processes. We also show the extent to which eclipse mapping with JWST is possible on our brightest system HD 189733 b.

**Author(s):** Michael R. Line, Everett Schlawin, Thomas P Greene, Jonathan Fortney, Marcia Rieke

**Institution(s):** University of Arizona, Arizona State University, NASA Ames, University of Santa Cruz

### **205.02D - A Multi-Dimensional Approach to Characterizing Exoplanet Atmospheres(Brian Kilpatrick)**

Planetary atmospheres are governed by a complex interplay of chemical, radiative, and advective processes that yield an inherently three dimensional structure. Probing the three dimensional nature of exoplanet atmospheres is challenging without the capability to spatially resolve them. Here I present the results of applying a multi-dimensional approach to the characterization of exoplanet atmospheres utilizing a broad range of observational techniques and theoretical frameworks to explore the atmospheric composition and structure of transiting exoplanets. Each analysis was performed with an emphasis on ensuring robustness of scientific results by applying multiple methodologies and engaging a diverse cross sections of the community in collaboration. I will present a set of Spitzer secondary eclipse observations of five different planets, analyzed with several of the most common methods of intrapixel sensitivity correction to investigate the performance of each technique while also probing albedo and recirculation. I will then present a community analysis of an HST Wide Field Camera 3 spectroscopic transit of WASP-63b probing chemical composition and providing evidence of possible disequilibrium chemistry. Finally, I will present a set of multi-epoch Spitzer secondary eclipse observations and phase curves of the canonical hot jupiters HD 209458b and HD 189733b at both 3.6 and 4.5 microns probing temporal variations in eclipse depth and providing the first three dimensional thermal map of an exoplanet atmosphere.

**Author(s):** Nikole K Lewis, Gregory S Tucker, Brian Kilpatrick

**Institution(s):** Brown University, Cornell University

### **205.04D - Investigations of Giant Worlds on the Cold Frontier of Exoplanet Science(Paul A. Dalba)**

The panoply of exoplanetary discoveries that has emerged over the past three decades has largely been shaped by observational biases. Limited observational baselines and detection efficiencies have so far restricted the majority of exoplanet studies to those with short-period orbits that are strikingly different than the planets in the Solar System. Yet, the fundamental questions surrounding planetary science, ones of formation, evolution, and even habitability, cannot be addressed without probing the outer reaches of planetary systems as well as the inner regions. In my dissertation, I

investigated the nature of the cold, long-period worlds that exist at the frontier of exoplanetary science. My studies involved the refinement of orbital ephemerides through transit detection and the development of new atmospheric characterization techniques through atmosphere modeling. Here, I will describe my efforts to recover transits of long-period exoplanets, including new results from a coordinated campaign of ground-based telescopes spread over two continents. I will also discuss my use of Solar System datasets for exoplanet applications. As inhabitants of Earth, we have the cosmic good fortune of being situated next to several long-period giant planets. These familiar gas giants, and especially the extensive observations of Saturn, enable a comparative approach to the study of exoplanets that is becoming increasingly important. Using Saturn's atmosphere as a "ground truth," I will demonstrate the scientific potential of transmission spectroscopy of cold gas-giant exoplanets. Additionally, I will present new results showing actual observations of refraction phenomena in Saturn's atmosphere and explain its benefit to the characterization of cold gaseous exoplanets. My dissertation laid the foundation for future investigations of cold giant exoplanets, which exist in an almost entirely unexplored regime of exoplanetary science. Using Saturn to provide context and motivation, I will present my efforts to confront the challenges facing this new discipline of exoplanetary science.

**Author(s):** Paul A. Dalba,

**Institution(s):** University of California Riverside, Boston University

### **206 - Galaxy Formation and Evolution IV 206.01 - Unveiling Quenching History of Cluster Galaxies Using Phase-space Analysis(Jinsu Rhee)**

We utilize times since infall of cluster galaxies obtained from the cosmological hydrodynamic N-body simulations and star formation rates from the SDSS data release 10 to study how quickly late-type galaxies are quenched in the cluster environments. In particular, we confirm that the distributions of both simulated and observed galaxies in phase-space diagrams are comparable and that each location of phase-space can provide the information of times since infall and star formation rates of cluster galaxies. Then, by limiting the location of phase-space of simulated and observed galaxies, we associate their star formation rates with times since infall using a novel method that employs the quantiles of each probability distribution. We adopt a flexible quenching model based on the "delayed-then-rapid" scenario where each key parameter is treated as a free parameter and find the best model reproducing the obtained relationship between time since infall and star formation rate. Finally, we see that the quenching parameters measured by the new method are consistent with the works of previous authors on the trend with galaxy stellar mass as well as the quenching efficiency. We emphasize that our method can be used in various research to find the relationship from two different probability distributions.

**Author(s):** Rory Smith, Seoyoung Lyla Jung, Hoseung Choi, San Han, Jinsu Rhee, Sukyoung K. Yi

**Institution(s):** Yonsei University

**206.03 - The development of kinematic structures of the galaxies in the New Horizon simulation(Minjung Park)**

Disk galaxies are believed to consist of structures with different kinematics and stellar populations: young disk stars rotating on the galactic plane and old stellar bulge and halo having non-ordered motions. In the favored LCDM paradigm, several internal and external processes work together in settling the kinematic components. Investigating the significance of processes responsible for each component of a galaxy is, therefore, essential to understanding the evolution of kinematics and morphologies of galaxies. Using the New Horizon simulation, which is a high-resolution cosmological zoom-in simulation, we can resolve the detailed structures for a statistically significant number of galaxies. We first decompose stellar particles in a galaxy into a rotating disk and a dispersion-dominated spheroidal component based on their orbits and then see how the stars in these components are formed and assembled into the galaxy. We find that disk stars are mostly young stars formed in situ, and spheroidal components consist of old stars born with misaligned orbits with respect to the galactic rotating planes, disrupted disk stars, and accreted stars (mostly distributed at large radii). In the star formation history, stars mainly form with chaotic orbits at high redshift  $z \sim 3$ , and thus galaxies are mostly spheroid-dominated. As redshift decreases, massive galaxies start to form disk stars predominantly ( $z \sim 1-2$ ), while less massive galaxies form these stars much later. This study highlights the relative importance of different growth channels for galaxies with different kinematics (i.e., disk-dominated galaxies, spheroid-dominated galaxies, and galaxies with second disks) and the role of mergers in these processes.

**Author(s):** Julien Devriendt, Hoseung Choi, Yohan Dubois, Sebastien Peirani, Marta Volonteri, Taysun Kimm, Minjung Park, Christophe Pichon, Sukyoung K. Yi, Sugata Kaviraj

**Institution(s):** Yonsei University, University of Oxford, Institut d'astrophysique de Paris, University of Hertfordshire, University of Oslo, Observatoire de la Cote d'Azur

**206.04 - Angular momentum evolution of galaxies in the EAGLE simulations(Claudia del P Lagos)**

Measurements of the angular momentum and spin of galaxies are becoming widely available thanks to the new generation of extragalactic IFU surveys. This is opening a new window in which to investigate galaxies and specifically the connection between their mass growth, quenching, morphological and kinematic transformation. Simulations of galaxy formation provide us with a unique opportunity to study causality in all the emerging correlations, such as the specific angular momentum-mass, spin-ellipticity, among other relations. I'll be discussing how we have used the EAGLE and Hydrangea

hydrodynamical simulation suites to investigate the connection between gas accretion, angular momentum, mass growth and environment in galaxies, and the main conclusions we have reached so far.

**Author(s):** Claudia del P Lagos

**Institution(s):** University of Western Australia

**206.06 - Preprocessing of Dark Halos in the Hydrodynamic Zoom-in Simulation of Clusters(San Han)**

To understand the galaxy population in clusters today, we should also consider the impact of previous environments prior to cluster infall, namely preprocessing. We use the Yonsei Zoom-in Cluster Simulation, a hydrodynamic high-resolution zoom-in simulation of 15 clusters, to evaluate the impact of preprocessing on cluster members, focused on the tidal stripping suffered by their dark matter halos. We find that  $\sim 48\%$  of today's cluster members were once satellites of other hosts. We find that the preprocessed fraction is poorly correlated with cluster mass and is instead related to each cluster's recent mass growth rate. Hosts less massive than groups are significant contributors, providing more than one-third of the total preprocessed fraction. We find that halo mass loss is a clear function of the time spent in hosts. However, two factors can increase the mass-loss rate considerably: the mass ratio of a satellite to its host and the cosmological epoch when the satellite was hosted. The latter means we may have previously underestimated the role of high-redshift groups. From a sample of heavily tidally stripped members in clusters today, nearly three-quarters were previously in a host. Thus, visibly disturbed cluster members are more likely to have experienced preprocessing. Being hosted before cluster infall enables cluster members to experience tidal stripping for extended durations compared to direct cluster infall and at earlier epochs when hosts were more destructive. This presentation will be a summary of our upcoming publication in the astrophysical journal.

**Author(s):** Luca Cortese, Rory Smith, Emanuele Contini, Barbara Catinella, Hoseung Choi, San Han, Sukyoung K. Yi

**Institution(s):** Yonsei University, International Centre for Radio Astronomy Research, Korea Astronomy and Space Science Institute, the ARC Centre of Excellence in All Sky Astrophysics

**206.07 - Mildly Suppressed Star Formation in Central Regions of MaNGA Seyfert Galaxies(Longji Bing)**

Negative feedback from accretion onto super-massive black holes (SMBHs), that is to remove gas and suppress star formation in galaxies, has been widely suggested. However, for Seyfert galaxies which harbor less active, moderately accreting SMBHs in the local universe, the feedback capability of their black hole activity is elusive. We present spatially-resolved  $H\alpha$  measurements to trace ongoing star formation in Seyfert

galaxies and compare their specific star formation rate with a sample of star-forming galaxies whose global galaxy properties are controlled to be the same as the Seyferts. From the comparison we find that the star formation rates within central kpc of Seyfert galaxies are mildly suppressed as compared to the matched normal star-forming galaxies. This suggests that the feedback of moderate SMBH accretion could, to some extent, regulate the ongoing star formation in these intermediate to late type galaxies under secular evolution.

**Author(s):** Longji Bing, Yong Shi, Yanmei Chen

**Institution(s):** School of Astronomy and Space Science, Nanjing University  
**Contributing Team(s):** MaNGA Team

## **206.02D - The First Census of Precise Metallicity Gradients in Dwarf Galaxies at Cosmic Noon(Xin Wang)**

Dwarf galaxies ( $M_{\text{star}} \sim 10^9 M_{\odot}$ ) provide unique probes of cosmic structure formation on the smallest scales, and represent the most compelling testbeds for galactic feedback physics since they are more susceptible to feedback processes than their high-mass counterparts. However, their chemo-structural properties at cosmic noon ( $z \sim 2$ ) have remained unexplored, due to their intrinsically small size and insufficient spatial sampling. To address this, we develop a highly efficient method to obtain sub-kiloparsec resolution (i.e. precise) gas-phase metallicity maps of strongly lensed galaxies using space-based slitless spectroscopy. Applying our method to the deep HST near-infrared grism data, we obtain precise metallicity maps of 81 star-forming galaxies at  $z \sim 1.2-2.3$ , over half of which reside in the dwarf mass regime. Our work presents the first statistically representative sample of high- $z$  dwarf galaxies with their metallicity spatial distribution measured with sufficient resolution. These metallicity maps reveal diverse galaxy morphologies, indicative of various effects such as efficient radial mixing from tidal torques, rapid accretion of low-metallicity gas, and a variety of feedback processes which can effectively affect the chemo-structural properties of dwarf galaxies. In particular, we find two galaxies at  $z \sim 2$  displaying greatly inverted metallicity radial gradients, strongly suggesting that powerful galactic winds triggered by central star bursts carry the bulk of stellar nucleosynthesis yields to the outskirts. We also observe an intriguing correlation between  $M_{\text{star}}$  and metallicity gradient, consistent with the "downsizing" picture that more massive galaxies are more evolved into later phases of disk growth, where they experience more coherent mass assembly at all radii thus showing shallower gradients. Furthermore, 10% of the metallicity gradients measured in our sample are inverted, which are hard to explain by currently existing hydrodynamical simulations and analytical chemical evolution models. Our method can also be applied to data from future space missions employing grism instruments, e.g., JWST, WFIRST, Euclid.

**Author(s):** Tucker A Jones, Tommaso Treu, Xin Wang

**Institution(s):** University of California, Los Angeles, University of California, Davis  
**Contributing Team(s):** the

GLASS team

## **206.05D - High Resolution spatial analysis of $z \sim 2$ lensed galaxy using pixelated source-reconstruction algorithm(Soniya Sharma)**

Strong gravitational lensing coupled with Integral field spectrographic observations (IFS) and adaptive optics (AO) imaging techniques have pioneered spatially resolved studies of high redshift galaxies ( $z > 1$ ). The most magnificent cases of strong lensing are the giant arcs/ multiple images around massive galaxy groups or clusters, yielding a total flux gain of a few times 10-100. However, the accuracy and precision of source-plane reconstructions of the most strongly lensed cases are fundamentally limited by two main factors: the lensing mass model and the effect of the differential point-spread-function (PSF). While a huge amount of effort has been made in the past decade to improve the lens models (e.g., Hubble Frontier Fields), relatively fewer works have been done on addressing the effect of the differential PSF. We conduct a detailed study to recover the source-plane physical properties of  $z \sim 2$  lensed galaxy by combining IFS observations on multiple images of the lensed target. To deal with PSF's from two observational data sets, firstly we demonstrate the use of a unique forward approach to obtain coadded brightness profile in the source plane. Further, to make the forward approach more generic, we develop a fully automated Bayesian image inversion technique implemented in the lensing software Lenstool. In my talk, I will present the case study of  $z \sim 2$  lensed galaxy in context of both these approaches. Then, I will finish with discussing the applications of this technique onto a large sample of lensed systems that will be available through future telescopes like JWST and GMT.

**Author(s):** Tiantian Yuan, Lisa Kewley, Johan Richard, Soniya Sharma

**Institution(s):** Australian National University, Swinburne University of Technology, CRAL, Lyon

## **207 - Astrophysics Archives in the 2020s**

### **207.01 - The Future Of Archive Services at the NASA Exoplanet Science Institute (NExScI)(G. Bruce Berriman)**

The NASA Exoplanet Science Institute (NExScI) at Caltech/IPAC is the science center for NASA's Exoplanet Exploration Program and as such, NExScI operates three scientific archives: the NASA Exoplanet Archive (NEA), the Exoplanet Follow-up Observation Program Website (ExoFOP), and the Keck Observatory Archive (KOA). The NASA Exoplanet Archive supports research and mission planning by the exoplanet community by operating a service that provides stellar and planet parameters confirmed and candidate planets, numerous project data including those from CoRoT, Kepler, K2 and now TESS. The ExoFOP provides an environment for exoplanet observers to share and exchange information about observing, data, observing notes, and results regarding the

Kepler, K2, and TESS candidates. KOA serves all raw science and calibration observations acquired by all active and decommissioned instruments at the W. M. Keck Observatory, as well as reduced data sets contributed by Keck observers. In the coming years, the NExSci archives will support a series of major endeavours allowing flexible, interactive analysis of the data available at the archives. These endeavours exploit a common infrastructure based upon modern interfaces such as JupyterLab and Python; the deployment of Python binary extensions for the compute-intensive Montage image mosaic engine is acting as a pathfinder for these efforts. Additionally, KOA is supporting an Observatory initiative to develop modern, Python based pipelines, and as part of this work, it has delivered a NIRSPEC reduction pipeline. The ensemble of pipelines will be accessible through the same environments.  
**Author(s):** David Ciardi, G. Bruce Berriman  
**Institution(s):** Caltech/IPAC-NExSci

#### **207.02 - Exploiting the new massive datasets from radio interferometry(Mark Lacy)**

Modern radio and mm/submm interferometers are capable of producing very large datasets are a challenge to transmit, store and process. In this talk I will discuss some of the mechanisms NRAO is considering for easing the path for users from obtaining the data through to publication through the “Science Ready Data Products” initiative, and also discuss the data storage and processing needs for the new VLA Sky Survey, which has recently begun taking data.  
**Author(s):** Mark Lacy  
**Institution(s):** National Radio Astronomy Observatory

#### **207.03 - The HEASARC and NAVO in the 2020s(Alan Smale)**

The HEASARC and NASA’s other multimission archives have been extraordinarily successful over the past decades in increasing the science productivity of NASA missions. In this talk I summarize the HEASARC’s current activities and our plans for the coming decade, and discuss NASA’s ongoing efforts to improve the interoperability of its astronomy archives. The High Energy Astrophysics Science Archive Research Center (HEASARC) is NASA’s primary archive for high energy astrophysics and cosmic microwave background (CMB) data, supporting the science goals of the Physics of the Cosmos theme. It provides vital scientific infrastructure to the community by standardizing science data formats and analysis programs, providing open access to NASA resources, and implementing powerful archive interfaces. These enable multimission studies of key astronomical targets, and deliver a major cost savings to NASA, proposing mission teams, and the community in terms of a reusable science infrastructure. HEASARC archive holdings exceed 100 TB, supporting 7 active missions (Chandra, Fermi, INTEGRAL, NICER, NuSTAR, Swift, XMM-Newton), and providing continuing access to data from

over 40 legacy missions. HEASARC scientists are engaged with the upcoming IXPE and XRISM missions and many other Probe, Explorer, SmallSat, and CubeSat teams. Within HEASARC, the LAMBDA thematic archive provides a permanent archive for CMB data from WMAP, COBE, IRAS, SWAS, and a wide selection of suborbital missions and experiments. As we enter the next decade our roles and interoperability will become even more crucial. The NASA Astronomical Virtual Observatories initiative (NAVO, 2014-present) is a partnership between HEASARC, MAST, IRSA and NED to maximize the science return from NASA astronomy data and resources. NAVO merges the strengths of NASA’s domain astrophysics archives, and provides consistent methods of accessing their data. VO protocols and infrastructure will be a key integral part of the astronomy of the 2020s, and the NAVO collaboration provides that integrating force for NASA missions, helping tie the vast new datasets from upcoming space and ground missions together with our heritage holdings to illuminate complex astrophysical processes.  
**Author(s):** Alan Smale  
**Institution(s):** NASA Goddard Contributing Team(s): HEASARC

#### **207.04 - The NASA Astrophysics Data System’s Decadal Plan for the 2020s(Alberto Accomazzi)**

The Decadal Survey provides projects such as the NASA Astrophysics Data System (ADS) a unique opportunity to envision their role in a future landscape which is still very much being mapped out. Science gains realized over the last decade have been made possible by a robust infrastructure of data archives working together to enable discovery of the scholarly literature, associated data, and measurements. Yet it is already clear that in order to properly support emerging cross-disciplinary research such as Multi-Messenger Astronomy and Exoplanet studies, additional efforts will need to be made to ingest, curate, and connect the relevant literature with data available from a wider array of archives and systems. In this talk I will describe how ADS is gearing up for this challenge and how it plans to use emerging technologies such as machine learning and cloud computing to underpin its mission, while soliciting input from the community on what additional data, services, and discovery capabilities it should support.  
**Author(s):** Alberto Accomazzi  
**Institution(s):** Harvard-Smithsonian Center for Astrophysics Contributing Team(s): ADS Team

#### **207.05 - Resources for Science with Large Surveys(Knut Olsen)**

The past decade has seen a boom in the generation of large survey datasets and in the scientific discoveries that have been made from them. Ongoing and future surveys promise groundbreaking new results in nearly all areas of astrophysics, including the study of moving bodies in our solar system, stars

and their planetary systems, the structure of our Milky Way and the nearest galaxies, the growth and evolution of galaxies, and the study of cosmology. Surveys are exploring new dimensions of discovery space, including the time domain. While surveys have grown ubiquitous in astrophysics, the level of access and ease of use by the community of survey data products varies greatly. The future holds only more such large survey data products in the format of images, catalogs, and spectra. We consider the resources, tools, and infrastructure that are needed to maximize the science output from current and future large datasets, and how national facilities might be able to support the community in this area.

**Author(s):** Melissa Lynn Graham, Knut Olsen

**Institution(s):** NOAO, University of Washington

#### **207.06 - The NASA/IPAC Infrared Science Archive (IRSA) in the 2020s (Harry Isaac Teplitz)**

Archival research is likely to significantly evolve in the next decade due to advances in data science and computing technology. New science questions will require researchers to combine data sets across the spectrum and to utilize much larger volumes, with correspondingly larger computing demands. Infrared data will continue to be a key component in archival research, with the enduring legacy of Spitzer, Herschel, and WISE, combined with new infrared missions in the 2020s. I will discuss how the NASA/IPAC Infrared Science Archive (IRSA) will respond to these challenges and support new areas of research.

**Author(s):** Harry Isaac Teplitz

**Institution(s):** Caltech/IPAC Contributing Team(s): IRSA Team

#### **207.07 - Enhancing Capabilities of NED in the Next Decade (Joseph Mazzarella)**

The NASA/IPAC Extragalactic Database (NED) assists and accelerates research for scientists, educators and students around the world by distilling and synthesizing data across the spectrum and providing value-added derived quantities for objects beyond the Milky Way. For nearly three decades the system has been growing and improving to meet the needs of scientists as information technologies advance. Over the past year alone, the NED team released the result of fusing data for 470 million sources in the 2MASS Point Source Catalog with data previously joined from over 110,000 catalogs and journal articles (doubling the size of the database), and we introduced a new user interface that streamlines common queries and provides interactive visualizations of linked tables and graphics in the search results. This year we plan to complete the integration of 750 million sources from the AllWISE Source Catalog along with data from thousands of journal articles, and deliver improved capabilities in the user interface. In this talk, I will briefly review recent science applications that have used NED and describe plans for enhancing the system further to

meet the challenges of supporting science discovery from data joined from future missions and surveys covering billions of galaxies and candidates. For example, coupling NED with popular science platform technologies (e.g., Project Jupyter) in a common ecosystem with other archives will enable users to run a wide range of statistical and machine learning algorithms to make discoveries directly from NED's unique data fusion. I will close with questions for the community to solicit input that helps prioritize new data sets and functionality to optimize science opportunities leveraging NED in the 2020s.

**Author(s):** Joseph Mazzarella

**Institution(s):** Caltech/IPAC-NED Contributing Team(s): NED Team

#### **207.08 - ESASky: all the sky you need (Guido De Marchi)**

ESASky is a discovery portal giving to all astronomers, professional and amateur alike, an easy way to access high-quality scientific data from their computer, tablet, or mobile device. It includes over half a million images, 300,000 spectra, and more than a billion catalogue sources. From gamma rays to radio wavelengths, it allows users to explore the cosmos with data from a dozen space missions from the astronomical archives of ESA, NASA, and JAXA and does not require prior knowledge of any particular mission. ESASky features an all-sky exploration interface, letting users easily zoom in for stars as single targets or as part of a whole galaxy, visualise them and retrieve the relevant data taken in an area of the sky with just a few clicks. Users can easily compare observations of the same source obtained by different space missions at different times and wavelengths. They can also use ESASky to plan future observations with the James Webb Space Telescope, comparing the relevant portion of the sky as observed by Hubble and other missions. We will illustrate the many options to visualise and access astronomical data: interactive footprints for each instrument, tree-maps, filters, and solar-system object trajectories can all be combined and displayed. ESASky also includes access to scientific publications, allowing users to visualise on the sky all astronomical objects with associated scientific publications and to link directly back to the papers in the NASA Astrophysics Data System.

**Author(s):** Guido De Marchi

**Institution(s):** European Space Agency Contributing Team(s): ESASky Team

#### **207.09 - Scientific Accessibility Through Astronomical Archives (Joshua E. G. Peek)**

The Mikulski Archive for Space Telescope's mission is to maximize the scientific accessibility and impact of astronomical data. In this presentation I will define scientific accessibility and discuss what MAST is doing today to maximize it. I will present data showing how archives like MAST allow for science to be done by a broader community than in typical classical-

mode astronomy. I will speak to new developments at MAST designed to maximize scientific accessibility in years to come.

**Author(s):** Joshua E. G. Peek

**Institution(s):** Space Telescope Science Institute

### **207.10 - astroquery: An Astronomical Web-Querying Package in Python(Brigitta Sipocz)**

astroquery (<http://astroquery.readthedocs.io>) is an Astropy coordinated package and is already well embedded in and a key component of the astronomical Python ecosystem. astroquery arose from user's desire to access databases from the Python command line in a scriptable fashion. Script-based data access provides the ability to make reproducible analysis and pipelines in which the data are retrieved and processed into scientifically relevant results with minimal user interaction, thus astroquery enables the creation of fully reproducible workflows from data acquisition through publication. The package currently consists over 45 modules that provide direct access to the most commonly used databases, archives and services. While most of the modules share a similar API, they are meant to be used independently. Astroquery has received significant code contributions from throughout the astronomical community, including both the user community and major telescope archives. This talk will describe the philosophy, basic structure, and development model of the astroquery package as well as a roadmap for future development.

**Author(s):** Brigitta Sipocz, Adam Ginsburg

**Institution(s):** DIRAC Institute, University of Washington, National Radio Astronomy Observatory Contributing Team(s): the Astroquery collaboration, a subset of the astropy collaboration

## **208 - Star Formation II**

### **208.01 - The SOFIA Massive (SOMA) Star Formation Survey - Latest Results(Jonathan C. Tan)**

The SOMA Survey aims to study at least 50 high- and intermediate-mass protostars in a range of evolutionary states and environments using SOFIA-FORCAST imaging from about 10 to 40 microns. These data help constrain the peak of the spectral energy distribution (SED), but also give much richer information via the resolved flux density profiles in the images. These MIR and FIR emissions probe warm dust that is often a signature of irradiated protostellar outflow cavities, which thus allows us to better understand the geometry of the protostellar cores and test theoretical models based on Core Accretion. Several follow-up projects are underway, including study of cm continuum emission from ionized jets with the VLA, molecular components with ALMA and NIR tracers of jets with HST. I give an overview of all these projects and show latest results from the survey.

**Author(s):** Yichen Zhang, Kei Tanaka, Jonathan C. Tan, Joshua Marvil, Viviana Rosero, Yara Yousef, James De Buizer, Mengyao Liu, Maria T. Beltr  n

**Institution(s):** Univ of Virginia, USRA/SOFIA, Chalmers Univ of Technology, NRAO Socorro, RIKEN, Arcetri Observatory, Osaka University

### **208.03 - Gravitationally dragged-in magnetic fields in IRDC G34.43+0.24(Archana Soam)**

As most of the molecular clouds are filamentary and elongated, the magnetic fields (B-fields) in these clouds are found either parallel or perpendicular to the main axes. In the present study, we mapped the B-fields in an IRDC G34.43+0.24 (G34 hereafter) through polarized dust emission at 850  $\mu$ m using POL-2 at JCMT. To investigate the B-fields in detail, we have divided the filament into north, central, and south regions. The fields are aligned along the filament in diffuse regions but perpendicular to the dense central and elongated clump region. This region shows a dragged-in B-field morphology. The field orientations are consistent with the previous 1.3 mm CARMA and 350  $\mu$ m CSO observations. Present POL-2 observations when combined with existing polarization observations suggest a defined field pattern in the cloud center. The results also match those found in NGC 6334 where a self-similar fragmentation regulated by B-fields is reported by Li et al. (2015). The magnetic field strength in central clumps MM1 and MM2 of this cloud are found to be  $\sim 1.1$  mG, which suggest that B-fields are important in evolution and/or fragmentation of the filament.

**Author(s):** Tie Liu, B-G Andersson, Chang Won Lee, o, Kristin Kulas, Paul Goldsmith, Michael Scott Gordon, Mika Juvela, Qizhou Zhang, Pak Shing Li, Archana Soam, Patrick Koch

**Institution(s):** oKorea University of Science and Technology, SOFIA Science Center, USRA, NASA Ames Research Center, East Asian Observatory, Korea Astronomy & Space Science Institute, Astronomy Department, University of California, Department of Physics, University of

### **208.05 - New evidence that stars form as wide binary pairs(Sarah Sadavoy)**

We study the formation and evolution of young binary systems. Specifically, we explore the relationship between young, embedded binaries and their parent dense cores from which they formed. We combine the uniform binary database from the VANDAM survey with core properties obtained from SCUBA-2 observations at 850  $\mu$ m for the Perseus molecular cloud. The systems are separated into tight binaries (< 500 au separations) and wide binaries (> 500 au separations), such that the wide binaries show a preferred alignment with the semi-major axis of their parent core, whereas the tight binaries show no preferred orientations. We test a number of simple, evolutionary models to account for the observed populations of embedded stars. In the model that best explains the observations, all stars form initially as wide binaries that are allowed to break up into separate stars or shrink into tighter orbits. If our simple model provides a good fit to other star-



forming regions, then the mass fraction of dense cores that become stars is double what is currently believed.

**Author(s):** Steven Stahler, Sarah Sadavoy

**Institution(s):** Harvard-Smithsonian CfA, University of Berkeley

#### **208.06 - High Resolution ALMA Observations of Dusty Disks Around Young Eruptive Protostars(Jacob White)**

Young protostars may commonly undergo the episodic accretion of disk material as evidenced by outbursts in which the luminosity can increase by orders of magnitude. These outbursting protostars, called FUors after the prototypical FU Orionis system, can have significant impacts on the evolution of the disk as well as the planet formation process. Although there are now more than a dozen such systems known, the physics that govern the transport mechanisms driving the observed outbursts still remain largely unconstrained. We conducted an ALMA survey of 9 FUor objects in Band 6. These observations probed the 1.3 mm (230 GHz) continuum at a high angular resolution of 0.15" (corresponding to spatial scales as low as 20 au), as well as the J=2-1 transition of the  $^{12}\text{CO}$ ,  $^{13}\text{CO}$ , and C18O circumstellar gas. Presented here is the analysis of the dust components of the survey. We provide tight constraints on the mass, morphology, spectral index, and general properties of the dust disks. We compare the resulting disk parameters to that predicted for young outbursting systems. In addition, we compare the bulk properties of the FUors to non-outbursting protoplanetary disks observed with ALMA.

**Author(s):** Fernando Cruz-Saenz de Miera, Jacob White, Agnes Kospal, Peter Abraham

**Institution(s):** Konkoly Observatory

#### **208.07 - Spatially resolved properties of $0.1 < z < 0.5$ galaxies from the MUSE-Wide Survey and CANDELS Survey(Marziye Jafariyazani)**

Studying internal processes of individual galaxies at kilo-parsec scales is essential to enhance our understanding of galaxy formation and evolution processes. This is specially the case for intermediate and high-redshift galaxies which most of them remained unresolved due to resolution limit of instruments. In this work, we investigate the distribution of mass, SFR and dust attenuation across individual galaxies for a sample of nearly 40 galaxies selected from the MUSE-Wide survey at  $0.1 < z < 0.5$ . High spatial resolution of the MUSE integral-field spectrograph has allowed us to derive reliable spatially resolved H-alpha and H-beta emission line maps with  $S/N > 3$  for every single pixel and measure Balmer decrement across individual galaxies. At the same time, resolved mass, SFR and dust maps are derived from pixel-by-pixel SED fitting on high resolution multi-band HST/ACS and HST/WFC3 data from the CANDELS survey. By combining these spectroscopic and photometric measurements, we extract radial mass, SFR, and dust profile of individual

galaxies in our sample. These profiles are found to be dependent of the integrated mass and SFR of each galaxy. Besides, the relation between the color excess of the ionized gas and the stellar continuum has been examined for this sample.

**Author(s):** Shoubaneh Hemmati, Bahram Mobasher, Marziye Jafariyazani

**Institution(s):** University of California, Riverside, IPAC

#### **208.02D - The Impact of Stellar Feedback on Astrochemistry(Brandt Gaches)**

Star formation is the lynch pin that lies in between the scales of galaxy and planet formation. Observational studies of molecular clouds, the sites of star formation, primarily use molecular line emission, providing dynamical and chemical information. Two of the key parameters of astrochemical models are far-ultraviolet (FUV) flux and the cosmic ray ionization rate. We use analytic accretion histories to predict the bolometric and FUV luminosities of protostar clusters and compare different histories with observed bolometric luminosities. We find that the Tapered Turbulent Core model best represents the observed luminosities and their dispersion. We extend the models to calculate the cosmic ray spectrum of protons accelerated in protostellar accretion shocks. We find that protostars are able to accelerate cosmic rays up to 10 GeV. We predict increased ionization rates within protostellar cores and molecular clouds hosting over 100 protostars. Our model is able to explain the substantial ionization rate, over 1000 times the typical, observed towards the OMC-2 FIR 4 protocluster. We model the impact of the protostellar FUV and cosmic rays on the astrochemistry on the natal molecular cloud. We couple the chemistry to the cosmic ray attenuation to solve the cosmic ray attenuation self-consistently. We find the inclusion of the embedded feedback significantly changes the Carbon chemistry and the CO-to-H<sub>2</sub> conversion factor. High-density, optically-thin tracers such as ammonia are noticeably affected. The inclusion of embedded protostellar feedback alters the chemistry throughout molecular clouds, coupling the physics ongoing on the smallest scales of star formation to molecular cloud scale. Our results show that astrochemical modeling should account for ongoing star formation to correctly account for embedded FUV radiation and cosmic rays.

**Author(s):** Thomas Bisbas, Brandt Gaches, Stella Offner

**Institution(s):** University of Massachusetts, Aristotle University of Thessaloniki, University of Texas, Universitat zu Koln

#### **208.04D - A Dynamic Formation Channel for Binaries in Embedded Clusters(Joshua Edward Wall)**

We present hybrid MHD+N-body simulations of star cluster formation and evolution including self consistent feedback from the stars in the form of radiation, winds, and supernovae from massive stars. The MHD is modeled with the adaptive mesh refinement code FLASH, while the N-body computations are

done with the 4th order Hermite code ph4 and stars are evolved using SeBa. We use a gravity bridge within the Astrophysical Multipurpose Software Environment (AMUSE) framework to couple the N-body dynamics and stellar evolution of the stars to the gas dynamics in FLASH. Our results include the observation of the formation of binaries in all simulations, with and without feedback, with roughly half of all stars with  $M > 8 M_{\odot}$  found in binaries, without any primordial binary formation needed. We find our binary fraction increases in a power law fashion as a function of primary mass, while our eccentricity distribution appears thermal. For a binary binding energy  $x$ , the binaries themselves are well separated into hard ( $|x|/\tilde{kT} \gg 1$ ) and soft ( $|x|/\tilde{kT} < 1$ ) binaries, with a clear division where the binary energy equals the mean cluster thermal energy,  $|x| = \tilde{kT}$ . Generally, the hard binaries are also massive, with semi-major axes  $1 \lesssim a \lesssim 20$  AU. Finally our mass ratio distribution is well fit by a power law  $f(q) \propto q^{-\hat{\Gamma}}$  for  $q < 0.5$  with  $\hat{\Gamma} = 0.5$ , but is multi-modal for  $q > 0.5$ .

**Author(s):** Ralf Klessen, Andrew Pellegrino, Mordecai-Mark Mac Low, Simon Portegies Zwart, Stephen McMillan, Joshua Edward Wall

**Institution(s):** Drexel University, Leiden Observatory, American Museum of Natural History, Penn State University, University of Heidelberg

## 209 - Space Mission Instrumentation II

### 209.01 - NASA Astrophysics CubeSats and SmallSats(Michael Garcia)

NASA has recently been increasing its investment in CubeSats and SmallSats in order to carry out specific science tasks. This is partially motivated by the new generation of launch vehicles which promises to have excess lift capacity, allowing “ride share” of small satellites at low cost. The small apertures allowed by CubeSats and SmallSats naturally lend themselves to observing bright objects (i.e., Earth observing, solar observing). However there are specific astrophysics problems which can be addressed even with modest apertures on a CubeSat or SmallSat in orbit. We discuss some of the current and planned NASA astrophysics CubeSats and studies of possible astrophysics SmallSats.

**Author(s):** Michael Garcia, Stefan Immler, Nasser Barghouty, William Latter

**Institution(s):** NASA HQ, Smithsonian

### 209.02 - Concordance: In-flight Calibration of X-ray Telescopes without Absolute References(Herman Marshall)

We describe a process for cross-calibrating the effective areas of X-ray telescopes that observe common targets. The targets are not assumed to be “standard candles” in the classic sense, in that the only constraint placed on the source flux is that it is the same for all instruments. We apply a technique developed by Chen et al. (J. Amer. Stat. Association, in press) that involves a popular statistical method called shrinkage estimation, which

effectively reduces the noise in disparate measurements by combining information across common observations. We can then determine effective area correction factors for each instrument that brings all observatories into the best agreement, consistent with prior knowledge of their effective areas. We have preliminary values that characterize systematic uncertainties in effective areas for almost all operational (and some past) X-ray astronomy instruments in bands covering factors of two in photon energy from 0.15 keV to 300 keV. We demonstrate the method with several data sets from Chandra and XMM-Newton. Support for this work was provided in part by the National Aeronautics and Space Administration (NASA) through the Smithsonian Astrophysical Observatory (SAO) contract SV3-73016 to MIT for support of the Chandra X-Ray Center (CXC), which is operated by SAO for and on behalf of NASA under contract NAS8-03060.

**Author(s):** Yang Chen, Vinay Kashyap, Xufei Wang, Paul Plucinsky, Matteo Guainazzi, Xiao-Li Meng, Herman Marshall  
**Institution(s):** MIT, ESA, CfA, Harvard, UMichigan

### 209.03 - First Flight of the Micro-X Sounding Rocket(David Goldfinger)

Micro-X is a sounding rocket borne X-ray imaging spectrometer that utilizes Transition Edge Sensor microcalorimeters to obtain high-energy resolution. The first flight on Micro-X took place this past July, where it attempted to observe the Cassiopeia A supernova remnant. Due to a failure of the attitude control system, the instrument was not able to observe its scientific target, however the onboard calibration source allowed for verifying the in-flight operation of the instrument. We present the results from that flight and an update on ongoing progress towards a second flight.

**Author(s):** David Goldfinger,

**Institution(s):** Massachusetts Institute of Technology, Northwestern University  
**Contributing Team(s):** Micro-X Collaboration

### 209.04 - Large aperture telescope pinwheel segments eliminates (almost) all image plane structured background(James Bernard Breckinridge)

The next generation large aperture telescopes use segmented apertures that are partitioned into hexagonal segments. These regularly spaced hexagonal segments produce unwanted diffraction patterns across the image plane to mask many important astronomical features. This paper shows that if the telescope aperture were to be partitioned into a more random structure by using curved-sided segments the unwanted spatially dependent diffraction is reduced by a factor of more than 104. One example is given by the need to image and characterize terrestrial exoplanets.

**Author(s):** James Bernard Breckinridge,

**Institution(s):** University of Arizona, California Institute of

**209.05 - Investigating the Origins of Matter with Ultra-Heavy Galactic Cosmic Ray Measurements(Jason Link)**

The production of elements from Hydrogen to Iron have long been understood to occur primarily through stellar nucleosynthesis. The production of elements heavier than Iron, the ultra-heavy elements, is less well understood. These elements are thought to be synthesized through neutron bombardment of atomic nuclei during energetic astrophysical events. Analysis of light curves from GW170817 suggests that elements like gold and platinum were produced in the binary neutron star merger that was observed by LIGO, FERMI and other instruments. Observations from FERMI of ICC 443 and W44 confirmed long held suspicions that cosmic rays are also accelerated by supernova remnants. The particles produced in these explosive astrophysical events propagate through the galaxy and can be directly sampled by cosmic-ray particle instruments. These measurements can allow us to quantify and constrain the elemental production source. This talk will discuss the present state of measurements, including discussion of the SuperTIGER-2 flight planned for launch from Antarctica in December 2018 as well as future plans to extend measurements to the end of the periodic table.

**Author(s):** Jason Link,

**Institution(s):** NASA Goddard, CRESST-UMBC Contributing Team(s): Super-TIGER Collaboration, HNX Collaboration

**209.06 - Nimble: A Mission Concept for Gravitational Wave Counterpart Astrophysics(Joshua Schlieder)**

In August 2017, the first gravitational waves from merging neutron stars were detected coincident with a short gamma-ray burst (sGRB) and triggered a world-wide observing campaign to identify and characterize the associated kilonova emission. This event led to numerous firsts and discoveries that began to unveil the mysteries of these energetic astronomical phenomena. However, many questions remain and the field of multimessenger astrophysics is prime for further discovery. Here we describe Nimble, a NASA Explorer class mission concept that couples a very wide-field gamma ray monitor with a multiwavelength telescope and rapid response spacecraft to enable the prompt detection and localization of sGRBs and follow-up of kilonovae. We will describe the science drivers for Nimble and detail the current engineering concept. Nimble will discover and characterize the counterparts of neutron star merger gravitational wave events and its flexible platform will allow for a wide range of additional multiwavelength time domain science.

**Author(s):** Joshua Schlieder

**Institution(s):** NASA Goddard Space Flight Center Contributing Team(s): The Nimble Team

**209.07 - Integration and Testing of the Deformable Mirror Demonstration Mission (DeMi) CubeSat Payload(Rachel Elizabeth Morgan)**

The Deformable Mirror Demonstration Mission (DeMi) will operate and characterize the on-orbit performance of a Microelectromechanical Systems (MEMS) deformable mirror (DM) with both an image plane and a Shack-Hartmann wavefront sensor (SHWFS). As part of a wavefront sensing and control system for internal coronagraphs on space telescopes, DMs enable exoplanet direct imaging by correcting optical aberrations and speckles due to mechanical, thermal, and optical effects. This talk provides updates on the payload assembly, alignment, calibration, and functional testing prior to integration with the spacecraft. The key DeMi mission requirements are to measure individual DM actuator wavefront displacement contributions to a precision of 12 nm, measure low order optical aberrations to  $\lambda/10$  accuracy and  $\lambda/50$  precision, and correct static and dynamic wavefront errors to less than 100 nm RMS error. The DeMi MEMS deformable mirror has 140 actuators with 5.5 micron stroke. The optical design contains both an image plane wavefront sensor and a pupil plane SHWFS and enables wavefront sensing from an internal stable laser as well as external stellar sources. Miniaturized high speed controller and driver electronics were developed for DeMi to fit within the CubeSat form factor and use commercially available components. During its planned year of on-orbit operations, the DeMi mission will take PSF measurements of 5 bright stars to demonstrate wavefront control of astrophysical objects in addition to DM characterization tests with the internal light source. A flight-like engineering model of the payload is being integrated and aligned to characterize the engineering DM behavior and calibrate the wavefront sensor sensitivity to poked actuators and low order Zernike modes including tip, tilt, focus, and astigmatism. Next, end-to-end closed loop payload operation tests will be conducted. The flight model will incorporate minor modifications and the testing will be repeated. We will present an overview of the DM/wavefront sensor calibration and operational tests and a discussion of lessons learned.

**Author(s):** John Merk, Gabor Furesz, Roedolph Opperman, Jennifer N Gubner, Derek Barnes, Yeyuan Xin, Mark Egan, Kerri L Cahoy, Ewan Douglas, Rachel Elizabeth Morgan, Gregory W Allan, Christian A Haughwout, Paula Do Vale Pereira, Bobby G Holden

**Institution(s):** Massachusetts Institute of Technology, Aurora Flight Sciences, Wellesley College, NASA Jet Propulsion Laboratory

**209.08 - A Quick look into the first discoveries of TESS(Xu Huang)**

The Transiting Exoplanet Survey Satellite promises to discover small planets around the nearest and brightest stars. After two months of observations, the TESS mission has recovered a few hundred planetary candidates. In this talk, we present an early

look into the TESS data and one of the first discoveries from the TESS mission - the detection of a transiting planet around PI Mensae. The solar-type host star is unusually bright ( $V=5.7$ ) and was already known to host a Jovian planet in a highly eccentric, 5.7-year orbit. The newly discovered planet has a radius about twice that of Earth and an orbital period of 6.27 days. Using archived radial velocity data, we determined the planet's mass to be about 4.8 ME. Using PI Mensae c as an example, I will review the process of planetary candidate identification in TESS Full Frame Images using the MIT Quick Look Pipeline.

**Author(s):** Maximillian Gunther, Jennifer Burt, Andrew Vanderburg, Xu Huang, Avi Shporer, Joshua Winn, Jason Dittmann

**Institution(s):** Massachusetts Institute of Technology, Department of Astrophysical sciences, Princeton University, Department of Astronomy, University of Texas, Austin  
Contributing Team(s): TESS collaboration

### **209.09 - TESS full orbital phase curve of a massive transiting hot Jupiter planet (Avi Shporer)**

High quality visible-light space-based time series photometry allow monitoring the entire orbital phase of transiting star-planet systems. Beyond the transit, the phase curve includes the secondary eclipse, when the planet moves behind its host star, and, modulations across the orbital phase shaped by the planet's atmospheric properties and the gravitational interaction between the planet and the star. Under favorable circumstances the secondary eclipse and orbital phase modulations are well measured. Those allow measuring the planet's geometric albedo in visible light, the heat distribution between the planet's day and night hemispheres, and the tidal distortion of the star by the planet. We present here our analysis of the visible-light orbital phase curve of a massive transiting hot Jupiter planet measured by the TESS mission.

**Author(s):** Avi Shporer, Xu Huang, Ian Wong

**Institution(s):** MIT  
Contributing Team(s): The TESS Team

## **210 - Gravitational Lenses, Waves, Relativistic Astrophysics & GRBs II**

### **210.01 - "Observing" JAB Simulations - Probing Near-Horizon Scales in AGN (Richard Anantua)**

Plasma emission models are self-consistently input into general relativistic magnetohydrodynamic (GRMHD) simulations of jet (or outflow)/accretion disk/black hole (JAB) systems in order to infer physical processes observed by very long baseline interferometers such as the Event Horizon Telescope (EHT). Inspired by physical processes in active galactic nuclei (AGN) such as equipartition and electron heating, models relating electron temperature or energy density to GRMHD variables are input in postprocessing to produce ray-traced intensity maps, spectra and light curves. Observational signatures such as asymmetric disk photon rings and jet collimation and magnetic field substructure are reproduced. The methodology is

applied here to Sgr A\* at the Galactic Center and the giant elliptical galaxy M87, though the methodology is readily generalizable to the near-horizon regions of any AGN.

**Author(s):** Eliot Quataert, Roger Blandford, Sean Ressler, Richard Anantua, Alexander Tchekhovskoy

**Institution(s):** UC Berkeley, Northwestern University, Stanford University

### **210.02 - Status of Advanced LIGO detectors at the start of the third observing run (Terra Hardwick)**

During the first two observing runs, the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves from the merging of multiple binary black hole systems and one binary neutron star system. Following a period of down time for upgrades, LIGO's third observing run will begin early 2019 and continue for approximately one year. Upgrades include improved stray light control, replacement of the test mass optics, increased laser input power, and squeezed quantum state injection. This talk discusses these upgrades and their impact on our sensitivity. We also discuss the next planned upgrades, prospects for getting to Advanced LIGO design sensitivity, and "A+" plans.

**Author(s):** Terra Hardwick,

**Institution(s):** Louisiana State University, LIGO

Contributing Team(s): LIGO Scientific Collaboration

### **210.04 - A Targeted Multi-Messenger Search for Continuous Gravitational Waves from 3C66B (Caitlin Witt)**

Fifteen years ago, the galaxy 3C66B was used as the target of the first multi-messenger gravitational wave search. Due to the observed periodicities present in the source, it has been theorized to contain a supermassive binary. Interest in the source has been revitalized after a 2010 paper indicating that the system had lower masses. Its apparent ~annual period would place the gravitational emission directly in the pulsar timing band. With the advances made in pulsar timing since the last study of 3C66B, we aim to further constrain the mass of the potential binary in 3C66B. In addition, we aim to quantify the improvement made by the addition of electromagnetic data to "blind" pulsar timing searches.

**Author(s):** Caitlin Witt, Sarah Burke-Spolaor

**Institution(s):** West Virginia University  
Contributing Team(s): NANOGrav Physics Frontier Center

### **210.05 - Nonlinear noise regression with machine learning at LIGO (Tri Nguyen)**

Since the sensitivity upgrade in 2015, the Laser Interferometer Gravitational-wave Observatory (LIGO) has detected a number of black-hole and neutron star mergers. However, since strong sources of gravitational waves (GWs) produce a typical displacement of about 10-18 m (about 1000 times smaller than

the diameter of a proton), techniques to reduce and filter instrumental and environmental noise have become increasingly important for the detection of weaker and more distant sources. Our group applied the Long Short-Term Memory (LSTM) neural network model, a subset of machine learning algorithms (MLAs), to noise regression analysis at LIGO. We used LSTMs because they are robust in handling sequential data. Given the time series from the GW and witness channels, the network predicts and subsequently subtracts background noise over a frequency band. Furthermore, unlike the current noise filtering technique, the Wiener filter, non-parametric MLAs like LSTMs, once trained, are capable of learning both the linear and nonlinear noise coupling mechanisms. For the linear contribution, the network matches the subtraction power of the Wiener filter. For the nonlinear contribution, the network performs well on generated mock data. Our framework is generic enough to be applied to a wide variety of series regression problems in many areas of science.

**Author(s):** Rana Adhikari, Tri Nguyen, Michael William Coughlin, Rich Ormiston

**Institution(s):** University of Rochester, University of Minnesota--Twin Cities, California Institute of Technology

#### **210.06 - Local Interstellar Cosmic-Ray Spectra and Diffuse Galactic Emission from Radio to Gamma Rays(Elena Orlando)**

Interactions of cosmic rays with the interstellar medium and the magnetic field produce diffuse emissions that extend from radio to gamma rays. The observation of this Galactic diffuse emission provides an important tool for understanding densities and spectra of cosmic rays in different places of our Galaxy. We show local interstellar cosmic-ray spectra and their properties recently derived by combining multi-frequency observations of the local Galactic diffuse emission from radio to gamma rays, with latest direct cosmic-ray measurements from Voyager 1 and AMS02, and with cosmic-ray propagation models in a self-consistent way. Implications for present observations of the diffuse emission in other places of the Galaxy are also discussed. Finally, predictions of the diffuse emission at MeV energies for AMEGO and e-Astrogam are shown. Support from NASA ADAP Grant No. NNX16AF27G is acknowledged.

**Author(s):** Elena Orlando

**Institution(s):** Stanford University

#### **210.07 - The Energetics and Geometry of the Binary Neutron Star Merger GW170817 revealed by its Radio Afterglow(Kunal Mooley)**

Radio afterglows of neutron star mergers inform us about the geometry and energy of the different ejecta components, and the physics of the shock occurring between the ejecta and the circum-burst environment. This information is complementary to the ejecta mass and composition information provided by the

early-time optical emission arising from the r-process nucleosynthesis of the neutron-rich dynamical ejecta (i.e. the kilonova/macronova signature). The radio afterglow of GW170817 was first detected 16 days after the merger. It evolved slowly with time ( $t_{0.8}$ ), peaked at about 150 days post-merger, and declined steeply ( $t_{-2.2}$ ) thereafter. Linear polarization fraction of the radio emission was found to be low. Radio VLBI observations of GW170817 revealed superluminal motion of a source that is compact on milli-arcsecond scales. These observational data give credence to an energetic and narrowly-collimated jet, with an opening angle of less than 5 degrees and observed from a viewing angle of about 20 degrees, surrounded by a wider angle outflow (cocoon). Apart from probing the energetics and geometry, the radio afterglow of GW170817 also strengthens the link between binary neutron star mergers and short-hard GRBs. GW170817 represents only an initial exploration of a rich scientific landscape populated by the stellar evolution, explosion and eventual merger of massive binary systems. The study of radio afterglows of neutron star mergers detected by LIGO/Virgo in their upcoming observing runs will be able to address many unsolved questions such as: How much energy do mergers release? What fraction of mergers produce relativistic jets? What effect does viewing angle have on the afterglow?

**Author(s):** Kunal Mooley

**Institution(s):** NRAO / Caltech Contributing Team(s): Mooley, Kunal P.; Hallinan, Gregg W.; Deller, Adam T; Corsi, Alessandra; Frail, Dale A.; Gottlieb, Ore; Nakar, Ehud; Hotokezaka, Kenta; Bourke, Stephen; Dobie, Dougal; Nayana, A.J.; De, Kishalay; Sphesihle Makhathini; Chand

#### **210.08 - Swift in the gravitational wave era: results from O2 and optimization for the future(Aaron Tohuwvohu)**

Swift's rapid slewing, flexible planning, and multi-wavelength instruments make it the most capable space-based follow-up engine for finding poorly localized sources. During O1 and O2 Swift successfully tiled hundreds of square-degrees of sky in the LVC localization regions, searching for, and identifying, possible X-ray and UV/O transients in the field. Swift made important contributions to the discovery and characterization of the kilonova AT 2017gfo, discovering the UV emission and providing the deepest X-ray upper limits in the first 24 hours after the trigger, strongly constraining the dynamics and geometry of the counterpart. Swift tiled 92% of the galaxy convolved error region down to average X-ray flux sensitivities of  $10^{-12}$  erg  $\text{cm}^{-2}$   $\text{s}^{-1}$ , significantly increasing our confidence that AT 2017gfo is indeed the counterpart to GW 170817 and sGRB 170817. However, there remains significant room for improvement of Swift's follow-up in preparation for O3. Swift is currently performing the Swift Gravitational Wave Galaxy Survey, pre-imaging 5000 of the brightest galaxies within 100 Mpc, to provide X-ray and UV templates for transient searches. We outline areas of improvement to the observing strategy itself for optimal tiling of the LVC localization regions. We also discuss ongoing work on

operational upgrades that will decrease latency in our response time, and minimize impact on pre-planned observations, while maintaining spacecraft health and safety. These upgrades further allow complex positional and temporal biasing of the Swift Burst Alert Telescope, increasing the likelihood of detecting a short GRB associated with a GW detected binary neutron star merger.

**Author(s):** Jamie Kennea, S. Bradley Cenko, Aaron Tohuvavohu, Phil Evans

**Institution(s):** Penn State University, NASA GSFC, University of Leicester  
**Contributing Team(s):** Swift-GW Follow-up Team

### **210.09 - Identifying Relativistic Astrophysical Transients with Gravitational-Wave Optical Transient Observer (GOTO)(Kendall Ackley)**

The Gravitational-Wave Optical Transient Observer (GOTO) is a wide-field robotic optical instrument currently in operation on La Palma, Canary Islands. The scalable design consists of 8 individual 40 cm diameter astrographs on a single mount to instantaneously image a large 40 square degree field-of-view. The primary aim of GOTO is to detect and study electromagnetic counterparts to gravitational-wave (GW) events from Advanced LIGO and Virgo. We describe the current status of our real-time operation, including how we control the instrument, post-process the nightly influx of data, and identify and categorize unique transients using in-house pipeline and control systems. Finally, we will discuss recent observational results since first light in June 2017.

**Author(s):** Duncan Galloway, Kendall Ackley,

**Institution(s):** Monash University, OzGrav  
**Contributing Team(s):** GOTO Collaboration

## **211 - Milky Way & Galactic Center III**

### **211.01 - Proper motions of Milky Way Ultra-Faint satellites with Gaia DR2 & DES DR1(Andrew B Pace)**

We present a new, probabilistic method for determining the systemic proper motions of Milky Way (MW) ultra-faint satellites in the Dark Energy Survey (DES). We utilize the superb photometry from the first public data release (DR1) of DES to select candidate members, and cross-match them with the proper motions from Gaia DR2. We model the candidate members with a mixture model (satellite and MW) in spatial and proper motion space. This method does not require prior knowledge of satellite membership, and can successfully determine the tangential motion of most of the DES satellites. With our method we present measurements of the following satellites that lack spectroscopic follow-up: Columba I, Eridanus III, Grus II, Phoenix II, Pictor I, Reticulum III, and Tucana IV, the majority of which are the first systemic proper motion measurements. We compare these to the predictions of Large Magellanic Cloud satellites and to the vast polar structure. With the high precision DES photometry we conclude that most of the newly identified member stars are very metal-

poor ( $[Fe/H] < -2$ ) similar to other ultra-faint dwarf galaxies, while Reticulum III is likely more metal-rich. The members we find are excellent targets for future spectroscopic follow-up.

**Author(s):** Ting Li, Andrew B Pace

**Institution(s):** Texas A&M University, Fermilab

### **211.05 - A new cumulative mass profile of the Milky Way using data from Gaia DR2 and HSTPROMO(Gwendolyn Eadie)**

Obtaining estimates of the Milky Way's (MW) total mass out to large distances is challenging because of incomplete, uncertain, and sparse data for Galactic tracers (e.g. halo and globular clusters). Analyses using the second Gaia data release (DR2) have so far helped constrain the total mass of the MW within  $\sim 20$  kpc, but the mass within  $\sim 200$  kpc --- where the dark matter halo dominates --- is still poorly constrained. Studies also report estimates within different distances from the Galactic centre, making it difficult to compare results. We instead employ a hierarchical Bayesian analysis that provides a cumulative mass profile (CMP) with uncertainties for the mass within any distance from the Galactic centre. Our method also overcomes some of the statistical challenges presented by incomplete data. In this talk, we will present our new results of the MW mass and CMP using data from Gaia DR2 and the HST Proper Motion project. We will compare our CMP to the range of mass estimates at different distances provided in the literature, and show the extent to which it agrees with other results. We also estimate the MW CMP using the complete velocity data of globular clusters provided in Vasiliev (2018). The results suggest that the latter catalog may be quite reliable, and thus provide a useful complete data set of globular cluster kinematics.

**Author(s):** Mario Juric, Gwendolyn Eadie

**Institution(s):** University of Washington

### **211.02D - HALO7D: Disentangling the Milky Way Accretion History with Observations in 7 Dimensions(Emily Cunningham)**

The Milky Way (MW) is shrouded in a faint metal-poor stellar halo. Its structure and kinematics provide a unique archaeological record of the MW's formation, past evolution, and accretion history. However, studies of the MW stellar halo are hindered by observational constraints. Prior to the era of Gaia, beyond  $D \sim 10$  kpc, our knowledge of the MW halo has been limited to line of sight (LOS) velocities and rare tracer populations (blue horizontal branch and red giant branch stars). However, even in the era Gaia, we are still missing tangential velocity information for halo main sequence stars. We aim to address these limitations with the HALO7D survey. The HALO7D dataset consists of highly accurate HST-measured proper motions (PMs) and very deep (8-24 hour integrations) Keck DEIMOS spectroscopy of MW main sequence turn-off stars in the CANDELS fields. This project provides the first

opportunity to measure 6D phase-space information plus chemical abundances (7 "Dimensions") for distant halo main sequence stars. I will present the first kinematic results from this survey. We use the HALO7D dataset to estimate the parameters of the halo velocity ellipsoid, and explore how the velocity distributions and anisotropy vary across survey fields and as a function of distance. This survey will vastly improve our understanding of the Milky Way structure, evolution and mass in a way that neither the HST proper motions nor Keck spectroscopy can do on their own.

**Author(s):** Alis Deason, Puragra Guhathakurta, Emily Cunningham, Roeland van der Marel, Jay Anderson, Evan Kirby, S. Tony Tony Sohn, Constance Rockosi

**Institution(s):** UC Santa Cruz, Space Telescope Science Institute, Durham University, California Institute of Technology  
**Contributing Team(s):** HSTPROMO, HALO7D

### **211.03D - The Stellar Density of the Major Substructure in the Milky Way Halo(Jake Weiss)**

We develop, test, and apply a statistical photometric parallax method using main sequence turn off (MSTO) stars in the Sloan Digital Sky Survey (SDSS). We show using simulated data that if our density model is similar to the actual density distribution of our data, we can reliably determine the density model parameters of at least three major substructures in the Milky Way halo, and a smooth background component, using the computational resources available on MilkyWay@home (a twenty parameter fit). As a test for the new model, we fit the stellar density in SDSS stripe 19. After confirming that the model is working as intended on both simulated and observed SDSS stripe 19 data, we moved on to fitting stripes 10 through 23 in the SDSS north Galactic cap. We found an oblate halo with an average flattening of 0.58. Seven streams were found in these fourteen stripes. The Sgr dwarf leading tidal tail detected in 8 stripes, with properties that are consistent with previous fits to the streams. The trailing tidal tail and the "bifurcated" stream were found at the previously identified distances. The Parallel Stream was traced across the sky at a distance of 15 kpc, and roughly tracks an orbit that was fit by previous authors to the Virgo Stellar Stream. A new stream, the Perpendicular Stream, was found at a distance of 15 kpc in the region of Virgo, but roughly perpendicular in orientation on the sky to the Parallel Stream. A stream possibly including the globular cluster NGC 5466 was also found at a distance between 5 and 15 kpc from the Sun. This publication is based on work supported by the National Science Foundation under grant No. AST 16-15688, the NASA/NY Space Grant fellowship, and contributions made by The Marvin Clan, Babette Josephs, Manit Limlamai, and the generous MilkyWay@home volunteers.

**Author(s):** Jake Weiss

**Institution(s):** Rensselaer Polytechnic Institute

### **211.04D - Unweaving the Tangled Web: Using BHB Stars to Separate Tidal Streams in the Galactic Halo(Paul Amy)**

Blue horizontal branch (BHB) stars are commonly-used and effective tracers for mapping substructure in the halo of the Milky Way (MW) through the identification of distance and kinematic overdensities. We use spectroscopically identified BHB stars from the Sloan Digital Sky Survey (SDSS) to identify and fit orbits to tidal debris streams, including Hermus and Hyllus. In addition, we develop new methods to search for streams, including methods that combine distance and line-of-sight velocity in a way that is sensitive to star streams that are extended along our line of sight. These streams are under-represented in the list of known halo substructures. Inclusion of new data, particularly from the Gaia mission, can improve our ability to isolate and analyze tidal streams. This project was funded by a Rensselaer Presidential Fellowship, NSF grant AST 16-15688, the NASA/NY Space Grant fellowship, and contributions made by The Marvin Clan, Babette Josephs, Manit Limlamai, and the 2015 Crowd Funding Campaign to Support Milky Way Research.

**Author(s):** Heidi Jo Newberg, Paul Amy, Charles Martin, Ziyi Lin, Keighley Rockcliffe

**Institution(s):** Rensselaer Polytechnic Institute

### **212 - Larger Efforts in Education & Public Outreach**

#### **212.01 - The Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC)(Renée Hlozek)**

The Large Synoptic Survey Telescope will generate a data deluge: millions of transients and variable sources will need to be classified from their light curves. Photometric classification has long been a problem of interest in the astronomical community, but the Photometric LSST Astronomical Time-series Classification Challenge (PLAsTiCC) brings a wide range of models together, simulated under LSST-like conditions for the first time. PLAsTiCC was delivered to the community through a Kaggle challenge, designed to stimulate interest in time-series photometric classification and deliver methodologies that will advance the LSST science case. We will give an overview of the road to PLAsTiCC, highlight the Kaggle leaderboard at the close of the challenge, and discuss the science-specific challenges open to the community.

**Author(s):** Hiranya Peiris, Emilie Ishida, Michelle Lochner, Lluís Galbany, Christina Peters, Mi Dai, Rafael Martínez-Galarza, Renée Hlozek, Christian Setzer, Kara Ponder, Tarek Allam, Anita Bahmanyar, Gautham Narayan, Alexandre Boucaud, Jason McEwen, Alex Mal

**Institution(s):** California Institute of Technology, oAfrican Institute for Mathematical Sciences, University of Cambridge, New York University, Space Telescope Science Institute, Harvard-Smithsonian Center for Astrophysics, LAL, University of California Berkeley,

### **212.02 - Making a Hard Astrophysical Problem Accessible: Our Experience with PLAsTiCC(Gautham Narayan)**

The Large Synoptic Survey Telescope will discover millions of transient and variable sources at an unprecedented rate. Categorizing and classifying these sources spectroscopically is impractical, and the astronomical community has moved towards using data science techniques to tackle this problem. The Photometric LSST Astronomical Time-series Classification Challenge (PLAsTiCC) brings together astrophysicists and members of the public with data science expertise to develop algorithms for classification and novelty detection in imbalanced, unrepresentative and high-dimensional datasets. While this asks for a level of involvement that is much higher than previous citizen-science projects, hosting a challenge such as this on a public platform like Kaggle democratizes science and allows much wider participation. To ensure that the contest remains fair, we distilled this complex problem into its essential components and developed various interactive resources to introduce astrophysical concepts to members of the public. We'll describe our Jupyter notebook-based approach to simplifying complex concepts together with interactive examples here, and how it may also be employed in the classroom to make rich lesson plans.

**Author(s):** Gautham Narayan

**Institution(s):** Space Telescope Science Institute  
Contributing Team(s): The LSST PLAsTiCC Collaboration, The LSST Dark Energy Science Collaboration, The LSST Transients and Variable Stars Science Collaboration

### **212.03 - Kaggle Community Solutions to the PLAsTiCC(Mi Dai)**

Through the Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC), we asked the general public to classify simulated light curves of a variety of different transients and variables from the Large Synoptic Survey Telescope (LSST). The training set of around 8,000 objects in 14 classes had spectroscopic typing (denoted only by a randomly assigned class number) with a test set of almost 3.5 million objects with 15 classes -- one class was designed as unknown to represent the objects that have theoretical models but have never been observed before. The challenge was hosted on Kaggle and ran for 3 months from September 28 to December 17th, 2018. The goal of this challenge was to help solve the needs of the transient and variable communities in both the LSST Dark Energy Science Collaboration and the LSST Transients and Variable Stars Collaboration, and to learn and discover novel techniques beyond the methods developed by the astronomical community. To that end, we selected one metric to balance the needs of many sciences which was implemented in the challenge. Here we present a small selection of new methods for classification that were created during the challenge, and how they compare with the traditional astronomical approaches.

**Author(s):** Mi Dai

**Institution(s):** Rutgers, The State University of New Jersey  
Contributing Team(s): The LSST PLAsTiCC Collaboration, The LSST Dark Energy Science Collaboration, The LSST Transients and Variable Stars Science Collaboration

### **212.04 - Validating the PLAsTiCC Simulations(Kara Ponder)**

The Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC) was a public data challenge to classify realistic simulations of astronomical transients and variables. The challenge was released on Kaggle on September 28, 2018, and closed on December 17, 2018. The simulations incorporate community-supplied models of transients and variables into a 3-year baseline cadence from LSST. Members of the LSST Dark Energy Science Collaboration and the LSST Transients and Variable Stars Collaboration validated the simulations by identifying and correcting various subtle sources of bias. In consultation with Kaggle, we explored how the contestants could game the data or the evaluation metric to win the challenge. We compared the simulations to publicly available catalogs that could be utilized for the challenge and employed various statistical tests and visual inspection to ensure our simulations were consistent with reality. We ran a preliminary classification code to search for unphysical correlations in the high-dimensional data that contestants could exploit. We will overview key validation tests used to verify these simulations.

**Author(s):** Kara Ponder

**Institution(s):** University of California Berkeley  
Contributing Team(s): The LSST PLAsTiCC Collaboration, The LSST Dark Energy Science Collaboration, The LSST Transients and Variable Stars Science Collaboration

### **212.05 - The Photometric LSST Astronomical Time Series Classification Challenge (PLAsTiCC): challenge design and evaluation criteria(Alex Malz)**

PLAsTiCC differs from previous astronomical classification challenges in three ways that complicate the conventionally simple question of, "Who should win?" First, because of the limited information anticipated of individual LSST-like light curves, classification submissions will be probability vectors, not labels; in the absence of certainty about whether a label is "right" or "wrong" we considered more nuanced performance metrics. Second, the winning classifier must serve the needs of a diverse community of scientists that will use the classification probabilities to answer myriad questions about the universe; a classifier that focuses on one class and ignores all others would be inappropriate, so we devised a way to level the playing field by penalizing neglect of any classes. Third, PLAsTiCC's engagement with competitors outside astronomy is reciprocated by the engagement of non-astronomers with astronomical data; we investigated how to disincentivize "gaming the system" by encouraging participants to treat the



challenge as we aim to treat the real data LSST will produce. We present our investigation of the optimal choice of the criterion for winning PLAsTiCC in the presence of these unique issues.

**Author(s):** Alex Malz

**Institution(s):** New York University Contributing Team(s): The LSST PLAsTiCC Collaboration, The LSST Dark Energy Science Collaboration, The LSST Transients and Variable Stars Science Collaboration

### **212.06 - Engaging Learners in Astrophysics via NASA's Universe of Learning Online Engagement, Partnerships, and Pathways(Laura Peticolas)**

The NASA's Universe of Learning (NASA's UoL) program creates and delivers science-driven, audience-driven resources and experiences designed to engage and immerse learners of all ages and backgrounds in exploring the universe for themselves. The project is the result of a unique partnership between the Space Telescope Science Institute, Caltech/IPAC, NASA Jet Propulsion Laboratory, Smithsonian Astrophysical Observatory, and Sonoma State University, and is one of 25 competitively-selected cooperative agreements within the NASA Science Mission Directorate STEM Activation (NASA SciAct) program. The NASA's Universe of Learning team draws upon cutting-edge science and works closely with Subject Matter Experts (scientists and engineers) from across the NASA Astrophysics themes of Physics of the Cosmos, Cosmic Origins, and Exoplanet Exploration. A key component of NASA's UoL is to develop programmatic pathways that give learners nationwide opportunities to engage in authentic science experiences with real data. We use a four-phase management process for the Sonoma State led pre-service faculty activities and remote telescope activities. The four phases are i. gathering data on audience needs (faculty and teen/young adult), ii. planning programs based on these needs, iii. implementing the programs, iv. evaluating and reassessing programs. In the first phase, the NASA's UoL external evaluator surveyed pre-service faculty within the California State University (CSU) system regarding incorporating astrophysics data into their science methods courses. We surveyed teens on the use of color to study telescope images. In the second phase, we are working with two CSU faculty to design a pilot course module on exoplanets. For teen/young adult audiences, we are focusing on authentic online research activities using exoplanets and variable stars. This planning phase includes the development of pathways for fictional "personas" in and out of different strands of informal science learning, using resources from the NASA's UoL program, collaborations with NASA SciAct, partnerships with CSU and remote telescope networks, and input from subject matter experts. We are transitioning into implementation (phase 3) and evaluation (phase 4).

**Author(s):** Anya Biferno, Brandon Lawton, Gordon Spear, Lindsay Bartolone, Mary E Dussault, Kathy Lestition, Robert Zelle, Gordon Squires, Rachel Zimmerman-Brachman, Laura Peticolas, Lynn Cominsky, Denise Smith

**Institution(s):** Sonoma State University, Smithsonian

Astrophysical Observatory, Space Telescope Science Institute, Caltech/IPAC, Jet Propulsion Laboratory - California Institute of Technology, NASA Jet Propulsion Laboratory Contributing Team(s): NASA's Universe of Learning

### **212.07 - NASA's Universe of Learning: Connecting Learners with the Discoveries and Scientists of NASA Astrophysics(Janice Lee)**

NASA's Universe of Learning (NASA's UoL) program inspires and enables learners of all ages and backgrounds to explore and deepen their understanding of the Universe. Through close collaboration with astronomers, engineers, and other Subject Matter Experts who span NASA's Astrophysics research areas (Physics of the Cosmos, Cosmic Origins, Exoplanet Exploration), we develop resources and experiences driven by fresh discoveries and cutting-edge science, with careful attention to learner-centered pedagogical best practices. In this talk, we will give an overview of NASA's UoL, and the essential roles that astronomers play in our program. Astronomers not only provide a direct link to current NASA Astrophysics research, they also: ensure the science content in our products is accurate and current; help learners connect to the people behind the science and act as role models; and provide an authentic perspective on the non-linear process of science. Research and evaluation have shown that providing direct links to the science in such ways is critical to quality of the learning experience. NASA's UoL leverages our established connections between our partner institutions (Space Telescope Science Institute, Caltech/IPAC, NASA Jet Propulsion Laboratory, Smithsonian Astrophysical Observatory, and Sonoma State University), the research community, and NASA Astrophysics missions to engage Subject Matter Experts in all of its projects. We will also discuss opportunities for astronomers to get involved. Currently, over 100 Subject Matter Experts are involved in NASA's UoL, who participate in a range of activities from volunteering as speakers and science reviewers, to brainstorming and guiding the development of products from inception to distribution. Come learn more about how you can contribute in ways that match your interest and availability! NASA's UoL is supported by NASA under cooperative agreement award number NNX16AC65, as part of the NASA Science Mission Directorate Science Activation program.

**Author(s):** Emma Marucci, Anya A Biferno, Brandon Lawton, Kathy Lestition, Janice Lee, Gordon Squires, Colleen Manning, Lynn Cominsky, Denise Smith

**Institution(s):** Caltech/IPAC, Goodman Research Group, STScI, Smithsonian Astrophysical Observatory, Sonoma State University, JPL

## **212.08 - Preparing for the 50th Anniversary of the Apollo Moon Landings (Jeffrey Bennett)**

The upcoming 50th anniversary of the Apollo Moon landings is likely to generate tremendous public interest, which means we have an opportunity to leverage that interest for science education and outreach. In this presentation, I will suggest a few ideas about how astronomers can capitalize on this opportunity, hoping to spur further discussion.

**Author(s):** Jeffrey Bennett

**Institution(s):** Big Kid Science

## **212.09 - The DAO Centennial: An Exemplary Outreach Project with the Royal British Columbia Museum (James Hesser)**

Notable anniversaries or unusual opportunities open windows for collaboration with local museums that may not include astronomy-focussed outreach in their regular activities or mandate. In turn, museum staff interpretative expertise can significantly enhance the impact of special exhibits developed in partnership with astronomy organizations. Over the past four decades there have been several such collaborative efforts in Victoria with the Royal British Columbia Museum (RBCM) involving differing combinations of NRC Herzberg staff, U. Victoria staff, and community members from the Victoria Centre of the RASC, the newly formed Friends of the Dominion Astrophysical Observatory (DAO), and others. Benefits of such collaborative efforts are particularly well illustrated by the collaboration between NRC Herzberg and the RBCM over the past two years to develop an exhibit for the DAO's 2018 centennial. The exhibit is designed to travel to other venues. The project includes an education outreach kit for use in schools, as well as an on-line portal. We also describe several predecessor activities that illustrate the breadth of successful outreach activities that have been enabled by partnering with local museum staff well experienced in conveying stories to the public in a compelling manner.

**Author(s):** James Hesser, Dennis Crabtree

**Institution(s):** National Research Council of Canada

## **213 - AGN Jets and Outflows I**

### **213.01 - Variability and Proper Motion of X-ray Knots in the Jet of Centaurus A (Bradford Snios)**

We report results from Chandra observations analyzed for evidence of variability and proper motion in the X-ray jet of Centaurus A. Using 15 years of archival images, an average proper motion of 11.3 mas yr<sup>-1</sup>, or 0.68c, is detected for both the X-ray knots and the substructure present within the jet. The three brightest knots (AX1A, AX1C, and BX2) are found to be stationary to an upper limit of 0.10c. Brightness variations up to 55% are detected for several X-ray knots in the jet. For the fading knots BX2 and AX1C, the changes in spectral slope expected to accompany synchrotron cooling are not found, ruling it out and placing upper limits of 80 and 160  $\hat{1}/4$ G,

respectively, on their magnetic field strengths. Adiabatic expansion is shown to account for the observed decreases in brightness. Constraints on models for the origin of the knots are established. Jet plasma overrunning an obstacle is favored as the generator of stationary knots, while moving knots are likely produced either by internal differences in jet speed or the late stages of jet interaction with nebular or cloud material.

**Author(s):** Eileen Meyer, Bradford Snios, Martin Hardcastle, Diana Worrall, Christine Jones, Mark Birkinshaw, Elke Roediger, Ralph Kraft, Paul Nulsen, William Forman, Sarka Wykes

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Hertfordshire, University of Bristol, University of Maryland, University of Hull

### **213.04 - JVL A Imaging of Heavily Obscured, Luminous Quasars at $z \sim 2$ (Pallavi Patil)**

The active galactic nucleus (AGN) phenomenon, driven by accretion onto supermassive black holes, is of fundamental importance to the evolution of the galaxies over cosmic time. Through the processes of radiative and mechanical energy transfer to the surrounding interstellar and intergalactic media, AGNs profoundly influence the formation and subsequent evolution of galaxies and their constituent dust, gas, and stars. Dust obscured quasars are likely going through early stages of such AGN-host galaxy interactions, termed AGN feedback, due to recent triggering of AGN activity. These galactic scale interactions are often hidden behind obscuring dust but are easy to probe at radio wavelengths. Therefore, radio observations with high-spatial resolution are essential to investigate the role and importance of feedback by radio jets in the obscured quasars. Here we present high-resolution JVL A imaging of 156 hyper-luminous and heavily obscured quasars found at redshifts from  $z \sim 0.4$ -3. These galaxies were selected to have extremely red MIR-optical colors in WISE and bright, compact radio emission in NVSS/FIRST. JVL A snapshot observations at 10 GHz with sub-arcsecond-scale angular resolution revealed that 115 out of 156 sources are indeed radio-loud, and have structures on scales  $\hat{\alpha} \times 2$  kpc (at  $z \sim 2$ ). Through detailed radio SED modeling, we have identified a few sources have peaked radio spectra, and thus belong to the class of High-Frequency Peakers (HFP), Gigahertz Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS) radio sources. This suggests that the radio jets could be recently triggered and are clearing their way out of the dense ISM of the host. We evaluate the implications of this study for our understanding of the impact of feedback from young jets on galaxy evolution.

**Author(s):** Mark Whittle, K. E. Nyland, Pallavi Patil, Carol Lonsdale, Mark Lacy

**Institution(s):** University of Virginia, US Naval Research Laboratory, National Radio Astronomy Observatory  
Contributing Team(s): Pallavi Patil

### **213.05 - Extremely High Velocity Outflows in Quasars(Paola Rodriguez Hidalgo)**

We present a survey of extremely high velocity outflows (outflowing at speeds between 0.1c and 0.2c) observed as broad blueshifted CIV absorption lines in Sloan Digital Sky Survey Data Release 9 catalogue quasar spectra (DR9Q). We normalized and analyzed the 6760 quasar spectra with signal-to-noise larger than 10 and of quasars with redshift larger than 1.9. This realm of the parameter space of quasar outflow's velocity has not been included in previous surveys of quasar spectra, and might pose the biggest constraints for theoretical models. Moreover, the kinetic luminosity of outflows at 0.2c is two orders of magnitude larger than those speeding at typically high velocities ( $\sim 10,000$  km/s). Studying extremely high velocity outflows can help us understand the interaction between the central supermassive black hole and the host galaxy, so we will discuss the characteristics and properties of the found sample.

**Author(s):** Carla Quintero, Paola Rodriguez Hidalgo, Patrick B. Hall, Abdul Moiz Khatri, Viraja Khatu, Norman Murray, Sean Haas

**Institution(s):** University of Washington Bothell, University of Toronto, Humboldt State University, Western University, York University, Canadian Institute for Theoretical Astrophysics

### **213.06 - Direct constraints on a quasar wind from observations of the Sunyaev-Zeldovich Effect(Mark Lacy)**

A deep observation with ALMA has revealed a probable first direct detection of the Sunyaev-Zeldovich Effect (SZE) from a quasar wind. The low level of the signal suggests that the wind is much weaker than predicted by most theories, having a kinetic luminosity only  $\sim 0.01\%$  of the bolometric output of the quasar. However, the bubble produced by the hot wind is comparable in total energy to those produced by radio jets in the intracluster medium of some nearby galaxy clusters, so it is plausible that feedback effects could be associated with this bubble. We only see the SZE on one side of the quasar, as expected from a simple wind model where the contribution of the kinetic and thermal SZE's are comparable. We also discuss other possible origins for the SZE, including a wind from a starburst.

**Author(s):** Craig Sarazin, Mark Lacy, Barnaby Rowe, Amy Kimball, Graca Rocha, Jason Surace, Brian Scott Mason, K. E. Nyland, Suchetana Chatterjee

**Institution(s):** National Radio Astronomy Observatory, Presidency University, University of Virginia, University College, London, Jet Propulsion Laboratory, California Institute of Technology

### **213.07 - The relation between active galactic nuclei obscuration and their host galaxies physical properties(Mojegan Azadi)**

Active galactic nuclei (AGN) release a tremendous amount of energy over a wide range of wavelengths. To study the emission mechanisms operating in the AGN and in the host galaxy and their inter-relationships, it is critical to disentangle the contributions from each as a function of wavelength. We present results of spectral energy distribution analysis for radio-loud quasars and galaxies from the 3CRR sample at  $1 < z < 2$ . These AGN are low-frequency radio selected thus are unbiased in terms of orientation and obscuration. We consider a multi-component model to fit the photometry over a wide range of wavelengths from X-ray to radio. The components at the highest energies account for the X-ray, UV and optical emission from the AGN and the accretion disk. At near-infrared to far-infrared wavelengths, a combination of a clumpy medium and a homogeneous disk accounts for the radiation from the dust grains in a torus-like geometry surrounding the central engine. At radio wavelengths a power-law/parabola component is included to account for the emission from the radio jets and lobes. In addition, an underlying component from UV to radio wavelengths is considered which accounts for the emission from stellar populations, cool dust and star formation in the host galaxy. Using this multi-component analysis, we investigate the physical properties of the obscuring torus in quasars and narrow line radio galaxies as well as the host galaxy of each class to test AGN Unification schemes.

**Author(s):** Mojegan Azadi

**Institution(s):** Harvard-Smithsonian

### **213.02D - Probing the physics of AGN feedback with high resolution X-ray spectroscopy(Anna Ogorzalek)**

Active galactic nuclei (AGN) can significantly impact the evolution of their host galaxies, as they can quench star formation by either expelling large fractions of gas with radiation and/or wide-angle outflows, or by heating up the halo gas with jets. Still a question for debate is how the AGN energy is transferred to the galaxy in either of the feedback modes. In this talk I will summarize my dissertation research, which involves novel applications of modern inference techniques to high resolution X-ray spectra in order to gain new insights into the physical processes behind AGN feedback. First, I will present our unprecedented measurements of the gas turbulent velocities in the cores of 13 nearby giant elliptical galaxies, which we obtained by statistically combining resonant scattering and direct line broadening techniques applied to deep XMM-Newton' Reflection Grating Spectrometer observations. This allowed us to explore the precise nature of the hot gas motions in massive galaxies for the first time. We found that the turbulent heat dissipation is sufficient to offset radiative cooling. In addition, I will also discuss how we have successfully applied our technique to the Hitomi observation of the Perseus Cluster. Second, I will introduce an improved Bayesian framework to modelling deep spectra of nearby AGN

with X-ray detected outflows. This approach treats the ionizing spectrum and wind absorption self-consistently within an MCMC analysis. For the first time we are able to perform robust model selection, while keeping all of the parameter space open. By way of example, we apply our approach to a new, deep observation of the Seyfert-1 galaxy NGC 4051 (700 ks of Chandra High Energy Transmission Grating), where we successfully map multiple absorbing components moving at  $\sim$ few 1000 km/s, and obtain one of the tightest outflow density constraints in the literature, thereby constraining wind's impact on the galaxy. Finally, I will conclude my talk by discussing the potential of both techniques within the context of upcoming high spectral resolution X-ray missions, such as XRISM, Arcus, and ATHENA.

**Author(s):** Anna Ogorzalek,

**Institution(s):** Stanford University, Kavli Institute for Particle Astrophysics and Cosmology

### **213.03D - Probing the Inner Regions of Supermassive Black Hole Accretion Disks and Jets(Mason Keck)**

Active galactic nuclei (AGN), which host actively accreting supermassive black holes (SMBHs), present multiple mysteries. Primary among these are the physics of inner accretion disks and the production of relativistic plasma jets. Observations of two types of AGN, Seyfert galaxies and blazars, provide some of the most revealing clues toward solving these mysteries. I examine the inner accretion flow of Seyfert galaxies within  $\sim 1/4$  Schwarzschild radii of the SMBH and the jet and its environment of blazars within  $\sim 1/4$  10,000 Schwarzschild radii of the SMBH based on their X-ray, optical, and radio emission. Through measuring the relativistic distortion of the X-ray emission from the inner accretion disk, important properties of the inner accretion disk and black hole can be determined, including the black hole spin. I present a measurement of the spin of the SMBH at the center of the Seyfert Galaxy NGC 4151 through X-ray spectroscopy with the NuSTAR and Suzaku X-ray observatories, showing that it has a near-maximal value. To better characterize accretion disks, I develop a time-resolved model of an optically-thick cloud eclipsing a SMBH accretion disk. Through probing blazar jets on  $\sim$ parsec (pc) scales with high-resolution Very Long Baseline Array (VLBA) observations, fundamental details of AGN jets can be determined. I present a multi-frequency study of ten blazar jets to probe the jet shape and magnetic field on pc scales with the VLBA. I show that the jet of 3C 273 is consistent with being conical with adiabatic lateral expansion on  $\sim 1/4$  pc scales. From estimating the SMBH masses in these sources with observations of emission lines with the Discovery Channel Telescope, I show that the regions probed with the VLBA are at a distance comparable to the Bondi radius. I discuss my results on the Seyfert galaxy NGC 4151 relative to the SMBH spin census. I compare NGC 4151 with a blazar, 3C 273, to put my results in broader context of AGN. I discuss the future of these studies with high spectral resolution X-ray missions such as Athena and with high frequency, higher angular resolution interferometer arrays such as the Event Horizon Telescope.

**Author(s):** Mason Keck

**Institution(s):** Boston University

## **214 - Catalogs, Surveys & Education Research**

### **214.01 - Engaging General Education Astronomy Students with Internet-Based Robotic Telescopes (Kimberly Coble)**

As part of a general education undergraduate astronomy course at a minority-serving university in the Midwestern US, students completed an observing project with the Global Telescope Network where they participated in realistic practices used by professional astronomers, including proposal writing and peer review. This study investigates students' experiences and perceived impacts of participation in the project. The data analyzed includes an essay assignment [N = 59] administered over seven semesters and individual interviews [N = 8] collected over two semesters. These data were coded iteratively into nine categories. We find that students expressed an overall strong positive affect, increased perception of self-efficacy, enjoyment of the experience of peer review, an appreciation for being able to use real scientific tools and to take on the role of astronomers, as well as a small number of dislikes such as real-world constraints on observing.

**Author(s):** Archana Dobaria, Kevin McLin, Berryhill Katie, Alejandra Le, Lynn Cominsky, Kimberly Coble

**Institution(s):** San Francisco State University, Chicago State University, Temple University, Solano Community College, Sonoma State University

### **214.02 - UVGAPS: The Ultraviolet Galactic Plane Survey(Steven Mohammed)**

The Ultraviolet Galactic Plane Survey (UVGAPS) produced a high resolution map of the Milky Way's Galactic plane in the NUV using the Galaxy Evolution Explorer (GALEX), an orbiting ultraviolet space telescope operated by NASA and Caltech between 2003-2013. In its last several years, the Galactic plane had only scarcely been observed by GALEX due to bright star protection limits set to protect the detectors. The full UVGAPS maps are just under 7200 square degrees (360 degrees x 20 degrees) with a full width half max resolution of 4.5-6", with 2" pixels, which is both a larger footprint at a higher resolution than previous UV all-sky surveys within the same region. Of the many astrophysical phenomena observable in ultraviolet wavelengths, we choose to focus on a few interesting objects: red clump stars, white dwarfs, bright blue objects and the Galactic dust that impacts all three. A new pipeline had to be developed to process the survey images due to a change in the GALEX observing methods from a dither mode to a long drift scan mode. We use an image source extractor to obtain the NUV photometry and several cuts to clean the data. We present a catalog of 2,986,045 objects with GALEX NUV band measurements. Despite the difference in observing strategy and analysis pipeline, we find good agreement between previously

targeted GALEX observations and the UVGAPS catalog in overlapping regions. The data were cross matched to Gaia DR2 and Pan-STARRS DR1, two visible-band surveys that have considerable coverage of the Galactic Plane. We characterize matched objects in color-magnitude and color-color space to highlight a range of objects, from main sequence stars to binaries detected with these data. The data will be publicly available and of particular interest to those planning follow-up observations with HST.

**Author(s):** Steven Mohammed, David Schiminovich, David W Hogg, Dun Wang

**Institution(s):** Columbia University, New York University

#### **214.03 - The VLA Sky Survey (VLASS): First Half-Epoch (1.1) Results and Future Prospects(Steven T. Myers)**

The VLA Sky Survey (VLASS) employs the Karl G. Jansky Very Large Array (VLA) at 2-4 GHz to survey the 33885 square degrees of the sky above Declination -40 degrees with an angular resolution of approximately 2.5 arc-seconds. The VLASS is a 7-year 5520 hour spectropolarimetric synoptic survey with each area of the sky covered in 3 epochs spaced 32 months apart, to a projected depth of 0.12mJy/beam rms noise per epoch and 0.07mJy/beam for 3 epochs combined. The VLASS employs on-the-fly mosaicking (OTFM) to raster-scan the sky with a net speed of approximately 20 sq. degrees per hour. The high-level science goals for the survey include the identification and precise location of radio transients, the measurement of magnetic fields in our galaxy and beyond, and the study of radio emission from galaxies and active galactic nuclei throughout the Universe including regions hidden behind obscuring dust. The VLASS was proposed by our community-led Survey Science Group in 2014. VLASS Pilot observations were taken in mid-2016, and the first epoch covering half the area (VLASS1.1) was observed from September 2017 to February 2018. The raw data from the VLASS are available in the NRAO archive immediately with no proprietary period. The Basic Data Products that will be produced by the survey team are public and will additionally include: calibrated visibility data, quick-look continuum images (with a goal of posting to the archive within 2 weeks of observation), single-epoch and cumulative combined-epoch continuum images and spectral image cubes, and basic object catalogs. Single-epoch and cumulative images are in intensity and linear polarization (Stokes IQU). In addition to the basic products provided by NRAO and served through the NRAO archive, there are plans for Enhanced Data Products and Services to be provided by the community in partnership with the VLASS team. In this presentation we describe the science goals, survey design, and technical implementation for the VLASS, and highlight results from the Pilot and VLASS1.1 observations, and plans for the upcoming VLASS1.2 observations starting in February 2019.

**Author(s):** Steven T. Myers

**Institution(s):** National Radio Astronomy Observatory  
Contributing Team(s): VLA Sky Survey Team, Survey Science

Group (SSG)

#### **214.04 - Early Cataloging of VLASS: Results and Planned Follow-up(Seth M Bruzewski)**

With the completion of the first half of the VLA Sky Survey (VLASS) Epoch 1, data from the observations has begun processing, and in some short time will be fully processed for more advanced analysis. Until such time, so called quicklook images are available for analysis; these are somewhat less well calibrated and cleaned than the full data release will be, but still a useful set of data to work on in the interim. Using a generalized cataloging method which can be applied to later data releases, we are able to find approximately 1.3 million sources in the sky above -40 degrees in Declination, which we can then use to examine the quality of the survey, and thus provide further feedback which may be incorporated into future epoch observations. We also compare this data with other large scale surveys in the radio and with the most recent FERMI source catalog in an attempt to locate previously undiscovered targets of interest.

**Author(s):** Seth M Bruzewski

**Institution(s):** University of New Mexico

#### **214.05 - ANTARES Live: Using a real-time alert-broker with ZTF(Gautham Narayan)**

The Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) is an alert-broker system applying data science and machine learning techniques to classify objects discovered by the Zwicky Transient Facility (ZTF) in real-time. We describe our infrastructure, machine learning stages and public interface. Our value-added data products are available to astrophysicists and can be used to enable new science. We briefly discuss future plans, focusing on scaling from ZTF to the alert volume we expect with the Large Synoptic Survey Telescope (LSST).

**Author(s):** Carlos Scheidegger, Thomas Matheson, Catherine Merrill, Carl Stubens, Gautham Narayan, Chien-Hsiu Lee, John Kececioglu, Monika Soraisam, Abhijit Saha, Richard Snodgrass, Peter Peterson

**Institution(s):** Space Telescope Science Institute, University of Arizona, NOAO  
Contributing Team(s): The ANTARES Collaboration

#### **214.06 - What Do Astronomers Do: A Survey of U.S. Astronomers' Attitudes, Tools and Techniques, and Social Interactions Engaged in Through Their Practice of Science(Timothy Spuck)**

Astronomy is one of the oldest STEM enterprises today. It is a discipline that has advanced our understanding of the universe and the technology we use today. Further, astronomy is a gateway science that inspires the imagination of young learners,

and can be used to promote STEM careers. In order to advance the astronomy enterprise, we must maintain an informed citizenry. The practice of astronomy has changed over time; astronomy today is much different than it was 50 years ago. In an effort to identify the current practice of astronomy, or what it is that today's astronomers do, 478 U.S. astronomers participated in this study focusing on their engagement in three areas of scientific practice: science attitudes, tools and techniques, and social interactions. In addition, astronomers' perceptions about career choice, work-related activities they engage in, motivations for doing astronomy, and changes needed in education were also explored. Data were collected over a three-month time period via an online survey and telephone interviews, and provides a solid foundation from which these findings and conclusions are drawn. Today's population of astronomers is largely white, male, and older, however, the field is moving toward gender balance. The population as a whole places great importance on the practice of attitudes such as thinking critically, respecting evidence, honesty, and objectivity. Unlike many might think, astronomers spend little time at the telescope collecting data-the vast majority of their time is spent working at a computer. Further, engaging in administrative duties, writing, using mathematics, searching for funding, mentoring others, and collaborating with colleagues are all critical tools/techniques and social skills in the practice of astronomy today. Finally, pop culture and personal experience plays a significant role in attracting individuals to a career in astronomy, and exploration and uncovering that which is unknown-the thrill of discovery-is what keeps them motivated.

**Author(s):** Timothy Spuck

**Institution(s):** Associated Universities Inc

#### **214.07 - Comprehensive Spatial Cross-matching and Application to the Chandra Source Catalog(Arnold H Rots)**

Cross-matching of sources between catalogs, purely on the basis of their positions, can be (and has been) performed with varying degrees of sophistication, accuracy, and reliability. The following properties can successively be taken into account to improve the reliability of the match results, from a simple nearest neighbor criterion to a near-perfect match probability:- Spatial separation- Positional uncertainty- Source density- Point Spread Function (PSF)- Self-consistent probability threshold- Matching ambiguityWe have developed a spatial cross-match tool that is based on the Bayesian algorithms described by Budavari, Heinis, and Szalay (ApJ 679, 301 and 705, 739) that were extended to allow the application of elliptical errors and the consideration of the PSF associated with the source detections. Subsequently, the self-consistent threshold criterion proposed by Budavari and Szalay is applied to the derived match probabilities in order to decide on the acceptance of the match; ambiguous matches are identified and separated out. The new elements are the generalization to elliptical position errors, the consideration of the role played by the PSFs, the self-consistent probability thresholding, and the

explicit identification of ambiguous matches. This has allowed us to derive cross-matches that are far more authoritative between catalogs that are based on observational data with widely different PSF characteristics and covering different parts of the electro-magnetic spectrum. Additionally, we expect to be able to extend the tool to perform cross-matching across a large number of multiple catalogs simultaneously. This is feasible since the underlying cross-match algorithm is based on pairwise probabilities, from which it will be straightforward to identify the connected components of an undirected graph developed from graph theory, thus drastically limiting the number of combinations that need to be considered. We will present authoritative cross-match catalogs of CSC Release 2.0 with SDSS, AllWISE, and Gaia. This work has been supported by NASA under contract NAS 8-03060 to the SAO for operation of the Chandra X-ray Center.

**Author(s):** Arnold H Rots, Francesca Maria Civano, Douglas Burke, Roger Hain, Dan T Nguyen, Tamas Budavari

**Institution(s):** Smithsonian Astrophysical Observatory, Johns Hopkins University

#### **215 - NASA Earth and Space Science Fellowship (NESSF) Astrophysics Fellows Forum**

##### **215.01 - Texas Spectroscopic Search for Ly $\alpha$ Emission at the End of Reionization(Intae Jung)**

Reionization is the last major phase transition of the intergalactic medium (IGM), and scrutinizing the detailed evolution of the IGM is a key frontier in observational cosmology. Due to the resonant nature of Ly $\alpha$  scattering by neutral hydrogen, the presence of neutral hydrogen in the IGM attenuates a Ly $\alpha$  emission strength. Thus, the distribution of Ly $\alpha$  emission provides a presently accessible method for studying the state of the IGM into the reionization era. We carried out 14 nights of deep spectroscopic observations using the Keck DEIMOS (optical) and MOSFIRE (near-infrared) spectrographs to search for Ly $\alpha$  emission from 178 photometric-redshift selected galaxies at  $z = 5.5 - 8.3$  from the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS) survey. We study the Ly $\alpha$  emission strength through constraining the Ly $\alpha$  equivalent width (EW) distribution with our spectroscopic dataset by constructing detailed simulations of mock emission lines, accounting for the observational conditions (e.g., exposure time, wavelength coverage, and sky emission) and galaxy photometric redshift probability distribution functions. Our measure of the EW distribution at  $6 < z < 7$  with the Ly $\alpha$  emission lines detected from the DEIMOS observations provides additional evidence that the Ly $\alpha$  EW distribution declines at  $z > 6$ , suggesting an increasing fraction of neutral hydrogen in the IGM. We will also present new results from our deepest ( $>15$ hr integration time) MOSFIRE observations, which includes a new  $z = 7.6$  Ly $\alpha$  detection, allowing us to constrain the Ly $\alpha$  EW distribution at  $z > 7$  and explore the evolution of the IGM at the end of cosmic reionization.

**Author(s):** Steven Finkelstein, Intae Jung

**Institution(s):** The University of Texas at Austin

**215.02 - Probing Structure Formation with the Cosmic Infrared Background Experiment 2 (CIBER-2)(Chi Nguyen)**

The integrated emission from all sources of light outside of the Milky Way, known as the Extragalactic Background Light (EBL), traces the history of star formation from the Epoch of Reionization (EOR) to the modern era. The measured fluctuations in the near infrared (IR) region of the EBL exceed the expected signal from known galaxy populations. These fluctuations can originate from sources at very high redshifts (EOR or earlier), or from stars that are gravitationally separated from their host galaxies during merging events at more recent epochs. To disentangle these two populations using their spectral signatures, the second Cosmic Infrared Background Experiment (CIBER-2) uses a 28.5-cm wide field imager with six wavebands from 0.5 - 2.5 micron to significantly improve the wavelength coverage and sensitivity to enable an assessment of these EBL components. CIBER-2 is scheduled to fly multiple times on a recoverable NASA Black Brant IX sounding rocket. In this talk, we show how CIBER-2 addresses near-IR fluctuations science, present the status and performance of the payload, and outline the remaining steps to ready the experiment for flight.

**Author(s):** Masaki Fukutani, shuji Matsuura, Isaac Witlin, Chi Nguyen, Kohji Tsumura, Peter Mason, Benjamin Stewart, Ryo Ohta, Kei Sano, Alicia Lanz, James Bock, Kenta Danbayashi, Kevin Kruse, Viktor Hristov, Dae-Hee Lee, Won-Kee Parko, Toshio Matsumoto, Takehik

**Institution(s):** Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), oKorea Astronomy and Space Science Institute (KASI), Rochester Institute of Technology, Jet Propulsion Laboratory (JPL), California Institute of Technology, The Observatories of the Carne

**215.03 - Development of Kinetic Inductance Detectors (KIDs) for Millimeter-wave Astrophysics(Anh Phan)**

The cosmic microwave background (CMB) polarization provides a powerful tool to study and understand the early universe. Here, we describe a program to develop microwave kinetic inductance detectors (MKIDs) that are optimized for measuring the low frequency end of the CMB spectrum (30 GHz, or 1 cm in wavelength) in order to remove astrophysical foregrounds. Specifically, the MKID design includes a coplanar waveguide (CPW) half-wave resonator, which is connected to a bandpass filter and a planar orthomode transducer (OMT). All components are formed from thin films of superconducting niobium patterned into CPW, which is relatively easy to fabricate. The MKID signal absorber uses an aluminum manganese (AlMn) alloy to achieve low frequency response and high sensitivity. AlMn is chosen as the absorber material because its transition temperature can be tuned by adjusting

the manganese concentration. We describe the design considerations, simulation results, and testing of AlMn prototype MKIDs.

**Author(s):** Anh Phan

**Institution(s):** University of Wisconsin-Madison

**215.04 - Doubling Dark Energy Constraints from Dense Galaxy Surveys(Andrew Repp)**

In this era of “precision cosmology,” profound questions remain unanswered, the nature of dark energy being perhaps the most significant of such. Unfortunately, standard techniques for addressing these questions depend on the power spectrum of galaxy counts, and for dense surveys this power spectrum reflects only a portion of the survey data’s cosmological information. Thus, standard methods of analysis applied to future surveys like WFIRST and Euclid will extract only a fraction of the information inherent in the data. By contrast, application of a specific nonlinear transformation to these surveys’ counts yields a “sufficient statistic” (denoted  $A^*$ ), whose power spectrum and mean reflect virtually all of the available information. We here describe our work of characterizing the  $A^*$ -power spectrum, thus allowing comparison of the measured spectrum to that expected for various cosmological parameter values. We also describe a planned “proof of concept” application to data from the Hawaii 2-0 survey. Our goal is to double the dark-energy information extracted from these future surveys and thus to impose correspondingly tighter constraints on the dark energy equation of state.

**Author(s):** Andrew Repp

**Institution(s):** University of Hawaii

**215.05 - GRB afterglows probing the circumgalactic medium in the early universe(Pradip Gatkine)**

The circumgalactic medium (CGM) is loosely defined as diffuse gas surrounding the galaxies within the virial radius (out to 100 to 300 kpc) and acts as the site of various galactic phenomena such as : galactic winds, outflows, accretion flows, and recycling flows. Promising theoretical and observational studies have suggested that a large fraction of the metals in the universe is stored in the CGM reservoirs around galaxies. Recent space- and ground-based studies of the CGM using bright background quasars have revealed a dynamic interplay between the galaxy ecosystem and surrounding CGM. In this study, we extend this investigation of the CGM to higher redshifts ( $z > 2$ ) by using the bright afterglows of gamma-ray bursts as background sources. Thanks to their bright UV/optical/NIR afterglows, promptly acquired spectroscopic data show exquisite absorption lines from both the CGM and interstellar medium (ISM) of the GRB host galaxy along the line of sight traced by the afterglow light. We will present results from the analysis of 27 high-resolution ( $R > 8000$ ) and high signal-to-noise (typical  $S/N \sim 15$ ) spectra of GRB afterglows covering a redshift range of

$z \sim 2$  to 6. By analyzing the transitions in low and high ionization states, we infer the kinematic and physical properties of the gas in cool and warm phases of the CGM. Our preliminary analysis suggests that the mass of the gas in the warm phase of the CGM around the GRB hosts at  $z > 2$  is roughly half the typical stellar mass of the GRB hosts ( $\sim 10^9$  solar mass). Through this study we establish GRB afterglows as one of the key probes of CGM evolution through the cosmic history.

**Author(s):** Sylvain Veilleux, Antonino Cucchiara, Pradip Gatkine

**Institution(s):** University of Maryland College Park, University of The Virgin Islands

#### **215.06 - The DEUCE payload: Sounding Rocket EUV Observations of Local B Stars to Determine Their Potential for Supplying Intergalactic Ionizing Radiation(Nicholas Erickson)**

The Dual-Channel Extreme Ultraviolet Continuum Experiment (DEUCE) is a rocket-borne spectrograph operating in the 650-1150Å range at medium resolution. DEUCE is designed to observe the nearby B stars Epsilon and Beta CMa, providing the first direct measurement of the flux of hot stars across the 912Å Lyman break. No such calibrated observations exist, meaning DEUCE will serve as a unique test of current stellar models in this critically ionizing bandpass. The primary goal of DEUCE is to better constrain the potential contribution of B stars to IGM ionization balance in the modern universe and gain insight into how hot stars could have contributed to IGM ionization at higher redshifts.

**Author(s):** Nicholas Erickson, James Green

**Institution(s):** University of Colorado, Boulder

#### **215.07 - Improving [CII] as a SFR Indicator by Disentangling the Ionized AND Neutral Components of [CII] 158 $\mu$ m Emission(Jessica Sutter)**

The brightest observed emission line from most normal star-forming galaxies is the [CII] 158  $\mu$ m line, making it detectable in even  $z \sim 6$  galaxies. It is thus imperative that we have the tools to fully understand how this emission line could be utilized as an indicator of star formation rate. There are two main challenges to utilizing the [CII] 158  $\mu$ m line as a star formation rate indicator: its multiphase origins and the so-called "[CII] deficit". In order to better understand and quantify the [CII] emission as an indicator of star-formation rate, the relationship between the [NII] 205  $\mu$ m emission and the [CII] 158  $\mu$ m emission has been employed to determine the fraction of [CII] emission that originates from the ionized and neutral phases of the ISM. Sub-kiloparsec measurements of the [NII] 205  $\mu$ m line in nearby galaxies have recently become available as part of the KINGFISH program. By using these two far-infrared lines along with the suite of KINGFISH data, an improved calibration of the [CII] emission line as a star

formation rate indicator and a better understanding of the cause of the [CII] deficit have been determined. We find that the [CII] emission originating in the neutral phase of the ISM does not exhibit a [CII] deficit and is therefore preferred over the total [CII] as a star formation rate indicator for the galaxies included in this sample.

**Author(s):** Daniel Dale, Jessica Sutter

**Institution(s):** University of Wyoming Contributing Team(s): KINGFISH Team

#### **215.08 - Search for Cosmic Ultra-High Energy Neutrinos with ANITA-IV(John Walsh Russell)**

The Antarctic Impulsive Transient Antenna (ANITA) is a balloon-borne experiment designed to detect radio pulses at approximately 37 km above the Antarctic ice sheet. Using antennas with both horizontal and vertical polarization channels measuring within a frequency range of 180-1200 MHz, the radio pulses detected are expected to correspond to emission from cosmic ray extended air showers in the horizontal polarization channel and in the vertical polarization channel from particle showers produced by in-ice neutrino interactions. This talk will discuss the techniques employed in analyzing the data collected from the December 2016 ANITA-IV flight, as well as recently published findings of the ANITA collaboration regarding the December 2014 ANITA-III flight. During the ANITA-III flight an event consistent with an upcoming ultra-high energy cosmic-ray (UHECR) was detected, but at a steep upcoming angle inconsistent with direct detection from stratospheric air showers, and with a waveform polarity inconsistent with reflected detection off of the ice. One other such event was detected during the ANITA-I flight. It has been proposed that these events may correspond to atmospheric decay of upward-propagating  $\bar{\nu}_\mu$ -leptons produced by an in-ice  $\bar{\nu}_\mu e$  interaction. However, this interpretation leads to contention with the standard model (SM) neutrino cross section.

**Author(s):** John Walsh Russell

**Institution(s):** University of Hawaii at Manoa Contributing Team(s): The ANITA Collaboration

#### **215.09 - The NICER-NuSTAR View of accretion disks in NS LMXBs(Renee Ludlam)**

Relativistic disk lines in neutron star low-mass X-ray binaries provide a valuable tool to determine the stellar magnetic field strength, the extent of a boundary layer, and even to place a limit on the radius of the compact object itself. Using NuSTAR, we have recently been able to obtain measurements of the inner disk around neutron stars that are unbiased by pile-up effects. Now, NICER affords the opportunity to search for low-energy relativistic lines down to 0.25 keV using detectors that are also free of distortions at high flux levels. The combined bandpass and sensitivity of NuSTAR and NICER open a new opportunity to capture multiple emission features, and to utilize them to



measure and map out different observables within the disk (e.g., temperature, ionization, elemental abundance, etc.).

**Author(s):** Renee Ludlam, Jon Miller

**Institution(s):** University of Michigan Contributing Team(s): NICER Burst and Accretion Working Group

#### **215.10 - Tracing Inner Disk H<sub>2</sub> and CO in Disks around Young Stars with HST-COS(Nicole Arulanantham)**

As the two most abundant molecules in protoplanetary disks around young stars, H<sub>2</sub> and CO are critical tracers of the planet formation environment. We use these two hot gas populations to map the radial distribution of material in the inner disks around a sample of 15 T Tauri stars. Each system was observed with the Cosmic Origins Spectrograph onboard the Hubble Space Telescope (HST-COS), which detected a suite of ultraviolet emission lines from electronic transitions of both molecules. We fit a 2-D radiative transfer model to these spectra and derive the gas disk structure that reproduces the UV-CO and UV-H<sub>2</sub> emission lines, assuming that Keplerian rotation is the dominant source of line broadening. We find that the population of CO has a cooler temperature than the H<sub>2</sub>, indicating that the molecules are probing distributions of material at different radial locations in the gas disk. By combining kinematic information from these two inner disk tracers for the first time, we provide a more complete census of molecular structure in the planet forming regions of our sample of young disks.

**Author(s):** Kevin France, Nicole Arulanantham

**Institution(s):** University of Colorado Boulder

#### **215.11 - Chaotic Tides in Migrating Gas Giants: Forming Hot and Warm Jupiters via High-eccentricity Migration(Michelle Vick)**

High-eccentricity migration is a possible mechanism for the formation of hot and warm Jupiters. In particular, the combination of Lidov-Kozai (LK) oscillations (where a giant planet is driven to a high-eccentricity orbit by a distant planetary or stellar companion) and tidal friction has been shown to produce such systems on Gyr timescales, provided that efficient tidal dissipation operates in the planet. We re-examine this scenario with the inclusion of dynamical tides. When the planet's orbit is in a high-eccentricity phase, the tidal potential of the star can excite oscillatory f-modes and r-modes in the planet. While the eccentricity remains large, the mode amplitudes can grow chaotically over multiple pericenter passages, drawing energy from the orbit and rapidly shrinking the semi-major axis. Eventually, the excited modes become too large and heat the planet as they dissipate non-linearly. We study the effect of this process on the planet's orbit. We find that this pathway produces very eccentric warm Jupiters on short timescales. Tidal friction efficiently circularizes these warm Jupiters to hot Jupiters due to their large eccentricities. This process can save some systems from tidal disruption when

orbital decay from dynamical tides is competitive with the eccentricity oscillations from the LK effect. As a result, accounting for dynamical tides increases the expected hot Jupiter production rate from the LK effect by a few percent for a range of planet masses and radii.

**Author(s):** Dong Lai, Kassandra R. Anderson, Michelle Vick

**Institution(s):** Cornell University

#### **215.12 - Towards space-quality photometry from the ground with beam-shaping diffusers for K2, TESS and Beyond.(Gudmundur Kari Stefansson)**

Precision ground-based photometry plays a key role in discovering and characterizing transiting exoplanet candidates. Using custom-fabricated beam-shaping diffusers, we demonstrate a path to achieving some of the highest differential photometric precisions from the ground. These diffusers are micro-structured optical components capable of molding the image of a star into a broad and stable top-hat shape, minimizing photometric errors due to non-uniform pixel response, atmospheric seeing effects, and telescope-induced variable aberrations seen in defocusing. I discuss our efforts in commissioning an optical diffuser on the ARC 3.5m Telescope at Apache Point Observatory demonstrating 62ppm precision in 30 minute bins-some of the highest photometric precisions from the ground. I will present our current results from our ongoing ground-based follow-up program to follow up K2 and soon-to-come TESS candidates. Being inexpensive and easily adaptable, I will highlight some of our ongoing efforts to install beam-shaping diffusers on other telescopes large and small.

**Author(s):** John Wisniewski, Joseph Huehnerhoff, Paul Robertson, Yiting Li, Marissa Maney, Brett M. Morris, Leslie Hebb, Gudmundur Kari Stefansson, Suzanne Hawley, Andrew Monson, Suvrath Mahadevan

**Institution(s):** Pennsylvania State University, University of Washington, University of Oklahoma, University of California Santa Barbara, Hobart and William Smith Colleges, Hindsight Imaging, University of California Irvine

#### **215.13 - Probing the Three Dimensional Nature of Exoplanetary Atmospheres(Brian Kilpatrick)**

Studies of our own solar system reveal a set of diverse and fascinating atmospheres. Planetary atmospheres are governed by a complex interplay of chemical, radiative, and advective processes that yield an inherently three dimensional structure. We expect exoplanet atmospheres to exhibit similar diversity and complexity that must be explored to further insights into the fundamental physical processes shaping them. However, our inability to spatially resolve them requires we employ novel observational techniques to probe their three dimensional nature. Here I present the analysis of multi-epoch secondary eclipse observations of the canonical hot Jupiters HD189733b and HD 209458b to probe variability in both time and space. This analysis investigates temporal variation in eclipse depth

due to interactions of radiative and wave dynamics deep in the planetary atmosphere as well as produces two dimensional maps of thermal distributions at multiple wavelengths providing our first three dimensional look at an exoplanet atmosphere.

**Author(s):** Nikole K Lewis, Gregory S Tucker, Brian Kilpatrick  
**Institution(s):** Brown University, Cornell University

#### **215.14 - Atmospheric Hazes of M-dwarf Temperate Planets(Sarah E Moran)**

We've begun to perform laboratory experiments to investigate the habitability of temperate exoplanets around M-dwarf stars. This set of experiments allows us to obtain the rate of haze production and measure the physical and chemical properties of the haze produced in an atmospheric chamber, which simulates the high energy radiation environment of planets hosted by M-dwarf stars. We next implement our laboratory results into a computational model for planetary atmospheres in M-dwarf systems, with the goal of understanding the effect of such hazes on the current habitability and past and future evolution for such planets. These experiments provide fundamental data in a novel planetary temperature and composition range which will only be increasingly populated as NASA's Transiting Exoplanet Survey Satellite continues to discover additional worlds. The experiments are aimed at furthering NASA's goal of characterizing nearby exoplanets and will focus on one of NASA's guiding scientific questions: Are we alone?

**Author(s):** Nikole K Lewis, Sarah M Horst, Sarah E Moran  
**Institution(s):** Johns Hopkins University, Cornell University

#### **Welcome from Paul Hertz, NASA Astrophysics Division Director**

#### **216 - HEAD I: Chandra at 20**

##### **216.01 - Twenty Years of Discovery with the Chandra X-Ray Observatory(David Buote)**

The launch of the Chandra X-ray Observatory twenty years ago signified the beginning of a golden age in x-ray astronomy. In this talk I will provide some historical overview and highlight a few of Chandra's great achievements.

**Author(s):** David Buote  
**Institution(s):** University of California, Irvine

##### **216.02 - Chandra's Legacy Observing X-rays from Supernova Remnants(Laura A. Lopez)**

Since its first-light image of Cassiopeia A, Chandra has revealed the in exquisite detail the complexity of supernova remnants (SNRs) at X-ray wavelengths. The metals synthesized in

explosions are X-ray bright for many thousands of years, and Chandra has offered an up-close view of the nucleosynthetic products of SNRs and their dispersal into the interstellar medium (ISM). In this talk, I will review the major advances facilitated by Chandra observations of SNRs, particularly regarding the nature of explosions, progenitor stars, and particle acceleration.

**Author(s):** Laura A. Lopez  
**Institution(s):** The Ohio State University

##### **216.03 - Two Decades of Gamma-ray Burst Observations Through Chandra's Eyes(Wen-fai Fong)**

Gamma-ray bursts (GRBs) are the most luminous explosions in the Universe. While long-duration GRBs signal the deaths of massive stars, short-duration GRBs likely originate from the mergers of two compact objects. Over the past two decades, rapid observations with Chandra have played a pivotal role in our understanding of the explosion physics and progenitors of GRBs. In this talk, I present some of the seminal observations of GRBs as seen through Chandra's eyes. These observations have revealed evidence for jet collimation, uncovered mysterious behavior such as X-ray flares and excess emission, and localized their positions to sub-arcsecond accuracy, all of paramount importance for understanding their stellar progenitors. I will also highlight the Chandra discovery of X-ray emission from a gravitational wave source, helping to elucidate the connection between short GRBs and neutron star mergers.

**Author(s):** Wen-fai Fong  
**Institution(s):** Northwestern University

##### **216.04 - Amazing Discoveries of Galaxy Clusters made with the Chandra X-ray Observatory(Julie Hlavacek-Larrondo)**

Galaxy clusters are fantastic laboratories for understanding the physics of the cosmos. They not only play a pivotal role in our understanding of black hole feedback and plasma physics, but they also provide some of the most compelling cases for dark matter and dark energy. None of these discoveries could have been accomplished without the unique capabilities of the Chandra X-ray Observatory. The goal of this talk is to highlight these discoveries - providing a summary of Chandra's greatest accomplishments over the last 20 years.

**Author(s):** Julie Hlavacek-Larrondo  
**Institution(s):** Université de Montréal

#### **218 - Extrasolar Planets: Detection - Transit Detections and Populations**

##### **218.01 - K2-266: A Compact Multi-Planet System With A Significantly Misaligned Ultra Short Period Planet(Joseph Rodriguez)**

With the recent success of the Kepler Mission combined with the ground based radial velocity and transit surveys, the field of extrasolar planets has rapidly expanded over the past decade. This has guided the transition of the field from pure discovery to the combination of discovery, atmospheric characterization, and demographics. Recently, we have discovered a compact six planet system of sub-Neptunes orbiting a nearby (78 pc) K-star. Interestingly, the system contains an 0.66 day ultra-short period super Earth that is significantly misaligned ( $>12$  degrees) to the other five planets. As results of its close proximity to its host star, the USP does transit our line-of-sight. This provides a rare opportunity to directly compare the misaligned planet to the other five planets in the system, potentially gaining insight into how it got to its current orbital configuration. K2-266 is the most planets discovered in one system from the repurposed Kepler mission, K2. In addition, we also identify a transiting planet candidate around a nearby, co-moving companion to K2-266. I will discuss the discovery and characterization of the K2-266 system, and the key questions this system may help us answer. J.E.R. is supported by the Harvard Future Faculty Leaders Postdoctoral fellowship.

**Author(s):** Andrew Vanderburg, Jason Eastman, Samuel Hadden, Samuel N Quinn, Juliette Becker, Joseph Rodriguez

**Institution(s):** University of Michigan, University of Texas, Harvard-Smithsonian CfA

#### **218.02 - A second terrestrial planet orbiting the nearby M dwarf LHS 1140(Kristo Ment)**

LHS 1140 is a nearby mid-M dwarf known to host a temperate rocky super-Earth (LHS 1140 b) on a 24.737-day orbit. Based on photometric observations by MEarth and Spitzer as well as Doppler spectroscopy from HARPS, we present the discovery of an additional transiting rocky companion (LHS 1140 c) with a mass of  $1.81 \pm 0.39$  Earth masses and a radius of  $1.282 \pm 0.024$  Earth radii on a tighter, 3.77795-day orbit. We also obtain more precise estimates of the mass and radius of LHS 1140 b to be  $6.98 \pm 0.98$  Earth masses and  $1.727 \pm 0.032$  Earth radii. The mean densities of planets b and c are  $7.5 \pm 1.0$  g/cm<sup>3</sup> and  $4.7 \pm 1.1$  g/cm<sup>3</sup>, respectively, both consistent with the Earth's ratio of iron to magnesium silicate. The orbital eccentricities of LHS 1140 b and c are consistent with circular orbits and constrained to be below 0.06 and 0.31, respectively, with 90% confidence. Because the orbits of the two planets are co-planar and because we know from previous analyses of Kepler data that compact systems of small planets orbiting M dwarfs are commonplace, a search for more transiting planets in the LHS 1140 system could be fruitful. LHS 1140 c is one of the few known nearby terrestrial planets whose atmosphere could be studied with the upcoming James Webb Space Telescope. This work was made possible with support from the David and Lucile Packard Foundation, the National Science Foundation, the John Templeton Foundation, NASA, and the Heising-Simons Foundation.

**Author(s):** Jason Dittmann, David W Latham, Jose-Manuel Almenara, Christophe Lovis, Francois Bouchy, Stephane Udry, Jonathan Irwin, David M Kipping, Ryan Cloutier, o, Ana-Cl

Wünsche, Jennifer Winters, Sarah Ballard, Zachory Berta-Thompson, Xavier Bonfils, Nicola Ast

**Institution(s):** University of California, Berkeley, oUniversité de Montréal, Universidade do Porto, Columbia University, Perth Exoplanet Survey Telescope, MIT, Harvard-Smithsonian Center for Astrophysics, Universidad de Concepcion, Instituto de Astrofisica de Cana

#### **218.03 - The International Beta Pic b Transit Campaign(Paul Kalas)**

Beta Pic b is the only extrasolar giant planet that is both directly imaged and has a near-edge-on orbit that permits a study of its circumplanetary environment via the transit technique once every 22 years. Based on the orbital elements determined via multi-epoch astrometry using the Gemini Planet Imager (Wang et al. 2016), we determined that the 1.2 au radius Hill sphere of the planet would begin transiting the stellar photosphere in April 2017, with closest approach to the planet occurring in late August 2017. Here we present an overview of multiple ground and spaced-based campaigns that monitored beta Pic spectroscopically and photometrically for over six months to search for the signatures of circumplanetary gas and dust. These efforts included HST/WFC3/UVIS photometry using spatial scanning that demonstrated absolute precision of roughly 0.1% in seven epochs of observation spread over 12 months. We also summarize the capabilities and results from campaigns conducted from South Africa and Australia (bRing, SALT/HRS), Antarctica (ASTEP, AST3), Chile (VLT/UVES, HARPS), as well as HST/COS and the BRITE nanosatellites from space. [This work benefited from NSF AST-1518332, NASA NNX15AC89G & NNX15AD95G/NEXSS, and HST-GO-14621/14894/15119/15396.]

**Author(s):** Paul Kalas, Jason Jinfei Wang, Lifan Wang, Anne-Marie Lagrange, Blaine Lomberg, Hui Zhang, Samuel N Mellon, Nick Suntzeff, Remko Stuik, Lyu Abe, Alfred Vidal-Madjaro, Tristan Guillot, Eric E Mamajek, Carlo Manara, Djamel Mekarnia, Sylvestre Lacour, Erns

**Institution(s):** Texas A&M University, oInstitut d'Astrophysique de Paris, Caltech, University of Rochester, Jet Propulsion Laboratory, Observatoire de Paris, Nanjing University, Space Telescope Science Institute, ESO, University of California, Leiden Observatory,

#### **218.04 - The Occurrence of Short Period Planets in Young Clusters Observed By K2.(Aaron C Rizzuto)**

The K2 mission has measured planet formation timescales and migration pathways by sampling groups of stars at key pre-main sequence ages: Over the past 10 campaigns, multiple groups of young stars have been observed by K2, ranging from the 10 Myr Upper Scorpius OB association, through the  $\hat{1}^{\circ}4120$  Myr Pleiades, the  $\hat{1}^{\circ}4600$ -800 Myr Hyades and Praesepe moving groups, to the original Kepler Field. The frequency, orbital and compositional properties of the exoplanet

population in these samples of different age, with careful treatment of detection completeness, will be sufficient to address the question of exoplanet migration as their host stars are settling onto the main sequence. Planetary Migration models for close-in exoplanets ( $a < 0.1$  AU,  $P < 20$  days) can be loosely divided into three categories: Disk-driven migration, binary-star planet interaction, and planet-planet interaction. Disk migration occurs over the lifetime of the protoplanetary disk ( $< 5$  Myr), while migration involving dynamical multi-body interactions operate on timescales of  $\sim 100$ 's of Myr to  $\sim 1$  Gyr, a lengthier process than disk migration. It is unclear which of these is the dominating mechanism. We will present the statistical results of our program to directly address the question of planet occurrence in the K2 young clusters with a uniform injection-recovery tests on a new K2 detrending pipeline that is optimized for the particular case of young, rotationally variable stars in K2 to robustly measure the detectability of planets of differing size and orbit. Initial results indicate that M-dwarf hosted planets at 650-750 Myr have inflated radii but a consistent occurrence compared to older counterparts. While 125 Myr old Pleiades has a lower occurrence rate of short period planets.

**Author(s):** Aaron C Rizzuto, Andrew Mann, Andrew Vanderburg, Adam L. Kraus, Michael Ireland

**Institution(s):** University of Texas at Austin, Research School of Astronomy and Astrophysics, Australian National University, University of North Carolina

#### **218.05 - A Uniform Analysis of Kepler/K2 Exoplanet Transit Parameters (Nicholas Saunders)**

The conclusion of observations by the K2 mission provides an opportunity to uniformly analyze and study the population of exoplanet discoveries. Transit detection and characterization methods have been improving since the transition from Kepler to K2, potentially introducing inconsistencies in measured planetary and stellar parameters. Variations in calculated values can arise when fitting transits with inconsistent aperture selection, limb darkening parameters, or de-trending parameters. I will present my results from an evaluation of the transit-fitting methods used to characterize K2 exoplanets, and generate a catalog with uniformly determined transit parameters. In addition to preserving the legacy of the K2 discoveries in a homogeneous catalog, this will provide valuable utility to the astronomical community by optimizing target selection for follow up efforts.

**Author(s):** Geert Barentsen, Nicholas Saunders, Christina L Hedges

**Institution(s):** NASA Kepler/K

#### **218.06 - The Elephant in the Room: Addressing Issues of Multiplicity in Kepler Occurrence Rates (Jessie Christiansen)**

With the completion of the final Kepler planet candidate catalogue, the stage is set for a comprehensive investigation of exoplanet occurrence rates. However, some crucial ingredients are still missing. Here I present work towards solving two pieces of the puzzle. The first is unresolved stellar multiplicity and its impact on detection efficiency and derived planetary parameters. We are undertaking a large, high-resolution multi-wavelength imaging survey of Kepler field stars to place constraints on the frequency of stellar companions; any difference between the Kepler field star multiplicity and the Kepler planet candidate host star multiplicity must be accounted for in order to derive accurate planet occurrence rates. The second is planet multiplicity and the impact of the presence of multiple signals in a light curve on the signal recoverability. Our analysis of the Kepler pixel-level simulated transit injections indicate that subsequently detected planetary signals in a given Kepler light curve are less likely to be detected than if the signals are treated independently. Correcting for this loss of detection efficiency goes a substantial way towards addressing the over-abundance of single-planet systems in the Kepler data when compared to the expectation from multi-planet systems.

**Author(s):** Courtney Dressing, Jessie Christiansen, Jonathan Zink, David Ciardi, Brad Hansen

**Institution(s):** Caltech/IPAC-NEoS, UCLA, University of California Berkeley

#### **218.07 - Winner of the 2018 Beth Brown Memorial Award: A Reanalysis of the Age of TRAPPIST-1 (Eileen Gonzales)**

TRAPPIST-1 is an M7.5 dwarf that hosts seven rocky earth-size planets, three of which are in its habitable zone. Given the abundance of M dwarfs throughout the Galaxy as well as the ease by which rocky planets might be uncovered around low mass stars with future studies like TESS, an inquiry into the uniqueness of the nature of the TRAPPIST-1 system is particularly relevant today. TRAPPIST-1 is classified as a field dwarf with kinematics that suggest it is an "old disk" star. However, the near infrared spectrum of TRAPPIST-1 exhibits a subtle peculiarity that causes it to be classified as an intermediate gravity object using spectral indices, indicating youth. To understand this subtle peculiarity as well as to place TRAPPIST-1 in context with other nearby M dwarfs, we have created a distance-calibrated spectral energy distribution (SED). Combining the most recent parallax measurement with optical and infrared spectra and all available photometry, we re-evaluate bolometric luminosity and effective temperature. We compare the resultant SED to a sample of old, young, and field age objects of similar properties. Using a FIRE echelle spectrum, we also investigate the near-infrared Y, J, H, and K bands to compare observables linked to gravity, atmosphere, metallicity and age effects.

**Author(s):** Eileen Gonzales, Johanna Teske, Kelle Cruz, Jonathan Gagné, Jacqueline K Faherty, Andrew McWilliam  
**Institution(s):** CUNY Graduate Center, American Museum of Natural History, Hunter College, University of Montreal, Carnegie DTM, Carnegie

## **219 - Plenary Lecture: Report of the 2018 AAS Task Force on Diversity and Inclusion in Astronomy Graduate Education, Alex Rudolph (Cal Poly Pomona) and Gibor Basri (UC Berkeley) and members of the Task Force Team**

### **219.01 - Report of the 2018 AAS Task Force on Diversity and Inclusion in Astronomy Graduate Education(Alexander L Rudolph)**

At the January 2017 AAS meeting in Texas, the AAS Council (now Board) approved the creation of a Task Force on Diversity and Inclusion in Astronomy Graduate Education. The task force was empaneled in November 2017. The task force has been meeting throughout 2018 to develop recommendations to astronomy departments and to the AAS regarding how to best promote diversity and inclusion in astronomy graduate education, building off of the 2015 Inclusive Astronomy conference and the resultant Nashville Recommendations. To accomplish this task, three working groups were created, led by members of the task force, on three topics: Admissions, Retention, and Data Collection and Dissemination. Presentations of the findings and recommendations of the task force have been made to the AAS Board, and to the Astronomy Department Chairs meeting held in November 2018. During this plenary session, members of the task force will present the findings of the task force, including specific recommendations to departments and to the AAS.

**Author(s):** Alexander L Rudolph

**Institution(s):** Cal Poly Pomona Contributing Team(s): Members of the AAS Task Force on Diversity and Inclusion in Astronomy Graduate Education

## **222 - NASA Decadal Preparations: Large Mission Concept Studies**

### **222.01 - The Habitable Exoplanet Observatory(Tyler Robinson)**

The Habitable Exoplanet Observatory (HabEx) is a concept large strategic mission being studied by NASA and the astrophysics community in preparation of the 2020 Decadal Survey. The primary HabEx mission design is a large (~4m) diffraction-limited optical space telescope, providing unprecedented resolution and contrast in the optical and with likely extensions into the near-ultraviolet and near-infrared domains. The primary goal of HabEx is to answer fundamental questions in exoplanet science. Here, fundamental concepts focus on searching for and characterizing potentially habitable worlds, providing the first complete "family portraits" of planetary systems around our nearest Sun-like neighbors, and

placing the Solar System in the context of the larger diversity of exoplanets. A second key aspect of the HabEx concept is that the mission will enable a broad range of Galactic, extragalactic, and Solar System astrophysics. Exciting areas of active astrophysical research that HabEx can further enable span resolved stellar population studies that inform the stellar formation history of nearby galaxies, to characterizing the life cycle of baryons as they flow in and out of galaxies, to detailed studies of planets, moons, and small bodies in our own Solar System. We present here on the HabEx team's efforts in defining a scientifically compelling mission concept that is technologically executable, affordable within NASA's expected and/or stated budgetary constraints, and timely for the coming decade. In particular, we present architecture trade study results, quantify technical requirements and predict scientific outcome for a variety of design reference missions, all with broad capabilities in both exoplanet science and cosmic origins science. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

**Author(s):** Tyler Robinson, Keith Warfield, B. Scott Gaudi, Sara Seager, Alina Kiessling, Bertrand Mennesson

**Institution(s):** Northern Arizona University, Massachusetts Institute of Technology, The Ohio State University, Jet Propulsion Laboratory Contributing Team(s): The Habitable Exoplanet Observatory Study Team

### **222.02 - Revealing the Invisible Universe with Lynx(Feryal Ozel)**

The next-generation X-ray observatory Lynx will provide unprecedented X-ray vision into the otherwise invisible Universe with unique power to directly observe the dawn of supermassive black holes, reveal the drivers of galaxy formation, trace stellar activity including effects on planet habitability, and transform our knowledge of endpoints of stellar evolution. In this talk, I will describe how these science goals will be enabled by a mission design that combines lightweight X-ray mirrors with a high-definition X-ray imager with 0.5" pixels, a microcalorimeter with 0.3 eV energy resolution, and a large effective area grating spectrometer with a resolving power of 5000. Just as importantly, these features will facilitate a broadly capable observatory for the community that is able to tackle not only the known outstanding key science questions but whatever new problems arise in the coming decade.

**Author(s):** Feryal Ozel

**Institution(s):** University of Arizona Contributing Team(s): Lynx Science and Technology Definition Team

### **222.03 - Origins Space Telescope(Alexandra Pope)**

Half of the light emitted by stars, planets, and galaxies over the lifetime of the Universe emerges in the infrared. The Origins Space Telescope (OST) will access this information-rich spectral

region to uncover the crucial missing pieces of our cosmic history. OST is a community-led, NASA-supported mission concept study for the Far-Infrared Surveyor, described in NASA's Astrophysics Roadmap, in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. The study team envisions a large aperture, actively-cooled telescope covering the full mid- to far-infrared spectrum enabling revolutionary scientific discoveries in many areas including: 1) OST will probe our earliest cosmic origins by charting the rise of dust and metals in galaxies over cosmic time, and determine how the coevolution of star formation and supermassive black holes leads to the diversity in galaxies today, 2) OST will follow the trail of water from the birth of the planet-forming disk to the assembly of pre-planetary materials, and in comets to understand the origin of Earth's oceans, and 3) OST will measure biosignatures in transiting exoplanet atmospheres at mid-infrared wavelengths to assess the habitability of nearby exoplanets and search for signs of life. Equally important to these compelling questions, OST will be a flagship general observatory which provides the astronomical community access to unprecedented discovery space in the infrared. OST will be up to a factor of 1000 more sensitive than previous infrared space telescopes. Its versatile instrument suite will enable deep and wide 3D surveys of the sky from the most distant galaxies to the outer reaches of our Solar system. This presentation will describe the OST baseline mission concept and spotlight its vast science potential.

**Author(s):** Alexandra Pope

**Institution(s):** University of Massachusetts Amherst  
Contributing Team(s): OST Study Team

#### **222.04 - LUVOIR: Telling the Story of Life(Courtney Dressing)**

The Large UV/Optical/Infrared Surveyor (LUVOIR) is one of four large mission concepts for which the NASA Astrophysics Division has commissioned studies by Science and Technology Definition Teams (STDTs) drawn from the astronomical community. We have developed two architecture variants: Architecture A with a 15-meter segmented primary mirror, and Architecture B with an 8-meter segmented primary mirror. LUVOIR will operate at the Sun-Earth L2 point. It is designed to support a broad range of exoplanet, astrophysics, and Solar System studies. The candidate instruments studied for LUVOIR are 1) a high-performance NUV/optical/NIR coronagraph with imaging and spectroscopic capability, 2) a UV imager and spectrograph with high spectral resolution and multi-object capability, 3) a high-definition wide-field optical/NIR camera, and 4) a high-resolution UV spectropolarimeter. LUVOIR is designed for extreme stability to support unprecedented spatial resolution and high-contrast direct observations of Earth-like exoplanets. It is intended to be a long-lifetime facility that is serviceable, upgradable, and primarily driven by guest observer science programs. In this presentation, we will describe the observatories and provide an overview of the transformative science LUVOIR can accomplish.

**Author(s):** Courtney Dressing, John O'Meara

**Institution(s):** University of California, Berkeley, Keck Observatory  
**Contributing Team(s):** The LUVOIR Mission Concept Team

#### **223 - Extrasolar Planets: Characterization & Theory Track 1: VIII. Measurements and Models of of Giant Planet Atmospheres D 223.01 - The GEMINI/GMOS optical transmission spectral survey of close-in gas giant exoplanets(Vatsal Panwar)**

Estimating the nature and abundances of chemical species and clouds in exoplanetary atmospheres forms the backbone of comparative exoplanetology. We present a long-term ground-based survey of a dozen transiting hot Jupiters observed in the visible bandpass using the Gemini Multi-Object Spectrograph (GMOS). By observing transits of an ensemble of hot Jupiters spanning a range of masses, radii, and host star types, and using a consistent methodology for extracting their transmission spectra across the sample, we derive common properties for their atmospheres. We present the main results of this survey, the challenges faced by such an experiment, and the lessons learned for future MOS observations and instrument designs. Ultimately, this survey aims at improving our understanding of the diversity of physical processes at play in exoplanetary atmospheres.

**Author(s):** Jean-Michel Désert, Kamen Todorov, Catherine Huitson, Marcel Bergmann, Vatsal Panwar, Jonathan Fortney, Jacob Bean, Kevin Stevenson

**Institution(s):** University of Amsterdam, University of Chicago, University of Colorado, Boulder, NOAO Gemini Science Center, University of California Santa Cruz, Space Telescope Science Institute

#### **223.03 - Constraints on the Na abundance of XO-2 b using ground-based mutli-object spectroscopy(Kyle Pearson)**

Exoplanets orbiting close to their host star are expected to support a large ionosphere, which extends to larger pressures than witnessed in our Solar System. These ionospheres can be investigated with ground-based transit observations of the optical signatures of alkali metals, which are the source of the ions. However, most ground-based transit spectra do not systematically resolve the wings of the features and continuum, as needed to constrain the alkali abundances. Here, we present new observations and analyses of optical transit spectra that cover the Na doublet in the atmosphere of the exoplanet XO-2 b. To assess the consistency of our results, observations were obtained from two separate platforms: Gemini/GMOS and Mayall/KOSMOS. To mitigate the systematic errors, we chose XO-2, because it has a binary companion of the same brightness and stellar type, which provides an ideal reference star to model Earth's atmospheric effects. We find that interpretation of the data is highly sensitive to time-varying translations along the detector, which change according to wavelength and differ

between the target and reference star. It was necessary to employ a time-dependent cross-correlation to align our wavelength bins and correct for atmospheric differential refraction. This approach allows us to resolve the wings of the Na line across 5 wavelength bins at a resolution of 1.6 nm and limit the abundance of Na. We obtain consistent results from each telescope with a Na amplitude of  $521 \pm 161$  ppm and  $403 \pm 186$  ppm for GMOS and KOSMOS respectively. The results are analyzed with a radiative transfer model that includes the effects of ionization. The data are consistent with a clear atmosphere between  $\sim 1\text{--}100$  mbar which establish a lower limit on Na at  $0.4\text{--}0.3 \pm 2$  ppm, consistent with solar. However, we can not rule out the presence of clouds at  $\sim 10$  mbar which allow for higher Na abundances which would be consistent with stellar metallicity measured for the host star.

**Author(s):** Tommi Koskinen, Kyle Pearson, Gaël Roudier, Caitlin Griffith, Robert Thomas Zellem

**Institution(s):** University of Arizona, Jet Propulsion Laboratory

### **223.05 - An absolute sodium abundance for a cloud-free 'hot Saturn' exoplanet (Nikolay Nikolov)**

Broad absorption signatures from alkali metals, such as the sodium (Na I) and potassium (K I) resonance doublets, have long been predicted in the optical atmospheric spectra of cloud-free irradiated gas-giant exoplanets. However, observations have only revealed the narrow cores of these features rather than the full pressure-broadened profiles. Cloud and haze opacity at the day-night planetary terminator are considered responsible for obscuring the absorption-line wings, which hinders constraints on absolute atmospheric abundances. Here we present an optical transmission spectrum for the 'hot-Saturn' WASP-96b obtained with the Very Large Telescope, which exhibits the complete pressure-broadened profile of the sodium absorption feature. The spectrum is in excellent agreement with cloud-free, solar-abundance models assuming chemical equilibrium. We are able to measure a precise, absolute sodium abundance of  $\log \epsilon_{\text{Na}} = 6.9 \pm 0.6 \pm 0.4$ , and use it as a proxy to the planet's atmospheric metallicity relative to the solar value ( $Z_p/Z_s = 2.3 \pm 8.9 \pm 0.4$ ). This result is consistent with the mass-metallicity trend observed for solar-system planets and exoplanets.

**Author(s):** Coel Helliero, Tiffany Kataria, Nathan Mayne, Adam Burgasser, Joanna Barstow, Nikolay Nikolov, Aarynn Carter, David Sing, Hannah R Wakeford, Zafar Rustamkulov, Christiane Helling, Jayesh Goyal, Barry Smalleyo, Benjamin Drummond, Ernst de Mooij, Tom Evans,

**Institution(s):** UCSD, oKeele University, University of Cambridge, University of St Andrews, JPL, University of Exeter, Queens University Belfast, JHU, University of Arizona, University College London, MIT, UCSC, Space Telescope Science Institute, Dublin City Uni

### **223.06 - Transmission Spectroscopy of the Hot Jupiter WASP-79b from 0.6 to 1.650 $\mu\text{m}$ (Kristin Showalter)**

As part of the PanCET program, we are conducting a spectroscopic study of WASP-79b, a Jupiter-size exoplanet orbiting an F-type star in Eridanus with a period of 3.66 days. Building on the original WASP and TRAPPIST photometry of Smalley et al (2012), we are examining HST/WFC3 data ( $1.125\text{--}1.650$   $\mu\text{m}$ ) as well as Magellan/LDSS-3c ( $0.6\text{--}1$   $\mu\text{m}$ ) data via the reduction and light-curve fitting processes described in Stevenson et al, 2014. We will discuss preliminary results, which show indications of a water feature at  $1.4$   $\mu\text{m}$  as well as a possible water feature at  $0.95$   $\mu\text{m}$ . We will also present a comparison to a spectroscopic evaluation conducted via a separate methodology which confirmed the presence of this feature. This suggested water feature makes WASP-79b a target of interest for the approved JWST Director's Discretionary Early Release Science (DD ERS) program, with ERS observations planned to be the first to execute in Cycle 1. Transiting exoplanets were recently approved for 78.1 hours of data collection, and with the delay in the JWST launch, WASP-79b is now a target for the Panchromatic Transmission program. This program will observe WASP-79b for 42 hours in 4 different instrument modes, providing substantially more data by which to investigate this hot Jupiter. Additionally, we will compare WASP-79b to other known hot Jupiters and evaluate the implications for the development and evolution of these systems.

**Author(s):** Sarah M Horst, David Sing, Hannah R Wakeford, Jonathan D Fraine, Kristin Showalter, Nikole K Lewis, Joseph Filippazzo, Kevin Stevenson, Mercedes Lopez-Morales

**Institution(s):** Johns Hopkins University, Cornell University, Space Telescope Science Institute, Harvard Smithsonian Center for Astrophysics

### **223.07 - Cloud Atlas: Heterogeneous Atmospheres of Directly-Imaged Planetary Mass Companions and Exoplanets (Yifan Zhou)**

Condensate clouds contribute to the most uncertainties in the studies ultra-cool atmospheres of brown dwarfs and exoplanets. The exoplanet cloud models urgently require precise examinations from the observations. Time-resolved observations of brown dwarfs, which compare the spectroscopic rotational phase variations of the heterogeneous clouds, have provided tight and non-degenerated constraints on these models. Using Hubble Space Telescope/Wide Field Camera 3 near-infrared direct imaging time-series, I developed new techniques for high-contrast time-resolved precision photometry and extended this method to directly-imaged planetary mass companions and exoplanets. I will present multi-color light curves for a sample of planetary mass companions that show evidence for patchy clouds in their atmospheres. We find color dependences of the rotational modulation amplitudes for these objects, which directly constrains the vertical cloud structures. By comparing the

clouds in brown dwarfs and directly-imaged planetary mass companion, we started to connect the cloud properties of brown dwarfs to lower surface gravity exoplanets. Using these observations, we also measured rotational periods of these objects, which offer an insight into the angular momentum evolutions of planetary mass companions and giant exoplanets.

**Author(s):** Yifan Zhou

**Institution(s):** University of Arizona

### **223.02D - Transmission Spectra of Hot Jupiters through Multiple Broadband Filter Observations(David Kasper)**

We present multi-broadband transit photometry of HD 189733 b and KELT-9 b observed with the 2.3-m Wyoming Infrared Observatory. With an ensemble of Sloan filter observations across multiple transits we create a ultra-low resolution transmission spectra to discern the nature of the exoplanet atmospheres. The photometric time series analyses are performed with a Markov-Chain Monte-Carlo method assisted by a Gaussian-processes regression model. Star spot corrections are employed for the HD 189733 data. We present our results for HD 189733 b which are consistent with previously published findings. We present preliminary z' secondary eclipse results for KELT-9 b in addition to preliminary transmission results. We interpret our results in the general discussion of Hot Jupiter condensates, i.e. clouds and hazes, and the connection between condensates and planetary parameters.

**Author(s):** Cristilyn N. Gardener, Bethany Ray Garver, Daniel Dale, David Jeffrey PeQueen, Daniel Ivan Rivera, Aman Kar, David Kasper, Henry Kobulnicky, Aylin Marie McGough, Hannah Jang-Condell, Kyla L Jarka, Adam D Myers, Jackson Lane Cole

**Institution(s):** University of Wyoming, Seattle Pacific University, Middle Tennessee State University, Embry-Riddle Aeronautical University, Colorado College, San Diego State University

### **223.04D - Estimation of Planetary Photometric Emissions for Extremely Close-in Exoplanets(Jennifer L Carter)**

The fine precision of photometric data available from missions like Kepler provide researchers with the ability to measure changes in light on the order of tens of parts per million (ppm). This level of precision allows researchers to measure the loss of light due to exoplanet transits as well as the light emitted by an exoplanet, or planetary photometric emissions. The planetary photometric emissions are due to the thermal emissions of the exoplanet, and reflected stellar light. In many cases it is assumed that the incident stellar light may be modeled as plane parallel rays. For extremely close-in exoplanets the finite angular size of the host star must be taken into account and the plane parallel ray model breaks down. One consequence of modeling the incident stellar radiation in this manner is the

creation of three distinct zones as opposed to the two zones (day and night) present in the plane parallel ray model. The three zones are the fully illuminated, penumbral, and un-illuminated zones. The existence of the penumbral zone means that more than half of the exoplanet will be at least partially illuminated by the host star. In this work we will present the geometry describing the reflected light of the fully illuminated and penumbral zones and will highlight exoplanets for which the penumbral zone is larger than the fully illuminated zone. We will conclude by comparing the reflected luminosity of the fully illuminated zone to that of an exoplanet modeled assuming plane parallel ray illumination.

**Author(s):** Jennifer L Carter,

**Institution(s):** Union College, University at Albany

### **224 - New Results from the Dark Energy Survey**

#### **224.01 - DES -- The Dark Energy Survey: Introduction, Status and Data Releases(Brian Yanny)**

The Dark Energy Survey (DES) has been mapping 5,000 square degrees of sky for more than five seasons, creating a deep, wide catalog of 300 million galaxy positions, magnitudes, colors and shapes. The current status of DES is presented, with updates on all publically available datasets. An introduction to the analysis techniques used by DES in constraining key cosmology parameters is also given.

**Author(s):** Brian Yanny

**Institution(s):** Fermi Nat'l Accelerator Lab Contributing Team(s): DES Collaboration

#### **224.02 - First Cosmology Results Using Type Ia Supernovae from the Dark Energy Survey(Christopher D'Andrea)**

We present the first cosmological constraints from the Dark Energy Survey - Supernova Program (DES-SN). We briefly describe submitted papers on the DES-SN discovery, spectroscopic selection, photometry, and calibration. Our cosmological analysis ('DES-SN3YR') uses a subsample of 207 spectroscopically-confirmed ( $0.02 < z < 0.85$ ) Type Ia supernovae (SNe Ia) from the first three years of DES-SN, combined with a low-redshift sample of 122 SNe. We highlight key features of our cosmological analysis, detailed in publications on the evaluation of systematic uncertainties, selection bias corrections, and the host-mass step. Although our sample is less than one-third the size of Pantheon, our constraints on the equation-of-state  $w$  are only larger by a factor of 1.4, demonstrating the quality of the DES-SN photometry and our per-SN constraining power. We find our DES SN Ia sample has the lowest intrinsic scatter of any rolling supernova search, inconsistent with the low-redshift sample, and a host-mass step consistent with zero, in tension with previous analyses. We have also used this sample to constrain  $H_0$  using the inverse distance ladder method. As the DES-SN3YR sample is only  $\sim 10\%$  of the quantity of photometrically-



identified SNe Ia in the full five-year DES-SN, we expect to significantly improve our cosmological constraints in future analyses.

**Author(s):** Christopher D'Andrea

**Institution(s):** University of Pennsylvania  
**Contributing Team(s):** The Dark Energy Survey

#### **224.03 - Dark Energy Survey Year 1 Results: Constraints on Extended Cosmological Models from Galaxy Clustering and Weak Lensing(Sujeong Lee)**

We present constraints on extensions of the minimal cosmological models dominated by dark matter and dark energy,  $\Lambda$ CDM and wCDM, by using a combined analysis of galaxy clustering and weak gravitational lensing from the first-year data of the Dark Energy Survey (DES Y1) in combination with external data. We consider four extensions of the minimal dark energy-dominated scenarios: 1) nonzero curvature  $\Omega_k$ , 2) number of relativistic species  $N_{\text{eff}}$  different from the standard value of 3.046, 3) time-varying equation-of-state of dark energy described by the parameters  $w_0$  and  $w_a$  (alternatively quoted by the values at the pivot redshift,  $w_p$  and  $w_a$ ), and 4) modified gravity described by the parameters  $\Omega_0$  and  $\Omega_0$  that modify the metric potentials. We also consider external information from Planck cosmic microwave background measurements; baryon acoustic oscillation measurements from SDSS, 6dF, and BOSS; redshift-space distortion measurements from BOSS; and type Ia supernova information from the Pantheon compilation of datasets. Constraints on curvature and the number of relativistic species are dominated by the external data; when these are combined with DES Y1, we find  $\Omega_k = 0.0020 \pm 0.0037 - 0.0032$  at the 68% confidence level, and  $N_{\text{eff}} < 3.28, (3.55)$  at 68% (95%) confidence. For the time-varying equation-of-state, we find the pivot value ( $w_p, w_a$ ) =  $(-0.91 \pm 0.19 - 0.23, -0.57 \pm 0.93 - 1.11)$  at pivot redshift  $z_p = 0.27$  from DES alone, and ( $w_p, w_a$ ) =  $(-1.01 \pm 0.04 - 0.04, -0.28 \pm 0.37 - 0.48)$  at  $z_p = 0.20$  from DES Y1 combined with external data; in either case we find no evidence for the temporal variation of the equation of state. For modified gravity, we find the present-day value of the relevant parameters to be  $\Omega_0 = 0.43 \pm 0.28 - 0.29$  from DES Y1 alone, and  $(\Omega_0, \Omega_0) = (0.06 \pm 0.08 - 0.07, -0.11 \pm 0.42 - 0.46)$  from DES Y1 combined with external data. These modified-gravity constraints are consistent with predictions from general relativity.

**Author(s):** Sujeong Lee,

**Institution(s):** The Ohio State University, Center for Cosmology and Astro-Particle Physics, The Ohio State University

#### **224.04 - Recent Cosmological Results from Cross-Correlations of DES with CMB Lensing(Eric Baxter)**

Gravitational lensing induces small distortions in the pattern of cosmic microwave background (CMB) fluctuations on the sky. Measurements of these CMB distortions and their correlation

with large scale structure are highly complementary to measurements of galaxy lensing. I will present recent cosmological results obtained by cross-correlating observations of structure from the Dark Energy Survey with measurements of CMB lensing by the South Pole Telescope and Planck.

**Author(s):** Eric Baxter

**Institution(s):** University of Pennsylvania

#### **224.05 - Cosmological Constraints from the DES Y1 redMaPPer Galaxy Cluster Sample(Matteo Costanzi)**

I will present cosmological results from the analysis of the galaxy clusters identified in the Dark Energy Survey Year 1 data. The DES Y1 data is based on optical/near-infrared imaging covering  $\sim 1800$  square degrees of the southern sky, taken from August 31, 2013 to February 9, 2014 by the Dark Energy Camera mounted on the 4-m Blanco telescope at Cerro Tololo Inter-American Observatory in Chile. For this analysis we combine cluster abundance and weak lensing mass measurements from DES Y1 data to simultaneously constrain cosmology and the observable-mass relation. The catalog contains 6504 clusters having richness greater than 20 in the redshift range  $0.2 < z < 0.65$ . For the mass estimates we rely on the stacked weak lensing analysis of the DES Y1 data which provides mean cluster masses for 12 bins spanning the relevant richness and redshift range. Thanks to the wide redshift range probed by the survey and the precise mass calibration, we are able to place constraints on the amplitude of matter fluctuations and the matter density which are competitive with the latest results from other probes of Large Scale Structure.

**Author(s):** Matteo Costanzi

**Institution(s):** INAF Trieste  
**Contributing Team(s):** Dark Energy Survey Collaboration

#### **224.06 - Recent Results in the $z < 10^{-10}$ Universe from the Dark Energy Survey(Stephanie Hamilton)**

The Dark Energy Survey (DES) is an ongoing cosmological survey in its sixth and final year on the 4-m Blanco telescope in Chile. DES is imaging 5000 sq. deg. of the Southern hemisphere sky in the grizY passbands to a limiting magnitude of  $r \sim 23.5$ . The combination of depth and area that makes DES a powerful probe of the dark energy equation of state also makes DES an invaluable tool for a wide variety of other science. In this talk, we present on the status of research within DES in the  $z < 10^{-10}$  universe. We will discuss recent results from the Milky Way working group on satellite dwarf galaxies and stellar streams. We will additionally discuss new results from the Solar System group regarding discoveries and dynamical analysis of Kuiper Belt Objects.

**Author(s):** Stephanie Hamilton

**Institution(s):** University of Michigan  
**Contributing Team(s):** Dark Energy Survey Collaboration

## **225 - Computation, Data Science, and Image Analysis**

### **225.01 - Point Spread Function Modelling and Spectro-perfectionism for Radial Velocity Spectrographs(Ryan Richard Petersburg)**

In the search for earth-like exoplanets, multiple radial velocity echelle spectrographs calibrated by ultra-precise laser frequency combs (LFCs) are being commissioned, enabling novel methods in the extraction of high-resolution spectra. Spectro-perfectionism, first devised by Adam Bolton and David Schlegel for the Sloan Digital Sky Survey spectrograph, incorporates information about the instrument's point spread function (PSF) to increase the signal-to-noise of the data and extract spectra above the diffraction-limited resolution of the spectrograph. We implement a similar technique in the extraction pipeline of the Extreme Precision Spectrograph (EXPRES) and compare it to the current standard, optimal extraction. To accurately measure the PSF of EXPRES, we have built a 500 GHz LFC, based on an aluminum nitride resonating waveguide developed by the Yale Nanodevices Lab. This device allows us to parameterize the two-dimensional analytic form of our instrument's PSF across the entire spectral range of the echellogram. We then apply this PSF to a Gold deconvolution algorithm that deconvolves the image to the sampling limit of the detector. Current results have shown a significant increase in both signal-to-noise and resolution for LFC and stellar spectra taken by EXPRES.

**Author(s):** Joel Ong, Ryan Richard Petersburg, Debra Fischer, Alexander Bruch, Hong Tang

**Institution(s):** Yale University Contributing Team(s): Yale Exoplanet Lab, Yale Nanodevices Lab

### **225.03 - Artificial Intelligence and Heliophysics: How Deep Learning and Data from the NASA Solar Dynamics Observatory's Atmospheric Imaging Assembly Resuscitated a Short-circuited Satellite(Richard Galvez)**

As our society becomes ever more reliant on space-based technology, any disruption to these systems inevitably translates to economic and personal losses. For example, unreliable global positioning systems disrupt operations that require high-precision geolocation, and perturbations to upper atmosphere and ionosphere of the Earth disrupts the propagation of radio waves used for long-distance communication and space-based communications. Extreme ultraviolet radiation (EUV) emanating from the Sun has profound effects on the upper atmosphere and ionosphere here on Earth. These high energy photons ionize and subsequently heat the upper atmosphere, causing strong variations on atmospheric density. Satellites in low-earth orbit can hence experience a significant drag making mission planning and orbit estimation very difficult. Atmospheric models that predict the state of the ionosphere therefore require good estimates of the spectrum of UV radiation coming from the Sun. The MEGS-A instrument onboard the Solar Dynamics Observatory (SDO)

was designed to provide such spectral measures in the EUV between 5 - 37 nm. Unfortunately, after about five years of observation, the MEGS-A instrument suffered an anomaly and has no longer been functional. As a result, no measures of lines shorter than 37 nm are available. Meanwhile, the SDO also has the atmospheric imaging assembly (AIA), an instrument designed to image the Sun at seven EUV channels, which is currently operational. There exists four years of operational overlap in the frequencies spanned by EVE MEGS-A and the AIA images; may it be possible to use modern advances in machine learning algorithmic research to learn the mapping from one instrument to the other? In this talk results are presented where a modified convolutional deep learning model was showed to be successful for this purpose, and to what extent. Additionally, comments on how casual structure can be introduced to deep learning problems will be discussed.

**Author(s):** Richard Galvez

**Institution(s):** New York University Contributing Team(s): Nasa Solar Dynamics Observatory

### **225.04 - Time Domain Astronomy with the 3.5-m Space Surveillance Telescope Data Archive(Deborah Freedman Woods)**

The Space Surveillance Telescope (SST) science program is a big data analytics project to reprocess five years of archival image data from the 3.5-m SST to identify variable stars and other transient phenomena. The image archive covers 30,000 square degrees of sky with at least 25 revisits, of which there are 15,000 square degrees with at least 400 revisits. Data processing is enabled by the Lincoln Laboratory Supercomputing Center (LLSC), where the operations are scaled for massively parallel computing. An initial subset of the data covering 600 square degrees of sky has been processed to date, from which over 6,000 periodic variable stars have been identified. An ensemble of five algorithms are used to test each source for variability, which helps solve the common problems of period aliasing and identifying period harmonics, with the exception of half-period identification for eclipsing binaries. The relative accuracy of these period-finding algorithms against estimated period, average magnitude, and classification type is discussed. The methods optimized for this analysis will be applied to processing the rest of the SST image archive and these techniques may help to inform upcoming sky-survey projects like the Large Synoptic Space Telescope (LSST). Distribution Statement A. Approved for public release: distribution unlimited. This material is based upon work supported by the United States Air Force and the National Aeronautics and Space Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Air Force or the National Aeronautics and Space Administration. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

**Author(s):** Erin Main, Kaylee de Soto, Deborah Freedman Woods, Umaa Rebbapragada, Vijay Gadepally, Jacob Varey, Jessica Ruprecht, Ashish Mahabal, Nathan Lauer  
**Institution(s):** MIT Lincoln Laboratory, Jet Propulsion Laboratory, California Institute of Technology, MIT, California Institute of Technology

### **225.07 - A deep learning approach to observational cosmology with Supernovae(Johanna Pasquet)**

Future large surveys like the Large Synoptic Survey Telescope (LSST) aim to increase the precision and accuracy of observational cosmology. In particular, LSST will observe a large quantity of well-sampled type Ia supernovae (SNIa) that will be one of the major probes of dark energy. However the spectroscopic follow-up for the identification of SN and the redshift estimation of their host galaxy will be limited. Therefore new automatic classification and regression methods, that exploit the photometric information only, become indispensable. We have developed two separate deep convolutional architectures to classify SN light curves and estimate photometric redshifts. PELICAN (deeP architecture for the LIght Curve ANalysis) is designed to characterize and classify light curves from multi-band light curves only. Despite using a small and non-representative spectroscopic training dataset (2,000 LSST simulated light curves) PELICAN is able to detect 85% of SNIa with a precision higher than 98%. The second Convolutional Neural Network (CNN) was developed to estimate galaxy photometric redshifts and associated probability distribution functions. We tested it on the Main Galaxy Sample of the Sloan Digital Sky Survey (DR12). The input consisted of 64x64 ugriz images and the CNN was trained with 80% of the statistics. We obtained a standard deviation  $\sigma_f(\Delta z)$  of 0.0091 ( $\Delta z = (z_{\text{spec}} - z_{\text{phot}})/(1 + z_{\text{spec}})$ ) with an outlier fraction of 0.3%. This is a significant improvement over the current state-of-the-art value ( $\sigma_f \sim 0.0120$ , Beck et al. 2016). Using SNIa candidates that were well-classified by PELICAN and whose host galaxy photometric redshifts were estimated by the CNN, we are able to construct a Hubble Diagram from photometric information only. The bias introduced by the methods compared to a spectroscopic analysis will be presented.

**Author(s):** Johanna Pasquet

**Institution(s):** CPPM, Aix Marseille University

### **225.02D - Evaluating the Effectiveness of Current Atmospheric Refraction Models in Predicting Sunrise and Sunset Times(Teresa Wilson)**

The standard value for atmospheric refraction on the horizon of 34', used in all publicly available sunrise and sunset calculators, is found to be inadequate. The assumptions behind atmospheric models that predict this value fail to account for real meteorological conditions. The result is an uncertainty of one to five minutes in sunrise and sunset predictions at mid-latitudes

( $\sim \pm 55''$  N/S). A sunrise/set calculator that interchanges the refraction component by varying the refraction model was developed. Two atmospheric refraction models of increasing complexity were tested along with the standard value. The predictions were compared with data sets of observed rise/set times taken from Mount Wilson Observatory in California, University of Alberta in Edmonton, Alberta, observations from various locations in Chile, and on-board the SS James Fergus in the Atlantic Ocean. Increasing the complexity of the model did not yield significantly better results. These observations make up the entirety of documented sunrise and sunset times. A thorough investigation of the problem requires a more substantial data set of observed rise/set times and corresponding meteorological data from around the world. A mobile application, Sunrise & Sunset Observer, was developed so that anyone can capture this astronomical and meteorological data using their smartphone as part of a citizen science project. Data analysis will lead to more complete models that will provide higher accuracy rise/set predictions to benefit astronomers, navigators, and outdoorsmen everywhere.

**Author(s):** Jennifer Lynn Bartlett, James L. Hilton, Robert Nemiroff, Teresa Wilson,

**Institution(s):** Michigan Technological University, US Naval Observatory

### **225.06D - Improving EoR power spectrum limit through hybrid interferometric calibration of the Phase II of the Murchison Widefield Array(Wenyang Li)**

The Epoch of Reionization (EoR) is the period when the first generation of stars and galaxies formed and started to ionize the predominant neutral intergalactic medium. The scenario of the EoR remains largely unexplored in the history of the universe. One promising tool to detect the EoR is known as 21 cm tomography, which utilizes the 21 cm emission from hyper-fine energy level transition in neutral Hydrogen to make a 3d map of the neutral medium over the history. However, interferometric arrays seeking to measure the 21 cm signal from the EoR must contend with overwhelmingly bright emission from foreground sources. Accurate recovery of the 21 cm signal will require precise calibration of the array, and several new avenues for calibration have been pursued in recent years, including methods using redundancy in the antenna configuration. The newly upgraded Phase II of Murchison Widefield Array (MWA) is the first interferometer that has large numbers of redundant baselines while retaining good instantaneous UV coverage. This array therefore provides a unique opportunity to compare redundant calibration with sky-model-based algorithms. We present our hybrid approach using both sky-model-based and redundancy-based algorithms in detail. By analyzing the MWA Phase II EoR high band data, as well as our calibration simulation, we conclude that our hybrid method improves the power spectrum limit. Having been equipped with the improved method, we further show the deep analysis on the power spectrum from 40 hours of Phase II EoR high band observations in 2016.

**Author(s):** Wenyang Li

**Institution(s):** Brown University Contributing Team(s): MWA collaboration

## **226 - Extrasolar Planets: Characterization & Theory Track 2: VII. Orbital Dynamics, Atmospheric Escape, and Star-Planet Interactions**

### **226.01 - Dynamical Constraints on the HR 8799 Planets with GPI(Jason Jinfei Wang)**

The HR 8799 system uniquely harbors four young super-Jupiters whose orbits can provide insights into the system's dynamical history and constrain the masses of the planets themselves. Using the Gemini Planet Imager (GPI), we obtained down to one milliarcsecond precision on the astrometry of these planets. In our orbit fits, we added the prior that the planets must have been stable for the age of the system (40 Myr) by running potential orbit configurations through N-body simulations and varying the masses of the planets. We found that only assuming the planets are both coplanar and near 1:2:4:8 period commensurabilities produces dynamically stable orbits in large quantities. Our posterior of stable coplanar orbits tightly constrains the planets' orbits, and we discuss implications for the outermost planet b shaping the debris disk. A four-planet resonance lock is not necessary for stability up to now. However, planet pairs d and e, and c and d, are each likely locked in two-body resonances for stability if their component masses are above 6 and 7 Jupiter masses, respectively. Lastly, we combine the dynamical and luminosity constraints on their masses. This work benefited from NASA's NExSS (NNX15AD95G) research coordination network sponsored by NASA's Science Mission Directorate.

**Author(s):** Robert De Rosa, Jason Jinfei Wang, Daniel Fabrycky, James Graham, Rebekah Dawson

**Institution(s):** UC Berkeley, Penn State University, Caltech, Stanford, University of Chicago Contributing Team(s): GPIES Collaboration

### **226.03 - Death Stars? Understanding how tight binaries impact TESS planets with SOAR speckle imaging(Carl Ziegler)**

It is not well understood how planetary systems can form and survive in the dynamically active region around close binaries. It is known that planets are suppressed in these systems, but, in general, the Kepler systems were too distant to resolve binaries at solar-system scales. The TESS planets are significantly closer (~80% within 200 pc), however, making it possible for ground-based instruments to detect the tight stellar companions that most sculpt or destroy planetary systems. High-resolution observations are also needed to vet every TESS planet candidate, checking for potential false positive signals and correcting the planetary radii, often initially underestimated due to transit dilution due to photometric contamination. The large number of planets TESS is detecting means a

comprehensive survey is not feasible on conventional instruments. We are using SOAR speckle imaging to observe every Southern bright ( $I < 12$ ) and near ( $d < 200$  pc) TESS planet host, approximately 1500 targets in total. SOAR speckle imaging is optimized for efficiency, routinely observing up to 300 targets a night, and achieves similar performance to adaptive optics systems on bright stars. SOAR can detect binaries at least as close as Neptune's orbit for every system in the survey. We expect to find approximately fifty tight binary systems, the properties of which will provide insight into how the presence of a secondary body shapes planet formation and evolution.

**Author(s):** Andrew Mann, Carl Ziegler, Andrei Tokovinin, Nicholas Law

**Institution(s):** University of Toronto, University of North Carolina, Chapel Hill, Cerro Tololo Inter-American Observatory

### **226.05 - Probing Terrestrial Exoplanet Atmospheric Escape By Observing H<sub>2</sub>O and CO<sub>2</sub> Isotopologue Bands with the James Webb Space Telescope(Andrew Lincowski)**

Terrestrial planets orbiting M dwarfs may soon be observed with the James Webb Space Telescope (JWST) to characterize their atmospheric composition and search for signs of habitability or even life. However, due to the super-luminous pre-main-sequence phase of the M dwarf host stars, their terrestrial planets may undergo significant atmospheric and ocean loss. Past atmospheric escape from terrestrial planets, especially around M dwarfs, may compromise the planet's habitability and leave behind abiotically generated oxygen, which could be a false positive for the detection of life. Consequently, determining if ocean loss has occurred will help assess a planet's habitability and whether or not any O<sub>2</sub> detected is biogenic. In the Solar System, differences in isotopic abundances have been used to infer the history of ocean loss and atmospheric escape (e.g. Venus, Mars). We find that similar measurements using transit transmission spectra of terrestrial planets around late-type M dwarfs like TRAPPIST-1 are within the observation capabilities of JWST, if the escape mechanisms and resulting isotopic fractionation are as severe as experienced by Venus (~D/H=100 times Earth's). Isotopologue bands are present throughout the near-infrared (1-8  $\mu$ m), including unique bands between 3-4  $\mu$ m. We present analyses of O<sub>2</sub>- and CO<sub>2</sub>-dominated atmospheres, containing a range of trace gas abundances. Transit signals of up to 100 ppm are possible for both HDO and <sup>16</sup>O<sup>12</sup>C<sup>18</sup>O isotopologues with fractionation of 100 times Earth's D/H or 180/160, respectively, when CO<sub>2</sub> is not the bulk gas. For TRAPPIST-1 b, the most likely in that system to have experienced ocean loss, these signals can be detected in 10 transits to attain S/N=5, with optimal use of JWST NIRSpec Prism. Consequently, H<sub>2</sub>O and CO<sub>2</sub> isotopologues could be used as indicators of ocean loss and atmospheric escape when planning observations with JWST of terrestrial planets around M dwarfs.

**Author(s):** Jacob Lustig-Yaeger, Victoria Meadows, Andrew Lincowski

**Institution(s):** University of Washington

**226.06 - Probing the Escaping Exoplanet Atmospheres with the Helium 1083 nm Line(Antonija Oklopčič)**

Atmospheric escape or mass loss is an important process in the evolution of atmospheres of extrasolar planets. However, there are many aspects of atmospheric escape that remain poorly understood, in part due to a small number of direct observations, obtained mostly via transit spectroscopy in the difficult-to-observe hydrogen Lyman-alpha line. In recent theoretical work (Oklopčič & Hirata, 2018), we demonstrated that the absorption line of helium at 1083 nm can be used as a powerful new diagnostic of escaping atmospheres. This line is accessible for ground-based observations using high-resolution spectrographs, which can enable more detailed studies of extended atmospheres for a much larger number of exoplanets than realistically possible with UV spectroscopy. Shortly after the theoretical prediction, excess absorption in the helium line was observed in WASP-107b (Spake et al., 2018) and HAT-P-11b (Allart et al., in press; Mansfield et al., in prep.). I will present new, improved theoretical models of upper planetary atmospheres used to interpret the observed 1083 nm transit absorption signatures and place constraints on the physical properties of extended exoplanet atmospheres. Observations in the helium 1083 nm line opened a new wavelength window into escaping atmospheres; by comparing the data with theoretical models, we can improve our understanding of the physical processes that drive atmospheric mass loss and, consequently, affect planetary evolution and demographics of planetary systems.

**Author(s):** Antonija Oklopčič

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

**226.07 - Constraining neutral hydrogen outflow and stellar host Lyman- $\alpha$  reconstruction for transiting super-Earth GJ1132b(William Waalkes)**

GJ 1132b is one of the few known Earth-sized planets, and at 12pc away it is also one of the closest known transiting planets. At 20x Earth insolation, this planet is too hot to be habitable but we can use it to learn about the presence and volatile content of rocky planet atmospheres around M dwarf stars. Using Hubble STIS spectra obtained during primary transit, we search for a Ly $\alpha$  transit. If we were to observe a deep Ly $\alpha$  transit, that would indicate the presence of a large neutral hydrogen envelope flowing from GJ 1132b. On the other hand, ruling out deep absorption from neutral hydrogen may indicate that this planet is not losing large amounts of neutral hydrogen, indicating it has either retained its volatiles or lost them very early in the star's life. We do not conclusively detect a transit but report a quantitative upper limit on the effective size of the cloud. We also analyze the stellar variability and Ly $\alpha$  spectrum of GJ 1132, a slowly-rotating 0.18 solar mass M dwarf with previously uncharacterized UV activity. Understanding the role

that UV variability plays in planetary atmospheres and volatile retention is crucial to assess atmospheric evolution and the habitability of cooler rocky planets.

**Author(s):** Eliza Kempton, Vincent Bourrier, Zachory Berta-Thompson, Elisabeth Newton, Jason Dittmann, Jonathan Irwin, David Ehrenreich, William Waalkes, David Charbonneau

**Institution(s):** University of Colorado, Boulder, Smithsonian Astrophysical Observatory, Harvard, Observatoire de Geneve, MIT, Grinnell

**226.02D - Constraining Exoplanet Properties Through Indirect Dynamical Methods(Juliette Becker)**

The wealth of data available for studying exoplanets allows for two new modes of analysis: large scale, population-wide exoplanet demographic studies and specific modeling of individual systems. These two efforts have been the main focus of my PhD, the goal of which has been the dynamical classification and study of exoplanet systems. To do this, I have studied several individual systems in depth. In the WASP-47 system, I discovered two new planets and used radial velocities, transit timing variations, and transit photometry to derive a deeper knowledge about this system, which contains to date the only hot Jupiter known to have short-period planetary companions. In the HIP 41378 system, I used numerical simulations and Bayesian statistical techniques to derive planet properties which were not immediately clear from the short-baseline data. These specific systems have spurred me to approach population-wide questions to explain the origin of the planet properties I measured. To do this, I have developed methods for deriving insights about classes of exoplanet systems (in particular, hot Jupiter hosting stars as a test case) from potentially biased sets of observational data. Additionally, I have used secular Laplace-Lagrange theory to model the dynamical interactions in multi-planet systems, using the observational sample as a starting point. The goals of these studies were to understand the components of multi-planet systems and systems containing hot Jupiters, with a specific emphasis at the intersection of those two sets, and the result is new conclusions about the distributions underlying the population of exoplanets in the galaxy.

**Author(s):** Juliette Becker

**Institution(s):** University of Michigan

**226.04D - On the Dynamics of Protoplanetary Disks(John Jacob Zanazzi)**

Protoplanetary disks are disks of gas and dust orbiting young stars which form planetary systems. This thesis is devoted to understanding how gravitational interactions in different astrophysical situations effect the structure and dynamical evolution of protoplanetary disks, shaping the planetary systems the disks give birth to. We show how disk warping in a hydrodynamical disk torqued by a spinning central star and inclined binary companion affects the disk's structure and

drives its long-term evolution. We look at how photoevaporation and the formation of a massive, short-period planet modifies the excitation between the spin-axis of a spinning oblate star and angular momentum axis of a protoplanetary disk generated by the gravitational torque from an inclined binary companion. We derive the conditions a protoplanetary disk must satisfy to undergo the Lidov-Kozai instability, where the disk's eccentricity grows from the gravitational torque exerted on the disk by an inclined binary companion. We derive the conditions a protoplanetary disk around an eccentric binary must satisfy to evolve into an orientation perpendicular to the binary's orbital plane (polar alignment). We show an extended circumplanetary disk can remain stably tilted out of the planet's orbital plane, provided the torques from the oblate planet and disk self-gravity are sufficiently strong to resist the tidal torque from the planet's host star.

**Author(s):** Dong Lai, John Jacob Zanzaki,

**Institution(s):** Canadian Institute for Theoretical Astrophysics, Cornell University

## **227 - Recent Exoplanetary Microlensing Discoveries as Pathfinding and Community Building for WFIRST**

### **227.01 - The Interior Structure and Formation of Low-Mass Planets(Leslie Anne Rogers)**

Sub-Neptune, super-Earth size exoplanets are a new planet class. Though absent from the Solar System, they are found by microlensing, radial velocity, and transit surveys to be common around distant stars. In this talk, I'll review both recent developments and outstanding puzzles in our understanding of the nature and origin of these enigmatic planets. I'll especially highlight the new insights expected from the WFIRST exoplanet microlensing survey.

**Author(s):** Leslie Anne Rogers

**Institution(s):** University of Chicago

### **227.02 - The Occurrence Rate of Giant Planets around M Dwarfs(Benjamin Montet)**

Radial velocity and transit surveys have allowed us to detect thousands of planets around other stars, but both methods are biased towards short period planets. This bias can be seen in the distribution of known planets: the median confirmed planet has an orbital period of only 11 days. For either technique, planets in wider orbits typically require long observing campaigns to discover, and observational biases mean their signals are harder to detect. However, these time constraints can be shortcut by combining multiple techniques. In particular, a giant planet in a wide orbit around its host star will manifest itself as a long-term trend in radial velocity data. By combining these data with high contrast imaging observations of the host star, which would detect stellar and brown dwarf companions that could also explain this long-term trend, the presence of a planet can be inferred. I will describe how this

method can be used to determine the occurrence rate of giant planets in wide orbits around M dwarfs, and how that occurrence rate varies with stellar mass and metallicity. I will also discuss how new instrumentation and future surveys will enable us to improve this measurement, and how these results can be combined with microlensing data to understand variations in planet occurrence across the galaxy.

**Author(s):** Benjamin Montet

**Institution(s):** University of Chicago

### **227.03 - Probing Exoplanet Populations with Kepler and Microlensing(Courtney Dressing)**

The NASA Kepler mission revolutionized exoplanet studies by discovering that planetary systems are common and that close-in small planets are surprisingly abundant. Although Kepler did detect two dozen planet candidates with periods longer than 300 days and radii smaller than 2 Earth radii, the transit method is inherently more sensitive to planets orbiting close to their parent stars because the geometric likelihood and frequency of transits declines with increasing orbital period. In contrast, microlensing surveys are most sensitive to colder planets orbiting near the Einstein ring radius at distances of a few AU. Combining transit and microlensing data is therefore a powerful way to probe the overall architectures of planetary systems. I will discuss the advantages and challenges of combining information from multiple planet detection methods and review our current knowledge of exoplanet demographics.

**Author(s):** Courtney Dressing

**Institution(s):** University of California, Berkeley

### **227.04 - Microlensing Results Challenge the Core Accretion Run-away Growth Scenario for Gas Giants(Daisuke Suzuki)**

The favored core accretion model of planet formation predicts a deficit of planets between the masses of Neptune and Saturn. This planet desert is a consequence of the runaway gas accretion process, which is thought to cause protoplanetary cores of about 10 Earth masses to rapidly grow to ~300 Earth masses rapidly through rapid accretion of Hydrogen and Helium gas. This process is expected to result in Jupiter-like planets and more numerous ~10 Earth mass failed Jupiter cores, in cases when the gas disk dissipated before runaway accretion could begin. This prediction can be tested with a comparison to results from ground-based microlensing surveys, which is sensitive to planets down to an Earth mass orbiting beyond the snow line. In this talk, we compare the microlensing measurement of the planet mass-ratio distribution to population synthesis models based on the core accretion theory. We show that the models predict ~10 times fewer planets at mass-ratios of  $10^{-4} < q < 4 \times 10^{-4}$  than found by the microlensing observations. This implies that the formation of gas giants may involve more complicated processes than assumed by the standard core accretion theory. Or, it implies

that the planet formation process may vary significantly as a function of host star mass, because the population synthesis models have been calibrated for planets around solar-type stars while microlensing observations are biased toward lower-mass stars. Finally, we briefly discuss the mass measurements of host stars (and planets) that the WFIRST microlensing survey will make for most planetary microlensing events.

**Author(s):** Dave Bennett, Chirstoph Mordasini, Shigeru Ida, Daisuke Suzuki

**Institution(s):** ISAS / JAXA, ELSI / Tokyo Tech, NASA / GSFC, University of Bern

### **227.05 - Exoplanet Populations beyond Kepler(Illaria Pascucci)**

We present a framework to extend exoplanet occurrence rates beyond the semi-major axis probed by Kepler. Using this framework we find that the most common planet inside the snowline scales with the mass of the central star and it is  $\sim 1/43$ -10 times less massive than the one outside, as identified via microlensing. By extending the Kepler statistics with RV data, we also find evidence for a drop in the giant planet occurrence rate beyond the snowline. We conclude by discussing the implications of these results on future missions.

**Author(s):** Andrew Gould, Rachel Fernandes, Illaria Pascucci, Gijs Mulders

**Institution(s):** LPL, MPIA, Department of the Geophysical Sciences U Chicago Contributing Team(s): Earths in Other Solar Systems team

### **227.06 - The WFIRST Exoplanet Microlensing Survey: Core Science Goals and Predicted Yields(Matthew Penny)**

One of WFIRST's primary mission goals is to conduct an exoplanet microlensing survey in the Galactic bulge. The survey will provide a statistical assay of the cold exoplanet population with masses greater than that of Mars and orbits beyond 1 AU, with a total planet yield comparable to Kepler's. It will also measure the mass function of free-floating planets potentially down into the mass regime of large Kuiper Belt Objects. The WFIRST microlensing survey parameter space spans critical mass and distance scales in planet formation theories, including the ice line, the isolation mass, and the critical mass for runaway gas accretion. I will give an overview of the WFIRST microlensing survey, and highlights of its expected results.

**Author(s):** Matthew Penny

**Institution(s):** Ohio State University Contributing Team(s): WFIRST Microlensing Science Investigation Team

### **227.07 - Mu and You: Public Microlensing Analysis Tools and Survey Data(Savannah Renee Jacklin)**

In the era of big survey astronomy, microlensing is becoming increasingly more accessible to astronomers with a wide variety of backgrounds and expertise. With the advent of public analysis tools, publicly available data, and a multi-tiered data challenge, it is now possible for any interested scientist to find, analyze, and derive physical properties for microlensing events. This is accomplished via a coder's choice of open source microlensing modeling codes, including MuLensModel, PyLIMA, MuLAN, and VBBinaryLensing. These public software tools allow users to fit microlensing light curves and derive the physical quantities of lens systems. These analysis codes are complemented by the release of the first public microlensing survey data sets. In particular, all data from the near-infrared and ongoing UKIRT microlensing survey of the Galactic bulge spanning 2015-2018 are now publicly available via the NASA Exoplanet Archive. Finally, as part of the 2018 Microlensing Data Science challenge, a Jupyter notebook has been created to facilitate interaction with MuLensModel, PyLIMA, and MuLAN in a user-friendly python-based package. The goal of this challenge is to increase the number and diversity of experts to the field of gravitational microlensing, and to recruit scientists with fresh ideas in anticipation of and preparation for WFIRST.

**Author(s):** Savannah Renee Jacklin, Calen Henderson

**Institution(s):** Vanderbilt University, NASA Exoplanet Science Institute, IPAC/Caltech

### **228 - Frontiers of Pulsar Astrophysics**

#### **228.01 - Illuminating a New Population of Rotation-Powered Pulsars(Elizabeth Ferrara)**

The launch of the Fermi Gamma-ray Space Telescope in 2008 provided pulsar astronomers a powerful tool in their hunt for new pulsars. Now, a decade later, we can see how the pulsar population landscape has been changed. The past ten years have witnessed dedicated partnerships of gamma-ray researchers with radio pulsar astronomers, leading to the discovery of several unexpected new classes of pulsars. In addition, powerful new computing algorithms have unveiled many more pulsars not seen outside the gamma-ray regime. We discuss these discoveries, and how regular monitoring of the gamma-ray sky has changed our understanding of both the physics of pulsars and their intrinsic populations.

**Author(s):** Elizabeth Ferrara,

**Institution(s):** University of Maryland, NASA Goddard Space Flight Center Contributing Team(s): Fermi-LAT Collaboration, Fermi Pulsar Search Consortium

#### **228.02 - Basic Physics with Exotic Millisecond Pulsars(Scott M. Ransom)**

Some of the highest profile, and highest impact, results from pulsar timing involve probing the high-density physics at the cores of the neutron stars or testing general relativity in new

and better ways. These efforts almost always involve the rarest and most exotic of recycled binary systems, including those which formed in unusual ways, or those whose orbits or companions were altered later, as often happens in globular clusters. We report recent results, using timing and search observations from the GBT and Arecibo, on several of these exotic systems. We have new and potentially exciting neutron star mass measurements and new tests of general relativity. And we suggest that it is well worth the efforts involved to uncover and examine these "1%" pulsar systems.

**Author(s):** Scott M. Ransom, Bridget Andersen, H. Thakur, Cromartie, Jason Hessels, Ryan S Lynch, Nicholas Clifford, Emmanuel Fonseca, Ingrid Stairs, Paulo Freire, Megan E. DeCesar, Paul Demorest

**Institution(s):** NRAO, McGill University, University of Virginia, MPIfRA, Lafayette College, ASTRON, University of Amsterdam, University of British Columbia, Green Bank Observatory

### **228.03 - Testing General Relativity Using a Pulsar in a Triple System (Anne Archibald)**

The millisecond pulsar PSR J0337+1715 is in a 1.6-day orbit with an inner white dwarf companion, and the pair is in a 327-day orbit with an outer white dwarf companion. This hierarchical triple provides an excellent laboratory to test a key idea of Einstein's theory of gravity, the strong equivalence principle (SEP): do all objects, even those with strong gravity like neutron stars, fall the same way in the same gravitational field? Almost all alternative theories of gravity predict violations of the SEP at some level. We have carried out an intensive program of timing this pulsar, and we are able to perform a very sensitive test of the SEP. I will discuss our methods, our result, and its theoretical implications.

**Author(s):** Anne Archibald, Duncan Lorimer, Jason Hessels, Ryan S Lynch, Scott M. Ransom, Adam Deller, David Kaplan, Ingrid Stairs, Nina Gusinskaia

**Institution(s):** Universiteit van Amsterdam, NRAO, University of British Columbia, University of Wisconsin-Milwaukee, University of West Virginia, Swinburne University of Technology, ASTRON

### **228.04 - The NANOGrav 11-year Data Set: New Insights into Galaxy Growth and Evolution (Maura McLaughlin)**

The NANOGrav collaboration monitors an array of over 70 precisely timed millisecond pulsars with the Green Bank Telescope and Arecibo Observatory in order to detect perturbations due to gravitational waves at nanohertz frequencies. These gravitational waves will most likely result from an ensemble of supermassive black hole binaries. I will present the most recent upper limits on various types of gravitational wave sources and will demonstrate that these limits are already constraining models for galaxy formation and evolution. I will then describe the dramatic gains in sensitivity

that are expected from discoveries of millisecond pulsars, more sensitive instrumentation, improved detection algorithms, and international collaboration and show that detection is possible before the end of the decade.

**Author(s):** Maura McLaughlin

**Institution(s):** West Virginia University Contributing Team(s): NANOGrav Physics Frontiers Center

### **228.05 - Current results and future prospects from PSR J1757-1854, a highly-relativistic double neutron star binary. (Andrew David Cameron)**

Pulsars, rapidly-rotating highly-magnetised neutron stars, can serve as useful laboratories for probing aspects of fundamental physics. Binary pulsars, especially those in tight binary systems with massive, compact companions, are useful in testing different theories of gravity, the current paradigm being General Relativity (GR). Additionally, binary pulsars can also be utilised to explore other areas of fundamental physics, such as the behaviour of matter at ultra-high densities and the neutron star moment of inertia. A standout example is PSR J1757-1854, a 21.5-ms pulsar in a highly-eccentric ( $e=0.61$ ), 4.4-hr orbit around a neutron star companion. This pulsar exhibits some of the most extreme relativistic parameters ever observed in a binary pulsar, reaching a maximum line-of-sight acceleration of close to 700 m/s/s and displaying among the strongest relativistic effects due to gravitational wave damping. To date, five post-Keplerian parameters have been measured in PSR J1757-1854, allowing for three independent tests of gravity to be conducted (of which GR passes all three) and for the component neutron star masses to be separated. The extreme properties of this system (particularly its high eccentricity) are expected to allow for future measurements of Lense-Thirring precession effects (allow for a measurement of the neutron star moment of inertia) and the relativistic deformation of the orbit, both of which remain almost completely unexplored by other binary systems. Although first discovered by the Parkes Radio Telescope in 2016 as part of the High Time Resolution Universe Southern Galactic Plane survey, it is ongoing observations with the Green Bank Telescope (GBT) which have provided the backbone of PSR J1757-1854's continuing study. The large-bandwidth, high-precision observations afforded by the GBT played a fundamental role in delivering the science derived from the pulsar so far, and will be critical in allowing it to reach its full scientific potential going forward. In this talk I will provide a progress report on the ongoing timing of the system, including a review of the latest mass measurements and gravity tests, with an emphasis towards the future science which this pulsar will make possible.

**Author(s):** Duncan Lorimer, Sarah Burke-Spolaor, o, Thomas Tauris, David Champion, Shivani Bhandari, Nihan Pol, Cherry Ng, Willem van Straten, Andrew Jameson, Chris Flynn, Caterina Tiburzi, Michael Keith, Norbert Wex, Maura McLaughlin, Andrew Lyne, Ramesh Karup

**Institution(s):** Dunlap Institute, University of Toronto, oCenter for Gravitational Waves and Cosmology, West Virginia University, Argelander-Institut fuer Astronomie, Universitaet



Bonn, Institute for Radio Astronomy & Space Research,  
Auckland University of Technology,

## **228.06 - New Wide-bandwidth Technologies for Studying Radio Pulsars with the Green Bank Telescope(Ryan S Lynch)**

The Green Bank Telescope (GBT) is a premier instrument for the study of pulsars, enabling advances in a wide range of fundamental physics and astronomy. The GBT has discovered and characterized the fastest spinning and most massive known neutron stars, placing important constraints on the equation of state of ultra-dense matter. The sensitivity and world-leading instrumentation of the GBT has led to precise tests of general relativity and alternative theories of gravity through observations of exotic binary pulsars. The broad radio frequency coverage of the GBT has also made it an excellent complement to pulsar observatories operating in different wavelength regimes, leading to the discovery of dozens of millisecond pulsars. The GBT plays a crucial role in on-going efforts to detect and explore the low-frequency gravitational wave universe via pulsar timing, and in the coming decade it will join other gravitational observatories to study supermassive binary black holes and exotic physics. One of the great strengths of the GBT is its cutting edge radio frequency and digital technology, and new advances in both areas promise to further enhance the GBT's capabilities for pulsar observations. I will discuss two such closely related projects currently underway at the Green Bank Observatory. The first is a new ultrawideband radio receiver that will cover the 0.7-4 GHz band. The detector is being optimized for wide-band, high precision timing of millisecond pulsars for gravitational wave detection, and has the potential to improve timing precision for such experiments by a factor of two. The second project uses new high-speed analog to digital converters and system-on-chip technology to directly sample the radio frequency provided by the ultrawideband receiver, while directly incorporating active identification and removal of man-made interference. Together, these projects will continue to make the GBT one of the best telescopes in the world for the study of radio pulsars.

**Author(s):** Ryan S Lynch

**Institution(s):** Green Bank Observatory Contributing Team(s): Green Bank Observatory

## **229 - First Results from the Kepler/K2 Supernova Experiment**

### **229.01 - Overview of the Kepler/K2 Supernova Experiment(Jessie Dotson)**

The Kepler space telescope was launched in 2009 and spent more than 9 years taking high-precision, high-cadence, uninterrupted light curves of a variety of astrophysical targets - including a large sample of galaxies. Over the first 8.5 years of operation, over 20 supernovae were observed by Kepler/K2 - providing data on novel supernovae including shock breakout and fast evolving luminous transients. The Kepler/K2

supernova experiment was executed during K2's 16th and 17th campaigns (December 2017 - May 2018). The fields of view of these two campaigns were chosen to include a large number of galaxies - which resulted in K2 data of an additional ~ 40 supernovae. In addition, the spacecraft was operated in its "forward facing" orientation - which permitted simultaneous observations of these fields from the ground. I will provide an overview of the Kepler/K2 supernovae dataset as well as discuss complementary observations taken by PanSTARRS1.

**Author(s):** Jessie Dotson

**Institution(s):** NASA Ames Research Center

### **229.02 - Type II Supernovae with K2/Kepler(Peter Garnavich)**

We discovered two transient events in the original Kepler field with light curves that strongly suggest they are type II-P supernovae. A handful of additional candidate type II-P events have been detected in the K2 data, although none are as spectacular as the two observed during the Kepler mission. The original Kepler events, KSN2011a and KSN2011d, provided high-quality light curves from their initial rise and were followed to the end of their plateau phase. The well-sampled rise was used to estimate the size of the progenitor star and idealized analytic models allowed us to constraint their explosion energies. The early light curves of the two events were significantly different. KSN2011d displayed an initial brightening that is well-matched by predictions of a shock breakout in a red supergiant star. In contrast, KSN2011a did not show evidence for a shock break out, but its early rise was faster than expected possibly due to the supernova shockwave moving into pre-existing wind or mass-loss from the RSG.

**Author(s):** Robert Olling, Peter Garnavich, Edward Shaya, Armin Rest, Ashley Villar, Brad Tucker, Dan Kasen

**Institution(s):** University of Notre Dame, Space Telescope Science Institute, Australian National University, University of California, Berkeley, University of Maryland, Center for Astrophysics Contributing Team(s): Kepler ExtraGalactic Survey

### **229.03 - A Fast-Evolving, Luminous Transient Discovered by K2/Kepler(Armin Rest)**

For decades optical time-domain searches have been tuned to find ordinary supernovae, which rise and fall in brightness over a period of weeks. Recently, supernova searches have improved their cadences and a handful of fast-evolving luminous transients (FELTs) have been identified. FELTs have peak luminosities comparable to type Ia supernovae, but rise to maximum in <10 days and fade from view in <30 days. Here we present the most extreme example of this class thus far, KSN2015K, with a rise time of only 2.2 days and a time above half-maximum of only 6.8 days. Possible energy sources for are the decay of radioactive elements, a central engine powered by accretion/magnetic fields, or hydrodynamic shock. We show

that KSN2015K's luminosity makes it unlikely to be powered by radioactive isotopes, and we find that the shock breakout into a dense wind most likely energized the transient.

**Author(s):** Richard Mushotzky, Steven Margheim, Francisco Forster, Giovanni Maria Strampelli, David James, Peter Garnavich, Alfredo Zenteno, Victoria Ashley Villaro, Edward Shaya, Chris Smith, Armin Rest, Brad Tucker, David Khatami, Dan Kasen

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Space Telescope Science Institute, University of California, Berkeley, Johns Hopkins University, University of Notre Dame, Australian National University, Cerro Tololo Inter-American Observatory, Universi

#### **229.04 - Kepler Observations of Stripped Envelope Core Collapse Supernovae**

#### **229.05 - K2 Observations of SN 2018oh Reveal a Two-Component Rising Light Curve for a Type Ia Supernova(Georgios Dimitriadis)**

The K2 Supernova Experiment, carried out during the forward-facing Campaigns 16 and 17, provided a unique opportunity for probing the early-time physical processes in Type Ia Supernovae (SNe Ia). The continuous, 30-minute cadence monitoring of ~10,000 galaxies with Kepler, alongside simultaneous observations from the ground, would enable us to study the explosion physics of these events with unprecedented quality. In this talk, we will present the early-time K2 light curve of SN 2018oh, the brightest SN Ia observed by Kepler, that shows an unusual two-component shape, where the flux rises with a steep linear gradient for the first few days, followed by a quadratic rise, as seen for typical SNe Ia. The K2 light curve is supplemented by multicolor Pan-STARRS1 and CTIO 4-m DECam observations, obtained within hours of explosion, that confirm this photometric evolution. SN 2018oh is especially blue during the early epochs, with the first rise-component peaking ~2 days after explosion at a temperature of ~17,500 K. We will compare SN 2018oh to several models that may provide additional heating at these early times, including the collision with a companion star and a shallow concentration of radioactive nickel in the ejecta. While all of these models generally reproduce the early K2 light curve shape, we slightly favor the interaction scenario at a distance of  $\sim 2 \times 10^{12}$  cm with a 1-6 solar mass Roche-lobe-filling companion star.

**Author(s):** Georgios Dimitriadis

**Institution(s):** University of California Santa Cruz

**Contributing Team(s):** K Mission Team, Kepler Extra-Galactic Survey, Pan-STARRS, DECam, ASAS-SN, PTSS/TNTS, Las Cumbres Observatory, ATLAS, Konkoly Observatory, ePESSTO, University of Arizona - Steward Observatory

#### **229.06 - Constraints on the ejecta properties of SN 2018oh from photometry and spectroscopy(Wenxiong Li)**

Supernova (SN) 2018oh (ASASSN-18bt), discovered by ASAS-SN and peaking at  $B=14.31 \pm 0.03$  mag on MJD 58162.7  $\pm$  0.3, is the first spectroscopically-confirmed SN Ia observed in the Kepler field. The continuous monitoring data from Kepler showed an excess emission in its early light curve, placing an interesting constraint on the nature of star companion to the exploding white dwarf (Dimitriadis et al. 2018; Shappee et al. 2018). Here, we present extensive optical, ultraviolet (UV), and near-infrared (NIR) photometry, as well as a dense sampling of optical spectra, for this object. The follow-up observations covered phases from about 18 days before to  $\sim 1400$  days after the peak brightness. SN 2018oh is relatively normal in its photometric evolution, with a rise time of  $18.3 \pm 0.3$  days and  $I^{\text{m15}}(B) = 0.96 \pm 0.03$  mag, but it seems to have bluer  $B-V$  colors (and hence a higher photospheric temperature) than other SNe Ia with similar light curves near peak. We construct the “uvoir” bolometric light curve having peak luminosity of  $1.49 \times 10^{43}$  erg  $\text{s}^{-1}$ . By fitting radiation diffusion models powered by radioactive decay of centrally located  $^{56}\text{Ni}$  and  $^{56}\text{Co}$ , we derive a nickel mass of  $0.55 \pm 0.04 M_{\odot}$  produced in the explosion. It is shown that for the best-fit diffusion model the moment when the luminosity, powered by radioactive material in the center, starts to emerge is +3.85 days after the moment of first light in the Kepler data. Thus the early flux detected by Kepler and ground-based telescopes should have other origins, e.g. the mixing of  $^{56}\text{Ni}$  to the outer layers of the ejecta or interaction between the ejecta and some nearby material (a non-degenerate companion star or CSM). The spectral evolution is characterized by prominent and persistent carbon absorption features. In SN 2018oh, the C II features (especially at  $6580 \text{\AA}$ ...) can be detected from the early phases to about 3 weeks after the maximum light with velocity down to  $\sim 47,000 \text{ km s}^{-1}$ , representing the latest detection of carbon ever recorded in a SN Ia. This indicates that a considerable amount of unburned carbon exists in the ejecta of SN 2018oh and may mix into deeper layers of the ejecta.

**Author(s):** Wenxiong Li, Griffin Hosseinzadeh, Han Lin, David Sand, Jun Mo, Jozsef Vinko, Jujia Zhang, Xiaofeng Wang

**Institution(s):** Tsinghua University, Harvard-Smithsonian Center for Astrophysics, Konkoly Observatory, Las Cumbres Observatory, University of Arizona, Key Laboratory for the Structure and Evolution of Celestial Objects, Yunnan Observatories, University of Szeged C

#### **229.07 - Constraining SNIa progenitor scenarios with K2 observations of SN2018agk(Gautham Narayan)**

We discuss SN2018agk -- one of the spectroscopically confirmed SNIa discovered by the Kepler Extragalactic Survey (KEGS) with K2 during the forward-facing campaign 17. We present the K2 light curve, complemented by multi-band CTIO 4m DECam imaging, and detail the constraints we infer from the observations. We compare our SN2018agk observations to

physical models of type Ia explosions, as well as other K2 SNIa with early-time observations such as SN2018oh. We discuss the implications of these objects for different SNIa progenitor scenarios.

**Author(s):** Gautham Narayan

**Institution(s):** Space Telescope Science Institute  
Contributing Team(s): The KEGS Collaboration

### **229.08 - Searching for Binary Companions in Kepler Type Ia SNe(Victoria Ashley Villar)**

Type Ia supernovae are likely ignited by thermonuclear runaway in carbon/oxygen white dwarfs; however, evidence exists to support both single- and double-degenerate progenitors. Early observations taken within a week of explosion can capture unique signatures of the single-degenerate channel with a companion in our line-of-sight. In particular, we expect a bright, blue precursor event lasting several days due to interaction of the supernova ejecta with a companion star. In this work, we present a comprehensive, statistical search for non-degenerate companions within Type Ia supernova light curves observed with Kepler/K2.

**Author(s):** Victoria Ashley Villar, Armin Rest

**Institution(s):** Harvard, Space Telescope Science Institute (STScI) Contributing Team(s): KEGs

### **229.09 - A Tidal Disruption Event in a Seyfert 2 Observed with K2(Edward Shaya)**

We report on a transient event, in the nucleus of galaxy 2MASX J08565098+2107380 ( $z=0.0817$ ), that occurred in the K2 Campaign 16 field. It was first noticed by PS1 and was followed up spectroscopically and photometrically by several ground based telescopes. K2 monitored it continuously for 79.5 days at 30 minute intervals, starting 15 days before the flux began to rise until more than a month past maximum light. The shape of the light curve (LC) does not match any supernova template, although the luminosity was within the SN range. The time to rise from 1 magnitude below maximum to maximum,  $\sim 24$  days in the rest frame ( $\sim 26$  days observed), was longer than in any reported SN event. And, the smoothly varying flux that appears to be gradually returning to pre-event non-varying levels is not typical of an active galactic nuclei outburst. However, the LC does closely resemble those of previous tidal disruption events (TDE, when a star is tidally disrupted by a black hole and part of the tidal debris gas gradually falls into the black hole), including the diagnostic  $t^{-5/3}$  drop after maximum for at least 100 days after maximum. A Sloan spectrum of the host galaxy from 2005 suggests the host was a Seyfert 2. However, spectra after the start of the event show broad emission lines typical of a Seyfert 1, which means that this is also Changing-Look event. It appears to be a Changing-Look event caused by a tidal disruption of a star. This TDE is one of the best observed TDEs thus far. Here is an opportunity to study a Seyfert 2 undergoing a measurable large perturbation to its fuel consumption.

**Author(s):** Richard Mushotzky, Tiara Hung, Ryan Foley, Peter Garnavich, Edward Shaya, Nathaniel Roth, Armin Rest, Brad Tucker, Maria Drout

**Institution(s):** University of Maryland, STScI, ANU, Carnegie Inst., UC Santa Cruz, Uof Notre Dame

### **229.10 - The K2: Background Survey and uncovering a WZ Sge star in K2(Ryan Gordon Ridden-Harper)**

The Kepler K2 mission has offered the unique ability to study extra-galactic transient phenomena on the scale of minutes-to-hours. Kepler has observed hundreds of thousands of objects, however, for each object, there are a multitude of surrounding pixels that only see background. These background pixels offer a possibility to conduct a large area and high cadence survey for short transient events such as kilonova, GRB afterglows, and other phenomena. I will present the search strategy and the first transients detected in the survey.

**Author(s):** Steven Margheim, Ryan Gordon Ridden-Harper, Peter Garnavich, Edward Shaya, Armin Rest, Brad Tucker

**Institution(s):** Australian National University, Space Telescope Science Institute, University of Notre Dame, University of Maryland, Gemini Observatory Contributing Team(s): Kepler Extra-Galactic Survey, Kepler Guest Observer Office

### **230 - Galaxy Formation and Evolution V 230.01 - A Cosmic Ray-Driven Model for Star Formation(Charles Steinhardt)**

We develop a model for star formation regulated by a combination of a temperature-dependent initial mass function and heating due to a combination of starlight, cosmic rays and at very high redshift, the cosmic microwave background. This produces an attractor, near-equilibrium solution which is consistent with observations of the star-forming "main sequence" over a broad redshift range. Additional solutions to the same equations may correspond to starburst and quiescent galaxies. This model makes several falsifiable predictions, including higher metallicities and dust masses than anticipated at high redshift and isotopic abundances in the Milky Way. It also predicts that stellar mass-to-light ratios are lower than produced using a Milky Way-derived IMF, so that stellar masses and star formation rates for high redshift galaxies will be overestimated. In some cases, this may also transform inferred dark matter profiles from core-like to cusp-like.

**Author(s):** Adam Jermyn, Charles Steinhardt, Jackie Lodman,

**Institution(s):** Niels Bohr Institute, Cambridge University, Cosmic Dawn Center, Caltech, KITP

### **230.02 - LEGO: Wide-Field Mapping of Milky Way Clouds to understand Extragalactic Line Emission(Jens Kauffmann)**

Modern instruments like NOEMA, ALMA, and the IRAM 30m-telescope now allow us to probe molecular emission from other galaxies on a regular basis. Past work focussed on bright lines of, e.g., CO and HCN, but investigations are now increasingly moving on to much fainter species. Line intensities and their ratios provide us with unique tools to assess, for example, the gas temperatures and densities in other galaxies. No other means exist to extract many of these critical parameters. It is therefore essential that we truly understand the physics driving line emission from molecular clouds. Our actual knowledge about the drivers of molecular line emission is, however, extremely limited. Consider HCN, a molecule that is used as a workhorse tracer of dense gas in galaxies. Current extragalactic research usually assumes that emission this molecular traces gas at densities of order  $10^5 \text{ cm}^{-3}$ . First wide-field imaging surveys in the Milky Way, however, demonstrate that this molecule is actually associated with gas of typical densities of order  $10^3 \text{ cm}^{-3}$ . This difference of two orders of magnitude has immediate implications for our understanding of star formation efficiencies in galaxies. LEGO, the first wide-field molecular line imaging survey systematically covering all environments in the Milky Way, currently generates the first comprehensive data set available to study how molecular line emission couples to the conditions in a molecular cloud. I present first results from the IRAM Large Program (about 600h allocated). The data can inform our future analysis of extragalactic molecular clouds, and they tell us important lessons about the formation and dispersion of molecular clouds in the Milky Way.

**Author(s):** Jens Kauffmann

**Institution(s):** Massachusetts Institute of Technology

### **230.04 - Illuminating Galaxy Assembly through Centrally Star Forming Galaxies(Sarah Tuttle)**

In our current understanding of galaxy evolution, we generally consider the inside-out mode to be primary - galaxies build stars and mass from the center outwards, with recent or ongoing star formation continuing in the disk. External processes may disrupt this disk-based star formation, but in general those processes are environmentally driven. We present a sample of spiral galaxies that are star forming centrally but possess reddish disks. This collection of galaxies was discovered in an attempt to select galaxies with ram pressure stripped disks. However, the current sample provided a selection of centrally star forming galaxies found across all environments. Initial selection was done using SDSS imaging and fiber spectroscopy combined with bulge disk decomposition. We will describe the sample and its characteristics relative to the larger SDSS sample. We will also present early integral field spectroscopy for a subset of galaxies, both from the SDSS MaNGA survey, as well as from the HET LRS2 instrument. This allows us to localize star formation and determine if similar

physical processes are driving the star formation across the environmental range.

**Author(s):** Myles McKay, Sarah Tuttle, Stephanie Tonnesen

**Institution(s):** University of Washington, Seattle, Center for Computational Astrophysics

### **230.05 - Dissecting the Anatomy of Bulge and Disk Dominated Galaxies through DARK SAGE(Antonio J Porras)**

We study the present-day connection between galaxy morphology and dark matter or baryonic spin using the semi-analytic model DARK SAGE, which self-consistently tracks the angular momentum of galaxy. Surprisingly, we find that bulge-dominated galaxies have a higher specific angular momentum for the halo than do disk-dominated galaxies. For the stellar component, disk-dominated galaxies have a higher specific angular momentum than bulge-dominated ones, as expected. By examining the size and velocity of our galaxy set, we find that for a fixed stellar mass, disk-dominated galaxies live in dark matter halos that are roughly 1/10th the mass of its bulge-dominated counterpart. We present preliminary results on the implications of these results

**Author(s):** Adam R. H. Stevens, Andreas Berlind, Antonio J Porras, Kelly Holley-Bockelmann

**Institution(s):** Vanderbilt University, International Centre for Radio Astronomy ResearchThe University of Western Australia

### **230.06 - The physics of Lyman-alpha escape from high-redshift galaxies(Aaron Smith)**

Lyman-alpha ( $\text{Ly}\alpha$ ) photons from ionizing sources and cooling radiation undergo a complex resonant scattering process that generates unique spectral signatures in high-redshift galaxies. I will present a detailed radiative transfer study of cosmological zoom-in simulations from the Feedback In Realistic Environments (FIRE) project, focusing on the time, spatial, and angular properties of the  $\text{Ly}\alpha$  emission. Many of the interesting features can be understood in terms of the galaxy's star formation history. I will also discuss my new resonant Discrete Diffusion Monte Carlo (rDDMC) method designed to break the efficiency barrier of Monte Carlo  $\text{Ly}\alpha$  radiative transfer in the high optical depth regime, which will enable fully coupled 3D  $\text{Ly}\alpha$  radiation hydrodynamics in the near future.

**Author(s):** Aaron Smith

**Institution(s):** Massachusetts Institute of Technology

### **230.07 - What drives the velocity dispersion of ionized gas in star-forming galaxies?(Xiaoling Yu)**

We analyze the intrinsic velocity dispersion properties of 648 star-forming galaxies observed by the Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) survey, to explore the relation of intrinsic gas velocity dispersions with star formation

rates (SFRs), SFRs surface density ( $\dot{\Sigma}_{\text{SFR}}$ ), stellar masses and stellar masses surface density ( $\dot{\Sigma}_*$ ). By combining with high  $z$  galaxies, we found that there is a good correlation between velocity dispersion and SFR as well as  $\dot{\Sigma}_{\text{SFR}}$ . But the correlation between velocity dispersion and stellar mass as well as  $\dot{\Sigma}_*$  is moderate. By comparing our results with predictions of theoretical models, we found that neither the energy feedback from star formation processes nor the gravitational instability fully can explain simultaneously the observed relationships with SFR and  $\dot{\Sigma}_{\text{SFR}}$ .

**Author(s):** Rogerio Riffel, Kaike Pan, Jianhang Chen, Yongyun Chen, Rogemar A. Riffel, Yanmei Chen, Songlin Li, Luwenjia Zhou, Yong Shi, Kai Zhang, Xiaoling Yu, Longji Bing, David R Law, Dmitry Bizyaev,

**Institution(s):** School of Astronomy and Space Science, Nanjing University, Space Telescope Science Institute 3700 San Martin Drive, Key Laboratory of Modern Astronomy and Astrophysics (Nanjing University), Ministry of Education, Sternberg Astronomical Institute, Moscow

### **230.08 - A Blind Test of Supervised Machine Learning for Galaxy Classification(Christopher Conselice)**

We present a study on determining the optimal ways in which supervised Machine Learning and Deep Learning can be used to classify galaxies. We carry this out using data from the Galaxy Zoo and Dark Energy Survey to determine how well a series of different Machine Learning methods (e.g., Convolutional Neural Network, K-nearest neighbour, Support Vector Machine, Neural Network, etc) do in predicting correctly the morphologies of spiral and elliptical galaxies. We present the results of this test and demonstrate that the deep learning method of Convolutional Neural Networks is the most successful, with a 99% success rate when using raw images and images after feature extraction. We also show that this method clearly identifies incorrect classifications from Galaxy Zoo, and leads to the (re)-discovery of the lenticular (So) galaxies as those systems with a low probability of being in either the spiral or elliptical class.

**Author(s):** Alfonso Aragon-Salamanca, Ting-Yun Cheng, Christopher Conselice

**Institution(s):** University of Nottingham Contributing Team(s): Dark Energy Survey

### **230.03D - Gas and galaxy evolution in extreme $z \sim 1$ clusters and extreme $z \sim 0.2$ starbursts(John F Wu)**

Intergalactic and interstellar gas play key roles in feeding and regulating the growth of galaxies. In the cluster environments that become more prevalent at lower redshift, ram pressure and tidal forces can vaporize and/or strip galaxies' cold gas and dust, reducing their future potential for star formation. In the field (especially at high redshift), continued availability of cold gas determines the pace and parameters of star formation in Lyman break galaxies (LBGs) and other populations. I will

report on multiwavelength observations of interstellar material in two distinct samples of galaxies that can be considered "extreme" in different ways, and that exemplify the external and internal factors influencing galaxy evolution. First, I will present ALMA and Herschel observations of star-forming galaxies in two  $z \sim 1$  galaxy clusters, which were selected via their Sunyaev-Zel'dovich decrements by the Atacama Cosmology Telescope (ACT) and are therefore among the most massive clusters at their redshifts. Dusty and gas-rich galaxies are found in the central regions of their cluster hosts, indicating that star-forming galaxies are able to maintain substantial gas reservoirs at these redshifts despite hostile environmental effects. Second, I will present VLT/SINFONI near-IR IFU observations of a sample of  $z \sim 0.2$  starbursts that have the highest UV surface brightness seen in the local universe, qualifying them as LBG analogs (LBAs). Intense star formation feedback is implied by high velocity dispersions and evidence of outflows in ionized gas, hard ionizing spectra, and abundant emission from post-shock molecular hydrogen. The LBAs also show an intriguing and unusually small discrepancy between extinction of stellar and nebular emission. This work has been supported by the National Science Foundation via grant AST-0955810.

**Author(s):** John F Wu

**Institution(s):** Rutgers University

### **231 - Milky Way & Galactic Center IV**

#### **231.01 - 3D kinematics of the bulge RR Lyrae stars: a centrally located, retrograde bulge population(Andrea Kunder)**

It has recently been discovered that the RR Lyrae stars (RRLs) typically associated with the Galactic bulge have a different rotation curve than the majority of the stars residing in the bulge. N-body simulations for the Milky Way motivated by these findings predict that the RRL population in the Galactic bulge is consistent with being the inward extension of the Galactic metal-poor stellar halo. Here we study the orbital motions of these "bulge" RRLs, using the proper motions from Gaia DR2, with the goal to assess if their orbits are indeed consistent with being a halo population. More than 50% of the bulge RRLs have orbits confining them to the innermost 2.5 kpc of the Galaxy, and ~80% never leave the innermost ~4 kpc of the Galaxy. This is similar to what is found for the bulge giants tracing out the bulge/bar within the central 3 kpc. However, the RRLs are on more eccentric orbits than the metal-rich giants, and we find that ~60% of the RRLs are on retrograde orbits, consistent with the bulge RRLs being part of an accreted component of the Galaxy, and inconsistent with the bulge RRLs belonging to an in situ formed halo. Within the central 3 kpc, the apocenter and pericenter distribution of the bulge RRLs are similar to that of the giants, indicating these populations follow similar density profiles. If the halo density profile in the bulge is indeed less steep than that of the bulge, the similarity in apocenters indicate that RRLs are not an inward extension of the halo but their own centrally located population.

**Author(s):** Alistair Walker, Roberto De Propriis, David Moise Nataf, Michael Rich, Andrea Kunder, Giuseppe Bono, Jesper

Storm, Dylon Maertens, Christian Johnson

**Institution(s):** Saint Martin's University, Cerro Tololo Inter-American Observatory, INAF, Rome Astronomical Observatory, via Frascati 33, 00040, Monte Porzio Catone, Italy, Finnish Centre for Astronomy with ESO, Finland, Leibniz Institut für Astrophysik (AIP),

### **231.03 - Direct Inference of the Vertical Stellar Age-Velocity Relationship Across the Galactic Disk from APOGEE and Gaia(Jonathan Bird)**

The combination of Gaia, Galactic spectroscopic surveys, and new machine-learning techniques has led to an unprecedented growth in the number and spatial extent of individual stars with precisely measured kinematics and reliable age estimates. With this in mind, we have constructed a probabilistic and empirical model of the stellar age-velocity relationship (AVR) -- the established observational metric of age-dependent kinematics in our Galaxy. The generative model is designed to predict the basic shape of the velocity distribution as a function of age at the Solar radius and any variation in the AVR with Galactocentric radius as well as the intrinsic ages of the observed stars. Here, we use a hierarchical bayesian approach to constrain the model parameters using a sample of Red Clump (RC) stars observed by the spectroscopic APOGEE survey and Gaia, enabling a precise measurement of the AVR across much of the Milky Way disk. Locally, the velocity dispersion is expected to grow as a power-law with age; we find a power-law slope of  $0.389 \pm 0.018$ , consistent with several previous studies. The bulk velocity dispersion of the disk also slowly decreases when moving radially outward from  $\hat{r}^{1/4} 6.5$  kpc to  $\hat{r}^{1/4} 12.5$  kpc. Even after conservative marginalization over all other model parameters, the formal precision of our constraint on the AVR parameters represent a new benchmark given the data sample size. Both the richness of the data and the simplicity of our model contribute to the success of our approach. Our results are a strong endorsement of the spectra-derived masses (and ages) for evolved stars and demonstrate their power when measuring age-dependent trends in the Galaxy, crucial fossil records for Galactic archeology. Our method is immediately extendable to upcoming data sets combining the power of Gaia and stellar ages derived from machine learning, setting the stage to dissect the age-dependent kinematics throughout the Galaxy.

**Author(s):** Jonathan Bird

**Institution(s):** Vanderbilt University

### **231.04 - Using Gaia DR2 to study the kinematics of highly r-process-enhanced stars(Ian Roederer)**

The astrophysical site and environment of the r-process, which produces about half of the heaviest elements on the periodic table, remain hotly debated. We discuss the kinematics of 35 field stars that are highly enhanced in r-process elements, a new advance enabled by parallax and proper motion measurements

from the second data release of the Gaia satellite. We compute six-dimensional positions and velocities, orbits, and integrals of motion (such as energies) for each of these stars, and we identify several kinematic groups of stars using clustering algorithms. We use these results to better understand the environments where r-process-enhanced stars were born. The eccentric orbits and lack of r-process-enhanced stars on disk-like orbits indicate that dwarf galaxy environments with low rates of star formation and iron production may be the key to producing r-process enhanced stars, rather than the nature of the r-process site. The low metallicities of the kinematic groups of stars suggest low-mass progenitor systems ( $M_V > -9$  or so) that were subsequently disrupted through tidal interactions with the Milky Way. I.U.R. acknowledges support from NSF grants AST 16-13536 and AST 18-15403, and K.H. and M.V. acknowledge support from NASA-ATP award NNX15AK79G.

**Author(s):** Monica Valluri, Kohei Hattori, Ian Roederer

**Institution(s):** University of Michigan

### **231.05 - The R-Process Alliance: The Search for R-Process-Enhanced Metal-Poor Stars in the Milky Way(Charli Sakari)**

The rapid (r-) neutron-capture process is responsible for creating the heaviest elements, yet there is still uncertainty about its astrophysical nucleosynthetic site(s). The r-process-enhanced metal-poor stars, which are enhanced in elements like Eu and Ba despite their deficiencies in Fe, will be crucial for understanding the r-process. These stars have retained the nucleosynthetic signature of an r-process event, and can therefore shed light on the yields, occurrence rates, and environments for r-process nucleosynthesis. In this talk, I report on the first results from an observational campaign by the R-Process Alliance (RPA) to identify new r-process-enhanced metal-poor stars; so far, the RPA has discovered >100 new r-process-enhanced metal-poor stars. I will discuss the constraints that these stars place on the site(s) for r-process formation, particularly the additional constraints that come from Gaia DR2 kinematics. Ongoing results from the RPA campaign will continue to shed light on the build-up of the Milky Way halo.

**Author(s):** Charli Sakari

**Institution(s):** University of Washington Contributing Team(s): The R-Process Alliance

### **231.06 - Revealing the origin of elements with the Maunakea Spectroscopic Explorer(Nicolas Flagey)**

Understanding when, where, and how the chemical elements were created remains one of the grand unanswered questions in astronomy and is a driving motivation for building the Maunakea Spectroscopic Explorer (MSE), an 11.25 m wide field telescope that observes more than 4000 targets per pointing, and which feeds fully dedicated banks of low, medium, and high resolution spectrometers. MSE produces the same number of

spectra as the SDSS Legacy Survey every 7 weeks and has flagship programs that aim at solving the debate about the astrophysical locations and details of the stellar nucleosynthesis. US scientists make up more than a quarter of the MSE Science Team that now involves more than 300 astronomers from 30 countries. Here, I will review the scientific potential of MSE for chemical tagging science and describe its strong synergies with facilities like GAIA. Entering the preliminary design phase, I will provide an update on the design of MSE and discuss the opportunities available to partners over the coming months and years.

**Author(s):** Nicolas Flagey

**Institution(s):** Canada-France-Hawaii Telescope Corporation  
Contributing Team(s): The MSE Team

## **232 - ISM & Related Topics I**

### **232.01 - Water Formation From First Supernovae(Alexander Gagliano)**

We report on the integration of a fully-implicit molecular network from Omukai et al. (2008) into Grackle, a chemical and cooling library for cosmological simulations. Our network evolves 26 additional species and is coupled to metal feedback from star formation. The network is valid in low-metallicity regimes and could provide insight into the production of simple molecules during the era of first metal enrichment. We validate this network in the context of Enzo and Gizmo simulations carried out with star formation in large ( $10^7 M_{\odot}$ ) halos, and discuss preliminary results in the case of H<sub>2</sub>O for the first supernovae in the universe.

**Author(s):** Joseph Smidt, Samuel Jones, Brandon K Wiggins, Alexander Gagliano,

**Institution(s):** University of Illinois at Urbana-Champaign, Los Alamos National Laboratory

### **232.03 - Investigating the Structure and Composition of Molecular Clouds in the pre-JWST Era(Laurie Chu)**

Molecular clouds provide us with insight into the earliest stages of star and planet formation. The dust grains within these clouds are a key component in allowing surface chemistry reactions to occur, leading to grain growth and eventually creating the building blocks for planets. However, the process of grain growth still remains poorly understood and requires information about both the dust and ice in the clouds. In order to understand the dust distribution in molecular clouds we have mapped the extinction in five small cores  $\approx 2$  pc in diameter. Utilizing data from UKIRT WFCAM JHK bands and Spitzer IRAC channels 1 and 2 we construct very deep, high spatial resolution extinction maps. We analyze their structure over evolutionary time as we witness these clouds transition from a quiescent stage (B59) into clouds undergoing collapse (LDN 63 and LDN 483) and finally Class 0 star-forming globules (B335 and LDN 694-2). CO maps of each cloud have also been observed in the submillimeter using JCMT. We will present a comparison of the extinction maps with the CO maps

to probe gas-freeze-out effects on dust grains and measure the cloud density. As another key component of molecular clouds, we have preliminary detections of H<sub>2</sub>O and CO ices from observations of bright background sources using IRTF SPeX L and M band spectra. These observations will also aid in planning and obtaining spatially-resolved maps of the ice distribution for the first time through our JWST NIRCам GTO program.

**Author(s):** Michael R. Meyer, Klaus Hodapp, Marcia Rieke, Laurie Chu, Thomas P Greene

**Institution(s):** University of Hawaii, Institute for Astronomy, University of Michigan, University of Arizona, NASA Ames Research Center  
Contributing Team(s): JWST NIRCам Science Team

### **232.05 - The W43 Complex in Radio Recombination Line Emission - First Results from GDIGS(Matteo Luisi)**

The HII region complex W43, located near the end of the Galactic bar and the inner Scutum arm, is one of the most active zones of star formation in the inner Galaxy. Here we present radio recombination line (RRL) data of W43 from GDIGS, a new C-band (4-8 GHz) survey of the Milky Way disk with the Green Bank Telescope. Our data are essentially extinction-free, with higher spatial and spectral resolution compared to previous large-scale RRL surveys. This allows us to determine the distribution and kinematics of the ionized gas. Using the WISE Catalog of Galactic HII Regions, we are able to distinguish between HII region RRL emission and emission tracing diffuse ionized gas known as the Warm Ionized Medium (WIM). We produce WIM-only datacubes and constrain the ionization state of the diffuse gas. We estimate the fraction of photons escaping from individual HII regions within the surveyed area by comparing our data to an empirical model of RRL emission near HII regions. Since these photons are believed to be responsible for maintaining the ionization of the WIM, GDIGS enables us to better understand the connection between HII regions and the WIM within this dynamically complex region.

**Author(s):** Matteo Luisi, Thomas Bania, Loren Anderson, Bin Liu, Dana Balser, L. Matthew Haffner, Trey V Wenger,

**Institution(s):** West Virginia University, Boston University, Chinese Academy of Sciences, University of Virginia, National Radio Astronomy Observatory, University of Wisconsin-Madison, Green Bank Observatory

### **232.06 - Ultraviolet HST Spectroscopy of CO and C I in Planck Cold Clumps(Cody Dirks)**

We report results of the first study utilizing the ultraviolet capabilities of the Hubble Space Telescope to investigate a sample of Planck Galactic Cold Clump (PGCC) sources. We have selected high-resolution spectra toward 25 stars that contain a multitude of interstellar absorption lines associated with the

interstellar medium (ISM) gas within these PGCC sources, include carbon monoxide (CO) and neutral carbon (C I). By building cloud-component models of the individual absorption components present in these spectra, we can identify and isolate components associated with the PGCC sources, allowing for a more accurate investigation of the ISM behavior within these sources. Despite probing a broad range of overall sightline properties, we detect CO along each sightline. Analysis of these sightlines reveals distinctly different behavior between sightlines with high carbon monoxide (CO) column density ( $N(\text{CO}) > 10^{15} \text{ cm}^{-2}$ ) and those below this threshold. We speculate that this may be related to the C I thermal pressure of the gas, though more work is necessary to confirm the nature of this behavior.

**Author(s):** Cody Dirks, Dave Meyer

**Institution(s):** Northwestern University

### **232.02D - Environmental Dependence of Dense Gas and its Relationship to Star Formation (Molly Jean Gallagher)**

Dense gas plays an important role in galactic evolution via its connection to star formation. Yet we are only beginning to explore how gas density and its relationship to the star formation rate (SFR) depend on galactic environment. I will present three comparisons between dense gas, SFR in nearby spiral galaxies. First, I present new ALMA maps of molecular lines that trace dense gas at  $\sim 0.5$  kpc resolution, particularly HCN(1-0). I use these to compare the dense gas fraction and dense gas star formation efficiency (SFE) to the local stellar surface density, molecular gas surface density, and dynamical equilibrium pressure. I find strong trends in both the dense gas fraction and the dense gas SFE with environment. This shows that gas density is influenced by large-scale environmental properties and that dense gas mass does not uniquely determine the SFR. Second, I compare these dense gas maps from ALMA and the EMPIRE survey on the IRAM 30m to high resolution ( $\sim 120$  pc) CO(2-1) maps from the PHANGS-ALMA survey. This allows me to compare the dense gas fraction to the cloud-scale molecular gas surface density in each part of each target galaxy. I find that the dense gas fraction strongly correlates with the cloud-scale molecular gas surface density, suggesting that both quantities reflect the underlying density distribution. These two sets of results together support a view of cold gas in galaxies where conditions in a galaxy determine the density distribution and then both the local dense gas fraction and mean cloud gas surface density reflect this same environment-dependent density distribution. Finally, I use the same ALMA HCN and high-resolution CO to present a preliminary comparison of the dense gas fraction and dense gas SFE to kinematic cloud properties including velocity dispersion.

**Author(s):** Molly Jean Gallagher

**Institution(s):** The Ohio State University  
**Team(s):** EMPIRE team, PHANGS team

### **232.04D - The CHESS Sounding Rocket Science Results: H<sub>2</sub> column densities towards $\hat{\text{I}}^2$ Sco and $\hat{\text{I}}^3$ Ara (Nick Kruczek)**

In this talk, we describe the scientific motivation and technical development of the Colorado High-resolution Echelle Stellar Spectrograph (CHESS) sounding rocket. CHESS is a far ultraviolet bandpass rocket-borne instrument designed to study the atomic-to-molecular transitions within translucent cloud regions in the interstellar medium. The targets for the final two flights of CHESS were  $\hat{\text{I}}^2$  Sco (a B1V star at  $d = 161$  pc) and  $\hat{\text{I}}^3$  Ara (a B1I star at  $d = 689$  pc). We present flight results of interstellar molecular hydrogen excitation, including measurements of the column densities and temperatures, on the sightlines. These results are compared to previous values that were measured using the damping wings of low-J H<sub>2</sub> absorption features in Copernicus spectra. For  $\hat{\text{I}}^2$  Sco, we find that the derived column density of the  $J'' = 1$  rotational level differs by a factor of  $\sim 2$  when compared to the previous measurements. We discuss the discrepancies and show that the source of the difference is likely the opacity of the higher rotational levels contributing to the  $J'' = 1$  absorption wing, increasing the inferred column density in the previous work. We extend this analysis to  $\sim 10$  FUSE spectra to explore the relationship between column densities and the number of rotational levels used to measure them, as well as how that influences the inferred molecular gas properties, such as kinetic temperature.

**Author(s):** Brian Fleming, Nick Kruczek, Kevin France, Nicholas Nell

**Institution(s):** University of Colorado Boulder

### **233 - AGN Jets and Outflows II**

#### **233.01 - Imaging the AGN Torus in Cygnus A (Richard Perley)**

We present the first direct imaging of the thick torus of the active nucleus of the powerful radio galaxy Cygnus A. The observations are made with the Jansky VLA at 34.5 and 44 GHz, with 45 mas resolution. An elongated structure, perpendicular to the radio jets, and centered on the nuclear core, is well resolved with a full length of  $\sim 400$  by 250 pc. The radio emission is reasonably characterized by optically thin free-free emission, with a brightness temperature at radius 100 pc of about 240 K. The implied EM is  $1.2 \times 10^6 \text{ pc/cm}^6$ . The spectrum of the radio core shows a sharp cutoff below 10 GHz, consistent with free-free absorption by gas in the torus. We discuss a simple model of a flaring dusty torus, with the ionization cone oriented along the jet axis roughly in the sky plane. The implied opening angle for the ionization cones is about 60 degrees, and the mean density of the torus is about  $540 \text{ cm}^{-3}$ . The torus gas mass is  $3 \times 10^8$  solar masses. The gas mass is comparable to a rough estimate of the stellar mass within this volume, and the sum of mass in gas and stars within 215 pc radius is a factor 3.5 below the mass of the supermassive black hole. The thermal pressure of the torus is well below the minimum energy pressures in the radio jet, implying the jets are not confined by



the thermal pressure of the ambient medium.

**Author(s):** Vivek Dhawan, Chris Carilli, Daniel Perley, Richard Perley

**Institution(s):** National Radio Astronomy Observatory, Liverpool John Moore University

### **233.03 - AGN feedback in galaxy clusters driven by intermittent accretion of cold gas(KwangHo Park)**

Recent observations of cool core clusters provide evidence that the presence of cold, atomic and molecular gas in their centers is more common than previously expected. This finding has important implications for the fueling of and feedback from the supermassive black holes (SMBHs) located in central cluster galaxies. Motivated by it, we run a suite of 2D and 3D hydrodynamic simulations to study the efficiency of radio-mode feedback driven by intermittent accretion of cold gas on the central SMBH. This type of fueling drives strong and recurrent AGN feedback episodes, whose duty cycle is determined by the presence of cold gas in the vicinity of the central SMBH. We find that intermittent AGN jets, with duty cycles shorter than the gas cooling time scale at the central region, are considerably more effective in suppressing the cooling flow than steady jets, the power of which does not significantly vary over time. Based on this, we suggest that the increased efficiency of AGN feedback is a natural consequence of intermittency driven by accretion of cold gas, and thus this effect plays an important role in preventing runaway cooling in galaxy clusters.

**Author(s):** Yu Qiu, Tamara Bogdanovic, KwangHo Park

**Institution(s):** Georgia Institute of Technology

### **233.05 - On the role of magnetic fields around active galaxies(Enrique Lopez Rodriguez)**

SOFIA's newest instrument, the far-infrared (FIR) polarimeter HAWC+, has made a surprising and unprecedented discovery by observing the prototypical powerful radio galaxy, Cygnus A. Our team previously found high mid-IR (MIR) polarization, and interpreted it as synchrotron emission from the radio core. However, we have now found with the FIR data from HAWC+ that the overall IR polarized flux has an IR bump (i.e. unlike synchrotron emission), which looks essentially identical to the AGN IR bump in the total flux spectrum. In other words, the whole IR bump (from near-IR to far-IR), which is widely attributed to the torus surrounding the hidden AGN, is highly polarized (10%), leaving almost the only mechanism of polarization to be from emission by aligned dust grains. This result suggests that the (unresolved) torus is a well-defined morphological feature, consisting of dusty gas clouds in a global and coherent magnetic field at scales of 10s of pc. Our previous MIR polarimetric observations have shown little polarization, if any, in the nuclei of radio-quiet (RQ) objects-Cygnus A is the only radio-loud (RL) one we have observed so far. This is particularly interesting for two reasons: 1) from the IR to the X-ray, aside from the synchrotron component, the total-flux

spectral energy distributions (SEDs) of RQ and RL AGN are virtually identical; and 2) advected magnetic fields are strongly implicated in almost all models for the launching and collimation of relativistic jets. The torus represents the AGN accretion flow on pc scales, and the FIR polarization found here (and the implied coherent magnetic field) may be the most telling and dramatic empirical difference between RL vs RQ AGN. I will present these results and the interpretation that magnetic fields potentially play a role on the confinement of dust in the torus.

**Author(s):** Makoto Kishimoto, Robert Antonucci, Ranga-Ram Chary, Enrique Lopez Rodriguez

**Institution(s):** SOFIA Science Center, Kyoto Sangyo University, University of California Santa Barbara, CalTech/IPAC

### **233.06 - Testing the IC/CMB model for the anomalous X-ray emission of powerful quasar jets with the Fermi/LAT(Peter Breiding)**

The Chandra X-ray Observatory has discovered kpc-scale X-ray jets in many powerful quasars over the past 2 decades (Harris & Krawczynski, 2006). In many cases, these X-rays cannot be explained by the extension of the radio-optical spectrum produced by synchrotron-emitting electrons in the jet, since the observed X-ray flux is too high and/or the X-ray spectral index is too hard. A widely accepted model for the X-ray emission, first proposed by Celotti et al. (2001) and Tavecchio et al. (2000), posits that the X-rays are produced when relativistic electrons in the jet up-scatter ambient cosmic microwave background (CMB) photons via inverse-Compton scattering from microwave to X-ray energies (the IC/CMB model).

However, modeling the X-ray emission in these jets with the IC/CMB model requires high levels of IC/CMB gamma-ray emission (Georganopoulos et al., 2006), which we have looked for using the Fermi/LAT gamma-ray space telescope. Another viable model for the large scale jet X-ray emission, favored by the results of Meyer et al. (2015) and Meyer & Georganopoulos (2014), is a second population of synchrotron-emitting electrons with up to multi-TeV energies. In contrast with the second synchrotron interpretation, the IC/CMB model requires jets with high kinetic powers (exceeding the Eddington luminosity in some cases), which remain highly relativistic ( $\Gamma \sim 10$ ) up to kpc scales. In this talk, I will present recently obtained deep gamma-ray upper-limits from the Fermi/LAT which rule out the IC/CMB model in a large sample of sources previously modeled with IC/CMB, and discuss the properties of the growing sample of non-IC/CMB anomalous X-ray jets and the implications for jet energetics and environmental impact.

**Author(s):** Eileen Meyer, Mary Keenan, Markos

Georganopoulos, Peter Breiding, Adursh Iyer

**Institution(s):** University of Maryland, Baltimore County, west virginia university

### 233.07 - Radio Emission from MaNGA Outflow Galaxies(Aisha Al Yazeedi)

Large scale outflows from galaxies are typically associated with AGN or star formation activity however it's still unclear how these outflows are generated and how the properties of the outflow are connected to their origins or their hosts. This requires measuring the spatially-resolved properties of the outflow and its host galaxy in multiple wavebands, in order to measure relevant parameters such as level of AGN galactic, rate and distribution of star formation, and geometry, content, and velocity of the outflow. To this end, we will present detailed analysis of the spatially-resolved radio and optical emission of two SDSS-IV MaNGA outflow galaxies.

**Author(s):** Rachael Malexan, Weizhe Liu, Ivan Katkov, Joseph Gelfand, Aisha Al Yazeedi, Jenny Greene, Nadia Zakamska  
**Institution(s):** New York University Abu Dhabi, Johns Hopkins University, University of Maryland, Princeton University

### 233.02D - X-ray Variability in the Nucleus of Cygnus A and the Radio Transient Cygnus A2(Martijn De Vries)

In 2015, a radio transient was discovered in Cygnus A with the VLA. This transient, named Cygnus A-2, is 0.42 arcsec removed from the AGN and can therefore not be resolved by most X-ray telescopes. We have looked for an X-ray counterpart to Cygnus A-2, using Chandra ACIS observations from 2015 to 2017. We simulated the source with Marx and compared it with the data, and find no evidence of an extension of the PSF in the direction of the transient. Based on this, we put an upper limit to the 2-10 keV X-ray luminosity of Cygnus A-2 of  $2 \times 10^{43}$  erg/s. Additionally, we present a spectral analysis of the AGN of Cygnus A using old and new Chandra observations. We compare the 2-10 keV X-ray luminosities with archival XMM-Newton, NuSTAR and Swift XRT data. The resulting light curve shows that the luminosity of Cygnus A was constant between 2000 and 2005, doubled in 2013 while observed by NuSTAR and Swift, and dropped back down in 2015. Previous analysis of the NuSTAR spectra has also indicated the presence of a fast, ionized wind, something not seen by Chandra and XMM-Newton. We discuss the possible connection between Cygnus A-2 and the X-ray light curve. The lack of X-rays from Cygnus A-2 in 2015 disfavors the interpretation of Cygnus A-2 as a steadily accreting black hole. Instead, we suggest that Cygnus A-2 is the radio afterglow of a tidal disruption event (TDE). This would explain the increase and subsequent fading of the X-ray luminosity between 2005 and 2015. A TDE could also have launched the short-lived, fast, ionized outflow seen by NuSTAR. If correct, it would provide further evidence that TDE rates in merging galaxies are much higher than previously thought.

**Author(s):** Aneta Siemiginowska, Antonia Rowlinson, Paul Nulsen, Michael Wise, Martijn De Vries

**Institution(s):** University of Amsterdam, Harvard-Smithsonian Center for Astrophysics, ASTRON, Institute for

### 233.04D - Cosmic Rays or Turbulence can Suppress Cooling Flows (Where Thermal Heating or Momentum Injection Fail)(Kung-Yi Su)

The quenching “maintenance” and “cooling flow” problems are important from Milky Way through massive cluster elliptical galaxies. Previous work has shown that some source of energy beyond that from stars and pure magnetohydrodynamic processes is required, perhaps from AGN, but even the qualitative form of this energetic input remains uncertain. Different scenarios include thermal “heating,” direct wind or momentum injection, cosmic ray heating or pressure support, or turbulent “stirring” of the intra-cluster medium (ICM). We investigate these in  $10^{12}$ - $10^{14} M_{\odot}$  halos using high-resolution non-cosmological simulations with the FIRE-2 (Feedback In Realistic Environments) stellar feedback model, including simplified toy energy-injection models, where we arbitrarily vary the strength, injection scale, and physical form of the energy. We explore which scenarios can quench without violating observational constraints on energetics or ICM gas. We show that turbulent stirring in the central  $\sim 1/4$  100kpc, or cosmic-ray injection, can both maintain a stable low-SFR halo for  $> 1$  Gyr timescales with modest energy input, by providing a non-thermal pressure which stably lowers the core density and cooling rates. In both cases, associated thermal-heating processes are negligible. Turbulent stirring preserves cool-core features while mixing condensed core gas into the hotter halo. Pure thermal heating or nuclear isotropic momentum injection require vastly larger energy, are less efficient in lower-mass halos, easily over-heat cores, and require fine-tuning to avoid driving unphysical temperature gradients or gas expulsion from the halo center.

**Author(s):** Kung-Yi Su

**Institution(s):** Caltech Contributing Team(s): Feedback In Realistic Environments (FIRE)

### 234 - X-Ray Pulsars and Neutron Stars

#### 234.01 - Future prospects for LIGO: The DNS merger rate revisited(Nihan Pol)

We present the Galactic merger rate for double neutron star (DNS) binaries using the observed sample of eight DNS systems merging within a Hubble time. This sample includes the recently discovered, highly relativistic DNS systems J1757-1854 and J1946+2052, and is approximately three times the sample size used in previous estimates of the Galactic merger rate by Kim et al. Using this sample, we calculate the vertical scale height for DNS systems in the Galaxy to be  $z_0 = 0.4 \pm 0.1$  kpc. We calculate a Galactic DNS merger rate of  $\mathcal{R}_{\text{MW}} = 47^{+33}_{-16} \text{ Myr}^{-1}$  at the 90% confidence level. The corresponding DNS merger detection rate for Advanced LIGO is  $\mathcal{R}_{\text{LIGO}} = 0.20^{+0.15}_{-0.07} \times \left( D_{\text{r}}/100 \text{ Mpc} \right)^3 \text{ yr}^{-1}$ , where  $D_{\text{r}}$  is the

range distance. We explore the effects of the underlying pulsar population properties on the merger rate and compare our merger detection rate with those estimated using different formation and evolutionary scenario of DNS systems. As we demonstrate, reconciling the rates are sensitive to assumptions about the DNS population, including its radio pulsar luminosity function. Future constraints from further gravitational wave DNS detections and pulsar surveys anticipated in the near future should permit tighter constraints on these assumptions.

**Author(s):** Nihan Pol, Duncan Lorimer, Maura McLaughlin  
**Institution(s):** West Virginia University

#### **234.02 - A changing boundary layer in a lower kHz quasi-periodic oscillation (Abigail L. Stevens)**

Kilohertz quasi-periodic oscillations (kHz QPOs) are the most rapid (quasi-)coherent kind of variability that have been detected in the light curves of accreting neutron star X-ray binaries. Previous spectral-timing work using the rms spectrum revealed that the lower kHz QPO emission is a Comptonized blackbody, consistent with that expected from the boundary layer between the accretion flow and neutron star surface. To better interpret the spectral variability, we present phase-resolved spectroscopy of a kHz QPO for the first time, using a method based on the energy-dependent cross-correlation function. We find that the Comptonized spectral shape changes as a function of QPO phase, and the variations of the spectral parameters must intrinsically lag one another. These spectral variations could be explained by radial oscillations in the boundary layer caused by unstable accretion onto the neutron star, which could be due to plasma instabilities, asteroseismic modes, or an opacity-radiation trade-off like in the variable star mechanism. These possibilities can be explored in greater detail with current and future X-ray missions such as AstroSat, NICER, eXTP, and STROBE-X.

**Author(s):** Diego Altamirano, Abigail L. Stevens, Phil Uttley  
**Institution(s):** Michigan State U., UAmsterdam, UMichigan, USouthampton

#### **234.03 - NICER observations of the Ultraluminous X-ray Pulsar NGC 300 ULX-1 (Paul S Ray)**

Recently, the ultraluminous X-ray source in the spiral galaxy NGC 300 was revealed to be an accretion-powered pulsar, with a spin period that is rapidly decreasing with time, from 31 seconds in 2016 December to 18.5 seconds at present. Since 2018 February 6, NICER has been monitoring this source, with intensive observations covering 2018 May through September. We will report on the spin evolution of this unique source, which includes the discovery of several "anti-glitches", where the rapid spin up is interrupted by sudden spindown glitches, in contrast to the usual spin-up glitches observed in radio pulsars. NICER is a 0.2-12 keV X-ray telescope operating on the International Space Station. The NICER mission and portions of the NICER science team activities are funded by NASA.

**Author(s):** Teruaki Enoto, Matthew Kerr, Sebastien Guillot, Wynn C.G. Ho, Paul S Ray

**Institution(s):** U.S. Naval Research Laboratory, Kyoto University, IRAP - CNRS, University of Southampton, Haverford College  
**Contributing Team(s):** NICER Working Group on Pulsation Searches and Multiwavelength Coordination

#### **234.05 - A Generalized Analytical Model for Thermal and Bulk Comptonization in Accretion-Powered X-ray Pulsars (Peter A. Becker)**

We discuss a new, enhanced analytical model describing spectral formation due to bulk and thermal Comptonization occurring in X-ray pulsar accretion columns. The new model provides improved physical self-consistency via the implementation of (1) a more realistic geometry for the accretion column; (2) a more rigorous accretion velocity profile that merges smoothly with Newtonian free-fall as  $r \rightarrow r_s$ ; (3) a more realistic free-streaming radiative boundary condition at the top of the column; and (4) a variable boundary condition at the stellar surface that can accommodate either a "soft landing" (zero surface velocity), likely appropriate for luminous sources such as Her X-1, or a "hard impact" onto the surface with a finite velocity, perhaps applicable in low-luminosity sources such as X Persei. The pencil and fan beam emission components are computed separately, supporting improved analysis of phase-dependent spectral data for X-ray pulsars. By improving the analytical treatment of the radiative properties of the accretion column, this new model also facilitates a more rigorous determination of source parameters such as magnetic field strength, accretion rate, electron temperature, etc. We discuss applications of the model to Her X-1, LMC X-4, Cen X-3, and X Persei.

**Author(s):** Michael Wolff, Peter A. Becker

**Institution(s):** George Mason University, Naval Research

#### **234.06 - A Self-Consistent Model for X-ray Pulsar Spectra and Pulse Profiles (Brent West)**

We discuss the observed spectra and pulse profiles for radiation originating along the walls of an accretion column in an X-ray pulsar, powered by mass transfer from a binary companion. The spectral calculations are based on the model of West, Wolfram, & Becker (2017), who for the first time solved a fully self-consistent photon transport equation coupled with a rigorous set of dynamical equations and boundary conditions that includes the effects of both radiation pressure and gas pressure in a dipole magnetic field geometry. The simulation of the observed spectra and pulse profiles is accomplished by integrating the height-dependent spectrum emerging from the accretion column, coupled with the effects of general relativistic light-bending and redshifting. The resulting self-consistent radiation-hydrodynamical model provides the most robust theoretical platform currently available for the interpretation of

phase-dependent spectra and pulse profiles. We discuss applications of the model to the high-luminosity sources Her X-1, Cen X-3, and LMC X-4, in which radiation pressure plays a central role in determining the accretion dynamics.

**Author(s):** Peter A. Becker, Kenneth Wolfram, Brent West  
**Institution(s):** George Mason University

### **234.04D - X-ray pulsars in nearby irregular galaxies(Jun Yang)**

The Small Magellanic Cloud (SMC), Large Magellanic Cloud (LMC) and Irregular Galaxy IC 10 are valuable laboratories to study the physical, temporal and statistical properties of the X-ray pulsar population with multi-satellite observations, in order to probe fundamental physics. The known distance of these galaxies can help us easily categorize the luminosity of the pulsars and their age difference can be helpful for studying the origin and evolution of compact objects. Therefore, a complete archive of 116 XMM-Newton PN, 151 Chandra (Advanced CCD Imaging Spectrometer) ACIS, and 952 RXTE PCA observations for the pulsars in the Small Magellanic Cloud (SMC) were collected and analyzed, along with 42 XMM-Newton and 30 Chandra observations for the Large Magellanic Cloud, spanning 1997-2014. From a sample of 67 SMC pulsars we generate a suite of products for each pulsar detection: spin period, flux, event list, high time-resolution light-curve, pulse-profile, periodogram, and X-ray spectrum. Combining all three satellites, I generated complete histories of the spin periods, pulse amplitudes, pulsed fractions and X-ray luminosities. Many of the pulsars show variations in pulse period due to the combination of orbital motion and accretion torques. Long-term spin-up/down trends are seen in 28/25 pulsars respectively, pointing to sustained transfer of mass and angular momentum to the neutron star on decadal timescales. The distributions of pulse detection and flux as functions of spin period provide interesting findings: mapping boundaries of accretion-driven X-ray luminosity, and showing that fast pulsars ( $P < 10$  s) are rarely detected, which yet are more prone to giant outbursts. In parallel we compare the observed pulse profiles to our general relativity (GR) model of X-ray emission in order to constrain the physical parameters of the pulsars. In addition, we conduct a search for pulsations in X-ray sources in the young local dwarf galaxy IC 10 to form a comparison sample for Magellanic Cloud X-ray pulsars.

**Author(s):** Jae Sub Hong, Jeremy drake, Andreas Zezas, Daniel Wik, Malcolm Coe, Jun Yang, Silas Laycock  
**Institution(s):** The university of Utah, harvard-smithsonian center for astrophysics, University of Massachusetts, University of Southampton

## **235 - Stars: Methods and Stellar Properties I**

### **235.01 - Modeling stars in different dimensions: a comparison of overshooting in 2D and 3D simulations(Jane Pratt)**

To interpret the high-quality data produced from recent space-missions it is necessary to develop theoretical and computational modeling of convection under realistic stellar conditions. We use the multi-dimensional, time implicit, fully compressible, hydrodynamic, implicit large-eddy simulation code MUSIC, to study the interaction between the convection zone and an interior radiative zone in two-dimensional and three-dimensional spherical simulations of a young sun. The young sun model chosen has a large convection zone and a realistic stratification in density, temperature, and luminosity produced by a stellar evolution calculation. Identical simulations of a large portion of the star are performed in 2D (assuming azimuthal symmetry) and in 3D. We analyze how the dimensionality of the fluid simulation impacts the frequency of intermittent events, and our models of overshooting and penetration.

**Author(s):** Jane Pratt, Isabelle Baraffe,  
**Institution(s):** Georgia State University, ENS Lyon, University of Exeter

### **235.02 - Role of Convection in the Driving Region of the $\dot{I}^2$ Cepheus variable $\dot{I}^2$ CMa(Robert G. Deupree)**

Two dimensional (2D) hydrodynamical simulations of a model of  $\dot{I}^2$  CMa are performed to explore the interaction of convection and radial pulsation. The model is based on results of Mazumdar, et al. (2006), for which the radial pulsation mode is identified as the first overtone. The driving region is located at a temperature of about  $2 \times 10^5$  K, and is produced by the iron group elements' high opacity. This also makes the region convectively unstable. The convective flow pattern is composed of narrow, rapidly moving, downward columns, and a significantly broader, slowly moving, upward flow. The convective energy transport varies by about a factor of two during a pulsation period, with a maximum of about 15% of the static model luminosity. The convective luminosity repeats reasonably well with a period longer than the pulsation period at low pulsation amplitude. This convective period depends somewhat on the total horizontal extent of the calculation. At full pulsation amplitude the pulsation and convective energy transport periods are the same. There is some variation in the pulsation amplitude with total horizontal extent at full pulsation amplitude, but all calculations show a appreciably larger amplitude than does the sum of all the pulsation modes of  $\dot{I}^2$  CMa.

**Author(s):** Robert G. Deupree  
**Institution(s):** Saint Mary's University

### **235.03 - Adaptive Kalman Filter-based Wavelet Shrinkage Denoising of Stellar Spectra(Sankalp Gilda)**

A new method is proposed to denoise stellar spectra based on wavelet shrinkage followed by adaptive Kalman thresholding. Discrete Wavelet Transform (DWT) builds on the classical short-time Fourier transform but allows for variable time-

frequency resolution. Wavelet shrinkage denoising involves applying DWT to the input signal, 'shrinking' certain frequency components in the transform domain, followed by applying inverse DWT to the reduced components. The performance of this procedure is characterized by the choice of the base wavelet, the number of decomposition levels, and the thresholding function. Typically, these parameters are chosen based on a 'trial and error' approach that is strongly dependent on the properties of the data being denoised. This work introduces an adaptive Kalman filter based thresholding method that eliminates the need for choosing the number of decomposition levels, and uses the 'Haar' wavelet basis that is found to be most suitable for stellar spectra. Various levels of Poisson noise were introduced into synthetic PHOENIX spectra, and the performance of several common denoising methods were tested against the proposed method. The proposed method proved to be superior in terms of noise depression and peak shape preservation.

**Author(s):** Sankalp Gilda

**Institution(s):** University of Florida

#### **235.04 - Physical Parameters of M dwarfs and M subdwarfs: An Automated Method for Low- and Medium-Resolution Spectroscopic Surveys(Neda Hejazi)**

Due to their ubiquity and very long main sequence lifetimes, M dwarfs provide an excellent tool to study the formation and chemical enrichment history of our Galaxy. These stars have also become attractive targets in the search for Earth-sized planets in habitable zones. However, their fundamental properties are still not well-constrained and detailed spectroscopic studies are required to determine the stellar parameters of these stars. Unfortunately, owing to their intrinsic faintness, the acquisition of the high-resolution, high signal-to-noise spectra of low-mass stars has been limited to small numbers of very nearby stars, mostly from the Galactic disc population. Old, metal-poor M subdwarfs, in particular, have been generally overlooked, except for a handful of cases. On the other hand, large numbers of low- and medium-resolution spectra of M dwarfs from both the local Galactic disc and halo populations are available from various surveys. In order to fully exploit these data, we have developed a pipeline to automatically determine the effective temperature, metallicity, -element enhancement and surface gravity of M dwarfs/subdwarfs using the latest version of BT-Settl model atmospheres. We have applied this pipeline to a sample of around 1600 high-proper motion ( $> 0.4''/\text{yr}$ ) M dwarfs/subdwarfs, collected from low/medium-resolution observations at the MDM observatory. Since a high proper motion sample overselects high-velocity stars, our catalog includes a significant number of stars associated with old stellar populations, i.e., thick disk and halo. The HR diagram, assembled using Gaia DR2 parallaxes and magnitudes, shows that stars with different metallicity ranges fall into clearly distinct loci; this allows us to tentatively calibrate color-metallicity-absolute magnitude relationships for M dwarfs and

M subdwarfs.

**Author(s):** Derek Homeier, Neda Hejazi, Sebastien Lepine

**Institution(s):** Georgia State University, Heidelberg University

#### **235.05 - Using APOGEE and Gaia to Probe the Galaxy With K and M Dwarfs(Sarah Jane Schmidt)**

K and M dwarfs are unique probes of local Galactic chemical evolution due to their ubiquity and long lives, but their complicated optical spectra have long prevented accurate and precise determinations of their iron and alpha abundances. The SDSS APOGEE-II high resolution infrared spectroscopy, combined with the ASCCAP model grid, includes parameters for dwarfs down to  $T_{\text{eff}} = 2500\text{K}$ . We examine these parameters compared to benchmark stars to cross check their precision and accuracy. We also cross-match the ASCCAP K and M dwarfs with Gaia parallaxes and photometry from SDSS, 2MASS, and WISE to examine the color magnitude diagrams of these cool stars and to obtain more reliable relationships between spectroscopic  $T_{\text{eff}}$  and metallicity with photometric classifications. Ultimately, we aim to examine the local chemical evolution of K and M dwarfs using both spectroscopic and photometric tools.

**Author(s):** Sarah Jane Schmidt, Jennifer Johnson

**Institution(s):** Leibniz Institute for Astrophysics Potsdam (AIP), Ohio State University

#### **235.06 - Classification of binary stars from light curves(Gabriella Contardo)**

In order to confirm and validate transiting exoplanets in large surveys, it is essential to know whether individual sources are single stars or two stars falling on the same pixel: either unresolved binaries or non-bound stars at different distances with similar sky-projected positions. Using spectroscopy and/or adaptive optics imaging it is often possible to establish the multiplicity of sources observed in transit surveys, however such observations are expensive and often not carried out on large scales. We aim to develop machine learning based approaches that can predict whether a point source is a single star, a background blend or a binary, from its light curve alone. We plan to explore both unsupervised and semi-supervised learning methods to achieve this goal. We will train a prediction model that projects Kepler light curves onto a "representation space" and can distinguish single stars from binaries, based on clustering in that space. We will also explore the features of light curves that differentiate between singles and binaries. These features may lead to new insights into the physical processes behind binary star evolution. We will use these new techniques to identify binaries and double stars in Kepler and TESS in order to improve exoplanet validation and learn about the statistics of the binary star population in these surveys.

**Author(s):** Gabriella Contardo, Rodrigo Luger, Ruth Angus,

**Institution(s):** CCA Flatiron Institute, AMNH

### **235.07 - The Limitations of Gyrochronology for Old Field Stars(Travis Metcalfe)**

Nearly half a century has passed since the initial indications that stellar rotation slows while chromospheric activity weakens with a power-law dependence on age, the so-called Skumanich relations. Subsequent characterization of the mass-dependence of this behavior up to the age of the Sun led to the advent of gyrochronology, which uses the rotation rate of a star to infer its age from an empirical calibration. The efficacy of the method relies on predictable angular momentum loss from a stellar wind entrained in the large-scale magnetic field produced by global dynamo action. Recent observational evidence suggests that the global dynamo begins to shut down near the middle of a star's main-sequence lifetime, leading to a disruption in the production of large-scale magnetic field, a dramatic reduction in angular momentum loss, and a breakdown of gyrochronology relations. For solar-type stars this transition appears to occur near the age of the Sun, when rotation becomes too slow to imprint Coriolis forces on the global convective patterns, reducing the shear induced by differential rotation, and disrupting the large-scale dynamo. After summarizing the evidence for this mid-life magnetic transition, I will reveal its signature in the observations that were originally used to validate gyrochronology. Chromospheric activity may ultimately provide a more reliable age indicator for older stars, and asteroseismology can be used to help calibrate activity-age relations for field stars beyond the middle of their main-sequence lifetimes.

**Author(s):** Travis Metcalfe

**Institution(s):** Space Science Institute

### **235.08 - Problems with and Prospects for K dwarf Gyrochronology: Insights from the K2 Survey of Ruprecht 147(Jason Curtis)**

Gyrochronology has been demonstrated to work at least up to the age of the Sun for F and G dwarfs. What comes later remains controversial, where periods for Kepler's asteroseismic touchstone stars have been used to argue for a reduced braking efficiency at older ages. However, this effect should not affect K dwarfs (0.6-0.9 solar masses), which are even more problematic to age-date with isochrone methods than F and G dwarfs. The difficulty with calibrating K dwarfs gyrochronology is that few are known with published periods that have precise ages older than the Hyades or Praesepe (650 Myr). This is because asteroseismology is not effective for this class of stars and those located in the older clusters surveyed with Kepler (NGCs 6811 and 6819) are too faint. Our K2 Survey of Ruprecht 147 remedies this by expanding the sample of 2.5 Gyr rotators from 0.85 solar masses from NGC 6819 down to 0.5 solar masses in Ruprecht 147. Our new sample shows tension with expectations from various empirical models (e.g., Mamajek &

Hillenbrand 2008, Barnes 2010, Angus et al. 2015), semi-physical models (e.g., van Saders et al. 2013, Matt et al. 2015), and the observed Praesepe period sequence projected forward in time to the age of Ruprecht 147 with the Skumanich Law, all of which predict periods for K dwarfs much longer than observed in the Ruprecht 147. This result is consistent with the mass-dependent epoch of stalled braking suggested by Agüeros et al. (2018).

**Author(s):** Jason Curtis, Marcel Agüeros

**Institution(s):** Columbia University

### **235.09 - An age-dating method that combines stellar evolution models with gyrochronology(Ruth Angus)**

By combining two different sets of observable stellar properties and dating methods that are sensitive to two different evolving processes in stars: core hydrogen burning and magnetic braking, it is possible to infer more precise and accurate ages than using either method in isolation. In this investigation, the observables of main sequence stars that trace core hydrogen burning and stellar evolution on the HR diagram are combined with their Kepler rotation periods in a Bayesian framework, to infer stellar ages from both stellar evolution models and gyrochronology. We show that incorporating rotation periods into stellar evolution models significantly improves the precision of inferred ages. Since ages predicted with gyrochronology can, in general, be much more precise than isochronal ages, care must be taken to ensure that the gyrochronology model being used is accurate. We provide open source code that infers stellar ages from spectroscopic parameters, apparent magnitudes, parallaxes and rotation periods.

**Author(s):** Timothy D Morton, David W Hogg, Megan Bedell, Ruth Angus, Jason Curtis, Daniel Foreman-Mackey, John Brewer

**Institution(s):** American Museum of Natural History, University of Florida, Flatiron Institute, Columbia University, Yale University, New York University

## **236 - HEAD II: Fermi at 10**

### **236.01 - Transient and Variable Gamma-ray Surprises in the Galaxy(Joel Barry Coley)**

The last ten years of observations performed with the Fermi Gamma-ray Space Telescope have revealed new and exciting surprises in our Galactic neighborhood at MeV-GeV energies. Thanks to its Large Area Telescope, which is sensitive to photons from 20 MeV to over 300 GeV, Fermi has opened a window into the gamma-ray sky from particle acceleration in the extreme environments of High-mass Gamma-ray Binaries and Pulsar Wind Nebulae to powerful gamma-ray flares traced to the Crab Nebula. In this talk, I discuss key multi-wavelength properties of transitional millisecond pulsars as they transition between their rotation-powered and accretion-powered states, powerful outbursts from thermonuclear eruptions on white dwarfs and the discovery of new gamma-ray binaries, including

the first gamma-ray binary found in another galaxy. Finally, I will discuss the synergy built through contemporaneous observations performed with Fermi and multi-wavelength observatories such as the Neil Gehrels Swift Observatory, NICER and TESS. Building on the success of Fermi, the time is now to address key astrophysical questions at largely unexplored wavelengths. This strengthens the case for missions such as the All-sky Medium Gamma-ray Observatory (AMEGO) to explore MeV energies.

**Author(s):** Joel Barry Coley,

**Institution(s):** Howard University, NASA Goddard Space Flight Center

### **236.02 - WIMP Dark Matter and more - a 10 year adventure with Fermi(Tim Linden)**

Over the last decade, the Fermi-LAT has served as one of the premier instruments for particle dark matter detection. This is primarily due to its extreme flux sensitivity, which place it among the first instruments able to probe the coveted "thermal annihilation cross-section", at which dark matter particles which obtain a relic abundance via thermal processes would be expected to annihilate to produce observable radiation. In this talk, I will review the status of Fermi searches for dark matter annihilation, including the strong constraints placed by studies of dwarf spheroidal galaxies, as well as the exciting hints for dark matter annihilation in the Milky Way galactic center. I will forecast our ability to use current and future Fermi-LAT data to probe dark matter candidates up to TeV masses over the next decade.

**Author(s):** Tim Linden

**Institution(s):** The Ohio State University

### **236.03 - Extreme Explosions - Gravitational Waves and Gamma Rays with Fermi(Adam Goldstein)**

August 17, 2017 was a ground-breaking moment for multi-messenger astronomy, and Fermi was an integral observer of the coincident discovery of gamma rays and gravitational waves from the merging of binary neutron stars, an event famously known as GW170817. I will discuss the observations made by the Fermi Gamma-ray Burst Monitor (GBM) of this foundational event and describe the unique contributions to astrophysics and fundamental physics that were made by Fermi's part in this discovery. I will also detail the special on-going collaboration between Fermi GBM and the gravitational-wave community. Finally, I will provide some results of an effort to perform joint sub-threshold searches of LIGO/Virgo and Fermi GBM data in an attempt to expand the gravitational-wave detection horizon for both previous LIGO/Virgo observing runs and the upcoming 3rd Observing Run.

**Author(s):** Adam Goldstein

**Institution(s):** Universities Space Research Association  
**Contributing Team(s):** Fermi GBM, LIGO/Virgo

### **236.04 - Extreme Accelerators of Cosmic Rays, Neutrinos, and Gamma Rays(John Beacom)**

The primary electromagnetic radiations of the Universe --- CMB photons and starlight --- are thermal spectra in the sub-eV or eV range. Based on these observations, there is no reason to suspect that much higher-energy radiations would be produced. And yet they are: cosmic rays are observed up to  $10^{20}$  eV, neutrinos up to  $10^{16}$  eV, and gamma rays up to  $10^{14}$  eV. Even the Large Hadron Collider at CERN only produces particles up to  $10^{13}$  eV. So how can natural sources produce radiations at much higher energies? Even more, at luminosities that can be detected from cosmic distances? The Fermi Gamma-Ray Space Telescope has played a key role in finding powerful natural accelerators and probing their nature. I will discuss key successes. These set the stage for greater challenges that will require new probes of gamma rays, as combined observations with cosmic rays and neutrinos.

**Author(s):** John Beacom

**Institution(s):** Ohio State University

### **236.05 - A Census of High Energy Gamma-ray Sources and the Extragalactic Diffuse(Marco Ajello)**

In this talk I will review our efforts to characterize the populations of sources detected by the LAT onboard the Fermi mission and our understanding of the extragalactic diffuse backgrounds

**Author(s):** Marco Ajello

**Institution(s):** Clemson University

## **237 - Space Mission Instrumentation III**

### **237.01 - Experimental tests and numerical simulations of the LISA Charge Management System(Henri Inchauspe)**

The LISA Charge Management System (CMS) is a critical part of the LISA payload. LISA, an ESA-NASA joint space mission, will be the first space-based gravitational wave observatory which will measure mHz gravitational waves well below what is accessible by ground-based observatories. Similar to the CMS tested on the LISA Pathfinder mission, the CMS will be embedded within the LISA Gravitational Reference Sensors and allow for minimizing charge-induced forces on the Test Masses (TMs), the references of inertia of LISA. The CMS is a UV-light based discharging system with no mechanical interaction between the TM and the payload allowing for true drag-free operation in the LISA band. This talk will present the ongoing state of the art research activities at the University of Florida focusing on experimental tests and software simulations of the CMS. Experimental tests are performed with the help of the University of Florida Torsion Pendulum and simplified - and soon LISA-like - Gravitational Reference Sensors, which include electrostatic and interferometric position sensors. The apparatus allows for the monitoring of the test mass charge

during charge control sessions to test various charge/discharge strategies and to compare the observed charge rate against a numerical model recently developed by our group. Description and updates on the experimental setup, the ongoing major upgrades, as well as a comparison between charge management testing measurements and the numerical model will be discussed in this talk.

**Author(s):** Nicholas Turetta, Henri Inchauspe, Samantha D. Parry, Taiwo Janet Olatunde, Stephen Apple, Peter J. Wass, Guido Mueller, John W. Conklin

**Institution(s):** University of Florida,

### **237.02 - Theoretical Limits for Exoplanet Detection with Coronagraphs on Obstructed Apertures(Ruslan Belikov)**

Obstructed and segmented apertures are common in exoplanet imaging telescopes and concepts. In particular, the WFIRST, LUVOIR, and HabEx telescopes have obstructed or segmented apertures as a baseline or option. Most ground-based observatories have obstructed apertures, and many exoplanet imaging space telescope concepts based on an unobstructed aperture (e.g. Exo-C, ACESat) can benefit from having an obstructed one. A number of coronagraph designs have been developed for obstructed apertures, but usually suffer a substantial performance hit compared to unobstructed aperture designs. Fortunately, the performance of obstructed coronagraph designs seems to be steadily improving. We explore the extent to which the performance of coronagraphs on segmented apertures can be improved in theory. Our methods involve generalizing some of the treatment for coronagraph theoretical limits from Guyon et al. 2006 to obstructed apertures, and extending it to higher order coronagraphs. In particular, we treat a coronagraph abstractly as a passive linear operator on the space of electric fields and study the fundamental performance limits and trades within the space of all such abstract coronagraphs. We show that a fundamental trade exists between the contrast, inner working angle, and sensitivity to stellar angular size. We also show that arbitrary tolerance to stellar angular size can be achieved at the cost of inner working angle. We present the effects of aperture obscuration and segmentation on these performance limits and trades, and show that although there is a definite effect, it is not very strong. This implies that there is still a lot of room for performance improvement for coronagraph designs on obstructed apertures. Although it is not known whether our performance limits can be reached with existing coronagraph architectures, they can at least be reached with a “brute-force” collection of ideal beamsplitters and masks. Our limits can thus be used as a target for future coronagraph technology development, as well as to show how much improvement in mission yields remains possible for any given aperture.

**Author(s):** Dan Sirbu, Ruslan Belikov, Eduardo Bendek, Jeffrey B Jewell, Stuart Shaklan, Olivier Guyon

**Institution(s):** NASA Ames Research Center, Subaru Telescope, NASA Jet Propulsion Lab

### **237.03 - Development of a PIAACMC high contrast imaging system for segmented apertures: overview and first results(Eduardo Bendek)**

Enabling small IWAs can dramatically increase a mission yield of Earth-like exoplanets in the habitable zones of their stars. Several studies showed that yield grows approximately inversely to IWA, meaning a mission with half the IWA doubles the yield of Earth-like exoplanets. Thus, advancing coronagraph architectures with small IWAs has a greater impact on expected yield than parameters such as increasing throughput or improving contrast. The PIAACMC (Phase-Induced Amplitude Apodization Complex Mask Coronagraph) is a high-performance coronagraph featuring close to 100% throughput, and inner working angles (IWAs) that can go as low as 0.5 L/D. Its sensitivity to tip/tilt aberrations is close to theoretically best for small inner working angles. This makes the PIAACMC a promising option for future exoplanet missions, if its performance can be demonstrated in the lab with realistic jitter and stellar angular sizes. Here we describe a new effort funded by NASA TDEM (Technology Development for Exoplanet Missions) called “Laboratory Demonstration of High Contrast Using PIAACMC on a Segmented Aperture”. The objective of this effort is to demonstrate and mature starlight suppression technology with the PIAACMC for segmented apertures. Specifically, we plan to perform a laboratory demonstration in vacuum of  $10^{-9}$  contrast with an inner working angle of 2 L/D (or better) in a 10% bandpass centered at 650 nm, using segmented apertures representative of those expected for the LUVOIR and HabEx missions (if segmented). This is the basis of the final milestone of our effort. We present our first results, which include a coronagraph design that passed that met our performance requirements in simulation, as well as the design and simulations of the layout on an optical bench.

**Author(s):** John Hagopian, Eduardo Bendek, Brian Kern, Ruslan Belikov, Dan Sirbu

**Institution(s):** NASA Ames Research Center, Lambda Consulting, Jet Propulsion Laboratory

### **237.04 - Demonstration of Multi-Star Wavefront Control for Future Missions to Directly Image Exoplanets(Dan Sirbu)**

Coronagraphic instruments will enable direct imaging of dim planetary companions around nearby stars. The majority of nearby FGK stars are located in multi-star systems, including the Alpha Centauri stars which may represent the best quality targets available for spectroscopic characterization due to their proximity and brightness. However, a binary system exhibits additional leakage from the off-axis companion star that may be brighter than the target exoplanet. Multi-Star Wavefront Control (MSWC) is a wavefront-control technique that allows simultaneous suppression of starlight of both stars in a binary system. MSWC would thus enable direct imaging of circumstellar planets in binary star systems such as Alpha Centauri. Here, as part of the technology demonstration effort



for MSWC at NASA Ames we are developing methods to enable coronagraphic instruments on future missions to directly image multi-star systems. We present simulated results in broadband showing multi-star imaging capabilities using MSWC for several instruments including: [1] the upcoming Wide Field Infrared Survey Telescope (WFIRST) and its coronagraph instrument demonstrator, [2] the HABitable Exoplanet Observatory (HABEX) mission concept, [3] the segmented Large UV/Optical/IR Surveyor (LUVOIR) mission concept, and [4] the small aperture Alpha CENTauri Direct imager (ACEND) mission concept. For each of these missions we are working with the science and technology definition teams to add multi-star imaging capability. Our approach has been to start with the planned instrument baseline performance for single-star wavefront control and demonstrate comparable performance for the multi-star imaging mode. We will also discuss algorithmic and hardware requirements to enable multi-star imaging for each of these cases.

**Author(s):** Chris Henze, Dan Sirbu, Yevgeniy Pluzhnyk, Ruslan Belikov, Eduardo Bendek

**Institution(s):** NASA Ames Research Center

### **237.05 - A Free Space Backlink For the LISA Mission(Daniel A Hillsberry)**

The Laser Interferometer Space Antenna (LISA) is a 2.5 Gm long Michelson interferometer aimed at detecting gravitational waves from cosmological sources at mass scales not accessible by ground-based observatories. The Michelson interferometer is formed between three drag-free spacecrafts in a triangular formation. The changing opening angles do not allow to use a fixed beam splitter but requires an artificial beam splitter which allows to correlate the laser frequency noise in both arms. One potential solution is known as a free space backlink which is currently being tested by our group

**Author(s):** Paul Fulda, Soham Kulkarni, John W. Conklin, Guido Mueller, Daniel A Hillsberry, Andrew Chilton

**Institution(s):** University of Florida, University of Florida Physics

### **237.06 - Standard Evaluation of exoplanet Yield for the LUVOIR and HabEx Concept Studies(Rhonda Morgan)**

The HabEx and LUVOIR concepts aim to directly image and spectrally characterize potentially habitable exoplanets. Using EXOSIMS, realistic mission observing constraints, and dynamically responsive scheduling, we simulate the exoplanet detection and characterizations over Monte Carlo realizations of synthetic planets around nearby stars. We use identical astrophysical inputs and the observing scenarios of each concept to evaluate a common comparison of the detection and spectral characterization yields of HabEx and LUVOIR. HabEx is evaluated for the 4m hybrid starshade and coronagraph architecture, the 4m coronagraph only architecture, and the 3.2 m starshade only architecture. LUVOIR is evaluated for the 15

m architecture A presented in their interim report. The scenarios are scheduled to respond dynamically to the number of detections/no-detections of a target and success of characterization as well as the optimal slews for the starshade. Yield analysis shows that both concepts can directly image and spectrally characterize earth-like planets in the Habitable zone and that each concept has complementary strengths.Â© California Institute of Technology 2018. All rights reserved. Government sponsorship acknowledged.

**Author(s):** Michael Turmon, Dmitry Savransky, Walker Dula, Karl Stapelfeldt, Rhonda Morgan, Bertrand Mennesson, Eric E Mamajek

**Institution(s):** NASA/Jet Propulsion Laboratory, Cornell University

### **237.07 - Effectuating an Astronomical Impact on the Future of Space Law and Policy(Charles Lee Mudd)**

Although space telescopes enhance observation of space, growth of orbiting research vessels necessitate ensuring space law and policy will be conducive to the needs of astronomers, astrophysicists, and space explorers of all kinds. For decades, a few treaties governed international use of and traffic in space. Domestic laws also regulated various aspects of space technology by those subject to their legal paradigm. Yet, the growth of the commercial space industry and the expected expansion of orbiting objects push the boundaries of existing space law and policy. For this reason, the United Nations and various state actors have begun to address the need to adapt space law and policy to address space traffic management, object registries, liability, space debris, and more. Certainly, we can expect governments to advocate policies beneficial to their interests. And, commercial actors will undoubtedly lobby to influence decisions. Yet, any effective policy development must include all interested sectors. Thus, the academic and scientific community must contribute its voice within the broader conversation on the development of space law and policy. There may be astro-focused researchers who do not think of space law and policy. Others may appreciate its existence but ignore such issues as peripheral. Perhaps, for most, the topic competes for temporal resources among various family, work, and neighborhood obligations. Yet, it could not be more important to the astronomical community. To begin with, we must ensure that domestic and international laws allow for continued exploration of space by those with the vision to do so. Although commercial exploration could enhance opportunities, its impact must be balanced to prevent imposing limitations (physical and legal) on academic and scientific initiatives. Moreover, the historic cooperation and collaboration within this international community can serve to counter political disagreement. This paper explores the manner in which space law and policy affects space research and advocates the need for vocal involvement to ensure legal and policy developments facilitate an open and collaborative future.

**Author(s):** Charles Lee Mudd

**Institution(s):** John Marshall Law School

### **237.08 - Southern TESS Exoplanet Follow-up with Veloce Rosso on the AAT(Chris Tinney)**

The new Veloce Rosso facility for the 3.9m Anglo-Australian Telescope commenced TESS candidate follow-up just 12 days after the first TESS sector results were released, and we will present results from these (and subsequent) runs. Veloce Rosso is a new precision radial velocity facility for the southern hemisphere, providing wavelength coverage of 580-930nm at a resolution of 80,000. It includes multiple innovations including being fed by a 19-element fibre IFU that uses octagonal fibres to segment a 2.5" aperture on-sky into a 0.5" wide x 12" long slit injected into Veloce; a commercial "off the shelf" temperature and pressure stabilisation system that delivers milli-pixel intrinsic spectrograph stability (corresponding to 4m/s variations from night to night); and simultaneous injection of both Menlo Systems astrocomb and ThXe signals, to calibrate these residual variations for every exposure to below 0.1m/s levels.

**Author(s):** Chris Tinney

**Institution(s):** UNSW Sydney Contributing Team(s): Veloce Team

### **237.09 - Recharacterization of previously known long-period planets in multi-sector TESS data(Tansu Daylan)**

We analyze new and archival light curve and radial velocity data of previously known exoplanets, as observed in the initial sectors of the Transiting Exoplanet Survey Satellite (TESS) mission. In particular, we focus on long-period planets that have been observed in multiple TESS sectors. Observations of many transits of these exoplanets by TESS allow us to update the planetary parameters such as ephemerides and orbital periods, probe companion planets, search for potential secondary eclipses, variations in transit times, and orbital decay. The information gain on these exoplanets realized by TESS is quantified by comparing the models fitted with and without the TESS data and those previously reported in the literature.

**Author(s):** Tansu Daylan, Maximilian N. Günther

**Institution(s):** Massachusetts Institute of Technology Contributing Team(s): TESS Team

### **238 - Instrumentation: Ground Based Imaging and Spectroscopy**

#### **238.01 - The Keck Planet Imager and Characterizer: integration, testing and early commissioning results(Nemanja Jovanovic)**

The Keck Planet Imager and Characterizer (KPIC) is an upgrade to the Keck II adaptive optics system enabling high contrast imaging and high-resolution spectroscopic characterization of giant exoplanets in the mid-infrared (2-5 microns). The KPIC instrument will be deployed in phases. Phase I entails the

installation of an infrared pyramid wavefront sensor module based on a fast low-noise SAPHIRA IR-APD array. The ultra-sensitive infrared wavefront sensor will enable high contrast studies of infant exoplanets around cool, red, and/or obscured targets in star forming regions. In addition, the light downstream of the wavefront sensor will be coupled into an array of single mode fibers with the aid of an active fiber injection unit (FIU) in order to route the light to the high-resolution infrared spectrograph Keck/NIRSPEC, so that high dispersion coronagraphy (HDC) can be implemented for the first time. HDC optimally pairs high contrast imaging and high-resolution spectroscopy allowing detailed characterization of exoplanet atmospheres, including molecular composition, spin measurements, and Doppler imaging. We will report on the recent integration and test of the Phase I of KPIC and present some early commissioning results.

**Author(s):** Mark Chun, Sylvain Cetre, Ed Wetherell, Nemanja Jovanovic, Jacques Delorme, Kent Wallace, Scott Lilley, Dimitri Mawet, Sam Ragland, Randy Bartos, Peter Wizinowich, Daniel Echeverri, Mike Fitzgerald, Charlotte Bond

**Institution(s):** Caltech, Keck Observatory, Institute for Astronomy, UCLA, JPL Contributing Team(s): UCLA team

#### **238.03 - WIRC+Pol: a low-resolution near-infrared spectropolarimeter(Samaporn Tinyanont)**

WIRC+Pol is a newly commissioned low-resolution ( $R \sim 100$ ), near-infrared (J and H band) spectropolarimetry mode of the Wide-field InfraRed Camera (WIRC) on the 200-inch Hale Telescope at Palomar Observatory. The instrument utilizes a novel polarimeter design based on a quarter-wave plate and a polarization grating (PG), which provides full linear polarization measurements (Stokes I, Q, and U) in one exposure. The PG also has high dispersion efficiency ( $\sim 95\%$ ) across the J and H bands. The instrument is situated at the prime focus of an equatorially mounted telescope. As a result, the system only has one reflection in the light path, providing minimal telescope induced polarization. A data reduction pipeline has been developed for WIRC+Pol to produce linear polarization measurements from observations. WIRC+Pol has been on-sky since February 2017. Results from the first year commissioning data confirm the expected high dispersion efficiency. We demonstrate the polarimetric stability of the instrument with RMS variation at 0.2% level over 30 minutes for a bright standard star ( $J = 8.7$ ). While the spectral extraction is photon noise limited, polarization calibration between sources remain limited by systematics, likely related to gravity dependent pointing effects. We discuss instrumental systematics we have uncovered in the data, their potential causes, along with calibrations that are necessary to eliminate them. We describe a modulator upgrade that will eliminate the slowly varying systematics and provide polarimetric accuracy better than 0.1%. WIRC+Pol will enable high-sensitivity polarimetry science on various targets such as brown dwarf atmosphere and supernovae. We present a tentative detection of polarization of SN2017eaw, the first observation of SN polarization in the near-IR.

**Author(s):** Max Millar-Blanchaer, Gautam Vasisht, Keith Matthews, Roger Smith, Tiffany Kataria, Eugene Serabyn, Shreyas Vissapragada, Charles Henderson, Heather Knutson, David Hale, Ricky Nilsson, Louis Santos, Dimitri Mawet, Jennifer Milburn, Samaporn Tinyanont

**Institution(s):** Jet Propulsion Laboratory, Cornell University, California Institute of Technology Contributing Team(s): WIRC+Pol

#### **238.04 - An Overview of SCORPIO, the Gemini-South Facility Instrument for LSST Follow-Up(Massimo Robberto)**

SCORPIO (Spectrograph and Camera for the Observation of Rapid Phenomena in the Infrared and Optical) is the facility class instrument for the Gemini South telescope designed for LSST followup studies. SCORPIO is a wide-band (0.385-2.35 $\mu$ m) 8-channel imager and medium-resolution ( $R \sim 4000$ ) spectrograph with high observing efficiency, fast acquisition time, and ultra-high readout speed capability. While SCORPIO is optimized for time-domain astronomy, its unique characteristics will enable the general community to efficiently carry out a large variety of astrophysics program. In this talk we illustrate the main characteristics of the instrument and provide a timely status report as the projects approaches the end of the Critical Design Phase to enter the construction phase.

**Author(s):** Alexander J. van der Horst, Jeffrey Radwick, Tom Hayward, Brian Chinn, Stephen Goodsell, Todd Veach, Scot Kleinman, Robert Barkhouser, Kathleen Labrie, Marisa Garcia Vargas, Amanda Bayless, Pete Roming, Ruben Diaz, Morten Andersen, Rebecca Thibodeaux, Kri

**Institution(s):** Space Telescope Science Institute, Gemini Observatory, Johns Hopkins University, FRACTAL S.L.N.E., Southwest Research Institute, George Washington University

#### **238.05 - SAPHIRA: The Only Astronomical Photon-Counting Near-Infrared Array(Dani Eleanor Atkinson)**

The SAPHIRA is currently the only astronomical device capable of counting photons in the NIR while showing other performance easily comparable to the ubiquitous HAWAII arrays. Initiated by the European Southern Observatory for work on the VLT's GRAVITY instrument and further development at the University of Hawai'i brought the dark current down orders of magnitude and improved various other characteristics. During this work the SAPHIRA was deployed at multiple telescopes, adding tip-tilt correction to the Robo-AO instrument during its stay at the Palomar 1.5m, while producing its first scientific publication at the same time. It is now an integral part of various instruments, including the Keck Planet Imager and Characterizer to the Subaru Coronagraphic Extreme Adaptive Optics. Development continues with the array's initial 320x256 size being brought up to megapixel and the pitch shrank down. The SAPHIRA gives unique capabilities that offer new abilities for new ground instruments and future

space telescopes. NIR Astronomy has a lot to gain from its further development.

**Author(s):** Dani Eleanor Atkinson, Don Hall, Shane Jacobson

**Institution(s):** NASA, University of Hawai'i

#### **238.06 - Looking Forward with TolTEC, A New Multiwavelength Imaging Polarimeter for the LMT(Natalie DeNigris)**

TolTEC is an upcoming multiwavelength imaging polarimeter designed to fill the focal plane of the 50-m diameter Large Millimeter Telescope (LMT). Combined with the LMT, TolTEC will be able to offer high angular resolution (5" -10" ) simultaneous, polarization-sensitive observations in three wavelengths: 1.1, 1.4, and 2.0 mm. Additionally, TolTEC will feature mapping speeds greater than 2 deg<sup>2</sup>/mJy<sup>2</sup>/hr, thus enabling wider surveys of large-scale structure, galaxy evolution, and star formation. These improvements are only possible using over 7000 low-noise, high-responsivity superconducting Lumped Element Kinetic Inductance Detectors (LEKIDs). To utilize three focal planes of detector arrays requires the design and integration of unique, large-scale cryogenic, electronic, and optical systems. In this presentation, I will describe the progress we have made in the design, fabrication, and assembly of TolTEC over the past year. As we plan to see first light at the LMT in Summer 2019, I will also provide an overview and timeline for TolTEC's upcoming science through the lens of its initial four Legacy Surveys.

**Author(s):** Natalie DeNigris, Grant Wilson

**Institution(s):** University of Massachusetts Amherst Contributing Team(s): TolTEC Team

#### **238.07 - Enabling Discoveries: the NSF Advanced Technologies and Instrumentation Program(Peter Kurczynski)**

The Advanced Technologies and Instrumentation (ATI) program within the Division of Astronomical Sciences at the National Science Foundation funds enabling technology and instrumentation for ground-based astronomy. We performed a literature review of nearly 500 awards over the thirty-year history of ATI, with particular emphasis on radio - submillimeter astronomy. A literature citation analysis shows that ATI awards have similar impact statistics as astronomy research awards. The impact of ATI is compared to other disciplines and placed in the context of emerging results from the "science of science." A longitudinal perspective illustrates how technology development in astronomy enables scientific discoveries.

**Author(s):** James E Neff, Peter Kurczynski,

**Institution(s):** National Science Foundation, Rutgers, The State University of New Jersey

#### **238.02D - Extreme Precision Photometry and Radial**

## **Velocimetry from the Ground(Gudmundur Kari Stefansson)**

Since the discovery of the first exoplanet more than two decades ago, the field of exoplanets has drastically expanded. This expansion has been driven in large part due to advances in instrumental capabilities, increasing our sensitivity to detecting and characterizing these exoplanetary worlds. In this dissertation talk, I discuss the development of new high-precision ground-based instrumentation for both transit photometry and radial velocimetry (RV). First, I discuss the use of beam-shaping diffusers to enable hitherto unachievable photometric precisions from the ground. Beam-shaping diffusers are micro-structured optical components capable of molding the image of a star into a broad and stable top-hat shape, minimizing photometric errors due to non-uniform pixel response, atmospheric seeing effects, and telescope-induced variable aberrations seen in defocusing. I discuss my efforts in commissioning an optical diffuser on the ARC 3.5m Telescope at Apache Point Observatory demonstrating 62ppm precision in 30 minute bins-some of the highest photometric precisions from the ground. Being inexpensive, beam-shaping diffusers can be easily adapted for use on telescopes large and small for precision photometry applications. Second, I discuss the design and use of two next generation fiber-fed ultra-stabilized RV spectrographs designed from the bottom-up to carry out dedicated surveys to discover and characterize rocky terrestrial worlds. The Habitable-zone Planet Finder (HPF) is a next generation high resolution ( $R \sim 55,000$ ) near-infrared (NIR) spectrograph installed on the 10m Hobby-Eberly Telescope (HET) in late 2017. NEID is the next generation high-resolution ( $R \sim 100,000$ ) optical spectrograph to be installed at the 3.5m WIYN Telescope at Kitt Peak in early 2019. I will discuss my efforts on the design and build of various subsystems for HPF and NEID, including the HPF and NEID Environmental Control Systems. Finally, I will discuss on-sky commissioning and early science results from HPF which has already demonstrated 1.53m/s precision in the NIR on the nearby bright M-dwarf GJ 699 over 3 months.

**Author(s):** Gudmundur Kari Stefansson

**Institution(s):** Pennsylvania State University

## **239 - IGM and QSO Absorption Line Systems II**

### **239.01 - Stacking the Cosmic Web in Lyman $\hat{I}\pm$ Emission with MUSE & EAGLE(Sofia Gallego Gallego)**

Cosmological simulations suggest that most of the matter in the Universe is distributed along filaments connecting galaxies. Illuminated by the cosmic UV background (UVB), these structures are expected to glow in fluorescent Ly  $\hat{I}\pm$  emission with a surface brightness (SB) that is well below current limits for individual detections. We perform a stacking analysis of the deepest MUSE/VLT data using three-dimensional regions (subcubes) with orientations determined by the position of neighboring Ly  $\hat{I}\pm$  galaxies at  $3 < z < 4$ . Our method increases the probability of detecting filamentary Ly  $\hat{I}\pm$  emission, provided that these structures are Lyman-limit systems (LLSs). By

stacking 390 oriented subcubes we reach a  $2\hat{I}$  sensitivity level of  $SB \hat{\sim} 0.44 \hat{A} - 1e\hat{\sim}^{20} \text{erg/s/cm}^2/\text{arcsec}^2$  in an aperture of  $1 \text{ arcsec}^2 \hat{A} - 6.25 \hat{A} \dots$ , three times below the expected fluorescent Ly  $\hat{I}\pm$  signal from the Haardt & Madau (HM) UVB at  $z \sim 3.5$ . No detectable emission is found on intergalactic scales, implying that at least two-thirds of our subcubes are not connected by oriented LLSs. On the other hand, significant emission is detected in the circumgalactic medium (CGM) in the direction of the neighbors. The signal is stronger for galaxies with a larger number of neighbors and appears to be independent of any other galaxy properties. We estimate that preferentially oriented satellite galaxies cannot contribute significantly to this signal, suggesting instead that gas densities in the CGM are typically larger in the direction of neighboring galaxies on cosmological scales. We construct mock cubes from the EAGLE simulations in order to constrain the Ly  $\hat{I}\pm$  signal from the Cosmic Web and the filament-galaxy connectivity. We found a strong correlation between the neighboring galaxy distance and the filament detection, and a small correlation with galaxy magnitudes and halo mass. Using our MUSE stacking results in combination with EAGLE constraints, we estimate a covering fraction of LLSs of about 10%, implying a photoionization rate below  $2 \times 1e-12 \text{ s}^{-1}$  at  $z \sim 3.5$ .

**Author(s):** Simon Lilly, Sebastiano Cantalupo, Sofia Gallego Gallego

**Institution(s):** ETH Zürich Contributing Team(s): MUSE Collaboration ii

### **239.03 - Extreme-UV Analysis of SDSS J1042+1646 from HST/COS Observations: Distance, Energetics, and Hints of an Accelerating Outflow(Xinfeng Xu)**

We determine the physical conditions and locations of outflows seen in quasar SDSS J1042+1646. These results are based on the analysis of our recent HST/COS observations. These data cover diagnostic-rich extreme UV range of 500 - 1050Å rest-frame. We have identified at least three significant outflow systems at velocities: -5300 km s<sup>-1</sup>, -7600 km s<sup>-1</sup> and -20000 km s<sup>-1</sup>. We also detected absorption troughs from both high-ionization species (ArVII, ArVIII, NeVIII, NaIX and MgX), and low-ionization species (NIV, OIV, OV, SV, SVI, CaVI and CaVII). Combined with troughs from excited states of OIV or OV, we are able to determine the electron number density, distance, mass flux and energetics of these outflows. Moreover, the outflow component of  $v \sim -20000 \text{ km s}^{-1}$  shows a velocity shift of -1500 km s<sup>-1</sup> over 6 years (2011 to 2017), which hints of an accelerating outflow.

**Author(s):** Timothy Reid Miller, Xinfeng Xu, Nahum Arav

**Institution(s):** Virginia Tech

**239.05 - Extreme UV HST/COS Observations of Two Outflows in PKS J0352-0711: Distances, Energetics, and AGN Feedback(Timothy Reid Miller)**

We analyze absorption troughs from two outflows within PKS J0352-0711 from spectra taken with HST/COS, which cover the diagnostic-rich 585-900 Angstrom rest-frame wavelength range. The higher velocity outflow (-3160 km/s) shows absorption troughs from high ionization potential (IP) ions including Na\_IX, Ca\_VII-VIII and Ar\_VIII as well as from low IP ions such as O\_III-V, Ca\_IV-VI, and S\_IV-V. There are also hints of more exotic ions of K\_IX, Cl\_V, and Cl\_VII. The lower velocity outflow (-1960 km/s) similarly has absorption troughs from both high IP ions (Mg\_X and Ne\_VIII) and low IP ions (O\_IV-V and N\_IV). Each outflow requires at least a two-phase photoionization solution. From column density ratios including  $O_{IV^*}/O_{IV}$  and  $O_{V^*}(J=2)/O_{V^*}(J=0)$ , of which observing  $O_{V^*}$  is a first, we determine the electron number density, distance, energetics, and potential for AGN feedback of each outflow.

**Author(s):** Timothy Reid Miller, Xinfeng Xu, Nahum Arav  
**Institution(s):** Virginia Tech

**239.06 - Probing the magnetoionized intragroup medium of NGC 2563(Anna Williams)**

We present the results of a study to observe magnetic fields within the intragroup medium of galaxy group NGC 2563. We use full polarization observations at S band (2-4 GHz) collected at the Karl G. Jansky Very Large Array to measure the polarization of extragalactic systems within 0.5 degrees of NGC 2563. Our survey detected 183 sources, 22 of which are at least 1% polarized. None of these polarized sources are associated with known group members, and determined to be background sources. We use the Faraday rotation of the polarized sources to probe the intragroup medium. When we compare the Faraday rotation of polarized sources with sightlines that pass within 420 kpc of the group center to those that pass through the outer 420 kpc, we see a slight increase in Faraday dispersion towards the center. This increase in Faraday dispersion follows the observed increase in electron density towards the center of the group, and is likely due to a combination of this property as well as an increase the magnetic field strength. Furthermore, we find that polarized sightlines that pass within 120 kpc of a known group member also show an increase in Faraday rotation dispersion, which may be due to magnetic field amplification via tidal interactions, ram pressure stripping, or turbulent wakes as the galaxies move through the intragroup medium. While this is the first study of its kind, we expect future all-sky surveys like the VLA Sky Survey will rapidly contribute to the detection of polarized sources towards galaxy groups and clusters. This will greatly improve our statistical understanding of the magnetized medium with large-scale galaxy structures, and help us to unravel the origin of large-scale magnetic fields in and around galaxies.

**Author(s):** Eric Wilcots, Anna Williams, Ellen Zweibel  
**Institution(s):** Macalester College, University of Wisconsin-

Madison

**239.07 - Constraining spins of black holes using quasi-periodic oscillations produced after they tidally disrupt stars(Dheeraj Ranga Reddy Pasham)**

SMBHs exist at the centers of almost all massive galaxies. However, most of them are dormant and thus remain undetected. Nevertheless, roughly once every 10,000-100,000 years a star will pass close enough to the black hole such that the tidal forces will disrupt the star to produce a flare that can shine across the entire electromagnetic spectrum. As the shredded material falls on the black hole it emits X-rays when closest to the event horizon. Thus, studying the X-rays that originate from strong gravity regime in the immediate vicinity of the black hole and thus encode the information about the black hole's mass and spin. I will discuss our recent discovery of a persistent, high-amplitude 131-second X-ray modulation from a recent quintessential tidal disruption event. The periodicity is remarkably stable over 2.5 years or 600,000 cycles and its fractional root-mean-squared (RMS) modulation amplitude is unprecedented with a value over 40%. This is unlike any known black hole system. Using a black hole mass implied from host galaxy scaling relations and comparing this stable periodicity/frequency to the fundamental frequencies of motion predicted from general relativity, we find that the oscillation is too fast for this black hole, unless it is rapidly spinning (dimensionless spin parameter  $> 0.7$ ). This discovery provides a new means to constrain spins of several massive black holes in future tidal disruption events. I will also discuss our efforts to discover similar signals in other tidal disruption flares using the soft X-ray missions including NICER and XMM-Newton.

**Author(s):** Frederick K. Baganoff, James Francis Steiner, Eric Robert Coughlin, Ronald Remillard, P. Chris Fragile, Nicholas Stone, Dheeraj Ranga Reddy Pasham, Deepto Chakrabarty  
**Institution(s):** Massachusetts Institute of Technology, College of Charleston, Columbia University

**239.02D - Multi-Phase Modeling of Intervening Quasar Absorption Line Systems at  $z < 1$ (Jackson M. Norris)**

To understand the formation and evolution of galaxies, it is essential to understand the gas that exists in the vicinity of galaxies. Mg+ absorption systems probe the circumgalactic medium (CGM) around galaxies and can provide hints to the nature of the gas around galaxies. To fully understand the complex structure of the CGM, it is necessary to investigate not only low-ionization transitions such as those of Mg+, but also transition lines associated with more diffuse high-ionization material usually observed in the UV. We report our analysis of eight intervening quasar absorption line systems, which probe the CGM at redshifts  $0.4 < z < 1.0$ . We model these systems as multi-phase material and constrain the parameters of our model by fitting to many ionization transitions including those of Mg+, C3+, O5+, Fe+, Ne7+, N4+, Mg0, O3+, S4+, Si+, Si3+,

C+, C2+, N+, N2+, and the H Lyman series. The talk will feature a system at redshift  $z = 0.48$  with a multi-phase structure that includes both gas with metallicity  $[\text{Fe}/\text{H}] < -2.5$  as well as low- and high-ionization gas with metallicity near solar. We will also discuss a low-ionization system with detected molecular H<sub>2</sub> that also has significant O<sub>5</sub><sup>+</sup> detected at nearly the same velocity. The physical properties of several other systems will be discussed, with a focus on new HST/COS coverage of high-ionization transition lines.

**Author(s):** Jackson M. Norris

**Institution(s):** The Pennsylvania State University

#### **239.04D - Kinematics of Circumgalactic Gas and Cold Gas Accretion at Redshift $z=0.2$ (Stephanie H. Ho)**

Galactic disks grow by accreting cooling gas from the circumgalactic medium (CGM). Decades of observations have also demonstrated that galaxies need a continuous gas supply to explain the star formation history and the stellar metallicity distribution of disks. However, direct observations of gas accretion onto galaxies remain sparse. I will present results of our survey that measures the kinematics of low-ionization-state gas in the CGM. We have observed quasars behind star-forming galaxies at  $z=0.2$ , and the quasar sightlines pass within 100 kpc of the foreground galaxies. We find that the Doppler shift of the circumgalactic absorption shares the same sign as the quasar side of the galactic disk, but the Doppler shifts are smaller than disk rotation predicts. The Doppler sign correlation implies the low-ionization-state gas in the inner CGM corotates with the disk. Altogether, our results indicate centrifugal force partially supports the circumgalactic gas, and therefore the angular momentum of the CGM delays accretion onto the disk. We have modeled the absorption kinematics using an inflow model with gas spiraling inwards near the disk plane. The model predicts the 3D orientation of the disk, which we test with new measurements. Our results suggest galaxies typically have inflow speeds of around 40 km/s, comparable to that of the cold inflowing gas we have identified around galaxies in the EAGLE simulations. We also find cold rotating gas disks with inflowing gas in EAGLE, and these disks extend to radii comparable to the impact parameters of our quasar sightlines around galaxies. Our analysis with EAGLE thereby further supports our inflow interpretation for the circumgalactic kinematic observations.

**Author(s):** Crystal L. Martin, Monica L. Turner, Stephanie H. Ho, Christopher W. Churchill, Glenn G. Kacprzak

**Institution(s):** University of California, Santa Barbara, New Mexico State University, Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Las Cumbres Observatory

#### **240 - Plenary Prize Lecture: RAS Gold Medal Lecture: Ripples from the Dark Side of the Universe, Sir James Hough (University of Glasgow, Scotland)**

##### **240.01 - Ripples from the Dark Side of the Universe(James Hough)**

In this talk I will review progress in the field of gravitational wave detection from the first days of the aluminium bar detectors to the present time where the laser interferometer detectors Advanced LIGO and Advanced Virgo have allowed gravitational waves to be detected and are opening up a new field of gravitational multi-messenger astrophysics. Many experimental challenges had to be overcome and new challenges are presenting themselves as we look to further enhance the performance of ground based detectors and look to lower frequencies with the space based detector LISA.

**Author(s):** James Hough

**Institution(s):** University of Glasgow, Scotland

#### **241 - Plenary Prize Lecture: HEAD Bruno Rossi Prize: Cosmic Rumbles and Fireworks from Merging Neutron Stars, Colleen Wilson-Hodge (NASA/MSFC)**

##### **241.01 - Cosmic Rumbles and Fireworks from Merging Neutron Stars(Colleen A. Wilson-Hodge)**

On August 17, 2017, a new era of astronomy began with the joint detection of merging neutron stars in gravitational waves as GW170817 and in gamma-rays as GRB 170818A, kicking off a world-wide campaign at all wavelengths. In my talk, I will tell the story of the GRB discovery with Fermi GBM, illustrating the exciting physics that we learned from this single event, along with the many open questions that still remain. I will discuss similar events that we have uncovered in the GBM data and describe our plans to improve GBM's response to these events in the new era.

**Author(s):** Colleen A. Wilson-Hodge

**Institution(s):** NASA MSFC Contributing Team(s): Fermi Gamma-ray Burst Monitor Team

#### **242 - AGN, QSO, Blazars I -- Posters**

##### **242.01 - Alignment of Molecular Gas Disks with Stellar Disks in the central Kiloparsec of Seyfert Galaxies(Hannah Crayton)**

We present an analysis of the disk orientations of the molecular gas and stars within the central kiloparsec of forty Seyfert galaxies observed as part of the Keck OSIRIS Nearby AGN (KONA) survey. Two complementary techniques are utilized for constraining the disk orientations based on the 2D gas and stellar kinematics, and a comparison of these results will be discussed. An assessment of the degree to which these circumnuclear gas and stellar disks are aligned and trends with the host galaxy type and environment will also be presented to test the hypothesis that the mechanisms driving the inflow of

gas fueling the AGN is dependent on these parameters. In this scenario, late type galaxies, where gas is abundant, are fueled by internal processes, and therefore would be predicted to have co-aligned gas and stellar disks. In contrast, early type galaxies are thought to be dependent on external accretion of material, which is influenced by environment, and would then be expected to have a higher degree of misaligned circumnuclear gas and stellar disks.

**Author(s):** Hannah Crayton, Erin K S Hicks, Moriah Parker

**Institution(s):** University of Alaska Anchorage

#### **242.02 - Peering deep in the radio to uncover the secrets of quasar feedback(Rachael Alexandroff)**

Theoretical models of quasar feedback involve radiatively-driven nuclear winds, which propagate into the surrounding interstellar gas (causing shock heating and plowed shells) and resulting in a galaxy-wide wind over the life time of the quasar. There are, however, few observational probes of this particular feedback phenomenon. One relatively unexplored route is to search for the shocked gas in the radio. Though only about 15% of quasars are traditionally “radio-loud”, meaning they launch radio jets that can be observed on scales of hundreds of kiloparsecs, we can identify populations of traditionally “radio-quiet” quasars that produce more radio emission than can be easily explained by just star formation. Indeed, the radio luminosity of powerful radio-quiet and radio- intermediate quasars is correlated with the velocity dispersion of ionized gas (measured via the strong [OIII]  $\lambda 5007\text{\AA}$ ... emission line), suggesting an intimate connection between radio emission and gas outflows. I will present our recent studies on the radio emission from radio-quiet quasars at  $z \sim 0.5$  where we use a combination of radio luminosity, spectral index and morphology in an attempt to disentangle jet- and wind-driven radio emission. Preliminary results from a recent radio survey of  $z \sim 0.5$  quasars with multi-component [OIII]  $5007$  emission suggests either the presence of bi-conical outflows or dual supermassive black holes and shows how radio data allows us to disentangle these scenarios. New sensitive radio surveys will be essential in allowing us to disentangle radio emission from jets/winds/star formation. This opens the radio regime as an additional avenue for studying multi-phase quasar winds and the interaction between quasars and their host galaxies.

**Author(s):** Nadia Zakamska, Rachael Alexandroff

**Institution(s):** University of Toronto, Johns Hopkins University

#### **242.03 - GeMS/GSAOI near-infrared imaging of $z \sim 0.3$ BL Lacs(Susan Elizabeth Ridgway)**

Bright quasars at low  $z$  have generally been found in massive, evolved host galaxies, consistent with formation at early epochs. However, deep, high resolution, multicolor imaging of some quasar hosts have found morphological evidence of tidal tails and colors indicative of active star formation. These results are

consistent with theories of galaxy formation and evolution in which merger processes trigger the activation of the quasar phase, and energetic feedback is essential. Understanding the role the black hole population plays in the galaxy formation process is important, but imaging the host galaxies around bright quasars is difficult because of the contribution of the bright nuclei. Very high resolution, deep imaging is necessary to successfully remove the nuclear component. We made high-resolution near-infrared images of several bright  $z \sim 0.3$  BL Lacs with the Gemini Multi-Conjugate Adaptive Optics System (GeMS)/GSAOI in order to study their host galaxies. We will present the results of this imaging with the 1 arcmin AO-corrected field provided by GeMS/GSAOI and compare with available HST imaging available in the archive.

**Author(s):** Peter Pessev, David Floyd, Susan Elizabeth Ridgway

**Institution(s):** NOAO, GTC, Monash

#### **242.04 - Modeling K2 blazar Flares(Michael T Carini)**

Observations of blazars with K2 have opened up new windows on the flaring behavior of blazars on timescales of hours to weeks. K2's high photometric precision and cadence allows the resolution of low amplitude, rapid flares not possible with ground based observations. The cadence and duration of the K2 observations, when combined with the K2 observing paradigm, provides us with a set of blazars light curves with flares that can be fit and have their properties determined. This poster will present the initial results of employing the process described by Valtaoja et al. (1999) and applied to optical and gamma ray blazar light curves by Chatterjee et al. (2012) to determine flare shapes, rise and fall times, and timescales.

**Author(s):** Michael T Carini, Jacob Lee

**Institution(s):** Western Kentucky University

#### **242.05 - High Ionization Quasar-driven Outflows in a $z \sim 1$ Post-starburst Galaxy(Cameren Neal Swiggum)**

We have discovered an unusual post-starburst quasar at  $z = 0.94$  in the Sloan Digital Sky Survey III. WISE data indicate that it is an extremely red quasar with a bolometric luminosity of  $\log(L_{\text{bol}}/L_{\text{sun}}) = 13$ . Photometric data spanning more than a decade show that the source has varied more than two magnitudes. Spectra obtained during a low state reveal the host galaxy and unusually strong emission lines of [OIII], [NeIII], and [Ne V]. The lines are blue shifted with outflow velocities up to  $\sim 4000$  km/s. The [NeV] to [NeIII] ratio is unusually high ( $\sim 3.5$ ). We consider whether the strong [Ne V] lines are of response to shocks from AGN driven winds or jets. We also consider the AGN's contribution to star formation quenching in the host galaxy.

**Author(s):** Adam Schaefer, Cameren Neal Swiggum, Christy Tremonti

**Institution(s):** University of Wisconsin Madison

#### **242.06 - Changing-state quasars in the Catalina Real-time Transient Survey and beyond(Matthew Graham)**

We report the results of a systematic search for quasars in the Catalina Real-time Transient Survey exhibiting both strong photometric and spectroscopic variability over a decadal baseline. We identify 81 sources with specific patterns of optical and mid-IR photometric behavior and a defined spectroscopic change. This forms a higher luminosity sample to compliment existing sets of changing-look quasars in the literature. Taken as a whole, we find that this population of extreme varying quasars is associated with changes in the accretion rate and that this is largely independent of source luminosity or amplitude of variation. We also discuss the prospects for the discovery of changing quasars in new surveys such as the Zwicky Transient Facility.

**Author(s):** S. G. Djorgovski, K.E. Saavik Ford, Andrew Drake, Daniel Stern, Matthew Graham, Barry McKernan, Nic Ross, Ashish Mahabal

**Institution(s):** California Institute of Technology, AMNH, Royal Observatory Edinburgh

#### **242.07 - Investigations of transforming BAL quasars(Sameer Sameer)**

We report on an X-ray and optical/UV study of eight Broad Absorption Line (BAL) to non-BAL transforming quasars at  $z \approx 1.7-2.2$  over 0.29-4.95 rest-frame years with at least three spectroscopic epochs for each quasar from the SDSS, BOSS, Gemini, and ARC 3.5m telescopes. New Chandra observations obtained for these objects show their values of  $\dot{M}_{\text{in}} \pm 0.5$  and  $\dot{M}_{\text{out}} \pm 0.5$ , as well as their spectral energy distributions, are consistent with those of non-BAL quasars. Moreover, our targets have X-ray spectral shapes that are, on average, consistent with weakened absorption with an effective power-law photon index of  $\Gamma_{\text{eff}} = 1.69 \pm 0.25$ . The newer Gemini and ARC 3.5m spectra reveal that the BAL troughs have remained absent since the BOSS observations where the BAL disappearance was discovered. The X-ray and optical/UV results in tandem are consistent with at least the X-ray absorbing material moving out of the line-of-sight, leaving an X-ray unabsorbed non-BAL quasar. The UV absorber might have become more highly ionized (in a shielding-gas scenario) or also moved out of the line-of-sight (in a wind-clumping scenario).

**Author(s):** Catherine Grier, Patrick B. Hall, D Schneider, John Ruan, Nabeel Ahmed, Neil Brandt, Filiz Ak Nurten, Adam D Myers, Scott Anderson, Bin Luo, P. Rodriguez Hidalgo, Sameer Sameer, Vivek Mariappan

**Institution(s):** Pennsylvania State University, Washington University, York University, Nanjing University, Erciyes University, Humboldt State University, University of Wyoming, McGill University

#### **242.08 - Using Dust to Trace the Growth of Supermassive Black Holes in Local Seyfert Galaxies(Nicole Sola)**

Maps of the dust distribution in the centers of a sample of local Seyfert galaxies have been generated with the aim of tracing the inflow of material toward the central. This is work that is being carried out as part of the Keck OSIRIS Nearby AGN (KONA) survey which has measured the distribution and kinematics of molecular gas in a sample of forty local Seyfert galaxies as spatial resolutions down to a few parsecs. Maps of the dust structures within the central kiloparsec provide the larger scale context needed to accurately interpret the observed gas kinematics. The dust maps are created through a combination of V-band images obtained with the Hubble Space Telescope, and H-band images obtained with the Hubble Space Telescope and laser adaptive optics assisted observations with the Keck Observatory. Classification of the dust morphology, and correlations of the dust structures with AGN and host galaxy properties will be presented.

**Author(s):** Nicole Sola, Erin K S Hicks

**Institution(s):** University of Alaska Anchorage

#### **242.09 - Using Disk Galaxy Simulations to Interpret Gas Inflow in Seyfert Galaxies(Angela R Cook)**

We present a study of the circumnuclear distribution and dynamics of the molecular gas in a sample of simulated galaxies representing the host properties of typical Seyfert disk galaxies. Within the central 500 pc, these n-body plus smoothed particle hydrodynamical simulations show inflow of gas driven by common disk processes (e.g. bars, spirals). Mock observations of this inflow provides a basis of comparison from which to interpret the complex gas motions measured within the central few hundred parsecs of Seyfert galaxies observed as part of the Keck OSIRIS Nearby AGN (KONA) survey. An analysis of the azimuthally averaged flux distribution and velocity dispersion of the molecular gas in the simulated galaxies, at a range of inclination angles, will be presented. A similar analysis of the stellar distribution and velocity dispersion, and a comparison of this to that of the molecular gas will also be discussed. Lastly, an analysis of these same observable quantities measured in the KONA sample will be compared to those seen in the simulations, and a preliminary characterization of the observed inflow in these galaxies will be shared.

**Author(s):** Erin K S Hicks, Angela R Cook

**Institution(s):** University of Alaska Anchorage

#### **242.10 - Orientation of Circumnuclear Stellar Disks in Local Seyfert Galaxies(Moriah Parker)**

An analysis of the circumnuclear stellar disks in a sample of local Seyfert galaxies observed as part of the Keck OSIRIS Nearby AGN (KONA) The degree to which the orientation of the stellar disks within the central 500 kpc is aligned with that of the large scale host galaxy disk is considered. The circumnuclear



stellar disk is constrained using two different techniques for fitting the 2-D kinematics and these are compared for consistency. Trends in the circumnuclear and host galaxy disk alignment with host galaxy properties such as Hubble type and environment, as well as AGN luminosity and AGN type, will also be presented.

**Author(s):** Erin K S Hicks, Hannah Crayton, Moriah Parker

**Institution(s):** University of Alaska Anchorage

#### **242.11 - Kinematic Study of Outflowing Gas for the nearby Seyfert Galaxies NGC 1068 & NGC 4151 using Hubble Space Telescope and Apache Point Observatory Spectra(Francisco Martinez)**

We are interested in the kinematics of outflowing emission line clouds in the narrow line region (NLR), and deciphering whether or not they are consistent with radiative driving as a function of distance from the central AGN. By using the Hubble Space Telescope's (HST) Space Telescope Imaging Spectrograph (STIS), we are able to obtain superior spatial resolution within their NLRs. With these data we perform spectral analysis to find the various multicomponent kinematics at work in the NLR and host galaxy. Coupled with these results, we match these data with ground based observations by using the Apache Point Observatory's (APO) Dual Imaging Spectrograph (DIS) to further map out the influence of the AGN on the host galaxy by measuring the extent of the rotating material in the plane of the galaxy. Further analysis includes BPT diagrams for determining the primary source of ionizing radiation along various slit positions overlapping the bright central nucleus.

**Author(s):** Dzhuliya Dashtamirova, D. Michael Crenshaw, Beena Meena, Crystal L. Gnilka, Francisco Martinez, Mitchell Revalski, Travis Fischer

**Institution(s):** Georgia State University, Catholic University of America

#### **242.12 - Probing the Narrow Line Region Kinematics of the Seyfert 2 Galaxy Mrk 78 using Apache Point Observatory (APO) and Hubble Space Telescope (HST) observations(Beena Meena)**

We present an analysis of resolved mass outflow and rotational kinematic components in the Seyfert 2 galaxy Mrk 78 using measurements from the APO's Dual Imaging Spectrograph (DIS) observations and the Space Telescope Imaging Spectrograph (STIS) on HST. Our goal is to determine the transition point between outflow and rotation and investigate the source of ionization as a function of position from the AGN using BPT diagrams. We are conducting this study as a pilot program to identify the most effective techniques for separating the contributions of the AGN and star formation to the ionization and kinematics of the circumnuclear gas in a large sample.

**Author(s):** D. Michael Crenshaw, Beena Meena, Crystal L.

Gnilka, Francisco Martinez, Mitchell Revalski, Travis Fischer

**Institution(s):** Georgia State University, The Catholic University of America

#### **242.13 - Quasar Accretion Disk Winds(Vincent James)**

We present results from the analysis of the X-ray spectra of a sample of high redshift quasars that show significantly blueshifted and highly ionized absorption lines. We interpret these blueshifted absorption lines as the result of near relativistic outflows and provide constraints on the wind properties. These properties are important in assessing the contribution of these winds to a feedback process that is thought to regulate the growth of their host galaxies. The outflow properties provide an insight to the dominant driving mechanism of the winds. Results from our correlation analysis between the properties of the quasar winds and their bolometric luminosities are compared to those of nearby Seyfert galaxies.

**Author(s):** Cristian Vignali, Vincent James, Giorgio Lanzuisi, Mauro Dadina, George Chartas, Massimo Cappi

**Institution(s):** INAF/OAS, Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Dipartimento di Fisica e Astronomia dell'Universita degli Studi di Bologna, Department of Physics and Astronomy, College of Charleston, Dipartimento di Fisica e Astronomia, Univ

#### **242.14 - The Black Hole-Host Galaxy Connection: Kinematics of A Nearby AGN Host(Emily Walla)**

The analysis of spatially-resolved spectra is important in understanding the dynamics of stars and gas around active galactic nuclei (AGN), galactic nuclei powered by supermassive black holes. In AGN, the energy of the black hole can reduce or stop stellar births as the gas in the galaxy is heated or ejected from the system, but how the AGN is related to the large-scale evolution and structure of its host galaxy is not fully understood. Spatially-resolved spectroscopy collected by the Multi Unit Spectroscopic Explorer (MUSE) on the European Southern Observatory's Very Large Telescope (VLT) provides insight into the motion and composition of regions within a galaxy. We present results from the analysis of a MUSE data cube of a nearby AGN host galaxy with a ring-shaped substructure on a scale of 600 parsecs. This galactic substructure plays an unusual role in affecting the impact of the central AGN engine by collimating and redirecting the outflows from the nucleus.

**Author(s):** Emily Walla, Stephanie Juneau, Leah Fulmer, Susan Ridgway

**Institution(s):** University of Arizona, National Optical Astronomy Observatory, University of Washington

#### **242.15 - Useful V Magnitude Comparison Sequences for Seyfert 1 Galaxy and Blazar Fields(Michael Joner)**

We present V magnitude comparison sequences for the fields of 26 extragalactic objects that have been monitored at the Brigham Young University West Mountain Observatory over the past decade. The current set of objects includes 22 Seyfert 1 galaxies and 4 BL Lac objects. In some of the sparse fields there are only 4 or 5 stable comparison stars that have been identified. In some of the more densely populated fields, we present as many as 12 suitable comparison stars.

**Author(s):** Michael Joner

**Institution(s):** Brigham Young University

#### **242.16 - HST/COS observations of quasar outflows covering the diagnostic-rich 500-1050Å rest-frame(Nahum Arav)**

We present HST/COS survey-observations of quasar outflows covering the diagnostic-rich 500-1050Å rest-frame. Among our findings:1) first detection of outflows troughs from  $\text{Ov}^*$ ,  $\text{Ne V/Ne V}^*$ ,  $\text{NeVI/Ne VI}^*$ ,  $\text{Ar VII}$ ,  $\text{Ar VIII}$ ,  $\text{Ca V/Ca V}^*$ ,  $\text{Ca VI}$ ,  $\text{Ca VII/Ca VII}^*$ ,2) Robust cases of two-ionization-phase outflow, which are the missing link between UV AGN outflows and X-ray warm absorbers.3) Determining the distances of the outflows from the central source, using multi-diagnostics for individual outflows, and their kinetic luminosity4) These findings demonstrate that outflows in luminous quasars have sufficient energy to fulfill the theoretical scenarios of AGN feedback processes.

**Author(s):** Timothy Reid Miller, Gerard Kriss, Xinfeng Xu, Nahum Arav

**Institution(s):** Virginia Tech, STScI

#### **242.17 - Spectral Energy Distributions of Far-Infrared-Selected X-Ray Luminous AGN in Stripe 82(C. Megan Urry)**

We compiled Spectral Energy Distributions (SEDs) of 90 Herschel SPIRE-detected sources that are also luminous X-ray sources survey ( $L_X > 10^{43}$  erg/s) in the Stripe 82X catalog and thus almost certainly AGN. All 90 AGN have spectroscopic redshifts or well-determined photometric redshifts. This is the largest statistically complete sample of luminous AGN with detections at both X-Ray (0.5-10 keV) and far-infrared wavelengths ( $\lambda > 100 \mu\text{m}$ ). We used AGNFitter to characterize the multi-wavelength SEDs, which span the wavelength range from  $500 \mu\text{m}$  to  $12 \mu\text{m}$  (10 keV). All of the sources have strong infrared components that peak at roughly  $50 \mu\text{m}$ , characteristic of thermal emission from warm dust with temperature  $\sim 50$ -100 K). In all cases the far-infrared emission outshines the SED components typically associated with AGN, namely, a big blue bump at  $0.1$ - $0.4 \mu\text{m}$  and hot dust (perhaps from an obscuring torus or disk) at  $2$ - $20 \mu\text{m}$  -- by factors of a few to as much as 50. The relative strength of the far-infrared component does not correlate strongly with the X-

ray luminosity; however, AGN with the strongest warm dust emission have much weaker big blue bumps and/or hot dust components, as well as slightly lower values of  $L_X$ , possibly indicating heavy obscuration. The mean SED for our sample is similar to that of warm ultra-luminous infrared galaxies (ULIRGs), which have previously been identified as a transition stage in the evolution of ULIRGs to optical QSOs. Further high-resolution imaging and spectroscopy of individual sources will be required to determine whether the strong far-infrared emission is primarily associated with dust on large scales or near the AGN.

**Author(s):** David B sanders, Kurt Hamblin, Conor McPartland, Eilat Glikman, Allison Kirkpatrick, T. Jane turner, Jason Brewster, C. Megan Urry

**Institution(s):** Yale University, Middlebury College, Institute for Astronomy, University of Kansas, University of Maryland Baltimore County Contributing Team(s): Accretion History of AGN (AHA) Team

#### **242.18 - The morphology of the 3-6 keV continuum and Fe-K emission of NGC 3393(Kieran Parker)**

Galaxies with a luminous centre are likely to have an active galactic nucleus (AGN). Within the AGN X-Rays are emitted from the accretion disk corona and also in the collimated jets undergoing Inverse Compton scattering. However, the details of this AGN feedback and especially how it interacts with the AGN's host galaxy, is poorly understood. It has been suggested that the interaction between the AGN feedback and the interstellar gas of the host galaxy could initiate star formation, a vital component to the mechanism of galaxy formation. Recent papers based on the Chandra data of ESO 428-G014 have shown the presence of kpc size 3-6 keV continuum and Fe-K emission. We explore how common this extended emission is by revisiting the Chandra data of Compton thick AGN NGC 3393. The observations, taken on the ACIS-S chip, have a combined exposure time of 334ks in the energy range 0.3 keV to 7 keV. We present a morphological analysis of this hard X-ray emission.

**Author(s):** Giuseppina Fabbiano, W. Peter Maksym, Kieran Parker, Martin Elvis

**Institution(s):** University of Southampton, Harvard Smithsonian Center for Astrophysics

#### **242.19 - HUBBLE SPACE TELESCOPE OBSERVATIONS OF EXTENDED [O III] $\lambda 5007$ EMISSION IN NEARBY QSO2s: PHYSICAL PROPERTIES OF THE OUTFLOWS(Anna Trindade Falcao)**

We used STIS long-slit medium resolution spectra (G430M,G750M) to analyze the extended [O III] emission in a sample of twelve QSO2s from Reyes et al (2008). The purpose of the study was to determine the properties of the mass outflows and their role in AGN feedback. We measured fluxes

and velocities as functions of deprojected radial distances. Using Cloudy Models and ionizing luminosities (derived from [O III] luminosities) we were able to estimate densities for the emission-line gas. From these results, we derived masses,  $dM/dt$ , kinetic energy, and  $d(KE)/dt$  as a function of radial distance for each of the targets. Masses were several times 106 solar masses, which are on the same order as the value determined from a recent photoionization study of Mrk 34 (Revalski et al, 2018). We measured mass outflows rates as high as 10s of solar masses per year. We compare these results to those from lower luminosity AGN, eg, Mrk 573.

**Author(s):** Steven Kraemer, Mitchell Revalski, Anna Trindade Falcao, D. Michael Crenshaw, Travis Fischer

**Institution(s):** Catholic University of America, Georgia State University Contributing Team(s): and the QSO Team

#### **242.20 - Ground-based light curves of NGC 4151, NGC 4593, and Mrk 509 for intensive disk reverberation mapping(Thomas Schmidt)**

In 2016 and 2017, the Neil Gehrels Swift Observatory carried out intensive X-ray, UV, and optical monitoring campaigns targeting the Seyfert 1 galaxies NGC 4151, NGC 4593, and Mrk 509. In coordination with these Swift campaigns, we obtained multi-band optical imaging data from observatories including Las Cumbres Observatory, the Liverpool Telescope, and several other facilities. The ground-based light curves achieved a near-daily cadence in ugriz and/or BVRI filters for durations spanning 2-9 months, covering a total number of 229 epochs in the case of Mrk 509, 175 epochs for NGC 4151, and 59 epochs for NGC 4593. The combined Swift and ground-based dataset provides comprehensive wavelength coverage from X-rays through near-IR for these monitoring programs. We present light curves measured from this ground-based campaign, which we use to measure wavelength-dependent time lags in order to constrain models for accretion disk continuum reverberation.

**Author(s):** Thomas Schmidt

**Institution(s):** University of California, Irvine Contributing Team(s): Intensive AGN Accretion Disk Reverberation Mapping Project

#### **242.21 - Luminous eBOSS Quasars Missing from Visually Inspected SDSS Catalogs(Alexandra N Higley)**

The Sloan Digital Sky Survey (SDSS) collaboration has provided many previous catalogs of quasar spectra that have been visually inspected to verify quasar classifications and redshifts. Recent versions of these catalogs have focused on manually classifying targets that were mostly related to quasar-specific programs. However, just as quasar targets can turn out to be galaxies and stars, programs aimed at galaxies and stars can accidentally target quasars. We report on our work to visually inspect spectra of bright quasars that were targeted as quasars by the SDSS-IV/eBOSS program but that have never previously appeared in SDSS catalogues of visually inspected quasars. We

manually processed objects from, typically "ancillary," SDSS programs such as the CHANDRAV1 and WHITEDWARF\_SDSS programs and provide classifications and redshifts for any quasars we recover. We compiled and visually inspected 2033 confirmed quasars that are particularly bright. As these objects are so bright, they are particularly useful for studies that require very high signal-to-noise observations or that focus on the most luminous quasars. In addition, these objects can now be correctly incorporated into eBOSS catalogs to study quasar clustering and Baryon Acoustic Oscillations, and can be used as test cases to train and improve automated spectral classification pipelines.

**Author(s):** Adam D Myers, Brad W Lyke, Alexandra N Higley, Danielle P Schurhammer

**Institution(s):** University Of Wyoming Contributing Team(s): SDSS-IV/eBOSS collaboration

#### **242.22 - Constraining origins of radio emission from radio-quiet Quasi-Stellar Objects (QSOs)(Amy Kimball)**

One of the most puzzling aspects of active galactic nuclei is the dominant physical origin of their radio emission. For radio-loud objects, it's clear that the dominant origin is the AGN radio-jet. But for radio-quiet objects, there is an ongoing controversy in the literature. Potential sources of radio emission include black hole spin, (scaled-down) AGN jets, shocks from AGN driven winds, and host galaxy star formation. In reality, all of these may contribute, but the question remains as to which one (if any) is the dominant source over different sources among the radio-quiet QSO population. I will present new results that are part of an ongoing study to constrain the AGN-jet emission from radio-quiet QSOs using high-resolution VLBI observations.

**Author(s):** Amy Kimball, Emmanuel Momjian, James Condon

**Institution(s):** National Radio Astronomy Observatory

#### **242.24 - A Survey of Kiloparsec-scale Outflows in Nearby Unobscured Quasars(Jessie Runnoe)**

Feedback driven by active galactic nuclei (AGN) is a potentially important ingredient in the coupled growth of supermassive black holes and their host galaxies. However, how ubiquitously or to what degree the large amounts of energy and momentum that are produced by AGNs can actually couple to the surrounding interstellar medium of the host galaxy is poorly constrained observationally. In particular, examples of spatially resolved quasar-mode feedback in Type 1 AGN remain scarce. With this motivation, we have undertaken a multi-wavelength observing program to study the multiphase outflows of nearby ( $z \sim 0.1$ ) Type 1 quasars. As the nearest unobscured supermassive black holes that approach the accretion rates seen in AGN at the epochs of peak accretion activity at high redshift, these are prime laboratories for studying quasar-mode feedback in galaxies. Targets for this survey are all Type-1 quasars

selected from a parent sample of nearby ultraluminous infrared galaxies and Palomar-Green quasars. We have begun observations with the Northern Extended Millimeter Array (NOEMA) to resolve molecular outflows in CO and with Magellan and Gemini to trace outflows of ionized gas using integral field spectroscopy. Here we present initial results from this ongoing effort, particularly highlighting the power and importance of multi-wavelength datasets to characterize outflow properties in these systems.

**Author(s):** Kayhan Gültekin, David Rupke, Jessie Runnoe  
**Institution(s):** University of Michigan, Rhodes College

#### **242.25 - Testing Models of Supermassive Black Hole Evolution with the Quasar Luminosity Function(Megan Tillman)**

The quasar luminosity function (QLF) describes the cosmic abundance of quasars at different luminosities and is a powerful tool in understanding how supermassive black holes (SMBHs) grow and evolve with their host galaxies. We compare the observed high-redshift QLF with predictions from four cosmological “zoom-in” simulations of massive galaxies from the FIRE project. The simulations predict a “kinked” relation between galaxy stellar mass and SMBH mass with three distinct regimes: (1) an early, slow growth phase regulated by stellar feedback, (2) a short phase of rapid growth, and (3) a later evolution along the local scaling relation. This prediction is in contrast to the commonly assumed linear relation between galaxy bulge mass and SMBH mass. We determine the Eddington ratio distributions associated with the three regimes, which we convolve with the stellar mass - halo mass relation and halo mass function to predict the QLF. The predicted QLF is consistent with the observed evolution of the QLF at high redshift ( $z \gtrsim 2$ ). This indicates that, as predicted by the FIRE simulations, high-redshift SMBHs may grow efficiently in a relatively short period, following an earlier phase during which SMBH growth was suppressed by stellar feedback. In ongoing work, we are quantifying more systematically the range of SMBH evolution models consistent with the observed QLF.

**Author(s):** Claude-André Faucher-Giguère, Sarah Wellons, Megan Tillman, Daniel Anglés-Alcázar

**Institution(s):** Texas A&M University, Flatiron Institute, Northwestern University

#### **242.26 - Ionization Mechanisms in Quasar Outflows(Jason Hinkle)**

The various ionization mechanisms at play in active galactic nuclei (AGN) and quasars have been well studied, but relatively little has been done to separately investigate the contributions of these ionization mechanisms within the host galaxy and outflowing components. Using Gemini integral field spectroscopy (IFS) data presented in a previous paper, we study the ionization properties of these two components in four nearby ( $z \lesssim 0.2$ ) radio-quiet Type 1 quasars. Emission line

ratios and widths are employed to identify the dominant ionization mechanisms for the host and outflow components in each object. We find that photoionization by the AGN often dominates the ionization of both gaseous components in these systems. In all cases, the outflowing gas is more highly ionized than the gas in the host, indicating that it is either more strongly exposed to the ionizing radiation field of the AGN or is of lower density than the gas in the host, or both. In two objects, a positive correlation between the line widths and line ratios in the outflowing gas component indicates that shocks with velocities of order 100 - 500 km/s may also be contributing to the ionization and heating of the outflowing gas component. The line ratios in the outflowing gas of one of these two objects also suggests a significant contribution from photoionization by hot, young stars in the portion of the outflow that is closest to star-forming regions in the host galaxy component. The data thus favor photoionization by hot stars in the host galaxy rather than stars in the outflow itself.

**Author(s):** David Rupke, Sylvain Veilleux, Jason Hinkle

**Institution(s):** University of Maryland, College Park, Joint Space-Science Institute, Rhodes College

#### **242.27 - Investigating the Effects of Non-Uniform Cadence on AGN Selection in LSST(Weixiang Yu)**

The Large Synoptic Survey Telescope (LSST) project is a decade-long optical sky survey, which will image the visible sky nearly every three nights. The dense temporal coverage of LSST will revolutionize the time-domain study of Active Galactic Nuclei (AGN) and enable robust AGN selection using its intrinsic time variability. While AGN selection by variability is very sensitive to cadence sampling, the exact effects on AGN selection from a non-uniform “rolling” cadence remains unclear. Unlike the baseline cadence, which provides uniform coverage to all areas in the Wide-Fast-Deep (WFD) footprint, the rolling cadence will increase the observing frequency of certain regions within a given time interval with the expense of dropping the observing frequency of the rest of the sky, and then focus on other selected regions in the next time interval. To assess the effects of non-uniform cadences on AGN selection, we start by simulating AGNs with a wide range of characteristic time scales following the damped random walk (DRW) model and damped harmonic oscillator (DHO) model. We then place the simulated objects across the WFD footprint to generate light curves, and finally using Markov Chain Monte Carlo to estimate corresponding model parameters. Based on how well the input parameters can be recovered, we are able to quantify the influence of non-uniform cadences on AGN selection.

**Author(s):** Jackeline Moreno, Weixiang Yu, Gordon Richards

**Institution(s):** Drexel University

#### **242.28 - Testing Quasar Accretion Disk Wind Models using the SDSS Spectral Database(Mason Rhodes)**

Radiation driven accretion disk winds are a leading model for the broad absorption lines (BAL) observed in quasars. This investigation provides a test of accretion disk wind models by comparing synthetic absorption spectral profiles to observed BAL parameters. We test how the physical properties of the quasar and the disk wind, such as orientation of the disk, black hole mass, and wind terminal velocity, affect the synthetic profiles. The synthetic spectra are then compared to the observed optical spectra of the Sloan Digital Sky Survey (SDSS) Data Release 12 (DR12) to provide a crucial test of radiation driven disk winds for BALs.

**Author(s):** Jack Gabel, Mason Rhodes

**Institution(s):** Creighton University

#### **242.29 - Spectral Energy Distributions of Luminous X-ray Selected AGN in Stripe 82X(Kurt Hamblin)**

Multi-wavelength data spanning X-ray-to mid-infrared wavelengths (0.5 keV-22  $\mu\text{m}$ ) are used to compile the continuum spectral energy distributions (SEDs) of 1597 luminous X-ray selected AGN ( $L_X > 10^{43}$  erg/s) from the Stripe 82X survey with spectroscopically confirmed redshifts. All of these sources have X-ray luminosities (0.5-10 keV) normally associated with luminous active galactic nuclei (AGN) and quasars. This is the largest statistically complete sample of luminous AGN with well-determined SEDs studied to date. The full sample can be split into two luminosity groups: 1) 1206 sources with high X-ray luminosity ( $L_X \geq 10^{44}$  erg/s, 75% of sample), which typically show broad emission lines characteristic of optically-selected quasars, and 2) 391 sources with lower X-ray luminosity ( $10^{43} < L_X < 10^{44}$  erg/s, 25% of sample), which exhibit narrower emission lines more typical of narrow-line Seyferts and star-forming galaxies. The median and range of SED shapes of the high luminosity X-ray selected sources both show characteristic features thought to be directly associated with AGN accretion, e.g., a big blue bump at UV-visible wavelengths (0.1-0.4  $\mu\text{m}$ ) and enhanced emission in the near/mid-infrared (2-20  $\mu\text{m}$ ). However, in the low X-ray luminosity sources, these features are less prominent, and there is a larger percentage of strongly reddened sources that lack any evidence for excess UV or near-mid-infrared emission. The most surprising finding is evidence for strong mid-far-infrared emission (~20-100  $\mu\text{m}$ ) in a substantial fraction of all X-ray-luminous AGN; such emission is rarely observed in previous studies of UV-selected quasars. Although the present sample is still biased toward unobscured AGN, it is far less biased than typical UV- or optically-selected samples and thus it suggests that the fuller AGN population includes far more obscured AGN than previously known. Further high-resolution imaging and spectroscopy of individual sources will be required to determine whether the strong mid-far-infrared emission is directly associated with the AGN or if it is primarily due to more widespread star formation in the host galaxy.

**Author(s):** David B sanders, Kurt Hamblin, Conor

McPartland, Eilat Glikman, T. Jane turner, Jason Brewster, C. Megan Urry

**Institution(s):** University of Maryland Baltimore County, Middlebury College, Institute for Astronomy, Department of Physics, University of Maryland Baltimore County, Department of Physics, Yale University Contributing Team(s): Accretion History of AGN (AHA) Collaboration

#### **242.32 - The seed factor: how a combination of four observables can unveil the location of the blazar GeV emission.(Adam Harvey)**

We present here a method for constraining the emission location of  $\Gamma^3$ -rays in powerful, lined blazars (i.e., flat spectrum radio quasars (FSRQs)). We have developed a diagnostic criteria, which we term the seed factor, to differentiate between  $\Gamma^3$ -ray emission due to external Compton (EC) scattering in the broad line region (BLR) and the molecular torus (MT). The seed factor is determined entirely by four observable quantities; the synchrotron and inverse Compton (IC) peak frequencies, and the respective peak luminosities. It may thus be possible to use the seed factor to constrain the emission location in a model-independent way. We also present preliminary results of our analysis regarding the seed factor in quasi-simultaneous multi-wavelength SEDs from the Fermi LAT Bright AGN Sample (LBAS), historical data from the ASDC SED Builder of FSRQs in the the Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (MOJAVE) sample, and quasi-simultaneous multi-wavelength SEDs from the Dynamic SEDs of southern blazars (DSSB) sample.

**Author(s):** Eileen Meyer, Adam Harvey

**Institution(s):** University of Maryland, Baltimore County

#### **242.33 - Examining the High-Energy Radiative Processes Occurring in Radio-Loud AGN Jets with Fermi-LAT Observations(Adurshsiva Iyer)**

It is now known that nearly all galaxies are home to a super-massive black hole (SMBH) at their centers, with some fraction of them hosting an Active Galactic Nucleus (AGN). In some cases, these systems produce relativistic jets of fully-ionized plasma moving close to the speed of light, which have been seen to be anomalously bright in the X-Ray range by numerous Chandra observations. A popular explanation for explaining the X-Rays from these jets has been Inverse Compton scattering of the Cosmic Microwave Background (IC/CMB), though this is only valid provided that the jets remain highly relativistic and are pointed to our line of sight at a relatively low angle (Georganopoulos et al. 2006). This model also requires that substantial gamma ray emission is detected from the jets, which we used the Fermi Large Area Telescope (LAT) to look for. We tested the IC/CMB model by determining the upper limits for sources detected by Fermi under the current 4 year catalog (3FGL). This was done by generating light curves to measure the total brightness of the jets over a time scale spanning the

entire Fermi mission using time bins spanning three weeks, as well as across each of Fermi's distinct energy bands using a combined binned likelihood analysis approach, iteratively calculating upper limits from lowest to highest Test Statistic (TS) values. We will explain this method in detail, which may be applicable to other cases where one wants to detect or put limits on faint, steady emission next to a competing brighter, but variable source.

**Author(s):** Adurshiva Iyer, Eileen Meyer, Markos Georganopoulos, Peter Breiding,

**Institution(s):** University of Maryland, Baltimore County, West Virginia University

#### **242.34 - The Connection between Jet Power and Jet Speed in RL AGN(Mary Keenan)**

Radio-loud AGN have large-scale jets of relativistic plasma propagating away from the central accreting black hole. Slowed plasma from these jets accumulates into giant radio-emitting lobes on either side of the host galaxy over the lifetime of the jet, resulting in a spatially extended, isotropic synchrotron emission which dominates at low frequencies. The other prominent source of emission at radio frequencies is due to the point source core itself, which can be enhanced by orders of magnitude due to relativistic beaming along the jet axis and typically dominates at higher frequencies. The two sources of emission can be separated through decomposing the low frequency spectrum. Once separated, the extended emission can be used as a proxy for jet power, as it has been shown to correlate with the kinetic power of the jet (Cavagnolo et. al 2010, etc.) and serves as a viable method of estimating it. We have compiled a large catalog of jet proper motions measured by VLBI, to investigate the relation between the apparent speeds and this kinetic jet power. We will present preliminary evidence that the kinetic power of the jet sets an upper bound on the Lorentz factor of the underlying flow within the jet, which is shown through the apparent speeds of plasma being ejected from the core, as measured by VLBI.

**Author(s):** Mary Keenan, Eileen Meyer

**Institution(s):** University of Maryland, Baltimore County

#### **242.35 - Athena: Studying the Energetic Universe(Laura Brenneman)**

The Athena X-ray observatory has been conceived to study the Hot and Energetic Universe. Its principal areas of study will include the physical and chemical evolution of the hot baryons in the warm-hot intergalactic medium, the physics of galaxy clusters, phenomena generated around black holes and feedback on all mass scales. Here I detail the science objectives and capabilities of Athena that pertain to its "Energetic Universe" theme, including a layered survey of AGN with redshift, targeted observations of compact objects including accreting black hole systems across all mass scales, the most sensitive observations ever taken of outflowing galactic winds,

and violent explosions throughout the Universe.

**Author(s):** Laura Brenneman

**Institution(s):** Smithsonian Astrophysical Observatory  
Contributing Team(s): The Athena Energetic Universe Working Group

#### **242.36 - Optimizing Multi-Wavelength Blazar Studies through Fermi-Swift Synergy(Christina Moraitis)**

Blazar flares seen by the Fermi Gamma-Ray Space Telescope Large Area Telescope (FermiLAT) are often followed up by Target of Opportunity (ToO) requests to the Neil Gehrels Swift Observatory (Swift). Using flares identified in the daily light curves of Fermi LAT Monitored Sources, we investigated which follow-up Swift ToO requests resulted in refereed publications. The goal was to create criteria of what Swift should look for in following up a Fermi-LAT gamma-ray flare. Parameters tested were peak gamma-ray flux, flare duration (based on a Bayesian Block analysis), type of AGN (BL Lac or FSRQ), and pattern of activity (single flare or extensive activity). We found that historically active sources and high-photon-flux sources result in more publications, deeming these successful Swift ToOs, while flare duration and type of AGN had no impact on whether or not a ToO led to a publication.

**Author(s):** Christina Moraitis, David J. Thompson

**Institution(s):** NASA Goddard Space Flight Center, Samford University

#### **242.38 - A Spectroscopic Study of Radio-Loud Narrow-Line Seyfert-1 Galaxies(Rae Stanley)**

Narrow-line radio-loud Seyfert-1 galaxies are an understudied small class of galaxies that have been identified by their H-beta absorption lines and their emission of synchrotron radiation primarily in the radio (Foschini et. al. 2014) (Smita et. al. 2012). Some of these galaxies have been observed to emit gamma radiation, suggesting the presence of relativistic jets originating from the black hole in the galactic center (Foschini 2013). It is not well understood why these galaxies emit relativistic jets, because their black holes are not thought to be large enough to accrete matter at a rate required to emit them (Foschini 2013). In addition to the mystery surrounding the black hole mass and accretion rate, Cameron (2001) suggests that interactions of ejected material from relativistic jets formed from the neutron stars in supernovae with the toroid accretion disk surrounding it could facilitate r-process nucleosynthesis up to  $A=132$  and could account for some of the diverse abundance of isotopes found in the universe. He also notes that the process in core collapse supernovae that creates these neutron stars also creates black holes in more massive stars. Since supermassive black holes at the centers of our studied galaxies emit relativistic jets and therefore are assumed to have a toroid accretion disk, it may be theoretically possible that these supermassive black holes are facilitating r-process nucleosynthesis by the same mechanism. Cameron (2001) also

notes that these r-process jets are identified by gamma-ray emission, which stems from beta decay of r-process elements. Using long-slit optical spectra taken by the Vatican Advanced Technology Telescope, we measure the black hole mass of a sample of 5 gamma ray emitting, narrow-line radio-loud Seyfert-1 galaxies and measure the abundance of Nickel and Aluminum - two elements with isotopes created specifically in r-process nucleosynthesis. Key words: Galaxies: active, Seyfert-1 - AGN: black hole mass, jets, accretion disks- Nuclear reactions: nucleosynthesis, abundances, gamma

**Author(s):** Rae Stanley

**Institution(s):** Marshall University Contributing Team(s): DrJon Saken, DrTimothy Hamilton, DrChristopher Corbly

#### **242.39 - SimBAL: Spectral Synthesis for Broad Absorption Line Quasars(Karen Leighly)**

Broad absorption lines are observed in the rest-frame UV spectra of 10-15% of quasars. The blueshifted lines provide unambiguous evidence of the presence of massive high-velocity outflows emerging from the central engine. It is plausible that these outflows carry enough energy to influence the evolution of the host galaxy. Although these objects have been studied for 30 years, and despite the abundance of data (tens of thousands of spectra observed by SDSS/BOSS), their potential impact on feedback is arguably less well understood than that of other channels, such as ultra-fast X-ray outflows or extended ionized and molecular outflows. Perhaps the reason for this lack of progress is that the richness and complexity of their spectra impedes analysis. Yet the same complexity offers a real opportunity for unraveling the physics of the outflows through detailed analysis of quasar spectra. We present SimBAL, a novel spectral-synthesis procedure that uses grids of ionic column densities generated by the photoionization code Cloudy and a Bayesian model calibration to forward-model broad absorption line quasar spectra. SimBAL analysis has many advantages over traditional analysis methods. It allows us to self-consistently model outflows in terms of the physical parameters of the gas, including ionization parameter, density, column density, and covering fraction, and to obtain uncertainties on the measurements. SimBAL excels in analysis of broad and blended absorption lines, and in many cases, we are able to map the physical parameters as a function of outflow velocity. A principal-components analysis method allows us to simultaneously model the continuum and emission line spectrum, thereby removing the ambiguity of continuum placement. We illustrate its use on the LoBAL quasar SDSS 0850+4451, a sample of FeLoBAL quasars, including an object with a remarkably massive outflow with outflow velocity approaching 0.1c, and a sample of PV quasars. Our long-term goal is to quantify the physical properties of the broad absorption line outflow phenomenon in general.

**Author(s):** Karen Leighly, Sarah C. Gallagher, Gordon Richards, Donald Terndrup

**Institution(s):** The University of Oklahoma, The University of Western Ontario, The Ohio State University, Drexel

University

#### **242.40 - Discovery of a remarkably powerful broad absorption line quasar outflow in SDSS J1352+4239(Hyunseop Choi)**

Quasars are among the most luminous and massive objects in the universe. Broad absorption line (BAL) features in quasar spectra are unambiguous signatures of strong quasar outflows. These outflows from the central engine are thought to play an important role in quasar feedback as the winds carry a significant amount of energy and matter to the host galaxy and potentially influence its evolutionary path. Outflows with the highest velocities and column densities are expected to be the most important. While X-ray ultrafast outflows (UFOs) are frequently relativistic, only a few percent of UV BAL objects are known to have extreme velocities. SDSS and BOSS spectra of SDSS J135246.37+423923.5 reveal it to be an “overlapping trough” FeLoBAL quasar with a thick cluster of absorption lines from Fe II and similar ions, resembling the “Iron Curtain” often seen in novae. Balmer emission lines observed in infrared spectra obtained with Gemini GNIRS and APO TripleSpec reveal a redshift of 2.26, which means that the minimum velocity of the outflow is at least -29000 kms<sup>-1</sup>. We analyzed the rest-UV spectrum using the spectral synthesis code SimBAL (Leighly et al. 2018) which uses a Markov Chain Monte Carlo (MCMC) method to measure the physical parameters of the absorbing clouds. We found an extraordinarily energetic UV outflow with the log kinetic luminosity of 47.1-47.5 [ergs<sup>-1</sup>], exceeding 10% of the bolometric luminosity (logLBol of 48 [ergs<sup>-1</sup>]). SDSS J1352+4239 has the fastest FeLoBAL outflow known with a width of about 15000 kms<sup>-1</sup> and maximum velocity reaching about -38000 kms<sup>-1</sup> (~0.12c). Our preliminary results show the total log column density of this outflow to be around 23 [cm<sup>-2</sup>]. The kinetic luminosity and location of the outflow (within ~5 pc of the black hole) make it likely that SDSS J1352+4239 is significantly impacting the galaxy nucleus. Although BAL features with high velocities (~0.1c) are not unknown, the combination of high column density and high velocity implies that this object has the largest kinetic luminosity reported to date in a BAL quasar.

**Author(s):** Karen Leighly, Sarah C. Gallagher, Donald Terndrup, Gordon Richards, Hyunseop Choi

**Institution(s):** University of Oklahoma, University of Western Ontario, Ohio State University, Drexel University

#### **242.41 - Massive Outflows in CII Low-Ionization Broad Absorption Line Quasars(Ryan Hazlett)**

About 20% of quasars have Broad Absorption Lines (BALs) in their spectra, indicating massive outflows emerging from the central engine. These outflows potentially remove accretion angular momentum, distribute metals into the intergalactic medium, and contribute to the evolution of galaxies through feedback. BAL quasars, identified by C IV absorption, exhibit a

diverse phenomenology that suggests a wide distribution of physical properties. A subset of BAL quasars shows P V absorption, and because phosphorus has a relatively low abundance these P V systems are inferred to have thick outflows and high ionization parameters. In a smaller subset, Mg II and Al III identify low-ionization broad absorption line quasars (LoBALs) with thick outflows approaching the hydrogen ionization front. Crossing the hydrogen ionization front results in a complex of Fe II absorption lines, creating FeLoBALs that can be difficult to analyze due to line blending. Between LoBALs and FeLoBALs lie C II LoBALs, identified by C II absorption at 1335 Å... that is present in the HII region through recombination onto C+2. We propose that these objects represent some of the thickest outflows that are accessible to detailed spectral analysis. Here we present new measurements of C II absorption-line equivalent widths in a set of P V broad absorption line quasars identified by Capellupo et al. (2017). We present analysis of a subset of these using SimBAL, a novel spectral-synthesis method that uses Bayesian model calibration to extract the physical conditions of the outflows.

**Author(s):** Donald Terndrup, Karen Leighly, Hyunseop Choi, Collin McLeod, Ryan Hazlett, Collin Dabbieri

**Institution(s):** University of Oklahoma, Ohio State University

## **243 - AGN, QSO, Blazars II -- Posters**

### **243.01 - Exploring AGN Unification Theory with the LOFAR Two-metre Sky Survey(Gaia Fabj)**

Active Galactic Nuclei (AGN) are believed to be a result of accretion of matter by a supermassive black hole (SMBH) at the center of its host galaxy. Unification models predict that type 1 AGNs (quasars, QSO) and type 2 AGNs (radio galaxies, RG) can be unified as a single class based on the fact that they have the same intrinsic sizes. This would result in different observed projected linear sizes, since these objects are oriented along different viewing angles. The goal of this project was to test the AGN unification models by looking at the projected linear sizes of a selected sample of radio sources using a low frequency survey provided by the Low-Frequency Array (LOFAR), the LOFAR Two-metre Sky Survey (LoTSS). To test these models, we looked at QSO and RG cumulative distribution functions (CDF) and at their size ratios as a function of low-frequency radio luminosity (151 MHz) and redshift.

**Author(s):** Gaia Fabj, Leah Morabito

**Institution(s):** CUNY College of Staten Island, University of Oxford, American Museum of Natural History

### **243.02 - The Clustering of Luminous X-ray AGN at $z \sim 2$ (Justin Johnson)**

We present a clustering analysis of luminous AGN in the Stripe82X and XXL-North fields. From computing the autocorrelation function of the AGN with  $L_x > 10^{44.5}$  erg/s, we find a bias of  $2.6 \pm 0.4$ . This corresponds to a typical dark matter halo mass of  $10^{12.3} M_{\text{sun}}/h$ , consistent with

measurements using optical quasars from large volume surveys.

**Author(s):** Justin Johnson, Claudia Megan Urry, Meredith Powell, Nico Cappelluti

**Institution(s):** University of Miami, Yale University

### **243.03 - Distribution of Quasars on the Celestial Sphere(Charles Hosewell McGruder)**

We employ the SDSS, Gaia, and WISE catalogs to study the distribution of quasars in a number of coordinate systems. Using bins of only 0.1 degree in width we compare the observed distributions with those expected from an isotropic distribution of quasars. We observe significant differences in the SDSS, Gaia and WISE distributions of quasars. We find, however, that all the observed distributions are anisotropic.

**Author(s):** Charles Hosewell McGruder

**Institution(s):** Western Kentucky Univesity

### **243.04 - Cosmology from UV/optical Spectra of Quasars(Gordon Richards)**

We explore ways in which Independent Component Analysis (ICA) of quasar continuum and emission-line properties can be used to constrain cosmological models. We first investigate how ICA might be used to improve the results of Risaliti & Lusso (2015) who have developed a new X-ray-based method to use quasars to constrain cosmological models. As very little of the sky has been imaged in the X-ray to the necessary level of sensitivity, we further examine how UV/optical spectroscopic samples of quasars alone can be used to calibrate quasars as standard candles. If our method proves fruitful it could be optimized from redshift 0.7 to 3.7 and provide independent constraints on cosmological parameters at high redshifts ( $z > 2$ ).

**Author(s):** Angelica Briana Rivera, Gordon Richards, Keziah Sheldon

**Institution(s):** Drexel University

### **243.05 - Decadal AGN Variability Survey in MACSJ1149(John Michael Della Costa)**

Active Galactic Nuclei (AGN) are galaxies that contain supermassive black holes which are actively accreting matter. AGN are known variable sources and display variability on timescales of months to years over a range of wavelengths. In this study, we identify AGN via their variability in the frontier field cluster MACSJ1149. We present a photometric analysis of over a decade of HST data for thousands of galaxies in the cluster region and detect significant variability in galaxies extending down to an apparent magnitude of  $m_i = 27.5$ . Our analysis utilizes HST images obtained in six different wavelengths from 435 nm to 1.6 microns and covers time scales 12 hours to 12 years apart. We present structure functions for the variable AGN and determine characteristic timescales for



variability at different wavelengths. We also compare individual light curves for the variables and discuss implications on accretion disk size. Finally, we present previously unknown supernovae candidates and a very resolved Einstein cross discovered in the field.

**Author(s):** Vicki Sarajedini, Lou Strolger, John Michael Della Costa

**Institution(s):** University of Florida, Space Telescope Science Institute, Florida Atlantic University

#### **243.06 - Color-Selected AGN and Variable Objects in the JWST North Ecliptic Pole Time-Domain Field(Cameron William White)**

We present early science results which use new observations in the recently established James Webb Space Telescope (JWST) North Ecliptic Pole (NEP) Time-Domain Field (TDF). Located within JWST's northern continuous viewing zone, the  $\sim 14'$  diameter JWST NEP TDF has been demonstrated to be the single best field for deep extragalactic time-domain studies with JWST due to its lack of bright foreground stars and low galactic foreground extinction (Jansen & Windhorst 2018). In preparation for the launch of JWST in 2021, the field has been targeted by multiple ground- and space-based observatories spanning the electromagnetic spectrum from X-ray to radio frequencies. In this study, we analyze near-UV, visible, and near-IR broadband photometry in the JWST NEP TDF taken with the Hubble Space Telescope WFC3/UVIS and ACS/WFC (see the companion poster by Jansen et al.) and with the MMT/MMIRS to make color selections of candidate Active Galactic Nuclei (AGN) within the field, and-where coverage of different epochs overlaps-examine the photometric variability thereof. We additionally incorporate medium-deep-deep Large Binocular Telescope and Subaru g- and z-band mosaics taken approximately one year apart to identify an initial sample of variable objects, demonstrating the potential of the JWST NEP TDF as the best continuously accessible survey field for time-domain science with JWST.

**Author(s):** Victoria Jones, Seth Cohen, Guenther Hasinger, Cameron William White, Christopher Willmer, Rolf A Jansen, Rogier Windhorst

**Institution(s):** Arizona State University, University of Hawaii, University of Arizona

#### **243.07 - Mining the Multiwavelength Sky for the Most Heavily Buried Quasars(Ryan C. Hickox)**

Understanding the full population of powerful active galactic nuclei is critical for understanding the origin of the largest supermassive black holes in the present-day Universe. In recent years, X-ray, infrared, optical, and radio surveys have made great progress in detecting and characterizing "hidden" obscured quasars, but the most heavily buried objects, with column densities well beyond the Compton-thick limit (as high as  $N_H > 10^{25} \text{ cm}^{-2}$ ), have been extremely challenging to

identify. We present our group's studies of these elusive, heavily obscured quasars, in which we use infrared, X-ray, and multiwavelength techniques to uncover a large number of these sources among the full population of galaxies, with some found in highly dust-reddened or merging systems. This work is supported in part by the National Science Foundation through CAREER award 1554584, and NASA through grant number NNX15AP24G.

**Author(s):** Wei Yan, Ryan C. Hickox, Christopher M. Carroll

**Institution(s):** Dartmouth College

#### **243.08 - Utilizing Independent Component Analysis to Explore the Diversity of Quasars(Angelica Briana Rivera)**

ICA (Independent Component Analysis) is a computational technique capable of reproducing spectra in a manner similar to PCA (Principal Component Analysis), but does not possess any requirements of orthogonality. The weights produced by this technique encode information concerning the correlations between spectral features. We use this information to analyze the optical variability in a subset of the SDSSRM sample consisting of 349 quasars observed up to 53 times over a period of 3 years, particularly in the context of the intrinsic Baldwin effect and the LUV-LX relation. We find that some preprocessing of the SDSSRM spectra is necessary in order to properly account for observational differences between epochs. Additionally, we have constructed a pipeline to coadd HST COS, FOS, GHRS, and STIS quasar data and rebin to the SDSS wavelength scale with the goal of investigating correlations between optical and UV emission using a sample of  $\sim 700$  quasars observed with both HST and SDSS. To further this goal/investigation, future work may include adding Chandra spectra/data points to the combined SDSS/HST data, allowing a more direct analysis of the correlation between UV and X-Ray emission and the effect of this correlation on the production of quasar winds.

**Author(s):** Paul Hewett, Gordon Richards, Angelica Briana Rivera

**Institution(s):** Drexel University, Cambridge University

#### **243.09 - The Electromagnetic Detectability of Supermassive Black Hole Binaries with LSST(Amelia M Henkel)**

The next generation of survey telescopes are expected to provide the first observations of electromagnetic counterparts to low-frequency gravitational waves produced during the inspiral and merging of supermassive black holes. However, it's not clear as to whether these sources will actually be detectable above the general variability of black hole accretion. We seek to better understand the prospects for supermassive black hole binary detectability with a set of simulated light curves that include a range of contributions from both quasar damped random walk (DRW) variability and periodic (sinusoidal)

signals. The light curves have noise, cadence, and duration matched to the likely design of the LSST Deep Drilling Fields. Within this analysis, we specifically probe how different black hole masses, mass ratios, luminosities, and orbital periods impact the reliability of binary identification and the accuracy of binary parameters fit using PyMC3. LSST probes a range of binary separations that matches near-future expectations for pulsar timing array detection of gravitational waves, and so we expect our research to indicate potential electromagnetic sources for current and future low-frequency gravitational wave observatories.

**Author(s):** Jonathan R. Trump, Amelia M Henkel

**Institution(s):** University of Connecticut

#### **243.10 - A Chandra X-ray Study of 3C Radio Galaxies and Their Lobes and Environments(Ajay Gill)**

This poster presents the results of a Chandra X-ray study that used quadrants to determine if there is an asymmetry in the total diffuse X-ray emission between regions that contain the radio lobes and regions that do not contain the radio lobes in 73 (11 FRI and 62 FR II) radio galaxies from the Third Cambridge (3C) catalogue. The counts from the X-ray nucleus of the sources were blanked and filled with a mean Poisson sampling of the background emission. The results indicate a few percent excess diffuse X-ray lobe emission in the medium, hard, and broad bands in both FRI and FR II radio sources. The excess emission in the lobes is diffuse and faint, since sources with bright compact emission associated with jets and hotspots were excluded, and it is seen at only a few percent of the background emission. We also find a few percent excess lobe emission in the medium, hard, and broad bands for sources with  $z < 0.28$  but do not find excess emission for sources with  $z > 0.28$ , which is consistent with the emission being of low surface brightness and unrelated to the energy density of the Cosmic Microwave Background (CMB), since the surface brightness decreases and the energy density of CMB increases with increasing  $z$ . We report X-ray emission associated with the radio hotspots of 3C41, 3C153, 3C263.1, and 3C337. We also confirm X-ray emission associated with the radio hotspots of 3C299, 3C325, and 3C349.

**Author(s):** Christopher P. O'Dea, Suman Kunduo, Stefi A. Baum, Ajay Gill, Preeti Kharb, Neil Campbell, Grant R. Tremblay,

**Institution(s):** oCentre for Nano and Soft Matter Sciences, P.B.No.39, Prof UR Rao Road, Jalahalli, Bengaluru, 56003, India, Department of Astronomy and Astrophysics, University of Toronto, 50 StGeorge Street, Toronto, ON M5S 3H4, Canada, School of Physics and Astronomy

#### **243.11 - Uncorrelated behavior of narrow absorption lines in NGC 5548(Maryam Dehghanian)**

The absorption and emission lines produced in a photoionized cloud correlate with changes in the ionizing radiation field. This

correlation, and the delay between changes in lines and the continuum, are used in reverberation mapping to measure the size of the source and mass of its central black hole in AGNs. The Space Telescope and Optical Reverberation Mapping Project (STORM), the largest-ever AGN monitoring campaign, surprisingly discovered that this correlation was violated in NGC 5548. The soft X-ray part of the SED was dramatically extinguished by an obscurer, a phenomenon seen in this object in 2013 by Kaastra et al. During part of the time that this obscurer was present, the absorption and emission lines did not respond to variations of the continuum. Here we model the decorrelation of the absorption lines from the continuum in terms of a varying obscurer covering factor, and identify the physics which makes this possible. We identify a cycle in which the soft X-ray portion of the SED varies, causing changes in the ionization of helium. The ionizing radiation produced in its recombination governs the ionization of the species observed with HST. Photoionization models reproduce the sense of the HST observations. The obscurer is likely to be part of the broad-line region which happens to cover our sight line to the central object. This shows the importance of cloud shadowing in understanding the physics of the emission-line clouds.

**Author(s):** Francisco Guzman, Bradley Peterson, Marios Chatzikos, Gerard Kriss, Peter van Hoof, Maryam Dehghanian, Gary Ferland

**Institution(s):** the university of kentucky, Department of Astronomy, The Ohio State University, Space Telescope Institute, Royal Observatory of Belgium

#### **243.12 - Analyzing Neutral Hydrogen Absorption Profiles in the Host Galaxies of 25 Active Galactic Nuclei.(Dianaly Cortés Rivera)**

The purpose of this research consists in searching for neutral hydrogen (HI) absorption in the host galaxy of a sample of 25 active galactic nuclei (AGN). We looked at these radio sources because the AGN are often characterized by the presence of a jet which is able to interact with gas throughout the host galaxy. Because of that we can study the kinematics of the gas to understand the effect of the jet and the relation that exists between the host galaxy and the AGN (Brinks and Mundell 96). The distribution of the HI can also give us information about the shape of the galaxy. Based on the line width and center we can obtain properties of the HI gas, such as its main velocity, if it's moving towards us (blueshift) or moving away from us (redshift). To achieve our goal, we take advantage of the sensitivity of the Arecibo's 305m telescope, because here we can observe in minutes what it could take hours in another radio telescope, to detect these absorption lines. Once we observed the galaxies, we had to convert the data into useful information to get the spectral graphs. Each galaxy has a file with the different scans and we wrote a script using the wdpss6 program on each scan to analyze the data. In order to reduce data, we added the individual scans into one scan, and then we averaged the polarization. Once it was polarization-averaged, we smoothed the data and then we plotted the results and analyzed the graphs. We detect HI absorption in 6 objects and rotation for

the galaxies NGC 2619 (G2) and 2MASX J12172779+1554132 (E1). For those 6 objects that appear to have a detection we made a baseline correction for this data, so it could fix any systematic oscillation that remained in the spectrum graph and do not confuse them with the real and important data. For NGC 2619 we can say that have a double-winged profile because that type of profile is a signature of rotation (Jones 18). So far, the other 19 objects have no detected HI absorption.

**Author(s):** Dianaly Cortés Rivera, Kristen M Jones

**Institution(s):** University of Puerto Rico, Arecibo Observatory

#### **243.14 - Radio-loud galaxy stability from three-dimensional high resolution hydrodynamic relativistic jet simulations(Geena Elghossain)**

We have used the Athena++ code on our ELSA cluster to create an array of three-dimensional hydrodynamic relativistic jets by varying physical conditions such as the initial jet velocity, jet-to-ambient matter density ratio, and adiabatic index. Such relativistic jets emerge from active galactic nuclei and can expand into giant radio lobes. This work is a significant improvement over our previous work with the Athena astrophysical code, where we produced lower resolution 3D simulations and crude 2D dimensional hydrodynamic relativistic jet simulations. Our new simulations employ a higher performance code that allows us to compute on finer meshes that yield substantially increased resolutions. These higher resolution simulations make our categorization of these AGN jet simulations into different Fanaroff-Riley types for radio galaxies more precise and confident.

**Author(s):** Paul Wiita, Yutong Li, Nicholas Tusay, Terance Schuh, Geena Elghossain

**Institution(s):** The College of New Jersey

#### **243.15 - Three-dimensional magnetohydrodynamic jet simulations of radio-loud AGN(Terance Schuh)**

We report on a suite of simulations of propagating three-dimensional non-relativistic and special relativistic magnetohydrodynamic (MHD) jets that have a range of initial jet velocities and ratios of jet density to external medium density. We use the Athena++ code to expand upon our previous set of over 50 3D special relativistic HD simulations by adding magnetic fields that can be dynamically important and examining their effects on the jet propagation. We focus on the differences in stability and morphology properties between runs and categorize the respective modeled AGN into Fanaroff-Riley class I (jet dominated) and FR class II (lobe-dominated) radio sources. Including magnetic fields in the simulations also allows for significantly better estimates of the variations of the synchrotron emission arising from these jets and this will be reported in future work.

**Author(s):** Paul Wiita, Xuanyi Zhao, Terance Schuh, Nicholas Juliano, Geena Elghossain

**Institution(s):** The College of New Jersey

#### **243.16 - The X-ray cavity around hotspot E in Cygnus A: a bubble**

**inflated by the outgoing jet(Amalya Cox Johnson)**

The powerful Fanaroff-Riley class II (FRII) radio galaxy Cygnus A (CygA) has a compact primary hotspot and a brighter secondary hotspot in each lobe. We report the discovery, in a 2 Msec Chandra X-ray image of Cyg A, of a "hole" surrounding the primary hotspot, with a radius of  $\sim 3$  kpc, in the X-ray emission from the eastern lobe. Fitting surface brightness profiles shows that the hole must be deeper along our line of sight than its projected width. The hole appears to be inflated by the expanding jet flowing out of the primary hotspot. Brightening on its rim is interpreted as X-ray synchrotron emission from a terminal shock. X-ray emission from the primary hotspot in the west is significantly brighter than in the east and there is no evident hole. These differences are likely due to Doppler beaming. We discuss some implications for the jets and hotspots of Cyg A. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1659473, and by the Smithsonian Institution.

**Author(s):** Richard A. Perley, Alastair Edge, Bradford Snios, Micheal Wise, Andrew J. Young, Martijn de Vries, Judith Croston, John P. McKean, diana worrall, Chris Carilli, Robert A. Laing, Brian McNamara, Amalya Cox Johnson, Mark Birkinshaw, William G. Mathews,

**Institution(s):** UCO/Lick Observatory, Department of Astronomy and Astrophysics, University of California, OSquare Kilometre Array Organisation, Jodrell Bank Observatory, Department of Physics & Astronomy, University of Waterloo, Hamburger Sternwarte, Universität Hamburg

#### **243.17 - ALMA Observations of the $z=1.51$ Lensed Ultraluminous Infrared Galaxy HS 0810+2554(Eric Davidson)**

We present preliminary results from ALMA observations of the  $z = 1.51$  lensed AGN HS 0810+2554. HS 0810+2554 is known to contain a small scale relativistic outflow of X-ray absorbing ionized material with velocities ranging between 0.1 and 0.4c, an outflow of UV absorbing material with  $v \sim 0.065c$ , and extended radio emission with a size of about 90 pc. The four lensed images and the Einstein ring of the host galaxy are clearly detected in the ALMA 2.1 mm continuum observation (beam size =  $0.11'' \times 0.06''$ ). The continuum emission is coincident with the optical emission of the four lensed images of the AGN, however, we also detect an Einstein ring in the continuum that implies a component of continuum emission that is extended. The molecular gas is detected through CO ( $2\hat{+}1$ ) and CO ( $3\hat{+}2$ ) emission and forms an Einstein ring indicating its extended nature. The spatially integrated CO ( $3\hat{+}2$ ) emission line profile is double peaked indicating the

presence of a rotating molecular torus. We present the continuum emission map at 2.1 mm, the CO ( $2\hat{+}1$ ) and CO ( $3\hat{+}2$ ) integrated line emission maps (moment zero) and intensity weighted velocity maps (moment one) of HS 0810. We finally compare the CO and IR properties of HS 0810 to those of local and distant AGN.

**Author(s):** Cristian Vignali, Massimo Cappi, Andrea Comastri, Eric Davidson, Marcella Brusa, Mauro Dadina, George Chartas, Giorgio Lanzuisi

**Institution(s):** College of Charleston, Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Universit`a di Bologna

#### **243.18 - Search for an AGN in the post-starburst galaxy PGC 043234, host of tidal disruption event ASASSN-14li(Linnea Dahmen)**

A galaxy's state at a given time can impact if and how certain galactic events occur. We analyze the environment of a single post-starburst galaxy, PGC 043234, which has the confirmed tidal disruption event, ASASSN-14l. Tidal disruption events occur when a star passes too close to a black hole and the tidal forces of that black hole rip the star apart. Recent studies have shown a large fraction of tidal disruption events have occurred in post-starburst galaxies, or galaxies that have halted their star formation. Simulations have shown an increased rate of tidal disruption events in galaxies with circumnuclear gas, or an active galactic nucleus (AGN). An active galactic nucleus is an extremely luminous center of a given galaxy, which is thought to be caused by gas accretion around the central supermassive black hole. There has not been enough data in nature to prove or disprove this theory. Determining the presence of an AGN would be suggestive of links between the TDE rate and circumnuclear gas, as well as between this activity and the end of the recent starburst. We use spectroscopic data from MUSE to examine how ionization varies throughout the galaxy. Specifically, we use Baldwin-Philips-Terlevich (BPT) diagrams to differentiate between star-forming ionization and harder ionization from AGN. We categorize every spatial pixel based on its ionization level to study the spatial extent of AGN-like ionization. This highlights whether AGN-like ionization is occurring in the center of the galaxy, ultimately indicating that there is not an AGN. We present these findings to explain in what context the tidal disruption event occurred and to shed light on how an AGN may evolve.

**Author(s):** Linnea Dahmen, Decker French

**Institution(s):** Pomona College, Carnegie Observatories

#### **243.19 - Complex Variability of AGN and XRBs Revealed by Recurrence Analysis(Rebecca Phillipson)**

The light curves in multiple bandwidths of many black hole X-ray binaries (XRBs) and active galactic nuclei (AGN) are complex and resist traditional time series analysis techniques (Phillipson et al. 2018). Recurrence plots (RPs) and their

quantitative analysis (RQA) were developed to study recurrences of dynamical trajectories in phase space. The structures present in RPs correlate to specific types of dynamical behavior in a system, including periodic, stochastic and chaotic motion, which are features of particular interest in the light curves of XRBs and AGN. The quantification of the structures in RPs has been applied to many fields, most recently in the characterization of stochastic behavior and nonlinear instabilities in the X-ray variability of microquasars, and the stability of orbits of terrestrial planets in the habitable zones of extrasolar systems. We apply the methods of RPs and their quantification to the three-year optical light curve of a Kepler AGN, which has been identified with a possible low-frequency quasi-periodic oscillation (Smith et al. 2018) corresponding to a temporal period of 44 days, and the X-ray light curves of four well-studied black hole XRBs from the RXTE, MAXI, and NuSTAR observatories. We provide evidence for traces of periodic, stochastic, and nonlinear, possibly chaotic, behavior in these light curves and compare to the results from our recent radiation-hydrodynamic simulations.

**Author(s):** Alan Smale, Michael S Vogeley, Stephen McMillan, Patricia Boyd, Rebecca Phillipson

**Institution(s):** Drexel University, NASA Goddard

#### **243.20 - Constraining LIGO: N-Body Simulations of Black Holes in an AGN Disk!(Jose Adorno)**

The gravitational wave detections made by LIGO suggest the need for an efficient source of Stellar Mass Black Hole (sBH) Binary formation and merger. Dense gas disks around supermassive black holes offer a promising environment for the formation and merger of these sBH binaries. The interactions between the torque from the dense gas in the disk and sBHs help form binaries which can quickly result in a black hole merger. I demonstrate, using N-body simulations, how sBH on prograde and retrograde orbits interact with each other during an AGN disk lifetime. My work shows that these gas disks are potentially excellent sources of sBH mergers detectable with LIGO. In future work, we hope to gauge how much of the LIGO measured sBH merger rate comes from mergers in gas disks at the centers of galaxies!

**Author(s):** K.E. Saavik Ford, Mordecai-Mark Mac Low, Amy Secunda, Jillian Bellovary, Betsy Hernandez, Andrea Mejia, Jose Adorno

**Institution(s):** American Museum Of Natural History

#### **243.21 - "Supersoft" X-ray Quasars & their Spins(Brian Guerrero)**

"Supersoft" X-ray quasars are supermassive black holes that are actively accreting large amounts of material and whose X-ray spectra are dominated by low energy emission. Such a spectrum may indicate that the emission is dominated by a thermal component from the accretion disk around the black hole. Modeling such a spectrum can provide valuable

constraints on the size of the inner edge of the accretion disk, which depends on both the mass of the black hole and its spin. Typical quasar spectra have contributions from both a thermal disk component and one or more non-thermal components, often modeled as power laws. There are usually degeneracies between these spectral components, limiting the constraints on the accretion disk parameters that we can obtain from broadband X-ray spectral modeling. However, these supersoft X-ray quasars may be completely dominated by the thermal disk component, offering a rare and rather unique opportunity to obtain strong constraints on the size of the accretion disk and therefore the spin of the black hole. There are only a few dozen supersoft X-ray quasars for which X-ray data exist. We present results from modeling Chandra X-ray Observatory data for these supersoft X-ray Quasars. The spectral fitting has allowed us to constrain the accretion disk parameters, in particular the black hole spins and sizes of the innermost stable circular orbits. When combined with independent mass estimates from optical spectroscopy, this research may provide an avenue to tightly constrain the spins of these black holes.

**Author(s):** Brian Guerrero, David Pooley

**Institution(s):** Trinity University

#### **243.22 - X-Ray Imaging of the Jet From the Supermassive Black**

##### **Hole M87(Jadyn Anczarski)**

The supermassive black hole, M87, has long been a target of interest for the study of black hole physics and relativistic jets across the electromagnetic spectrum. In April 2017, the Event Horizon Telescope and many ground- and space-based observatories undertook a campaign to study nearby supermassive black holes, including M87, at many wavelengths. With the inclusion of phased ALMA, the EHT data should have sufficient resolution to image the event horizon of the black hole. As part of this campaign, we observed M87 with the Chandra X-ray Observatory for a total of 26.24 ks over two exposures, enabling us to study M87 at high energy. We report the results of imaging and spectroscopy of the X-ray jet, focusing on the X-ray nucleus, which includes emission from both the core and a bright knot in the jet called HST-1. We present a deconvolved image to explore the relative intensity of the core and HST-1. Our analysis of this deconvolved image suggests that HST-1 was significantly fainter than the core. We found no evidence of strong variability in the X-ray brightness during our observation, but compared to the historically recorded spectra of the core, we discovered a slight decrease in the photon index (to  $\Gamma = 2.05 \pm 0.06 / -0.07$ , compared to a typical value of  $\Gamma = 2.25 \pm 0.10$  in the recent past). M87 was also fainter than in recent observations ( $L_X \sim 1.25 \times 10^{41}$  erg s<sup>-1</sup>). In light of the historical variability of HST-1, we explore the possibility that the lower photon index may be due to a smaller HST-1 contribution to the nuclear emission.

**Author(s):** Michael Nowak, Jadyn Anczarski, Frederick K. Baganoff, Joseph Nielsen, Sera Markoff, Daryl Haggard

**Institution(s):** Villanova University, University of

Amsterdam, McGill University, Massachusetts Institute of Technology, Washington University in StLouis

#### **243.23 - Constraining LIGO: Grinding Down Stars and Stellar Remnants into Accretion Disks(Syeda Sadika Nasim)**

Active galactic nuclei (AGN) are powered by the accretion of matter onto supermassive black holes (SMBH). Most accretion models take the form of disks of gas around the SMBH. Stars and stellar remnants also orbit the SMBH. Orbiting objects whose paths are inclined with respect to the plane of the disk experience a drag force when plunging through the disk, and through repeated passage, orbiters can have their orbits ground-down until they are fully embedded within the disk. Using two different accretion disk models, Sirko & Goodman (2003), and Thompson, Quataert & Murray (2005), we determine the grind-down time for stars and stellar remnants, as a function of initial orbital inclination, and initial orbital radius, while allowing both of these parameters to change. Orbital grind-down time in AGN disks is important to estimate because stellar-mass black holes (sBH) within AGN disks are likely to merge at a higher rate than in the field. Accurate estimates of orbital grind-down time can help constrain predictions of the AGN channel for LIGO.

**Author(s):** Barry McKernan, K.E. Saavik Ford, Syeda Sadika Nasim,

**Institution(s):** Hunter College CUNY, Borough of Manhattan Community College CUNY, American Museum of Natural History

#### **243.24 - The evolving X-ray spectrum of active galactic nuclei: evidence for an increasing reflection fraction with redshift(Mathilda Avirett-Mackenzie)**

The cosmic X-ray background (XRB) spectrum and active galaxy number counts encode essential information about the spectral evolution of active galactic nuclei (AGNs) and have been successfully described by XRB synthesis models for many years. Recent measurements of the 8-24 keV AGN number counts by NuSTAR and Swift-BAT are unable to be simultaneously fit by existing XRB synthesis models, indicating a fundamental breakdown in our understanding of AGN evolution. Here we show that the hard X-ray number counts can be successfully modeled with an XRB synthesis model in which the reflection strength in the spectral model increases with redshift. We show that a similar increase in reflection strength is a natural outcome of connecting the reflection to the incidence of high column density gas and the growth in the AGN obscured fraction to higher redshifts. However, this physically-motivated model of the evolution of the reflection strength cannot entirely account for the NuSTAR number counts. Therefore, an additional hard X-ray dominated population of AGNs -- evolving separately from the main population -- must be included in future XRB synthesis models.

We suggest that Compton-thick AGNs associated with major galaxy mergers may be the missing component.

**Author(s):** David Ballantyne, Mathilda Avirett-Mackenzie

**Institution(s):** Georgia Institute of Technology

### **243.25 - Faraday Depolarization as an Indicator of a Jet-ISM Interaction in NGC 3665(Evan Sheldahl)**

We present the results of a full-polarization, spatially-resolved study of the jetted active galactic nucleus (AGN) hosted by the nearby galaxy NGC 3665. By analyzing archival data from the Very Large Array, we have identified an intriguing region of rapidly varying polarization angle and low polarized flux in the nucleus compared to that of the jets. This region is spatially coincident with a central molecular disk, raising the possibility that the observed polarization properties in the center of NGC 3665 are a result of Faraday depolarization caused by the production of thermal gas as the jet ionizes the interstellar medium (ISM). NGC 3665 thus represents a rare example of depolarization potentially caused by a jet-ISM interaction. While there is no evidence of a molecular outflow in NGC 3665, the jets may inject enough energy into the ISM to contribute to the observed low star formation efficiency in the central molecular disk. We discuss prospects for future radio polarimetric and molecular gas observations as a means of improving our understanding of how jets influence galaxy evolution.

**Author(s):** Evan Sheldahl, K. E. Nyland,

**Institution(s):** National Radio Astronomy Observatory, Naval Research Laboratory

### **243.26 - Chandra X-ray Observations of Radio-Selected Dual AGNs(Arran Gross)**

Merger simulations predict a population of kpc-scale dual active galactic nuclei (dAGNs), where synchronized black hole accretion is triggered by tidally induced gas inflows. In this framework, dAGNs are thought to be the progenitors of merging supermassive black holes (BHs). We present Chandra observations of four previously radio-identified dAGNs between  $0.04 < z < 0.22$  in the Stripe 82 field. With a mean integration time of 24 ks, we detect 6 AGNs and obtained 3-sigma upper limits for 2 AGNs. We compare the X-ray, H-alpha, and radio luminosities of our dAGNs against those of the general AGN population from the literature, which are mostly hosted by isolated galaxies. The dAGNs straddle the parameter space between nearby Low Luminosity AGNs (LLAGNs) and low-redshift QSOs, and they follow the same luminosity correlations established by isolated AGNs. Furthermore, we measure the BH mass of the dAGNs using the M-sigma relation and find that they lie closely within the BH fundamental plane, which is a relation between the radio luminosity, X-ray luminosity, and BH mass for both stellar-mass BHs and supermassive BHs. Finally, we estimate nuclear obscuration of the dAGNs using the X-ray hardness ratio, the X-ray-to-[O III] luminosity ratio,

and the X-ray-to-mid-IR luminosity ratio. Considering the significant contribution from star formation to the [O III] and mid-IR luminosities, we find no convincing evidence that the dAGNs are more obscured than comparable AGNs in the general population, in contrast to the predictions from simulations. To reconcile the high AGN duty cycle in mergers and the lack of nuclear obscuration, we suggest that the dAGNs may have been triggered by minor tidal perturbations instead of massive gas inflows.

**Author(s):** S. G. Djorgovski, Dylan Paré, J. M. Wrobel, Hai Fu, Arran Gross, Joshua L Steffen, Adam D Myers

**Institution(s):** University of Iowa, California Institute of Technology, University of Wyoming, NRAO

### **243.27 - A Radio + X-ray Search for Massive Black Holes in Nearby Blue Compact Dwarf Galaxies(Colin Latimer)**

Nearby blue compact dwarf galaxies are arguably our best local analogues of galaxies in the earlier Universe. They can provide a close-up view of intense star formation and the early stages of massive black hole growth, which is difficult to obtain from faint galaxies at high redshift. Here we present high-resolution Chandra X-ray Observatory and Very Large Array observations of a sample of five nearby blue compact dwarf galaxies with stellar masses less than the Small Magellanic Cloud. We study star-formation related emission and search for signatures of accreting massive black holes at radio and X-ray wavelengths, which are more sensitive to lower black hole accretion rates than optical searches. We do not find compelling evidence for active massive black holes in our target galaxies, which on average have stellar masses that are more than an order of magnitude lower than previous samples of dwarf galaxies found to host massive black holes. Our results suggest that moderately accreting massive black holes in low-mass dwarf galaxies are not so common as to permit detection in a small sample.

**Author(s):** Amy Reines, Colin Latimer

**Institution(s):** Montana State University

### **243.28 - A gamma-ray QPO in the high redshift blazar B2 1520+31?(Paul Wiita)**

We detected a possible quasi-periodic oscillation (QPO) of  $\sim 71$  days in the 0.1-300 GeV gamma-ray light curve from Fermi-LAT observations of the high-energy peaked blazar B2 1520+31. We identify and confirm that quasi-period using Lomb Scargle periodogram (LSP), and weighted wavelet z-transform (WWZ) analyses. Using this QPO period, and assuming it originates from accretion-disk fluctuations, we can estimate the central supermassive black hole mass to be  $\sim 10^{10}$  solar masses. We also discuss other possible radio-loud active galactic nuclei emission models capable of producing a gamma-ray QPO of such a period in a blazar.

**Author(s):** Paul Wiita, Cosimo Bambi, Zhongli Zhang, Alok

Gupta, Ashutosh Tripathi, Pankaj Kushwaha

**Institution(s):** The College of New Jersey, Fudan U., ARIES, Shanghai Astronomical Obs., USao Paulo, Eberhard-Karls-U

### **243.29 - Lyman $\hat{I}\pm$ structures of “Green Bean” AGN Ionization Echoes(William Keel)**

“Green Bean” systems are galaxies with strong AGN-like emission from extended regions, and where the AGN as observed is insufficient to power these emission-line regions. They were selected based on combinations of SDSS colors and sizes, and are most efficiently found near  $z=0.3$ . These are strong candidates for luminous AGN ionization echoes, in which the AGN has faded strongly over the relevant light-travel times of order 105 years. To test the idea that similar systems could comprise some of the “orphan” Lyman  $\hat{I}\pm$  blobs seen at higher redshifts, we have obtained far-ultraviolet observations of 4 Green Beans with the Advanced Camera for Surveys Solar-Blind Camera (ACS SBC) on the Hubble Space Telescope. Lyman  $\hat{I}\pm$  is traced both by a combination of imaging in filters F140LP and F165LP, and complementary P130L prism observations. Even this small sample exhibits diverse Lyman  $\hat{I}\pm$  morphologies, including extended clouds similar to high-redshift Lyman  $\hat{I}\pm$  blobs, linearly-aligned compact emission knots, and filaments on a wide range of linear scales. Lyman  $\hat{I}\pm$  emission is detected over extents similar to those in [O III], to projected radii 18-45 kpc. The resolved emission ranges from 25-60% of the total from these objects, and the extended structures have Lyman  $\hat{I}\pm$  luminosities 1043-1044 erg/s. This work includes HST programs 14749 and 15247.

**Author(s):** Paul Torrey, Tohru Nagao, Nancy Levenson, James Turner, Rebecca Davies, Hai Fuo, Ruben Diaz, Claudio Ricci, Sangeeta Malhotra, Kohei Ichikawa, William Keel, Mischa Schirmer, Taiki Kawamuro

**Institution(s):** NASA GSFC, oU Iowa, MPIA, University of Alabama, Natl Astron Obs, PUC Chile, Ehime U., Columbia U, U Florida, Gemini Obs, MPE, STScI

### **243.30 - Modelling Optical Light Curves of AGNs Using Variable Viscosity Parameter(Shrey Ansh)**

AGNs are known to exhibit a highly stochastic variability at different time scales across all parts of the electromagnetic spectrum. It is difficult to ascertain if this variability at different time scales can be caused by a single mechanism. Lyubarskii in 1997 proposed a “variable alpha’ (viscosity parameter) model to investigate  $1/f$  power dependence of X-Ray light curves. Our project is aimed at investigating the output of optical light curves as a consequence of this variable alpha. We constructed a Markov Chain Monte Carlo simulation, where alpha which is oscillating at its local viscous timescale is introduced in the Shakura and Sunyaev “standard” accretion disc. Our theoretical prediction is then compared to the V-band optical light curve as observed on the CRTS telescope. We investigated the variation in luminosity for black holes which differ in mass,

accretion rate and luminosity and compared that to our theoretical light curve obtained as a result of variable alpha.

**Author(s):** Jack Gabel, Shrey Ansh

**Institution(s):** Creighton University

### **243.31 - Black Hole - Galaxy Scaling Relationships for RM AGNs(Misty Bentz)**

We have examined the host galaxies of 37 AGNs with reverberation-based MBH measurements using high-resolution optical HST images and deep ground-based near-IR images. With two-dimensional image decompositions, we have separated the AGNs from their host galaxies, allowing a re-examination of the MBH-Lbulge and MBH-Lgalaxy relationships. Constraining the stellar M/L with the V-H color, we have also examined the MBH-Mbulge and MBH-Mstars relationships. The best-fit correlations agree well with the sample of early-type quiescent galaxies with MBH measurements from dynamical modeling and the small sample of late-type galaxies hosting megamasers, as well as with the expectations from large-scale hydrodynamic simulations. We also find that MBH/Mstars  $\sim 0.01$ -1.0% and is a strong function of MBH.

**Author(s):** Misty Bentz

**Institution(s):** Georgia State University

### **243.32 - The Occasional Slumbering Balrog in a 100Mpc<sup>3</sup> Mine: Examining Simulated AGN Feedback in Galaxy Groups(Allison Rose Erena)**

We examine the history of active galactic nuclei (AGN) in galaxy groups, using the hydrodynamical cosmological simulation Illustris to shed light on the following broad areas in the evolution of galaxies and their group environment: the missing baryon problem, heating of the intragroup medium (IGM), and quenching of star formation. We explore the activity of black holes in several groups and their member subhalos, utilizing information about accretion rates to look for periods of AGN. Additionally, we measure the frequency and duration of these periods, and examine the conditions in the subhalo when AGN began. We show that such periods of activity occur most frequently in the brightest group galaxy (BGG), and explore links between star formation rate and accretion rate as a function of redshift. We also include a comparison with information on AGN gathered from observational data.

**Author(s):** Allison Rose Erena, Eric Wilcots, James D. Lowenthal

**Institution(s):** Smith College, University of Wisconsin, Madison

### **243.33 - Unraveling the Physics of Quasar Jets Using HST Polarimetry(Devon Clautice)**

Polarization is a critical parameter for understanding jet flows, as their radio to optical emission is produced by synchrotron radiation, which is naturally polarized, with the inferred magnetic field direction indicating the magnetic field direction in the emission region. Polarization has proven essential in characterizing the physics of FR I jets, where it has helped us map out their magnetic field and energetic structure and the relationship of this structure to the high-energy emission and particle acceleration. To date, high-quality HST polarimetry has been analyzed for just one FR II jet, that of PKS 1136-135. To rectify this, we have obtained new HST polarimetry observations of three key FR II jets - 3C 273, PKS 0637-752, and 1150+497. These new observations allow for the determination of the magnetic field structure and confirmation of which emission mechanisms are operating to create the observed optical to X-ray emission, and will allow us to greatly advance modeling efforts for these jets and nail down their kinetic power, a key parameter for understanding quasars and their cosmological effects.

**Author(s):** Rita Sambruna, Sebastian Jester, William B. Sparks, John Biretta, Mark Birkinshaw, Herman Marshall, diana worrall, Chi C. (Teddy) Cheungo, Devon Clautice, Paolo Coppi, Christopher P. O'Dea, Yasunobu Uchiyama, Stefi A. Baum, Claudia Megan Urry, Jean Eilek,

**Institution(s):** Yale University, oNaval Research Laboratory, George Mason University, Massachusetts Institute of Technology, Rikkyo University, Jagiellonian University, Florida Institute of Technology, Max-Planck-Institut für Astronomie, Space Telescope Science Inst

### **243.34 - VERITAS Observations of Very High Energy Gamma-rays from Microquasar SS 433(Alice Curtin)**

SS 433 is a binary system with an A-type star that is orbiting a black hole. The system emits two jets of relativistic particles that produce very high-energy gamma-rays when they interact with the interstellar medium. Two very high energy gamma-ray observatories, VERITAS and HAWC, observed the region around SS 433. HAWC was able to detect gamma-ray emission from SS 433. However, VERITAS does not observe a strong gamma-ray signal from the direction of SS 433. We simulated HAWC data onto the VERITAS camera to compare the measurements made using HAWC with those made using VERITAS. In this presentation, I discuss the discrepancies between HAWC and VERITAS measurements, and possible reasons for these discrepancies along with possible solutions.

**Author(s):** Alice Curtin, Anushka Udara Abeysekara, David Kieda

**Institution(s):** University of Utah Contributing Team(s): VERITAS Collaboration

### **243.35 - Probing binary supermassive black hole systems with the VLBA(Peter Breiding)**

Current models for galaxy evolution invoke mergers between galaxies in order to explain correlations between the central supermassive black hole (SMBH) and various host galaxy properties (e.g., Ferrarese et al., 2000 and Gebhardt et al., 2000). It is believed that as a result of these mergers, dual ( $< \sim 1$  kpc) and binary ( $< \sim 10$  pc) SMBHs are formed. At small separations ( $< 1$  kpc), these binary black holes would emit strong gravitational wave signatures which could be detected by pulsar timing arrays and upcoming space-based interferometers, such as the Laser Interferometer Space Antennae (LISA). In a sample of  $\sim 15,900$  Sloan Digital Sky Survey (SDSS) quasars, Eracleous et al. (2012) found 88 objects with velocity-offset broad emission lines (originating from the quasar broad line region) with respect to the host galaxy rest frame. The leading explanation for such offset, broad-emission lines is the presence of a binary SMBH. This poster will present recent high-resolution ( $\sim 0.1''$ ) very long baseline array (VLBA) X-band observations of 35 candidate binary SMBH systems from the Eracleous et al. (2012) sample, aimed at directly testing this hypothesis by the identification of dual, unresolved compact radio cores. Additionally, these observations provide a key test of the two competing theories for the velocity-offset broad lines: jet-broad line cloud interactions and recoiling SMBHs. A systematic census of the dual SMBH population will help constrain the strength and distribution of objects emitting gravitational waves at the long wavelengths these detection techniques are sensitive to. Additionally, determining the occurrence rate of dual active nuclei in galaxy mergers can help directly measure merger-induced active nucleus activity, SMBH growth, and the physical processes that drive both the remnant's dynamics and the inspiral of the black hole pair.

**Author(s):** Sarah Burke-Spolaor, Peter Breiding,

**Institution(s):** University of Maryland, Baltimore County, West Virginia University

### **243.36 - Spectral Energy Distribution Analysis of WISE-Selected Obscured AGNs in Major Mergers from the SDSS(Madalyn Elizabeth Weston)**

The debate on whether or not major galaxy mergers produce active galactic nuclei (AGNs) rages on, with the majority of infrared-selected-AGN papers finding a connection and many X-ray-based studies finding none. We use a catalog of visually-selected major mergers and interactions from the SDSS, with stellar masses above  $2 \times 10^{10} M_{\odot}$  and redshifts  $z \leq 0.08$ , to select AGNs using BPT-analysis (optical AGNs) and WISE color-color selection ("dusty" AGNs). In line with other studies, we find that major mergers (interactions) are 5--17 (3--5) times more likely to have red [3.4]-[4.6] colors associated with dust-obscured (infrared) AGNs when compared to non-merging control galaxies with similar masses. We find no enhanced frequency of optical AGNs in merging over non-merging galaxies. Most mergers and interactions hosting dusty



AGNs are star-forming. Central to the AGN-merger debate is star formation in these systems, which can produce dust and obscure shorter wavelengths or heat the dust causing a false infrared AGN detection. Therefore, disentangling the amount of buried SF versus AGN activity in these systems is key to understanding the major merger-induced triggering of central supermassive black holes. In our ongoing research, we analyze the SEDs of merging galaxies, and a sample of statistically-matched control galaxies, to quantify the amount of plausibly buried SF and AGN activity. Our preliminary results show that 98% of all WISE-selected AGNs, and all WISE AGNs hosted by a merging system, have a significant AGN component through SED analysis. A key objective for robust SED analysis is obtaining accurate and uniform flux measurements across different wavelength regimes. We present a new Python-based homomorphic aperture photometry code specifically tailored to nearby merging systems: MergerPhot. This code is designed to self-consistently quantify the multiwavelength fluxes and flux errors of merging galaxies from GALEX, SDSS, 2MASS, and WISE. MergerPhot also accounts for the issue of splicing common in other automatic photometry codes.

**Author(s):** Nicholas Putnam, Daniel H. McIntosh, Kameswara Mantha, Lauren Higgins, Madalyn Elizabeth Weston  
**Institution(s):** University of Missouri - Kansas City

### **243.37 - Dynamical Reconstruction of the Parsec-Scale Jet of the Blazar 3C 273 at 43 and 15 GHz(John Martin Hunter)**

The Event Horizon Telescope (EHT) uses very long baseline interferometry (VLBI) at 230 GHz to image regions near supermassive black holes in the centers of galaxies. Currently, this array is able to handle nearby sources, such as Sagittarius A\* and M87, due to their large angular size and large black hole mass in the case of M87. However, we hope that the EHT will be able to handle a larger number of differing sources as more telescopes are added. New imaging techniques are being developed to exploit the full potential of the EHT's high angular resolution and also offer the promise of improving the image quality of lower-frequency VLBI data. In order to accomplish this, we are developing a pipeline in the sparse modeling imaging library (smili) that takes real Very Long Baseline Array (VLBA) data of the parsec-scale jet of the blazar 3C 273 at both 43 and 15 GHz and dynamically reconstructs the evolution of its jet over 10 and 22 years, respectively. We then conduct a wavelet-based decomposition and analysis of significant structural patterns in the jet by implementing a newly developed wavelet-based image structure evaluation (WISE) algorithm into smili. We find that our new pipeline is able to handle the changing patterns of intensity typical of blazars with accuracy and smoothness in frame-to-frame reconstruction. We also report a number of interesting findings concerning the behavior of knot generation, velocity and acceleration profiles of the jet, and lifetimes of these knots.

**Author(s):** John Martin Hunter, Michael Johnson, Svetlana Jorstad, Alan Marscher, Kazunori Akiyama, Vincent Fish  
**Institution(s):** Boston University, Harvard-Smithsonian

Center for Astrophysics, MIT Haystack Observatory  
 Contributing Team(s): Event Horizon Telescope Imaging Team, BU Blazar Group, MOJAVE Program

### **243.38 - Gemini Near Infrared Spectrograph Distant Quasar Survey: The First Year(Brandon Matthews)**

We present the first installment of spectroscopic measurements performed with the Gemini Near Infrared Spectrograph Distant Quasar Survey (GNIRS-DQS). This is a three-year project, launched in 2017, aimed at obtaining high quality near-infrared spectroscopy of 416 Sloan Digital Sky Survey (SDSS) quasars between redshifts of 1.5 and 3.5 in the  $\sim 1.0\text{--}2.5\ \mu\text{m}$  band. A combination of the GNIRS and SDSS spectra will cover principal quasar diagnostic features, chiefly the C IV, Mg II, H $\beta$ , and [O III] emission lines, in each source. The spectral inventory will be utilized primarily to develop prescriptions for obtaining more accurate and precise redshifts, black hole masses, and accretion rates for all quasars. Additionally, our measurements will facilitate a more complete understanding of how the rest-frame UV-optical spectral properties of quasars depend on redshift and luminosity, and test whether the physical properties of the quasar central engine evolve over cosmic time. Our raw data are immediately available to the public through the Gemini Observatory Archive, and our final reduced and calibrated spectra will be made available shortly thereafter on a dedicated public website. This work is supported by National Science Foundation grants AST-1815281 and AST-1815645.

**Author(s):** Joseph F. Hennawi, Chris J. Willott, Sarah C. Gallagher, Ohad Shemmer, Ileana Andrichow, Michael A. Strauss, Sergio Cellone, W. N. Brandt, Paulina Lira, Beverley J. Wills, Michael S. Brotherton, Richard M. Plotkin, Donald P. Schneider, Todd A. Boroson, Gord  
**Institution(s):** Drexel University, oICRAR-Curtin, University of Illinois at Urbana-Champaign, University of Michigan, NRC Herzberg, Princeton University, The University of Texas at Austin, University of North Texas, Universidad Nacional de La Plata, University of W

### **243.39 - Identifying a Robust and Practical Quasar Accretion-Rate Indicator Using the Chandra Archive(Andrea Marlar)**

We present preliminary results of a Chandra X-ray Observatory archival project aimed at identifying a robust and practical accretion-rate indicator for quasars. Our quasar sample is limited to sources that do not have broad absorption lines, are not radio loud, have high-quality data in the C IV and H $\beta$  spectral bands, and that have Chandra coverage. We search for correlations between basic quasar accretion-rate diagnostics, such as the optical-X-ray spectral slope, emission line widths and equivalent widths, and velocity shifts. These will be utilized to develop a prescription for the most robust accretion-rate estimate that can be practically applied at the highest accessible

redshifts. The results of this project will also be used to identify quasar candidates for which deeper X-ray observations could yield accurate measurements of the hard-X-ray power-law photon index, needed to further confirm our conclusions.

**Author(s):** Andrea Marlar, Gordon Richards, Michael Brotherton, Ohad Shemmer

**Institution(s):** University of North Texas, Drexel University, University of Wyoming

#### **243.40 - Presence of ionized reflection in the Broad Line Radio Galaxy (BLRG) 3C109 and its connection to the jet(Sulov Chalise)**

Relativistic Active Galactic Nuclei (AGN) jets, whose formation is poorly understood, have a significant impact on the evolution of their host galaxies. BLRGs, the radio-loud analogues to Seyfert 1 galaxies, are excellent sources to study the AGN jet-forming region, as they are neither totally obscured nor overpowered by the jet. We present recent high-quality X-ray (NuSTAR and XMM-Newton), optical/UV (XMM-OM) and radio (13.5-18 GHz) observations of 3C109 ( $z = 0.3056$ ), which is one of the most luminous BLRGs. We find that 3C109 possesses long-term variability but no significant short-term variability in the X-ray band. Using the X-ray reflection spectrum along with the optical/UV data, we can put stringent constraints on parameters like the high-energy cutoff, reflection fraction and inner-disk radius. The radio data will be used to connect the central engine, as probed by X-rays, to any changes in the jet. Our results will be placed into the wider context of what is known about the jet formation in BLRGs.

**Author(s):** Laura Brenneman, Anne Lohfink, Erin Kara, Sulov Chalise, Helen Russell

**Institution(s):** Montana State University, University of Maryland, Smithsonian Astrophysical Observatory, University of Cambridge

#### **243.41 - Monitoring Accretion Flares and Other Unusual Events in Quasars in the SDSS-RM Survey(Robert William Bickley)**

The Sloan Digital Sky Survey Reverberation Mapping Project (SDSS-RM) is a pioneering new multi-object reverberation mapping campaign that has been monitoring 850 quasars with photometry and spectroscopy since 2014. The primary goal of this campaign is to perform reverberation mapping and mass estimates for a large set of quasars spanning redshifts  $0 < z < 3$ . However, by virtue of the large number of objects surveyed and the long monitoring duration, the survey has also observed a number of unusual variability events. We report the details of some of these events here, and find that they are largely consistent with flares associated with the accretion disk and / or accretion jet. We also make predictions for similar unusual quasar variability events in the upcoming SDSS-V Black Hole Mapper and LSST surveys.

**Author(s):** Robert William Bickley, Jonathan R. Trump

**Institution(s):** University of Connecticut

#### **244 - Astronomy Education Research In & Out of the Classroom -- Posters**

##### **244.01 - What does a Successful Postdoctoral Fellowship Publication Record Look Like?(Oliwia Krupinska)**

Obtaining a prize postdoctoral fellowship in astronomy and astrophysics involves a number of factors, many of which cannot be quantified. One criterion that can be measured is the publication record of an applicant. The publication records of past fellowship recipients may, therefore, provide some quantitative guidance for future prospective applicants. We investigated the publication patterns of recipients of the NASA prize postdoctoral fellowships in the Hubble, Einstein, and Sagan programs, using the NASA ADS reference system. We find that fellowship recipients between the years 2014 to 2017 had a median of  $6 \pm 2$  first-author publications, and  $14 \pm 6$  co-authored publications, at or near the time of application. The full range of first author papers is 1 to 15, and for all papers ranges from 2 to 76, indicating very diverse publication patterns. Thus, while fellowship recipients generally have strong publication records, the distribution of both first-author and co-authored papers is quite broad; there is no apparent threshold of publications necessary to obtain these fellowships. We also examined the post-PhD publication rates for each of the three fellowship programs, between male and female recipients, across the four years of the analysis and find no consistent trends. We hope that these findings will prove a useful reference to future junior scientists.

**Author(s):** Dawn Gelino, Oliwia Krupinska, Kevian Stassun, Joshua Pepper

**Institution(s):** Lehigh University, Fisk University, Vanderbilt University, NASA Hubble Fellow Program (NHFP) Co-Lead, NASA Exoplanet Science Institute, Caltech

##### **244.02 - Astronomy for Students with Blindness/Visual Impairments: The Career Exploration Lab(Thomas Madura)**

For students with blindness/visual impairments (B/VI), the possibility of a future in astronomy, or any science, technology, engineering, and mathematics (STEM) field, seems daunting. In order to bolster astronomy opportunities for high school students with B/VI (ages 14 -- 20), we developed a series of Career Exploration Labs (CELs) that employ a combination of tactile astronomy instruction via 3D printing technologies and 3D-printed models, professional scientists with B/VI acting as role models, and partnerships with local STEM industries that provide insights into possible career paths. In partnership with the South Carolina Commission for the Blind and the Michigan Bureau of Services for Blind Persons, to date, we have held three week-long CELs (June 2017; June and July 2018), serving a total of thirty high school students with B/VI. We gathered pre- and post-intervention data via student surveys,

assessments of students' astronomy knowledge and spatial thinking skills, and video recordings of the CEL activities in order to study to what extent the CEL model can enhance students with B/VI's attitudes towards, interests in, and capacities to participate in astronomy. Once fully tested and refined, we will make our 3D models and associated activities freely available to the community for further use and study. This work serves as a testbed for an expanded international program aimed at helping increase the representation of persons with B/VI in astronomy and STEM fields.

**Author(s):** Kenneth Silberman, Shannon McVoy, Kyle Walker, Thomas Madura, Carol Christian, David Hurd

**Institution(s):** San Jose State University, Edinboro University, Space Telescope Science Institute, South Carolina Commission for the Blind, NASA Goddard Space Flight Center, Michigan Bureau of Services for Blind Persons

#### **244.03 - Informed Consent and Citizen Science(Annie Wilson)**

Engagement in Citizen Science takes many forms, but always includes one vital component: everyday people submit data for scientists to use. In this presentation, we identify potential ethical concerns that arise when involving volunteers in science, and how best to navigate doing citizen science in a post-Cambridge Analytics world. Specifically, we discuss how to make sure citizen scientists are able to provide informed consent, issues of proper attribution and data handling, and the special case of working with students who may be compelled to participate but may or may not be able to give informed consent. We also look at other data issues, including providing appropriate credit for contributions and protecting privacy.

**Author(s):** Annie Wilson, Alison Reiheld, Pamela Gay,

**Institution(s):** Youngstown State University, Southern Illinois University Edwardsville, Astronomical Society of the Pacific, CosmoQuest Contributing Team(s): CosmoQuest Team

#### **244.04 - Complex Motivations of Citizen Scientists(Nicole Gugliucci)**

Online citizen science projects engage thousands of users in science research. These volunteers expend time and effort to classify objects in large datasets that cannot be reasonably done by smaller teams of professional scientists or by computer algorithm. As large science projects rely more on citizen participation, it is important to understand the motivating factors for citizen scientists. In order to delve into these motivations, we analyzed interviews from 30 citizen scientists selected from the user base of CosmoQuest, a suite of online citizen sciences projects that ask participants to explore the surfaces of solar system objects using images from several NASA missions. Using a basic thematic analysis approach and a theoretical framework that classified motivations as either intrinsic or extrinsic, we found that almost all participants

reported complex mix of motivational factors, usually from both broad categories. The most frequent intrinsic motivator was “interest in the subject” and the most frequent extrinsic motivator was “helping or giving back to science.” When compared to the participants’ reported frequency of interaction with projects, we found that those that did citizen science on a more frequent basis were more likely to list intrinsic motivators than those that were more sporadic. Motivations were not reported to have changed over the lifetime of engagement with the process for most participants who were still engaged. This interview protocol also explored reasons for ending a participation session or for stopping citizen science activities altogether. We found that many reports reasons for ending engagement are beyond the scope of a citizen science practitioner, such as the change in the life circumstances of the volunteer. However, we were able to gain insight into some ways that projects can encourage further participation and things to avoid so that participation is not discouraged. These results provide new insights into how motivational factors are tied in to participation rates and how certain factors of the project itself can be tweaked to encourage participation over a longer term.

**Author(s):** Georgia Bracey, Maya Nona Bakerman, Sanlyn Buxner, Nicole Gugliucci

**Institution(s):** Saint Anselm College, Planetary Science Institute, Southern Illinois University Edwardsville  
Contributing Team(s): CosmoQuest Team

#### **244.05 - Heterogeneity and Variability of “Astronomy on Tap” Public Outreach Events(Emily Rice)**

Astronomy on Tap (AoT, <http://astronomyontap.org>) is a series of free public outreach events featuring engaging science presentations combined with music, games, and prizes in a fun, interactive atmosphere. AoT events feature one or more presentations given primarily by local professional scientists and graduate students, but also by visiting scientists, undergraduate students, educators, amateur astronomers, writers, artists, and other astronomy enthusiasts. Events are held at social venues like bars, breweries, coffee shops, and art galleries in order to bring science, the stories behind the research, and updates on the latest astronomy news directly to the public in a relaxed, informal atmosphere. Since the first New York City event in April 2013, over 600 AoT-affiliated events have been held in over 50 locations worldwide. The flexible format and content of a typical AoT event is easy to adapt and expand based on the priorities, resources, and interests of local organizers. In this poster we highlight the heterogeneity and variability of AoT events by describing how organizers have modified the typical AoT format to best take advantage of local resources and meet the needs and interests of local organizers and audiences.

**Author(s):** Emily Safron, Cameron Hummels, Jeffrey Silverman, Brian Levine, Andrés Plazas, Rachael Livermore, Emily Rice, Daniel Angerhausen, Mark Popinchalk, Sandy Seale, Eleni Vardoulakio, Stephanie LaMassa, Nathalie Ouellette

**Institution(s):** CUNY Graduate Center, Universität Bonn, Princeton University, Astronomical Society of the Pacific, Las Cumbres Observatory, CUNY College of Staten Island, University of Melbourne, American Museum of Natural History, Space Telescope Science Institute

**244.06 - Using an Online Focus Group to Predict the Popularity of APOD Images on Facebook (Oindabi Mukherjee)**

How accurately is it possible to predict social media engagement with future Astronomy Pictures of the Day? APOD selection criteria are diverse and include educational value and topicality, but for people to be interested in learning more about an image, it first has to capture their attention, and Facebook Likes and Shares are indicative of engagement. Therefore, it is sometimes useful to estimate the likely future popularity of images being considered for APOD. This study analyzes the predictive value of a comparatively small "focus group" page on Facebook named Sky. Some images being considered for APOD are first posted to Facebook Sky and their relative engagement statistics there are noted. To access predictive value, correlations between Likes and Reach for images posted to Facebook Sky that have gone on to be posted to APOD and Facebook APOD are analysed for data recorded in 2017.

**Author(s):** Jerry Bonnell, Oindabi Mukherjee, Robert Nemiroff

**Institution(s):** Michigan Technological University, University of Maryland

**244.07 - Can Grandeur Overcome Insecurity?**

**Seeking Specific Astronomy Course Experiences That Can Diminish Stereotype Threat and Enhance Students Self-efficacy (Lindsay House)**

"It has been said that astronomy is a humbling and character building experience." -Carl Sagan. Introductory astronomy aims to foster scientifically literate individuals who have an interest in understanding their place among the cosmos. Learning astronomy is not only humbling; we claim it can also help students overcome insecurities and self-doubts, including those that arise from gender and racial discrimination. But what specific knowledge, realizations, or experiences best facilitate this? In order to find out, we are conducting a study to track introductory astronomy students' class-by-class motivation and sense of self-efficacy, detect any changes, and determine what specific experiences or topics in the course provoked them. We hypothesize that certain elements of experiences throughout the astronomy course can have a notably strong impact on students' self-efficacy, by allowing them to abate feelings of social categorization. Currently, we are developing survey questionnaires that will be administered to high-enrollment introductory-level general astronomy courses. One will be a comprehensive pre/post survey examining interest, motivation, and astronomy self-efficacy. Another will be a brief after-every-

class survey administered to gauge changes in these variables as the semester progresses. Applied to volunteers from an introductory astronomy course, these should let us gauge overall changes in students' interest, motivation, and astronomy self-efficacy, and attribute changes to specific course experiences. Follow-up interviews will be used to illuminate the specific experiences, reactions, and realizations revealed by the every-class questionnaire.

**Author(s):** Lindsay House

**Institution(s):** University of North Carolina Greensboro

**244.08 - Evaluating the Use of Video Games and Lecture Tutorials Together in an Introductory Astronomy (Christopher Stockdale)**

I present the results of a pilot program in the general education astronomy and space science course at Marquette University using "At Play in the Cosmos: The Video Game" in conjunction with "Lecture Tutorials for Introductory Astronomy, Third Edition" (Prather et al. 2013) and "Horizons: Exploring the Universe, Fourteenth Edition" (Seeds and Backman 2018). At Play in the Cosmos (designed by Bary and Frank; Norton Publishing) is an interactive video game that was intended as a supplement for "Astronomy: At Play in the Cosmos" (Frank 2016). I am using the Video Game as a stand alone component for the course, that the students are accessing independently as a supplement to the course work in the fall of 2018. I am gauging student interest in the Video Game as a supplemental learning tool and their thoughts about how easy it is to use and navigate. I will also compare student's overall course performance with those students who are not engaged in the study, to determine if there is any measurable improvement in their course grade and other assessment tools.

**Author(s):** Christopher Stockdale

**Institution(s):** Marquette University

**244.09 - Investigating How ASTR 101 Students Learn about the Path of Sun and Shadows (Noella Dcruz)**

Joliet Junior College, a community college in Illinois, offers a one semester astronomy course for non-science majors. The daily path of the Sun and shadows it creates of a flagpole planted vertically in the ground are two of the many topics covered in this course. We examine three learning sequences for these topics to determine which is the most effective for our ASTR 101 students. The first learning sequence starts with lecture, followed by a planetarium presentation of the Sun's daily path and then a workbook tutorial from the Lecture Tutorials for Introductory Astronomy workbook by Prather, Slater, Adams & Brissenden. This sequence ends with a small group discussion. The second learning sequence consists of lecture, followed by the first part of the workbook tutorial, after which a planetarium presentation of the Sun's daily path is given. Then students complete the remainder of the tutorial and end with a small group discussion. Think-pair-share questions

are asked throughout both these sequences. The third learning sequence is a self-directed one and involves our online ASTR 101 students, who learn the material via the textbook and from brief notes that we provide. We are collecting data for this project via a pre-course survey, a post-topic survey, quiz questions, think-pair-share questions, the small group discussion, test questions and final exam questions on this topic. We will present analysis of the data from Spring 2018 and Fall 2018 and what it reveals about these learning sequences.

**Author(s):** Noella Dacruz

**Institution(s):** Joliet Junior College

#### **244.10 - Analyzing Student Interactions During Collaborative Exams(Ryan Orchid Cook)**

Collaborative, two-stage exams are becoming more popular in physics and astronomy courses, and their supposed benefits in terms of collaborative learning have been reported in the field of physics. Yet oftentimes students complain that collaborative work consists of the “smartest” person in the group simply providing the rest of their group members with the answers, dominating the group interactions without providing struggling students with any understanding of the concepts being assessed. Or that the less-involved students (“slackers”) simply sit back quietly, allowing other group members to do all of the work, reaping the benefits without contributing to the group discussion. In five introductory astronomy courses ( $n = 473$ ) conducted during the Fall 2017/Spring 2018 school year, students were required to periodically answer individual multiple-choice exam questions, then immediately re-answer a subset of them as part of a collaborative group exam. We will present results on a comparison of individual student responses to the group responses to determine how groups arrive at a consensus when answering questions. We will address what factors influence the group decision-making process, such as: the frequency with which the actions of the higher-performing students control the group, the minimum number of students required to be in agreement before an answer is chosen, and the frequency of occurrence when all individuals within a group answer incorrectly, but the group answers correctly.

**Author(s):** Scott Miller, C. Renee James, Ryan Orchid Cook

**Institution(s):** Sam Houston State University

### **245 - Computation, Data Science, and Image Analysis -- Posters**

#### **245.01 - Making organizational research software more discoverable(Alice Allen)**

Software is the most used instrument in astronomy, and organizations such as NASA and the Heidelberg Institute for Theoretical Physics (HITS) fund, develop, and release research software. NASA, for example, has created sites such as [code.nasa.gov](http://code.nasa.gov) and [software.nasa.gov](http://software.nasa.gov) to share its software with the world, but how easy is it to see what NASA has? Until recently, searching NASA's Astrophysics Data System (ADS) for NASA's astronomy software has not been fruitful; NASA has

funded the Astrophysics Source Code Library (ASCL [ascl.net](http://ascl.net)) to improve the discoverability of these codes in ADS. The ASCL, now celebrating its 20th anniversary, is a free online registry of software used in astronomy research and is indexed by ADS, Web of Science, and other resources. Adding NASA and HITS astronomy research codes to the ASCL with appropriate tags enables finding this software easily not only in the ASCL but also in ADS and other services that index the ASCL. This poster presentation covers the changes the ASCL has made to enable discovery of NASA software in ADS and the results of this work.

**Author(s):** Peter Teuben, Robert Nemiroff, Judy Schmidt, Alice Allen,

**Institution(s):** Astrophysics Source Code Library, Michigan Technological University, University of Maryland

#### **245.02 - Exploring Space with Neural Networks(Gregory Nero)**

Exploring large astronomical imaging datasets by hand can be time consuming, and writing a suitable algorithm for gathering interesting targets can be even more difficult and inefficient. Neural networks are becoming very popular in astronomy due to their ability to work directly with complex image data. There is a growing interest in using deep learning methods for detection and classification of features in large and complex collections of images. By employing image data from the Spitzer Space Telescope's GLIMPSE and MIPS GAL infrared surveys of the Galactic plane and a citizen science data catalog of bubble-like formations from the Milky Way Project, we show neural networks to be a useful and potentially revolutionary way to explore large sets of astronomical images.

**Author(s):** Joshua Peek, Gregory Nero, Craig Jones, Sarah Kendrew

**Institution(s):** Rochester Institute of Technology, European Space Agency, Space Telescope Science Institute, Space Telescope Science Institute

#### **245.03 - A Data Pipeline for the Minor Planet Center(Saneyda Hernandez)**

We present a software pipeline for automatic preparation of image data for submission to the International Astronomical Union's Minor Planet Center. The pipeline draws upon existing software tools, and will allow users to characterize digital images to the astrometric and photometric standards of the MPC. The pipeline is part of a larger project aiming to broaden user input to the MPC by providing efficient, automated, web-based user support for a wide range of observational data.

**Author(s):** Saneyda Hernandez, Jennifer Scott, Mike Hankey

**Institution(s):** Towson University, American Meteor Society

#### **245.04 - Signal-Dependent Interpixel Capacitance in HgCdTe Detector Arrays for NEOCam(Alyssa Bulatek)**

A first-order correction for signal-dependent interpixel capacitance (IPC) was developed for long-wave HgCdTe infrared detector arrays like those that will fly on NASA's Near Earth Object Camera (NEOCam) mission. IPC was not previously known to have a dependence on signal strength, but a recent paper provided evidence of this effect in mid-wave HgCdTe arrays for the James Webb Space Telescope (JWST). To characterize this dependence for NEOCam arrays, we used dark exposures of one test array to measure the spread of signal from hot pixels of various signal strengths to their four nearest neighbors. We fit an exponential functional form to this distribution and applied it to proton irradiation data taken with two different test arrays in order to measure the magnitude of the correction. Preliminary examinations of these data show a 10 to 20 percent decrease in the average number of pixels affected by a single proton hit after the correction. Further exploration of the dependence of IPC on background strength will improve the accuracy of the correction. An IPC correction algorithm will be present in the data reduction pipeline for NEOCam, which is designed to identify and characterize most potentially hazardous near-Earth objects (NEOs) that are larger than 140 meters in diameter.

**Author(s):** Craig McMurtry, Alyssa Bulatek, Judith Pipher

**Institution(s):** Macalester College, University of Rochester

#### **245.05 - Cloud Services as an environment for large scale astronomical image analytics.(Dino Bektsev)**

The Large Synoptic Sky Survey is a next generation sky survey. LSST will produce 15-30TB of data a night and, at the end of the survey, promises to deliver the largest non-proprietary dataset in the world, estimated to consist of 60PB of raw data and a 15PB catalog. To process the data and produce the catalog, the LSST Software Stack implements many new and advanced astronomical image analysis techniques. Making these techniques available to the astronomical community would benefit individual users through to small scale surveys. Our ability to use the LSST Software and deliver on its full potential is, however, limited by the expertise, compute and storage resources required to deploy and run on scale. Cloud Services have already been identified as a prime resource for large scale data storage and analytics. Their adoption by the astronomy community has been slow because much of the functionality required is not easily available. We investigate the benefits and challenges related to using Cloud Services as compute and storage resources for astronomical image analytics. We do this by showing how to deploy LSST image analysis code using Google and Amazon cloud services.

**Author(s):** Parmita Mehta, Colin Slater, Andrew Connolly, Dino Bektsev, Magdalena Balazinska, Mario Juric

**Institution(s):** University of Washington

#### **245.06 - Real Time Image Differencing with the LSST Alert Production Pipeline(Meredith L. Rawls)**

The Alert Production (AP) Pipeline for the Large Synoptic Survey Telescope (LSST) must promptly process new images from the telescope to enable rapid-response time domain science. It begins with raw telescope data and uses image differencing to identify time-variable sources and associate them with previously detected objects. We present an overview of the AP Pipeline and illustrate its utility with Dark Energy Camera (DECam) data from the High Cadence Transient Survey (HiTS). We use DECam images from 2014 as a template for images which revisit the same region of the sky in 2015. We compile catalogs of detected sources and associated objects, create light curves for a handful of interesting objects, and compare initial results with the first HiTS data release. The AP Pipeline is part of the LSST Science Pipelines and is available on GitHub at [https://github.com/lsst/ap\\_pipe](https://github.com/lsst/ap_pipe).

**Author(s):** Christopher Morrison, Simon Krughoff, Krzysztof Findeisen, Meredith L. Rawls, John Swinbank, Eric Bellm,

**Institution(s):** University of Washington, LSST Project Office, DIRAC Institute  
**Contributing Team(s):** LSST Data Management

#### **245.07 - Machine Learning Techniques to Identify the Weirdest Objects in the Transient Universe(Dennis Adam Crake)**

Over the next decade, dedicated time-domain survey projects such as the Large Synoptic Survey Telescope (LSST) and the recently launched Transiting Exoplanet Survey Satellite (TESS) will look at large areas of the sky with unprecedented sensitivity, recording the light curves of billions of variable sources over the mission lifetime. Perhaps the most scientifically promising aspect of these surveys is their potential for the discovery of new or unique objects within the transient Universe, however the resulting onslaught of data will be overwhelmingly difficult to analyse and classify without significant autonomous processing. In this project we tackle the challenge to identify the weirdest light curves by employing state-of-the-art machine learning techniques for outlier detection. Using a large set of Kepler light curves as test ground, we adapt algorithms such as Unsupervised Random Forests and Auto-encoding Neural Networks by reading extracted features from the data (such as the power of the Lomb-Scargle periodogram) to identify the outlying, scientifically compelling objects. We also investigate how using different features leads to the discovery of different types of outliers, such as rotationally variable stars, pulsating white dwarfs, and complex variability patterns such as that of Boyajian's star. The methods developed as part of this project would be readily adaptable to autonomous classification for upcoming surveys such as LSST.

**Author(s):** Rafael MartÃ-nez-Galarza, Dennis Adam Crake,

**Institution(s):** University of Southampton, Harvard-Smithsonian Center for Astrophysics

#### **245.08 - Jointcal: Optimized Astrometry & Photometry for Thousands of Exposures with Large Mosaic Cameras(John K Parejko)**

We showcase Jointcal, a new software package developed for the Large Synoptic Survey Telescope (LSST) to optimize the astrometric and photometric calibrations of a set of mosaic camera images of an area of sky. The Jointcal algorithm incorporates object matching both between exposures and to external reference catalogs, and produces more accurate distortion and throughput models than if the astrometry and photometry were fit on the individual exposures. This is especially true when the images are significantly deeper than those of the reference catalogs (for example, LSST's 30-second r-band exposure depth will be 24.7 compared with  $r < 20$  for Gaia's final survey depth). We demonstrate Jointcal's performance on data from Hyper Suprime-Cam, DECam, and simulated LSST exposures, and compare it with the output of the LSST single sensor processing pipeline. The Jointcal package is part of the LSST Science Pipelines and is available on GitHub: <https://github.com/lsst/jointcal>

**Author(s):** Pierre Astier, Jim Bosch, Dominique Boutigny, John K Parejko

**Institution(s):** University of Washington, Princeton University, LPNHE/INP3/CNRS

#### **245.09 - Biases in Maximum-Likelihood Photometry(Stephen Portillo)**

Understanding photometric biases and uncertainties is important when using survey photometry, especially at lower signal-to-noise. Maximum-likelihood estimators for non-linear models have a systematic bias that scales with the inverse of the square of the signal-to-noise ratio. We show that in model-fitting photometry, the estimated flux is biased high because the model is non-linear in position and shape parameters. This bias is worse for galaxies because each parameter contributes: while a 1% bias is expected for a  $10^{\text{th}}$  point source, a  $10^{\text{th}}$  galaxy with a simplified Gaussian profile suffers a 2.5% bias. This bias can be subtracted out, but the reported uncertainty must be correspondingly increased. When the position is determined from multiple bands, the flux bias is split between the different bands. In forced photometry, however, the flux estimates in the forced bands are biased low instead of high, compounding the bias in color. Comparing catalogs of Stripe 82 made from individual runs with those made from stacked imaging, we show that this bias is present in the Sloan Digital Sky Survey.

**Author(s):** Douglas Finkbeiner, Joshua Speagle, Stephen Portillo

**Institution(s):** University of Washington, Harvard-Smithsonian Center for Astrophysics

#### **245.10 - AstroCut: A cutout service for TESS full-frame image sets(Clara Brasseur)**

The Transiting Exoplanet Survey Satellite (TESS) launched last March and had its first data release in the fall. Like that of the Kepler mission, the TESS data pipeline returns a variety of data products, from light curves and target pixel files (TPFs) to large full frame images (FFIs). Unlike Kepler, which took FFIs relatively infrequently, TESS takes FFIs every half hour, making them a large and incredibly valuable scientific dataset. As part of the Mikulski Archive for Space Telescope's (MAST) mission to provide high quality access to astronomical datasets, MAST has built an image cutout service for TESS FFI images. Users can request image cutouts in the form of TESS pipeline compatible TPFs without needing to download the entire set of images (750 GB). For users who wish to have more direct control or who want to cutout every single star in the sky, the cutout software (python package) is publicly available and installable for local use. In this poster we present the use and design of this software, both locally and as a web service.

**Author(s):** Rick White, Arfon M Smith, Susan E Mullally, Mike Fox, Clara Brasseur, Carlita Phillip, Jonathan Hargis, Scott W. Fleming

**Institution(s):** Space Telescope Science Institute

#### **245.11 - Interacting And Searching For TESS Data At MAST(Scott W. Fleming)**

We provide an overview of the ways astronomers can interact with TESS data at the Mikulski Archive For Space Telescopes (MAST). MAST is the primary archive for TESS data products, including full frame images, target pixel files, light curves, data validation products, and the TESS Input Catalog. We demonstrate how users can retrieve data through our web search interface, the MAST Portal, and via scripts through our API and astroquery package. We show our use of our FFI cutout tool to create target pixel files based on the TESS full frame images using only the pixels you want to use, instead of downloading the entire set of files. We show our TESS Archive Manual website, which contains information and numerous tutorials, both web- and Python-notebook-based, to get you started using TESS data at MAST. Finally, I showcase Exo.MAST, a search interface designed specifically to enable searches for MAST observational data based on exoplanets, including Kepler, K2, HST, and TESS.

**Author(s):** Scott W. Fleming

**Institution(s):** STScI Contributing Team(s): the MAST team

#### **245.12 - Stratospheric Terahertz Observatory 2 (STO2) Data Reduction(Volker Tolls)**

The Stratospheric Terahertz Observatory 2 (STO2) balloon observatory consists of a 0.8-meter Cassegrain telescope with single-pixel heterodyne receivers with hot-electron bolometer (HEB) mixers and a digital FFT 1-GHz bandwidth backend to observe [CII] at 1.9 THz (158  $\mu\text{m}$ ) and [NII] at 1.46 THz (205

um). It flew from McMurdo station in the Antarctic in December 2016 allowing 20 days of observations of  $\sim 2.5$ sqdeg of the Galactic plane between  $265^\circ < l < 335^\circ$  and  $-1^\circ < b < +1^\circ$  including Trumpler 14, parts of the Eta Carina region, NGC3576, and RCW38. The data reduction of these observations faced challenges comparable to the reduction of the Herschel/HIFI HEB bands 6 and 7. In this poster we describe the methods how we handled the removal of standing waves and other HEB receiver artifact that remained after the standard reference observation subtraction. We applied more than one reduction and calibration method to the data to confirm that the detected spectral features are fully preserved and properly calibrated. When the data reduction is finished, the final data products will become publicly available.

**Author(s):** Chris Walker, Paul Goldsmith, Gary Melnick, Volker Tolls, Youngmin Seo, Russel F. Shipman, Bill Peters, Dave Hollenbach, Aemil Kavak, Craig Kulesa, Antony A. Stark  
**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Arizona, JPL, University of Groning, SETI Institute, SRON Contributing Team(s): STO- Team

#### **245.13 - Using Deep Learning Techniques to Classify Stars and Galaxies in Keck DEIMOS Spectra(Arush Sahai)**

Spectroscopy is a bedrock of astronomy; it provides detailed data about the chemical composition of objects being studied. Existing techniques for classifying stars, galaxies, quasars, etc. from their spectra involve a computer spectral classification done by cross-correlation, which is subsequently checked by the human eye. This process will not scale easily to massive datasets from upcoming fiber spectrographs. In this work, we study the use of deep neural network models for binary classification of 1D spectra into stars and galaxies. The training data comes from spectroscopic surveys conducted using the DEIMOS spectrograph on the Keck Telescope. We have tried several pre-processing techniques before feeding the data into the neural network and obtained the best performance from spectra adjusted to a logarithmic wavelength scale such that redshifts have an additive rather than multiplicative effect. In this process, we also combine adjacent flux values into larger bins as a form of smoothing and resolution reduction. We find that resolution reduction from 8192 pixels to 256 pixels does not impact the performance of the network, implying that the network is learning to recognize the shape of the continuum and large-scale features rather than relying on absorption and emission lines. Using a Convolutional Neural Network, we obtain accuracy that approaches a human expert. We have demonstrated the potential of using deep learning techniques to classify spectra, and more research needs to be done for finer-grained classification and velocity estimation. This research was funded in part by the National Science Foundation and the National Space and Aeronautics Administration/Space Telescope Science Institute. High school student Arushi Sahai conducted this research under the auspices of the Science Internship Program at the University of California Santa Cruz.  
**Author(s):** Emily Cunningham, Vikram Sahai, Arushi Sahai,

Puragra Guhathakurta

**Institution(s):** University of California Santa Cruz, Menlo School

#### **245.14 - Monitoring and forward modeling OH sky emission lines in high resolution spectra(Kyle F Kaplan)**

We present the first results for a new project to monitor the hydroxyl radical OH sky emission lines arising from the Earth's mesosphere with high resolution infrared and optical spectra from the Habitable-zone Planet Finder (Mahadevan et al. 2012, Proc. SPIE, 8446, 84461S), NEID (Schwab et al. 2016, Proc SPIE, 9908, 99087H), IGRINS (Park et al. 2014, Proc. SPIE, 9147, 91471D), and APOGEE (Wilson et al. 2010, Proc. SPIE, 7735, 77351C) which provide an untapped and ever growing number of high quality sky spectra. Chemical reactions form OH in excited rovibrational levels with non-LTE level populations. The OH radiatively decays to the ground rovibrational levels giving rise to a rich spectrum of emission lines that make up the majority of the sky emission in the infrared and present an unwanted source of contamination (Rousselot et al. 2000, A&A, 354, 1134; Meinel 1950, AJ, 111, 555). The OH lines are highly variable making them difficult to fit and remove from spectra, but recent progress has been made on this problem (e.g., Noll et al. 2014, A&A, 567, A25; Davies et al. 2007, MNRAS, 375, 1099). Their variability also presents an opportunity to probe the conditions of the Earth's upper atmosphere where the OH forms (e.g., Singh & Pallamraju 2017, AnGeo, 35, 227; Noll et al. 2015, ACPD, 14, 32979). Deep sky spectra such as those by Cosby & Slinger (2007, CaJPh, 85, 77) and Olivia et al. (2015, A&A, 581, A47) reveal the detailed non-LTE behavior of the OH rovibrational level populations. We forward model the OH emission line intensities based on these known trends in observed level populations and the theoretical transition probabilities from Brook et al. (2016, JQSRT, 168, 142). Our modeling varies the vibrational temperatures, rotational temperatures, and fraction of cold vs. hot OH over multiple iterations to find the best fit to the observed OH spectrum. By carefully measuring each spectrometer's dispersion profile, we can fit and subtract the OH lines in a noise free manner. We also monitor the variability of the OH emission over short and long time scales and compare our model fits to atmospheric conditions during observations.

**Author(s):** Christian Schwab, Sam Halverson, G. N. Mace, Kyle F Kaplan, Suvrath Mahadevan, Chad Bender, Cullen Blake  
**Institution(s):** The University of Arizona, University of Pennsylvania, Pennsylvania State University, The University of Texas at Austin, Macquarie University, MIT Kavli Institute for Astrophysics



#### **245.15 - Catastrophic Outlier Identification in Photometric Redshifts with Effective Probability Distributions(Michael Wyatt)**

We present an exploration of the use of features of redshift probability distribution functions to identify potential catastrophic outlier galaxies in photometric redshift determination. For this study we utilize effective redshift probability distributions (EPDFs) naturally output for each galaxy by SPIDERz, an empirical support vector machine (SVM) algorithm for photo-z determination. Considering both real and simulated data sets, we find that the identification of multiple probability peaks in EPDFs can potentially serve as a useful method for flagging catastrophic outliers, while simultaneously flagging an acceptably low fraction of non-outliers, under certain circumstances. However, the fraction and distribution of flagged non-outliers vary substantially depending on flagging parameters and data set characteristics. We demonstrate these effects, and show that modification of the SVM training set to obtain a more even distribution of galaxies in redshift bins across the entire range of redshifts can result in a more desirable distribution of flagged catastrophic outliers and flagged non-outliers.

**Author(s):** Michael Wyatt, Jack Singal

**Institution(s):** University of Richmond

#### **245.16 - Galaxy Classification with Neural Networks in SDSS(James Andrew Casey-Clyde)**

The acquisition of astronomical data is growing on par with the sophistication of observing equipment, with the size of astronomical datasets rapidly outpacing the ability of astronomers to analyze them. In order to keep up with this expanding amount of data, astronomers must increasingly turn to more powerful and more sophisticated computational techniques. In the past few years, this has come to include the use of newer machine learning techniques, such as Convolutional Neural Networks (CNNs), to aid in such analyses. We approach the problem of big data in regards to galaxy classification with such techniques, using image data from SDSS in concert with classification labels from the GalaxyZoo project to train our model and differentiate between galaxy types.

**Author(s):** Jean Donet, Nima Maghoul, James Andrew Casey-Clyde, Hiren Thummar

**Institution(s):** San Jose State University

#### **245.17 - Using machine learning algorithms to discover extragalactic compact stellar system candidates(Devin Cunningham)**

With the advent of large-scale, publicly-available surveys bringing big data into astronomy, novel computational approaches are available for scientific discovery. Using machine learning algorithms, it is now possible to uncover astronomical objects which may otherwise have been overlooked by

traditional methods. This has been demonstrated by the success of automated morphological classifications, galactic feature reconstruction, and the exciting detection en masse of exoplanets. By utilizing ensemble learning algorithms with photometric quantities from large databases such as the Sloan Digital Sky Survey and the NASA/IPAC Extragalactic Database, we present a new approach to classifying and discovering candidate extragalactic globular clusters and ultra-compact dwarfs, which could help to build a larger sample for the astronomical community.

**Author(s):** Aaron Romanowsky, Devin Cunningham

**Institution(s):** San Jose State University

#### **245.18 - An Improved Method for Far Infrared Galaxy SED Fitting(Spencer Scott)**

In this work, we examine spectral energy distribution (SED) fitting techniques commonly used to measure the dust temperatures of galaxies. Using toy models, we show that current far infrared (FIR) fitting techniques do not accurately recover the temperature of the dust within a galaxy. Instead, current fitting techniques recover temperatures which are higher than the actual mean of the dust temperature due to fact that hotter blackbodies are brighter than cooler blackbodies at all wavelengths. We demonstrate a method for FIR SED fitting which uses Markov Chain Monte Carlo (MCMC) methods to recover a distribution of dust temperatures given a galaxy's SED. We show that the mean dust temperature of the distribution recovered using MCMC methods on generated data is significantly different from the temperature recovered from conventional curve fitting techniques. We then demonstrate the power of our fitting method on synthetic SEDs generated using cosmological galaxy formation simulations coupled with 3D dust radiative transfer models. Using this simulated data, we also establish a temperature distribution shape to use for this MCMC method based on the temperature of the CMB at a given redshift. Code to implement MCMC curve fitting will be made publicly available.

**Author(s):** Desika Narayanan, Spencer Scott, George Privon

**Institution(s):** University of Florida, Harvard University

#### **245.19 - WebbPSF Update: Providing High-Fidelity Time variable Point Spread Functions for JWST Based on Thermal Modeling(Keira Brooks)**

During the mission lifetime, JWST's Optical Telescope Element (OTE) will be exposed to not only the harsh environment of space, but also to structural and thermal variations due to internal vibrations and slewing relative to the Sun. The cryo-vacuum testing of the integrated OTE and instrument module in 2017 provided vital information about the expected structural and thermal performance of the observatory on-orbit. Based on those results, as well as additional structural and thermal models, we have expanded the capability of the widely-used JWST point spread function (PSF) modeling package,

WebbPSF, to include time-dependent variations in the wavefront error. This capability is particularly significant for cases in which PSF variations over time will impact science goals, such as coronagraphy. By continuously improving the models in WebbPSF with higher-fidelity and scientifically-significant data, we provide the community with more accurate simulated PSFs for modes that are often less-supported, like coronagraphy. Here we present the impacts of JWST's structural and thermal slew models on PSFs as integrated into WebbPSF for observation and post-processing planning.

**Author(s):** Marshall Perrin, Kyle Van Gorkom, Laurent Pueyo, Keira Brooks

**Institution(s):** Space Telescope Science Institute, University of Arizona

#### **245.20 - Flash Echoes from Circular Rings II(Oindabi Mukherjee)**

A flash or a variable source of light occurring near a reflective circular ring might be seen later in echoes from the ring. At first, two bright images of flash will appear on the ring, and these images will soon move apart and fade. However, there is a range of flash-positions and ring-orientations where a second pair of flash images suddenly becomes visible, making four images of the flash simultaneously visible on the ring. These image pair events are bright and can be seen in the light curve even if not angularly resolved. Measuring flash reflection attributes in brightness, position and polarization with time can completely resolve the geometry and distance of the system. Two practical cases are briefly discussed -- gas rings near a supernova and dust rings in planetary disks near a variable star. For clarity and simplicity, the light from these systems are computed assuming that the reflecting ring is optically thin.

**Author(s):** Oindabi Mukherjee, Robert Nemiroff

**Institution(s):** Michigan Technological University

#### **245.21 - Developing Novel Algorithms to Recover Faint Circumstellar Shell Structures from ADI data(David Melnick)**

We present the preliminary results for an ADI data reduction technique, commonly used in detecting faint companions or elongated disk structures in protoplanetary disk imaging, however applied to the circumstellar dust shell imaging of the archetype of optically-thin PPNe, IRAS 07134+1005, taken with Gemini/NICI as our feasibility study. We take elements of the Karhunen-Loeve Image Projection (KLIP) and Locally Optimized Combination of Images (LOCI) algorithms to process high-contrast ADI data of the circumstellar shell of this low-mass evolved star. With our algorithm, we intend to improve upon the sensitivities of previous studies, to recover the PPN faint circumstellar shell structures. From this, our goal is to develop these techniques to explore the possible mechanisms of mass loss and circumstellar shell shaping, without the hindering effects of the bright central star.

**Author(s):** Toshiya Ueta, David Melnick

**Institution(s):** University of Denver

#### **245.22 - Automated RFI Flagging for HI Spectra(Eun Ju Jong)**

Manual flagging of RFI is extremely time-consuming and error-prone. We present a machine learning algorithm which automatically identifies radio frequency interference (RFI) in HI spectra. Our algorithm uses the features of polarization asymmetry (defined as  $|\text{polA} - \text{polB}|/[\text{polA} + \text{polB}]$ ) along with the skew and standard deviation of each channel over time to evaluate the presence of RFI. The algorithm was tested on hundreds of spectra taken by the Undergraduate ALFALFA Team (UAT) as part of the APPSS survey. It outperforms humans not only in speed, but in visually identifying RFI when it is weak or mimics properties of signals. This work has been supported by NSF grants AST-1211005 and AST-1637339.

**Author(s):** Eun Ju Jong, Gregory Hallenbeck

**Institution(s):** Washington & Jefferson College  
**Contributing Team(s):** Undergraduate ALFALFA Team

#### **245.23 - Fitting HI Spectra with Neural Networks(Gregory Hallenbeck)**

The number of extragalactic sources of HI detected in radio surveys is growing exponentially. It will soon no longer be feasible for human researchers to individually fit spectra. We present algorithms for automatically extracting the typical parameters of interest for the 21 cm HI line--recessional velocity, velocity width, and integrated flux--using neural networks. Features are produced by convolving spectra with templates generated with the Busy Function. We present the results of fitting hundreds of spectra with many different shapes, and at a wide range of signal to noise ratio. Additionally, we compare with prior methods of automated source extraction. This work has been supported by NSF grants AST-1211005 and AST-1637339.

**Author(s):** Eun Ju Jong, Gregory Hallenbeck, Ryan Muther

**Institution(s):** Washington & Jefferson College, Northeastern University

#### **245.24 - Studying the Effects of Masking and Deconvolution Algorithms in Imaging(Dilys Ruan)**

Usually when observers get their data from a radio interferometer, they synthesize an image using a deconvolution algorithm they know from experience. Instead, we would like to formally quantify which algorithms might be preferable in certain circumstances, and specifically when masking might be necessary. With four datasets, we have many trials in which we change specific parameters such as: deconvolution algorithm, iterations, number of visibilities (interferometer responses), number of sources, masking, and threshold. Masking helps in

situations where the algorithm doesn't have enough information to find a solution image. In this case, if a mask isn't specified, divergence is likely. However, ultimately on a systematic level, it matters more with which deconvolution algorithm one uses. While there are many different types of deconvolution algorithms, we've focused on Hogbom, Multi-scale, and Maximum Entropy Method (MEM).

**Author(s):** Kumar Golap, Takahiro Tsutsumi, Dilys Ruan,  
**Institution(s):** University of New Mexico, National Radio Astronomy Observatory

#### **245.25 - Analysis of Radio Single-Dish and Interferometer Image Combination Methods(Miles Lucas)**

I will report on the methodology and some results of testing methods and parameters of combining single dish and interferometer radio images. The metric for analyzing combinations used a ratio of the power spectrum densities of a test image and a true model to determine the accuracy of close UV-spacings. The methods tested were CASA's feather task, using a startmodel in CASA's clean task, a modified joint-deconvolution CLEAN algorithm, and third-party solution tp2vis. Using simulated images based on the VLA and GBT telescopes of models with various amounts and sizes of structures, many permutations of simulation and imaging parameters were tested along with the combination methods. Some preliminary conclusions are that feathering is weak without adequate single-dish UV coverage overlap, joint deconvolution works well with dirty images, multiscale deconvolution performed well with joint deconvolution with low single-dish UV coverage overlap, and images with few, simple sources do not benefit from combinations in this testing. In addition, this paper presents an open-source codebase to allow researchers to test their own models and parameter permutations to determine their best options for combining data.

**Author(s):** Kumar Golap, Takahiro Tsutsumi, Miles Lucas,  
**Institution(s):** Iowa State University, National Radio Astronomy Observatory

#### **245.26 - The AMReX block structured adaptive mesh refinement library: Astrophysical Applications(Andrew J Nonaka)**

Multiphysics PDE simulation at scale can be a challenging task given rapidly evolving supercomputing architectures. As part of the DOE Exascale Computing Project (ECP), researchers at LBNL, NREL, and ANL have publicly released the AMReX software framework for massively parallel block-structured adaptive mesh refinement (AMR) applications. The core libraries include linear solvers, particle support, embedded boundary geometry representation, profiling tools, visualization kits, and hybrid MPI+X parallelism. AMReX has an open development model where users are encouraged to contribute

new features. There is extensive documentation and a wealth of tutorial codes available on the project site, <u><https://amrex-codes.github.io/amrex/></u>AMReX is the basis for many mature scientific applications, including Castro, a compressible astrophysics code; Maestro, a low Mach number astrophysical code; and Nyx, an N-body hydro cosmological simulation code.

**Author(s):** Andrew J Nonaka

**Institution(s):** Lawrence Berkeley National Laboratory  
Contributing Team(s): AMReX Team

#### **245.27 - The MAESTROeX low Mach number stellar hydrodynamics code(Duoming Fan)**

Modeling astrophysical phenomena that occur in the low Mach number regime is often computationally prohibitive because the time step is constrained by both characteristic fluid velocity and a much larger sound speed. In order to efficiently compute these types of stellar flows, we present our low Mach number, adaptive mesh refinement hydrodynamics code, MAESTROeX. The basic principle behind our low-Mach number scheme is to filter out the acoustic waves from the governing equations, which results in a time step constraint that is based only on the fluid velocity rather than the sound speed. We also employ a novel one-dimensional time-dependent radially-averaged base state whose evolution is coupled to the evolution of the full state. This allows for the proper capture of the effects of an expanding star in full-star simulations. Several astrophysical applications are presented here to demonstrate the accuracy and efficiency of MAESTROeX compared to more traditional compressible flow codes.

**Author(s):** Michael Zingale, Duoming Fan, Alice Harpole, Andrew J Nonaka

**Institution(s):** Lawrence Berkeley National Laboratory, Stony Brook University

#### **245.28 - Modelling rotating massive stars with MAESTROeX(Alice Harpole)**

MAESTROeX is an open source adaptive mesh refinement code for modelling low Mach number stellar hydrodynamics. We present ongoing work using MAESTROeX to study the convective cores of massive stars in the lead up to core collapse. Such systems are challenging to model using standard compressible codes due to the very low Mach number of the convective flow, but by using a low Mach number scheme which filters out sound waves we can get considerable computational speed up, making the problem more tractable. We describe our work to produce the first long-timescale fully 3d models of convective cores with rotation, including discussion of the effects we expect rotation to have on the stars' late stage evolution and the challenges of including rotation in our current scheme. MAESTROeX is freely available at <https://github.com/AMReX-Astro/MAESTROeX>. The work at Stony Brook was supported by DOE grant DE-SC0017955 through a contract with MSU and DOE/Office of Nuclear

Physics grant DE-FG02-87ER40317.

**Author(s):** Alice Harpole, Doreen Fan, Michael Zingale, Andrew J Nonaka

**Institution(s):** Stony Brook University, Lawrence Berkeley National Laboratory

### **245.29 - The Castro Adaptive Mesh Refinement Hydrodynamics Code: Applications, Algorithm Development, and Performance Portability(Michael Zingale)**

We describe the recent developments in the open source Castro adaptive mesh refinement (radiation) hydrodynamics code, with full self-gravity, general equations of state, and arbitrary nuclear reaction networks. Since its initial release, Castro has been used for models of core-collapse and Type Ia supernovae (in the Chandra, sub-Chandra, and double degenerate progenitor scenarios), X-ray bursts, and exoplanet dynamics. The core solvers have evolved significantly since the initial release. We detail a new spectral deferred correction time-integration framework, enabling a push to higher order accuracy. We show some initial tests of this new methodology. We also highlight the work on performance portability, allowing us to reuse the same computational kernels on CPUs and GPUs. Finally, we discuss the development model for Castro, including open code repos, regular regression testing, and distribution of all files needed to rerun our science models in the core repository. Castro is part of the AMReX Astrophysics suite of simulation codes and is freely available at <http://github.com/AMReX-Astro/Castro>. The work at Stony Brook was supported by DOE/Office of Nuclear Physics grant DE-FG02-87ER40317 and contract 7418390 with Lawrence Berkeley National Laboratory as part of the Exascale Computing Project ExaStar collaboration.

**Author(s):** Michael Zingale, John Bell, Weiqun Zhang, Donald Willcox, Maximilian Katz, Ann Almgren, Alice Harpole, Maria Barrios Sazo

**Institution(s):** Stony Brook University, Lawrence Berkeley National Laboratory, NVIDIA

### **245.30 - Fluka Simulation of sFLASH Experiment(Ricardo Alberto Gonzalez)**

The Telescope Array (TA) is the largest cosmic ray detector in the Northern Hemisphere. It consists of a surface detector of plastic scintillation counters overlooked by 3 fluorescence detector sites. They are used to measure cosmic rays from 1 PeV to 100 EeV and higher by observing extensive air showers in the atmosphere. To determine the shower energy, it is important to understand the fluorescence yield (FY), which is a conversion factor from the energy deposition in air to the fluorescence light. (s)uper (F)luorescence (A)ir (S)hower (sFLASH) is an auxiliary experiment of TA, carried out at SLAC, that measures FY in air produced by high energy electrons in a volume called the active region. In this work, we report the results of a FLUKA

simulation of sFLASH to gauge our understanding of the energy deposition in the experiment. FLUKA energy deposition density plots and Geant4, an alternative simulation software, energy deposition plots of the active region were compared to verify if accuracy of energy deposition in sFLASH is within 3%.

Preliminary results show that when comparing both simulations' plots the energy deposition density measurements are similar enough to be within the 3% accuracy. Further comparisons are being made to arrive at a more concrete answer. The sFLASH FY systematic uncertainty will be reduced using the energy deposition data of sFLASH FLUKA simulations. This will improve energy estimations of high energy cosmic rays in experiments such as TA and Auger.

**Author(s):** Dmitri Ivanov, Ricardo Alberto Gonzalez, John Matthews

**Institution(s):** University of Puerto Rico, Mayaguez, University of Utah  
**Contributing Team(s):** sFLASH collaboration

### **245.31 - A Branch and Bound Algorithm for Faint Moving Object Detection(Peter Whidden)**

Searching for distant asteroids in large imaging surveys poses many computational challenges. We demonstrate a branch and bound algorithm for discovering distant moving objects (e.g. Kuiper Belt Objects) close to and even below the detection thresholds of single astronomical images. By generating image pyramids, objects can be located efficiently and accurately. Similar to "shift-and-stack" and "track before detect" this approach combines information from multiple images. However branch and bound allows entire regions of the object search space to be eliminated while guaranteeing that no objects are overlooked. We present an analysis of the performance of the algorithm and compare it to other methods.

**Author(s):** Andrew Connolly, Dino Bektsev, Hayden Smotherman, Peter Whidden, Bryce Kalmbach

**Institution(s):** University of Washington

## **246 - Elliptical Galaxies -- Posters**

### **246.01 - The Demographics of Central Massive Black Holes in Low-Mass Early-Type Galaxies(Anil Seth)**

We present observational evidence for the presence of black holes at the centers of the five nearest early-type galaxies with stellar masses between 1 and 10 billion  $M_{\odot}$ . Using adaptive optics kinematics from Gemini and VLT, we find that all five galaxies appear to host central massive black holes. To derive dynamical black hole masses in these galaxies, we developed a novel technique to use high-resolution HST spectroscopy to accurately model mass-to-light variations seen in these nuclei. We find that four of the five galaxies have central black holes dynamically with masses below 1 million  $M_{\odot}$ , with the lowest mass black hole being only  $\sim 10,000 M_{\odot}$ . This work provides a first glimpse of the demographics of black holes in this galaxy mass range and at velocity dispersions below 70 km/s, and thus provides an important extension to the bulge

mass and galaxy dispersion scaling relations. The ubiquity of central black holes in these galaxies provides a unique constraint on massive black hole formation scenarios, favoring a formation mechanism that produces an abundance of low-mass seed black holes.

**Author(s):** Dieu Nguyen, Nadine Neumayer, Anil Seth

**Institution(s):** University of Utah, MPA, NAOJ

#### **246.02 - Dust-to-Gas Ratios in Early-Type Galaxies(Trevor Schlack)**

Dust-to-gas ratios in the inner and outer regions of early-type galaxies with extended HI distributions were calculated in order to determine the possible origins of the gas. Out of the 15 galaxies sampled, 10 had detectable dust and gas masses in both regions. The dust mass of each region was measured by fitting a modified blackbody to the flux in the 100, 160, 250, 350, and 500  $\mu\text{m}$  bands. The images were taken from the PACS (100 and 160  $\mu\text{m}$ ) and SPIRE (250, 350, and 500  $\mu\text{m}$ ) instruments on the Herschel Space Telescope. The gas mass of each region was measured using HI and CO maps obtained during the Atlas3D survey. Of the galaxies with detected dust-to-gas ratios, we see a variety of patterns included galaxies with higher dust-to-gas ratios in their outer regions than in their centers. This variety of dust-to-gas ratios patterns observed implies that it may be common for galaxies to suffer multiple episodes of accretion.

**Author(s):** Alison Crocker, Trevor Schlack

**Institution(s):** Reed College

#### **247 - Extrasolar Planets: Characterization & Theory -- Posters**

##### **247.01 - Effects of High and Low Surface Pressure on Exoplanetary Spectroscopy(Carlos Llorente)**

In the search for life outside our solar system, we can use Earth as a model of what to look for. Earth's spectral signature in the visible and infrared has already been determined, and simulations have been done examining the Earth's evolution over geologic time and placing the Earth in orbit around stars with different stellar types. Here we begin to modify the Earth itself, specifically the surface pressure, in order to determine the effect on the spectral signature of an Earth-like planet as it evolves over time. We use a coupled radiative-convective climate model and photochemical model code called ATMOS to generate globally averaged temperature and chemical profiles. The simulations model an Earth-like atmosphere across six points in Earth's evolutionary history (from 3.9 Ga to 0.3 Ga) at four different surface pressures (from 0.5 bar to 2.0 bar) for a total of 24 simulations. Our results show that increasing surface pressure leads to hotter surface temperatures and an upwards scaling effect on the atmospheric structure. Atmospheric features such as the ozone layer and tropopause form higher in the atmosphere, which has implications for the detection of ozone and water on transiting exoplanets.

**Author(s):** Carlos Llorente, Lisa Kaltenegger

**Institution(s):** Cornell University, Georgia Institute of Technology

##### **247.02 - The Perturbed Assembly of Compact Planetary Systems(Christopher E O'Connor)**

The Jovian planets Jupiter and Saturn are thought to have dominated the dynamics of the Solar System from its earliest stages. Recent studies of extrasolar planetary systems suggest a correlation between the occurrence of super-Earths on orbits interior to 1 AU and that of Jovian planets at greater distances. We have investigated the effect of these companions on the formation of super-Earths within 1 AU, in a scenario where the latter planets assemble by giant impacts out of 20 to 25 Earth-masses of solid material distributed within 1 AU of the central star. Secular perturbations from the companion(s) increase the number of accretion events, thereby diminishing planetary multiplicities while augmenting planetary masses. The resulting systems of super-Earths tend to be dynamically hot, with substantial eccentricities and mutual inclinations. The outcome of perturbed planetary assembly in situ is sensitive to the architecture of the companions' orbits. Our results indicate that the occurrence and early orbital evolution of Jovian planets are major factors in studying the demographics of observed planetary systems.

**Author(s):** Brad Hansen, Christopher E O'Connor,

**Institution(s):** University of California, Los Angeles, Cornell University

##### **247.03 - Simulated Emission Spectra of Hot Jupiters with Active Clouds from 3-D GCMs(Caleb Harada)**

Observations of scattered light and thermal emission from hot Jupiter exoplanets have suggested the presence of inhomogeneous aerosols in their atmospheres. Three-dimensional general circulation models (GCMs) with temperature-dependent, radiative feedback-driven (i.e. active) cloud formation have been developed to understand the physical processes that underlie the dynamical structure of these distant atmospheres. In this work, we investigate how different assumptions about aerosol modeling in the GCM affect emission spectra at all orbital phases. Using a GCM with active cloud modeling, we calculate emission spectra of a representative hot Jupiter for several cases with different assumed cloud parameters, including extended thick clouds, compact thick clouds, and compact thin clouds. We compare the results with emission spectra predicted for a clear atmosphere, and for atmospheres with aerosols that were simply included in the final step of the GCM (i.e. post-processed). Our preliminary findings show that actively including aerosols with radiative feedback in the GCM results in emission spectra and Doppler shift signatures that are dissimilar to both the clear and post-processed cloud cases. This work further demonstrates the importance of radiative feedback in cloudy atmospheric models, and shows the extent

to which different initial cloud conditions affect emission spectra.

**Author(s):** Eliza Kempton, Emily Rauscher, Caleb Harada, Michael Roman

**Institution(s):** University of Maryland, University of Michigan

#### **247.05 - Evryscope Constraints on TRAPPIST-1 Superflare Occurrence and Planetary Habitability(Amy Glazier)**

The ultracool dwarf (UCD) TRAPPIST-1 is close to Earth (~12 pc) and possesses several Earth-sized terrestrial planets, making it a compelling target for exoplanet characterization. TRAPPIST-1 is an active M8V star with frequent flaring, as is typical of UCDs. UCDs have been observed to undergo particularly extreme outbursts known as superflares; a superflare from Proxima Cen b, for example, was recently observed by the Evryscope team. Superflares can render planets uninhabitable primarily by two processes. They may erode a planet's atmosphere over long timescales, or destroy atmospheric volatiles such as ozone over geologically short timescales. Both UV flux and particle bombardment play roles in these processes. If TRAPPIST-1 is subject to frequent superflares, the habitability of its planets may be severely impacted. As yet, only one 1033-erg event has been observed from TRAPPIST-1; the occurrence rate for higher-energy superflares remains unknown. The Evryscope at CTIO observes the entire southern sky at a two-minute cadence, and is thus especially well suited to characterize the superflare occurrence rate for ultracool dwarves such as TRAPPIST-1. Particle bombardment can be probed by radio observations: Strong gyrosynchrotron radiation is indicative of ~MeV particles being injected into the stellar environment, which can erode the atmosphere of close-orbiting planets. Hence, simultaneous radio observations from the Very Large Array (VLA) can further inform habitability considerations by showing whether optical flares are accompanied by radio-emitting processes, such as gyrosynchrotron emission or the electron cyclotron maser instability. Pairing Evryscope optical observations with VLA radio observations constrains the flare occurrence rate for TRAPPIST-1 and provides information on the habitability of its planets. We present here the preliminary results of this analysis.

**Author(s):** Anna Hughes, Daniel del Ser, Octavi Fors, Henry T Corbett, Nicholas Law, Ward S Howard, Robert Quimby, Amy Glazier, Jeff Ratzloff

**Institution(s):** University of North Carolina - Chapel Hill, University of British Columbia, Institut de Ci ncies del Cosmos (ICCUB), Universitat de Barcelona, San Diego State University

#### **247.06 - Astrometric orbital motion of the wide planetary-mass companion GSC6214-210 b(Logan Pearce)**

Direct-imaging surveys discovered a class of 5-20 M<sub>Jup</sub> substellar companions at separations >100 AU from their host stars, which present a challenge to planet and star formation models. Detailed analysis of the orbital architecture of these systems can provide constraints on possible formation mechanisms, including the possibility they were dynamically ejected to a wide orbit. We present astrometry for the wide (240 AU) planetary-mass companion GSC~6214-210 b (14.5 M<sub>Jup</sub>) obtained using NIRC2 with adaptive optics at the Keck telescope over nine years. Our measurements achieved astrometric uncertainties of ~1 mas per epoch. We determined a velocity vector of 1.12 +/- 0.15 mas yr<sup>-1</sup> (0.61 +/- 0.09 km s<sup>-1</sup>), the first detection of orbital motion for this companion. We compute the minimum periastron for the companion due to our measured velocity vector, and derive constraints on orbital parameters through our modified implementation of the Orbits for the Impatient rejection sampling algorithm. We find that close periastron orbits, which could indicate the companion was dynamically scattered, are present in our posterior, but have low likelihoods. For all orbits in our posterior, we assess the detectability of close-in companions that could have scattered GSC~6214-210 b from a closer orbit, and find that most potential scatterers would have been detected in imaging. We conclude that formation at small orbital separation and subsequent dynamical scattering through interaction with another potential close-in object is an unlikely formation pathway for this companion. We also update stellar and substellar properties for the system due to the updated distance from Gaia DR2.

**Author(s):** Logan Pearce, Brendan Bowler, Adam L. Kraus, Aaron Rizzuto, Michael Ireland, Trent Dupuy

**Institution(s):** University of Texas at Austin, Australian National University, Gemini Observatory

#### **247.07 - Modelling Earth's Atmospheric Absorption in Support of Palomar/NESSI(Teagan King)**

One of the Jet Propulsion Laboratory's Exoplanet Discovery and Science group objectives is to determine the chemical composition and temperature profile of exoplanets, factors which could provide insight on whether or not they have resources to host life. NESSI, a near-infrared wide-field spectrograph at Palomar Observatory's Hale 200" telescope, measures molecular absorption features which constrain the content of exoplanet atmospheres. During a transit in front of a host star, light from the host star passes through the exoplanet's atmosphere and proceeds through the Earth's atmosphere before reaching ground-based observatories such as Palomar. The objective of this project is to reduce the influence of time-varying features due to telluric absorption in support of determining spectral features due to exoplanets. NASA Goddard's Planetary Spectrum Generator models the absorption due to Earth's atmosphere taking into account

altitude-dependent pressure broadening and effects on molecular lines. Mixing ratios of molecules in a synthetic atmosphere were retrieved using a Monte Carlo Markov Chain in conjunction with the outputs of this radiative transfer code. This approach will allow for a more accurate retrieval of abundances of molecules in exoplanet atmospheres because it adjusts for distortion due to the medium between the astrophysical signal and the observatory. This project supports all exoplanet transit spectroscopy ground datasets, in view of complementing science generated by existing (Hubble Space Telescope, Spitzer) and future (James Webb Space Telescope and ARIEL) observations from space.

**Author(s):** Robert Zellem, Mark Swain, Teagan King, Gaël Roudier

**Institution(s):** Whitman College, Jet Propulsion Laboratory - California Institute of Technology

#### **247.08 - Using Gravity Darkening on Variable Stars to Constrain Planetary Formation Theories(Samuel Myers)**

We set out to constrain planet formation around high-mass, fast-rotating stars by measuring the spin-orbit misalignment of planets with orbital periods between 10 and 100 days. Planets in this range likely have orbital configurations preserved from initial formation due to weaker stellar tidal forces farther from the host star. Measurements of spin-orbit misalignments for these planets can thus help to constrain theories of planetary formation and evolution by providing a glimpse into the early history of different planetary systems. Stars in this mass range darken as a function of increasing distance from the star's pole due to rapid rotation, a phenomenon referred to as gravity darkening. The characteristic asymmetric transit lightcurves that such gravity darkening produces can be used to measure a planet's spin-orbit alignment. Unfortunately, stars in this mass range are often also variable stars. This can be problematic for efforts to constrain the orbital parameters of planets orbiting them and requires additional work to properly analyze these systems. We examine Kepler Objects of Interest 972 and 1814, a planetary candidate and confirmed planet respectively. We demonstrate a technique for removing stellar photometric variability from lightcurves and apply gravity darkening techniques to constrain spin-orbit misalignment. We then briefly discuss our work with other systems and the implications of our results on theories of planetary formation and evolution.

**Author(s):** Jason Barnes, John P Ahlers, Samuel Myers

**Institution(s):** University of Idaho Contributing Team(s): Samuel Myers

#### **247.09 - First Exoplanet Mass Measurements from NASA Keck Key Strategic Mission Support Program Challenge the Core Accretion Theory(Aparna Bhattacharya)**

The distribution of exoplanets orbiting beyond the snow line found by microlensing indicate a smooth power-law distribution ranging from a super-Jupiter mass ratio of  $q = 10^{-2}$  down to close to the mass ratio of Neptune,  $q \sim 10^{-4}$ , with the  $q = 10^{-4}$  planets being 60 times more common than planets with  $q = 10^{-2}$ . However, the favored core accretion theory predicts a deficit of planets in the 20--80 Earth-mass range, due to the run away gas accretion process that is thought to accrete most of the mass of gas giant planets. This mass range translates into a mass ratio of  $q = 10^{-4}$  at the typical host star mass probed by microlensing, and the microlensing data indicates that there is no gap at this mass ratio range. It is unclear if this implies a basic revision of the core accretion theory or if the mass gap exists in the exoplanet mass distribution, but is washed out by the mass distribution of microlens planet host stars. We present the first results of the NASA Keck Key Strategic Mission Support that uses the WFIRST exoplanet mass measurement method to determine the masses of exoplanet host stars and their planets. We use both Keck and HST high angular resolution imaging to determine the masses of microlens host stars and planets from the Suzuki et al. (2016) statistical sample to investigate this predicted planet gap at 20--80 Earth-masses. Our early results reveal several planets with measured mass in this mass range, suggesting that the core accretion may be in need of revision.

**Author(s):** Aparna Bhattacharya, Daisuke Suzuki

**Institution(s):** NASA Goddard Space Flight Centre, University of Maryland College Park, JAXA Contributing Team(s): Keck KSMS team, MOA, GMRG

#### **247.10 - Using Mineral Physics Theory and Data to Help Constrain Knowledge of Super-Earth Exoplanet Interior Structures and Dynamics With an Eye Towards the Possibility of Life(David A. Boness)**

With new exoplanet detection instruments, such as TESS, yielding a bounty of observations of large terrestrial planets (super-Earths) around other stars, there is a rapidly growing dataset that can be examined with knowledge that has been gained over decades from geophysical theory and modeling and from high-pressure mineral physics theory, computation, and experiment. From an astrobiology perspective, we want to know if other not-too-distant planets have convecting liquid iron-nickel cores, generating magnetic fields protecting from host star wind, while having mantle minerals that convect with plate tectonics recycling elements, and with liquid water at a biohabitable depth. Since the detection instruments cannot directly ascertain exoplanet structure and dynamics, we consider candidates from the NASA Exoplanet Archive that might have a liquid metallic outer core, a convecting mantle, and possible liquid water in deep pores or on the surface.

**Author(s):** David A. Boness

**Institution(s):** Seattle University

#### **247.11 - Measuring the Rotation Rate of the Planetary-Mass Companion DH Tau b(Wenhao Jerry Xuan)**

DH Tau b is a planetary-mass companion orbiting the T Tauri star DH Tau (~0.5 solar masses) with a projected separation of 340 AU. With an age of ~2 Myrs, it is one of the youngest planetary-mass companions discovered to date. DH Tau b straddles the deuterium-burning limit with an estimated mass of 8-22 Jupiter masses, and like many directly imaged companions it is unclear whether it formed like a star (i.e., via turbulent fragmentation) or like a planet (i.e., either disk instability or core accretion). To shed light on DH Tau b's formation history, we obtain the first-ever measurement of rotational line broadening for this object using high-resolution (R ~25,000) near-infrared spectroscopy from Keck/NIRSPEC. We then compare DH Tau b's rotation rate with previously established trends in mass and age for both bound and free-floating planetary-mass objects, and find that DH Tau b reinforces existing trends in rotation rates from this population.

**Author(s):** Brendan Bowler, Marta Bryan, Wenhao Jerry Xuan, Heather Knutson, Björn Benneke

**Institution(s):** Pomona College, California Institute of Technology, University of California, Berkeley, University of Texas at Austin, Université de Montréal

#### **247.12 - Comparing Earthshine Observations to Models of Earth-as-an-Exoplanet(Nicholas Tasker)**

Discovering life on a planet outside our Solar system (an exoplanet) is the Holy Grail for the exoplanet and astrobiology communities. The hunt for life as we know it on exoplanets rests on the characterization of biosignatures in the reflected (and emitted) spectra of Earth-like exoplanets. Our knowledge of these biosignatures naturally comes from what we see of Earth's surface and atmosphere. Observing the Earthshine, the sunlight reflected from the Earth to the Moon and back to us, we can observe the Earth as if it were an exoplanet. Using Earthshine observations we can study the appearance of biosignatures on the spectrum of exoplanet-Earth. In this study, we compare Earthshine observations from the William Herschel Telescope (WHT) with models of the Earth. To model the Earth we use NASA MODIS data for the surface and cloud properties of the Earth on the date which the earthshine was observed. We then use these data as input in a radiative transfer code that models horizontally homogeneous and heterogeneous planets. We will compare both our homogeneous and heterogeneous models with the earthshine data. This comparison could inform the search for habitable exoplanets by showing us what potential signal from an Earth-like planet may look like, and thereby leading to improvements on our models of signals from other worlds.

**Author(s):** Nicholas Tasker, Theodora Karalidi, Jonathan Fortney

**Institution(s):** UC Santa Cruz

#### **247.13 - Assessing the Role of Clouds on the Spectra of Exoplanet Atmospheres(Zafar Rustamkulov)**

Clouds in the atmospheres of exoplanets are important in shaping their reflection, emission, and transmission spectra. However, their role in these different observational geometries can vary significantly. Here we present simple analytic models for understanding how clouds can alter the information content of a planetary spectrum. This is characterized by the column density of a given molecule, as well as the breadth of pressure levels that contribute to the total spectrum. The modeling framework allows for a range of cloud optical depths, pressure levels, cloud and surface albedos, and cloud coverage fractions. We show how clouds can increase the signal in reflection spectra, decrease the signal in transmission spectra, and produce a wider range of behavior in emission spectra. This work provides an approachable introduction for understanding the results of more sophisticated numerical models, and highlights how bulk cloud properties can add nuance to exoplanet atmosphere characterization.

**Author(s):** Zafar Rustamkulov, Jonathan Fortney

**Institution(s):** University of California, Santa Cruz

#### **247.14 - Through Thick, Thin, and Halo: Galactic Kinematics of Exoplanet Host Stars with Gaia(Analís Lawrence)**

The physical and kinematic properties of exoplanet host stars provide important clues about the environment, galactic context, and conditions in the protoplanetary disk when these planets formed. Gaia's second data release has offered the opportunity to examine the kinematic properties of known exoplanet systems for the first time. We compiled over 5000 host stars of confirmed and candidate planets using publicly accessible databases, supplemented with our own literature-based collection, altogether including radial velocity, transiting, and directly imaged systems. Host star parallaxes and proper motions were established by crossmatching the list with Gaia DR2. Since absolute radial velocities have not been measured for most systems, host star coordinates, parallaxes, and proper motions were used to marginalize over radial velocities in Toomre diagrams. This allowed the host stars to be broadly characterized by galactic disk membership. We recover several notable thick disk/halo systems including Kepler-444, the oldest known system of terrestrial sized exoplanets, and Kapteyn's star, the oldest known potentially habitable planet. We also identify ~4500 thin disk, ~700 thick disk/halo, and 11 likely halo host stars. The prevalence of thick disk and halo candidates suggest that conditions for forming terrestrial planets, and perhaps the conditions for life, were present around some of the earliest stars in our galaxy.

**Author(s):** Brendan Bowler, Analís Lawrence,

**Institution(s):** University of Florida, The University of Texas at Austin



#### **247.15 - Moderate Resolution Spectroscopy of Directly Imaged Exoplanets(Kielan Wilcomb)**

Recent direct imaging of exoplanets has revealed a population of Jupiter-like objects that orbit at large separations ( $\sim 10$ -100 AU) from their host stars. These planets, with masses of  $\sim 2$ -14 MJup and temperatures of  $\sim 500$ -2000 K, remain a problem for the two main planet formation models-core accretion and gravitational instability. We present results from our ongoing survey of directly imaged planets with moderate ( $R \sim 4000$ ) spectral resolution. We are making use of OSIRIS on the W.M. Keck I 10 meter telescope, which offers some of the best spectra to-date for directly imaged substellar companions. Thus far, we have observed eight companions in the K band ( $\sim 2.2 \mu\text{m}$ ), including the “super-Jupiter” Kappa Andromeda b (Kappa And b). Our spectra reveal resolved molecular lines from water and CO, allowing for the derivation of atmospheric properties such as temperature, surface gravity, metallicity, and C/O ratio. In particular, we confirm that Kappa And b has a low surface gravity, consistent with a young age and mass near the deuterium burning limit. We also find that Kappa And b potentially has a sub-solar metallicity. We compare our spectra of the companions in K band to those of other brown dwarfs and gas giant planets, and to each other. Our survey will improve our knowledge of the intricate atmospheres of young, substellar objects.

**Author(s):** Kielan Wilcomb, Jean-Baptiste Ruffio, Laci Shea Brock, Quinn Konopacky, Travis Barman, Bruce Macintosh, Christian Marois

**Institution(s):** UC San Diego, Stanford University, University of Arizona, NRC-Herzberg

#### **247.16 - Hidden Gems: Investigating Doppler Signatures in High Resolution Emission Spectra of Non-Transiting Hot Jupiters(Deryl Eden Long)**

Our work presents high resolution emission spectra for non-transiting hot Jupiters produced by coupling a 3D global circulation model (GCM) and detailed radiative transfer model. Non-transiting planets are far more common than transiting ones, and are therefore an abundant, although more difficult to characterize, population of planets for study. Ground-based observations to obtain high-resolution spectra require very bright targets, however the number of giant planets which transit very bright host stars is limited. By applying our technique for interpreting high resolution spectra to systems with non-transiting geometry, we can greatly increase the number of high-quality targets for these observations and subsequent interpretations. Our method provides the first study of atmospheric Doppler signatures due to winds and rotation in high-resolution emission spectra of non-transiting planets. We produce emission spectra as a function of orbital phase for the archetypal hot Jupiters HD 209458b, HD 189733b and WASP-43b. We artificially tilt these planets to view them at varying non-transiting inclinations and present results displaying how the Doppler signatures change with orbital inclination.

**Author(s):** Eliza Kempton, Deryl Eden Long, Emily Rauscher  
**Institution(s):** University of Michigan, University of Maryland

#### **247.17 - Exoplanet Demographics for EPRV and Direct Imaging Yield Calculations(Shannon D. Dulz)**

Simulated exoplanet yields of future space-based direct imaging missions are currently being used to inform and guide the design of WFIRST, HabEx, and LUVOIR. We are developing a series of simulations to determine the extent to which precursor surveys, specifically ground-based EPRV surveys, could boost the exoplanet yields and the detection efficiency of such missions. Here we discuss the first step in this process: generating planetary systems consistent with the measured occurrence rates. We combine the demographics measured from multiple planet detection methods, including transits, RVs, and microlensing. We assess the impact of a stability criterion based on mutual Hill radii in suppressing planet occurrence rates at large semi-major axes to estimate occurrence rates for currently immeasurable planets. The resulting self-consistent occurrence rates will be used as input to the EPRV survey simulations, from which recovered orbital parameters will then ultimately be incorporated into comprehensive direct imaging exoplanet yield calculations.

**Author(s):** Christopher Stark, Peter Plavchan, Justin Crepp, Rhonda Morgan, Patrick Newman, Shannon D. Dulz, Stephen Kane

**Institution(s):** University of Notre Dame, Space Telescope Science Institute, George Mason University, University of California, Riverside, NASA/Jet Propulsion Laboratory

#### **247.18 - Optimizing JWST NIRISS SOSS Order 2 Precision For the Detection of K and Na(Lindsey Wiser)**

The NIRISS (Near Infrared Imager and Slitless Spectrograph) instrument on JWST (James Webb Space Telescope) has the potential to revolutionize our understanding of exoplanet atmospheres through direct imaging and transit spectroscopy. The key question we address is: what new information can we expect to gain using the SOSS (Single Object Slitless Spectroscopy) mode of the NIRISS instrument? Other JWST instruments have high sensitivity at longer wavelengths, but NIRISS SOSS is unique in its ability to make high-precision spectroscopic time-series observations at wavelengths smaller than one micron with its 2nd Order, which includes the potential for detection of K and Na. These shorter wavelengths that NIRISS SOSS provides ( $0.6 - 2.7 \mu\text{m}$ ) also include cloud and haze features that must be used in order to constrain planetary properties, including the absolute abundances of molecules. Analysis of those abundances provides insight into the formation and evolution of planets. In preparation for JWST launch, we analyze the capabilities of NIRISS SOSS for a variety of planetary and stellar cases. We start by using a 1-D forward

model for predicting the transmission spectrum of a planet with specified characteristics. We then use an instrument noise simulator to extract the expected instrumental error from NIRISS SOSS for a variety of stellar cases. Finally, we use information content theory to calculate the uncertainty on physical characteristics of the atmosphere given the generated observation. We develop an optimal observing strategy to maximize Order 2 precision and minimize uncertainty on physical characteristics of the atmosphere unique to that wavelength range. We identify necessary conditions and minimum abundances of Na and K for the detection of their signatures to be possible using NIRISS SOSS. This in-depth understanding of NIRISS SOSS capabilities can be used by observers to optimize their use of the telescope.

**Author(s):** Natasha E Batalha, Lindsey Wiser, Jonathan D Fraine, Nikole K Lewis, Joseph Filippazzo, Katherine Alatalo

**Institution(s):** Johns Hopkins University, Space Telescope Science Institute, UC Santa Cruz, Cornell University

#### **247.19 - Revised Exoplanet Radii and Habitability Using Gaia Data Release 2(Daniel Johns)**

The second data release of the Gaia mission (Gaia DR2) brought with it updated distances, luminosities, and radii of 1.6 billion stars. A small portion of these stars are hosts to known exoplanets. Here, we report the calculation of revised radii and densities for 320 non-Kepler exoplanets using these new data and present updated calculations of the incident flux received by 690 exoplanets. Using the newly calculated incident fluxes, we were able to determine whether these planets orbit within their habitable zones. We report three new planets that are found to orbit within their habitable zone: HIP 67537 b, HD 148156 b, and HD 106720 b. We also report one planet, BD+49 898 b, that is seen to receive an incident flux that places it outside of its habitable zone. Our sample consists of mostly hot-Jupiters, but an evaluation of the habitable zone brings about the possibility of habitable exo-moons or habitable Trojan companions. Using the Gaia DR2 data, we calculate a mean percentage change in planetary radius of +3.76 %. We report a -6.46 % median percentage change in planetary density and report a new highest-density exoplanet, KELT-1 b, at a revised density of 22.1 g cm<sup>-3</sup>. Our results highlight the importance of re-examining planetary system parameters whenever more precise stellar parameters are released.

**Author(s):** Jacob McCann, Duncan Wright, Jonathan Horner, Madison Huff, Connor Marti, Robert Wittenmyer, Daniel Johns

**Institution(s):** Kutztown University, University of Southern Queensland, Westminster College, Williams College

#### **247.20 - Prioritizing Exoplanet Targets for Atmospheric Study using NASA's TESS Mission(Junellie Gonzalez Quiles)**

NASA's Kepler mission has found that M dwarfs can host an abundance of exoplanets. These often seem to be small planets

with less than twice the size of the Earth, which are of the most interest due to its potential for harboring life. TESS, the Transiting Exoplanet Survey Satellite, is on the hunt for these planets orbiting nearby stars. While TESS will find the planets, it cannot study their atmospheres in search of biological signatures alone. Instead, the James Webb Space Telescope (JWST) will characterize the atmospheres of the most promising planets from TESS. Using simulated TESS data for planets around small stars, we aim to understand the planetary systems around these stars, as well as prioritize those planets that have the most promising atmospheres for atmospheric follow up with JWST. Planet formation theory predicts a relationship between the orbital spacing between planets in a system, and the bulk density of the planets. Using this relationship and a realistic synthetic TESS sample, we apply this theory to predict what the densities of those planets will be. Obtaining these densities is crucial to predicting the thickness of their atmospheres, from which we can make a recommendation as to which planets are of interest to observe with JWST. Crucially, we recommend the amount of time it would require to observe their atmospheres with JWST, so that the exoplanet community can prioritize this precious resource.

**Author(s):** Junellie Gonzalez Quiles, Sarah Ballard

**Institution(s):** University of Maryland, College Park, Massachusetts Institute of Technology

#### **247.21 - Retrieving Water Vapor from the Reflection Spectra of Earth-Like Worlds: Exploring Large Direct Imaging Missions(Adam J.R.W. Smith)**

Future space telescopes will be able to make direct observations of reflected light from potentially Earth-like exoplanetary atmospheres, with the goal of characterizing these atmospheres for signs of life. Atmospheric water vapor is one such critical component. Assessing the necessary spectral resolution and signal-to-noise ratio determine the presence of water and the amount of water vapor in an atmosphere will help guide the design of these telescopes and followup observational strategies. To that end, we use a state-of-the-art atmosphere model to calculate line-by-line planetary geometric albedos and reflection spectra, coupled with a Markov-chain Monte Carlo retrieval method, to retrieve H<sub>2</sub>O abundance in simulated Earth-like atmospheres with a focus on the 0.95  $\mu$ m water feature.

**Author(s):** Katherina Feng, Adam J.R.W. Smith

**Institution(s):** University of California, Santa Cruz

#### **247.22 - Modeling and Simulation of Exoplanetary Atmospheric Haze: Spectroscopic Muting(Oliver Conor Frederick Brown)**

Observation of the transmission spectra of exoplanets reveals information about the planetary system, the planet atmosphere and habitability. However prominent spectral features are often obscured. Atmospheric haze has become the leading candidate

for flattening of spectral transmission of exoplanetary occultation. Where strong absorption lines would be predicted, muted spectra and broad absorption features are seen instead. These features may demonstrate how the planetary atmospheres become opaque to stellar light in transit. In this work, we employ large-scale reactive molecular dynamics simulations to understand the formation of haze particles under different atmospheric conditions. In particular, we study if the nucleation and aggregate formation are enhanced and to what extent with seeding of the haze clusters with ions.

**Author(s):** Hossein Jooya, Vasilii Kharchenko, Hossein Sadeghpour, Oliver Conor Frederick Brown,

**Institution(s):** University of Southampton, Harvard-Smithsonian Center for Astrophysics

### **247.23 - The Young Exoplanet K2-25b: Flat Spectrum and High Eccentricity (Pa Chia Thao)**

Transiting planets in nearby young clusters offer the opportunity to study the dynamics and atmospheres of planets during their early stages. K2-25b is a close-in ( $P=3.48$  days), Neptune-sized exoplanet that orbits a mid-M dwarf in the Hyades cluster (650 Myr). We combined photometric observations of K2-25 covering a total of  $> 40$  transits and spanning 3 years, drawn from a mix of spaced-based telescopes (Spitzer Space Telescope and K2) and ground-based facilities (Las Cumbres Observatory and MEarth). With the data covering  $0.6\mu\text{m}$  to  $4.6\mu\text{m}$ , it enabled our study of the transit depth as a function of wavelength (transmission spectroscopy), a probe of the planet's atmosphere. Each dataset at a common wavelength was combined and fit with a MCMC framework, yielding consistent planet parameters. We found that K2-25b's transmission spectrum is consistent with being flat, and rule out a solar-composition atmosphere. Further HST data are needed to determine if K2-25b's atmosphere has a high mean molecular weight or contains clouds/hazes. We also found that K2-25's orbit is eccentric ( $e > 0.20$ ) for all reasonable stellar densities and independent of data source. The high eccentricity is suggestive of a complex dynamical history and motivates future searches for additional planets or stellar companions. We are grateful for the support of the Texas Astronomy Undergraduate Research experience for Underrepresented Students (TAURUS) at the University of Texas at Austin.

**Author(s):** Andrew Mann, Elisabeth Newton, Marshall C. Johnson, Pa Chia Thao, Isabel Kain

**Institution(s):** University of North Carolina Chapel Hill, Massachusetts Institute of Technology, The University of Texas at Austin, Ohio State University, Northeastern University

### **247.24 - Eccentricity Thresholds for Planetary Deglaciation at Varying Obliquity (Igor Palubski)**

In this study we explore and identify the minimum eccentricity thresholds for deglaciation of globally ice-covered extrasolar planets with different obliquities. Using a one-dimensional

Energy Balance Model, we calculate the latitudinal ice thickness and extent on Earth-like planets receiving different values of instellation from a G-dwarf star, for obliquities from  $0^\circ$  to  $90^\circ$ . For orbiting planets that are completely frozen at apoastron, we find that the minimum eccentricity required to fully thaw the ice sheets at periastron decreases with increasing instellation. Increases in obliquity raise these minima, and this effect is most strongly apparent at eccentricity values below  $\sim 0.75$ . However, the influence of obliquity diminishes at higher values of eccentricity, and has little effect on planets with extreme eccentricities above  $\sim 0.85$ , due to the increasing effectiveness of larger eccentricity as the primary means of thawing the ice. Additionally, we find that the region where seasonal ice is present in the eccentricity-instellation parameter space diminishes with increasing obliquity. This diminishment is due to rapidly-increasing ice sheet thickness on planets with initially thin ice at low obliquities, preventing the occurrence of seasonal ice. Outside of this region, the planet is either completely frozen or fully thawed throughout the entire planet's year. Our work has important implications for planets discovered at large orbital distances from their parent stars and whose eccentricities and obliquities are currently unconstrained by observations. Such planets may exhibit temporal surface habitability despite technically orbiting outside of their host stars' traditional habitable zones.

**Author(s):** Aomawa Shields, Igor Palubski

**Institution(s):** UC Irvine

### **247.25 - BAFFLES: Bayesian Ages For Field Low-mass Stars (Adam Stanford-Moore)**

Age is a fundamental parameter of stars, yet ages derived from spectroscopic indicators in field stars often do not address the astrophysical scatter. We have developed a Bayesian framework to produce the age posterior for a single star from its B-V color, calcium emission strength ( $R'_{HK}$ ), and lithium abundance, and their associated uncertainties. Current methods to determine the ages of stars do not provide a statistically robust estimate for the uncertainty in the derived age. BAFFLES infers stellar age from measurements of calcium emission and lithium absorption and properly incorporates astrophysical scatter in the derived age. We empirically determine the likelihood functions for calcium and lithium as a function of age from literature measurements of these indicators. These literature measurements are of stars that are members of nearby moving groups and clusters with well-determined ages. In addition, combining lithium and calcium posteriors for a single star allows us to increase the precision on the inferred age. We are currently investigating extending our framework to additional age indicators, including H-alpha emission, X-ray emission, and rotation period. Our work is motivated by improving mass determination of self-luminous planets. For self-luminous planets and brown dwarfs, the accuracy in the age of the host star sets the precision in the derived mass.

**Author(s):** Robert De Rosa, Bruce Macintosh, Adam Stanford-Moore, Eric Nielsen

**Institution(s):** Stanford University Contributing Team(s):  
Gemini Planet Imager Exoplanet Survey

#### **247.26 - Diversity Amongst Terrestrial Exoplanet Modeling(Ryan Felton)**

As the James Webb Space Telescope and other future large aperture space observatories come online the suite of detected Earth sized exoplanets will increase. The need will arise for the atmospheres of these planets to be characterized. Although much of the work on Earth-sized worlds has focused on potentially habitable planets, we need to place such worlds in a broader context of Earth-sized, and likely rocky, planets. To characterize a diversity of Earth-sized planets, we will first need to understand the signatures observed in their atmospheres. To contribute to this task our group is using 1-D photochemical models to study the carbon cycle on abiotic terrestrial planets, similar in bulk composition to Titan. We present the results of our new Titan-like exoplanet model, and compare it to models of Archean Earth and Mars, as well as to Cassini-Huygens data from Titan. We focus heavily on atmospheric haze, redox state and solar forcing results while also considering planet size and distance from host star. CH<sub>4</sub> and CO<sub>2</sub> photolysis play large roles in haze production and control as seen on Titan and predicted for Early Earth. As these atmospheres have very different redox states, it is important to consider their hazes when studying atmospheric carbon cycling.

**Author(s):** Marc Neveu, Ryan Felton, Shawn David Domagal-Goldman, Steve Desch, Giada Arney

**Institution(s):** Catholic University of America, NASA Headquarters D.C., NASA Goddard, Arizona State University

#### **247.27 - Atmospheric Evolution of Exoplanets around M Dwarfs(Kathleen Mandt)**

One of the most compelling questions for exoplanets located within the potential habitable zone of their host star is whether they are able to retain an atmosphere. The primary approach that has been taken to answer this question is to determine how much of the atmosphere, with a particular focus on water, can be lost during energy limited escape. This approach has been a critical first step in determining the maximum loss rates of exoplanet atmospheres. We have conducted a pilot study that builds on this work by mapping out pathways for atmospheric evolution of GJ 1132 b. We have done this by adding the influence of non-hydrodynamic thermal escape, and potential contributions by volcanic outgassing and impacts, and photochemistry. Through this study we have determined upper and lower limits for the abundance of important volatiles as a function of time.

**Author(s):** Abigail Rymer, Kathleen Mandt, Olivier Mousis

**Institution(s):** Johns Hopkins University Applied Physics Laboratory, Laboratoire d'Astrophysique de Marseille

#### **247.28 - Architecture for space-based exoplanet spectroscopy in the mid-infrared(Joseph J Green)**

Characterizing exoearths at wavelength about 10 micron offers many benefits over visible coronagraphy. Apart from providing direct access to a number of significant bio-signatures, direct-imaging in the mid-infrared can provide 1000 times or more relaxation to contrast requirements while greatly shortening the time-scales over which the system must be stable. This in turn enables tremendous relief to optical manufacturing, control and stability tolerances bringing them in-line with current technology state of the art. In this poster, we examine a reference design that co-optimizes a large, segmented, linearized aperture telescope using one-dimensional phase-induced aperture apodization to provide high-contrast imaging for spectroscopic analysis. By rotating about a parent star, the chemical signatures of its planets are characterized while affording additional means for background suppression.

**Author(s):** Michael Rodgers Rodgers, Thomas Nick Gautier, Joseph J Green, Samuel Case Bradford, Gautam Vasisht

**Institution(s):** Jet Propulsion Laboratory, Synopsys, Inc

#### **247.29 - The Perilous Lives of Planets in Binary Star Systems(Adam L. Kraus)**

The majority of solar-type stars are found in binary systems, and the dynamical influence of binary companions is expected to profoundly influence planetary systems. However, the difficulty of identifying planets in binary systems has left the magnitude of this effect uncertain; despite numerous theoretical hurdles to their formation and survival, at least some binary systems clearly host planets. We present high-resolution imaging of nearly 500 Kepler Objects of Interest (KOIs) obtained using adaptive-optics imaging and nonredundant aperture-mask interferometry on the Keck II telescope. We super-resolve some binary systems to projected separations of under 5 AU, showing that planets might form in these dynamically active environments. However, the full distribution of projected separations for our planet-host sample more broadly reveals a deep paucity of binary companions at solar-system scales. Our results demonstrate that a fifth of all solar-type stars in the Milky Way are disallowed from hosting planetary systems due to the influence of a binary companion. We now update these results with multi-epoch imaging to reject non-comoving background stars and securely identify even the least massive stellar companions, as well as tracing out the orbital motion of stellar companions and robustly determining occurrence rates for wider binaries that are subject to numerous selection biases in the original Kepler survey. These results are beginning to reveal not just the fraction of binaries that do not host planets, but also potential explanations for planet survival even in some very close, dynamically active binary systems.

**Author(s):** Adam L. Kraus, Daniel Huber, Aaron C Rizzuto, Andrew Mann, Michael Ireland, Trent Dupuy

**Institution(s):** UT-Austin, Australian National University,

Gemini Observatory, University of Hawaii - IfA, UNC

### **247.30 - Chemical Analysis of Tabby's Star (KIC 8462852)(Stacey Thomas)**

KIC 8462852 is a star of interest due to its unusual flux phenomena. Although there is now a better understanding of the star's photometric fluctuations, the star has of yet been fully characterized. Our research focuses on determining the composition of KIC 8462852. We have used medium-resolution spectra obtained with the 3.5-m WIYN telescope and HYDRA spectrograph in single-object mode to determine the abundances of numerous elements. We have used the MOOG spectral analysis software, linelist data retrieved from VALD, and KURUCZ model atmospheres to determine the abundances via spectral synthesis. We present our initial results.

**Author(s):** Cintia Fernanda Martinez, Katia Cunha, Stacey Thomas, Verne Smith, Simon Schuler

**Institution(s):** University of Tampa, Steward Observatory, Observat rio Nacional, NOAO

### **247.31 - High-Resolution Follow-up Observations to Break Microlensing Models Degeneracy(Clement Ranc)**

Gravitational microlensing occupies a unique niche in exoplanet sensitivity with its ability to detect planets beyond the snow line. In this region, the core-accretion theory predicts that planets formation is most efficient because the condensation of ices provides a higher density of the solid material required to initiate the planet formation. The microlensing planets sample can be used to derive occurrence rates of planets as a function of the planet-to-host mass ratio. The resulting mass-ratio function is then used to test the predictions from planets formation theory/models. These statistical studies must include all the possible interpretations of a microlensing event to be accurate, i.e., the degenerate models and their mutual relative probability. Presently, many analyses use the chi-squared to weighting degenerate microlensing model solutions. The method is well justified if the chi-squared surfaces in the vicinity of each degenerate solution in the parameter space have a similar shape or volume. Conversely, when the chi-squared surfaces are different, we need more complex methods to sample the multimodal posterior distribution. In this poster, we use the analysis of the microlensing event OGLE-2006-BLG-2006/MOA-bin-17 to test several Monte Carlo algorithms to derive an accurate relative probability between degenerate solutions. These degeneracies include a lens consisting of a star hosting a giant planet beyond the snow line. Observations of this event by the OGLE and MOA collaborations in 2006 have revealed caustic crossing features only partially constrained by the data and making harder an unequivocal lens characterization from the light curve. Moreover, we performed high-resolution follow-up observations of this target as part of

the NASA Keck Key Strategic Mission Support program in support of WFIRST, entitled Development of the WFIRST Exoplanet Mass Measurement Method. We will show how the joint interpretation of high-resolution images with the light-curve best-fit models yields the lens mass and distance. This method is similar to the expected primary mass-measurement method for the future WFIRST Microlensing Survey.

**Author(s):** Clement Ranc, David Bennett

**Institution(s):** NASA Goddard Space Flight Center

**Contributing Team(s):** The OGLE Collaboration, The MOA Collaboration, The KSMS Microlensing Team

### **247.32 - Detection of water in the atmosphere of the hot Jupiter HD 102195b(Joe Llama)**

The composition and structure of hot Jupiter atmospheres provide a fossil record of their primordial origins, potentially holding the key to distinguishing between the various proposed formation mechanisms. High-resolution spectroscopic observations of exoplanet atmospheres enable us to resolve molecular bands into many individual spectral lines in a pattern that is unique to each molecule. By then exploiting the Doppler shift of the planet over multiple nights we can separate the planet spectrum from that of the host star and Earth's atmosphere. Here, we use the high-resolution infrared spectrograph IGRINS ( $R=45,000$ ,  $\lambda=1.4-2.5$  microns) on the 4.3m Discovery Channel Telescope to observe the spectrum of the hot Jupiter HD 102195b. Our analysis reveals a 4 $\sigma$  detection of water in the atmosphere of this heavily irradiated hot Jupiter.

**Author(s):** Jayne Birkby, Tomas Cabrera, Jessica Luna, Larissa Nofi, Matteo Brogi, Joe Llama

**Institution(s):** Lowell Observatory, MIT, University of Amsterdam, University of Warwick, University of Texas Austin

### **247.33 - Ageing M & K Type Stars by Way of Rotation and Flux(Kasey Purcell)**

Red Dwarf stars (dwarf K and M stars, or dK/M stars) make up over 90% of the local stellar population. This is among the reasons they are being targeted by numerous planet-hunting programs, and an increasing number of exoplanets continue to be discovered orbiting dK/M stars. This makes it critically important to devise an accurate method for determining the ages of field dK/M stars. However, due to their long lifetimes, and very slow nuclear evolution, the best method for determining ages would seem to be through an age-dependent observable quantity, such as stellar rotation rates. Over the past several years we have furnished relationships between stellar rotation rate and age for dK/M stars. To assess the habitability of planets hosted by these stars, we also need to delineate the X-UV (X-ray to ultraviolet) radiation environments these planets are currently exposed to, and have been exposed to in the past. In this study, we have utilized UV observations of dK/M stars carried out with the International Ultraviolet Explorer (IUE)

satellite and the Hubble Space Telescope (HST), in combination with stellar ages, to build up reliable Age-Rotation-Activity relationships for dK/M stars and determining the X-UV environments that exoplanets around these stars will be subjected to over the course of their lifetimes. We gratefully acknowledge support for this project from Villanova CURF, NASA, and the National Science Foundation.

**Author(s):** Scott Engle, Kasey Purcell

**Institution(s):** Villanova

#### **247.34 - The young planetary system K2-25: constraints on companions and starspots (Isabel Kain)**

The abundance of planets with orbital periods of a few to tens of days suggests that exoplanets experience complex dynamical histories. Planets in young stellar clusters or associations have well-constrained ages and therefore provide an opportunity to explore the dynamical evolution of exoplanets. K2-25b is a Neptune-sized planet in an eccentric 3.48 day orbit about an M4.5 dwarf star in the Hyades cluster (650 Myr) and is the most accessible transiting planet in a cluster to date. In order to investigate its non-zero eccentricity and tight orbit, we analyze transit timing variations (TTVs) which may reveal clues to the migration processes that may have acted on the planet. We obtained 21 non-consecutive nights of photometric data from the MEarth and Spitzer telescopes, and additionally analyze long-cadence data from K2. Each transit lightcurve is fit individually to investigate whether inhomogeneities on the stellar surface (such as spots or plages) are differentially affecting our transit observations. The measured transit depth and duration do not vary significantly between transits, indicating that the features on the stellar surface are not changing at a level detectable in our data. We then looked for TTVs as evidence of a long-period or non-transiting perturber in the system, but find no evidence for companions. The MEarth team is grateful for support from the David and Lucile Packard Fellowship for Science and Engineering, the John Templeton Foundation (awarded to D.C.), and the National Science Foundation, and NASA. ERN acknowledges support from the NSF through the GRF and the AAPF programs (award AST-1602597).

**Author(s):** Jennifer Winters, Pa Chia Thao, Andrew Mann, Elisabeth Newton, Jason Dittmann, Jonathan Irwin, Isabel Kain, David Charbonneau

**Institution(s):** Northeastern University, Columbia University, MIT Kavli Center for Astrophysics and Space Research, Harvard-Smithsonian Center for Astrophysics, MIT Kavli Institute for Astrophysics and Space Research, The University of North Carolina Chapel Hill

#### **247.35 - VPlanet: The Virtual Planet Simulator (Rory Barnes)**

Planetary systems evolve due to a myriad of processes, often non-linearly, which complicates simulating exoplanetary

systems. The relevant physical processes have often been modeled and explored within sub-disciplines of science, so a universal model of planetary system evolution must unite theories developed in multiple scientific disciplines. We present a new interdisciplinary model of planetary system evolution that self-consistently couples stellar, orbital, tidal, rotational, atmospheric, internal, magnetic, climate, and galactic evolution for generic planetary systems, but focusing on systems with habitable worlds. We have combined all these processes into a single open-source software package called VPlanet.

**Author(s):** Russell Deitrick, Rodrigo Luger, Thomas Quinn, Pramod Gupta, Victoria Meadows, Shawn David Domagal-Goldman, David Fleming, Peter Driscoll, Diego McDonald, Rory Barnes, Hayden Smotherman, Caitlyn Wilhelm, John Armstrong, Benjamin Guyer

**Institution(s):** University of Washington, University of Bern, Center for Computational Astrophysics, Weber State University, Carnegie Institute for Science, NASA Goddard Space Flight Center  
**Contributing Team(s):** The Virtual Planetary Laboratory

#### **247.36 - Linking M-Dwarf Planet Composition and Orbital Dynamics through N-Body Simulations (Quadry Chance)**

NASA's Transiting Exoplanet Survey Satellite (TESS) mission will furnish a large number of small, rocky planets for atmospheric study. The majority of these planets will orbit M dwarfs (stars half the mass of the Sun or smaller). Indeed, one of the first planet discoveries from the mission is of an M dwarf only 15 pc away. The sheer number of forthcoming M dwarf planets from TESS will exceed our capacity for follow-up observations. This is particularly pressing for the most precious follow-up resource: atmospheric characterization with the James Webb Space Telescope (JWST). We use N-body simulations to predict the approximate composition of planets around these stars during the period of planet formation characterized by slow accretion by large bodies. We address two outstanding questions with these simulations. First, how does material move from its original location in the protoplanetary disk to its final destination within planets? Here, we focus upon the condensation temperature of particular compounds. Second, how do likely mechanisms of atmospheric loss affect the ratio of volatile compounds within the nascent planet and how does this loss vary with the disk's initial conditions? This work will both advance our understanding of how rocky planets come to obtain their atmospheres, and inform optimal selection of targets for atmospheric characterization by JWST.

**Author(s):** Keivan G Stassun, Sarah Ballard, Quadry Chance  
**Institution(s):** Fisk-Vanderbilt Bridge Program, Vanderbilt University, Massachusetts Institute of Technology, Fisk University

**247.37 - Plans for a Participating Scientist Program (PSP) for the WFIRST Coronagraph Instrument (CGI)(Jason Rhodes)**

NASA's Wide Field Infrared Survey Telescope (WFIRST) will have a Coronagraph Instrument (CGI) that will serve as a technology demonstration, paving the way for a future direct imaging mission that will take images and spectra of Earth-like planets around Sun-like stars. The CGI tech demonstration is envisioned to take place over three months of observations during the first 18 months of WFIRST's operations. The WFIRST Project plans to solicit proposals from the community for members of a Participating Scientists Program (PSP) - well before launch - to help plan, and eventually, execute the CGI technology demonstration observations and analysis. This small team will be tightly integrated with the WFIRST CGI Project and help define target lists, write software, analyze data, and assess the performance of the CGI relative to its design. The PSP will be encouraged to help push the performance of CGI to its intrinsic limits in order to maximize its technology demonstration value, and which effort may justify potential future science programs that use CGI on WFIRST.

**Author(s):** Jason Rhodes, Jeffrey Kruk, Dominic Benford  
**Institution(s):** NASA JPL, NASA HQ, NASA GSFC

**247.38 - TYCHO: Simulating the Lives of Exoplanets within Stellar Clusters(Joseph Paul Glaser)**

As we discover an ever-increasing amount of planets around other stars within the Galaxy, our insights into their evolution from stellar debris disks to fully-fledged worlds are constantly put to the test. To fully understand the diverse population of exoplanets, we must turn to study their early lives within open clusters, the birthplace of most field stars. Indeed, when we study planets within clustered environments, we notice highly eccentric and odd systems that seem to indicate the importance of dynamical pathways created by interactions with additional bodies (like in the case of HD 285507b). However, it has proven difficult to investigate these effects as many current numerical solvers for the multi-scale N-Body problem are simplified and limited in scope. To remedy this, we aim to create a physically complete computational solution to explore the role of stellar close encounters and interplanetary interactions in producing the observed exoplanet populations for both open cluster stars and field stars. We present a new code, TYCHO, which employs a variety of different computational techniques, including multiple N-body integration methods; close encounter handling; modified Monte Carlo scattering experiments; and a variety of empirically informed initial conditions. Herein, we discuss the methodology in detail, its implementation within the AMUSE software framework and some initial promising applications to exoplanet surveys.

**Author(s):** Aaron Geller, Joseph Paul Glaser, Stephen McMillan, Mark Giovannazzi, Jonathan Daniel Thornton  
**Institution(s):** Drexel University, Northwestern University, The Adler Planetarium, University of Pennsylvania

**248 - Gamma Ray Bursts -- Posters**

**248.01 - Beyond Synchrotron Effects in Gamma-Ray Burst Afterglows(Taylor Evan Jacovich)**

Gamma-ray burst (GRB) afterglow modeling has long relied on only synchrotron emission to calculate the broadband spectrum and light-curves. Although this works for many afterglows, certain physical conditions would require that Synchrotron Self-Compton (SSC) effects be considered to properly describe the afterglow emission. Even in cases where SSC effects are small, their inclusion further constrains GRB parameter space. We present modifications to the hydrodynamic afterglow fitting routine boxfit that allows for the rigorous treatment of SSC effects for both electron cooling and emission on the afterglow spectrum over all of parameter space, by producing a smoothed approximation of the Inverse-Compton Y parameter that is continuous and applicable for all times and physical parameter values. We further address first order Klein-Nishina corrections to SSC effects and modify our Y parameter accordingly. Finally, we discuss the overall effects of SSC on the parameter space when compared with synchrotron-only model fits of the emission, first by discussing the outcomes of synthetic data fitting, then by comparing results from fitting the afterglow of GRB 070125.

**Author(s):** Alexander J. van der Horst, Paz Beniamini, Taylor Evan Jacovich,

**Institution(s):** The George Washington University, Smithsonian Astrophysical Observatory Contributing Team(s): George Washington University

**248.02 - Optimizing the Search for Gamma-Ray Counterparts to Gravitational-Wave Observations(Collin Lewin)**

Since discovering the first gamma-ray counterpart to a gravitational-wave (GW) signal in 2017, the Fermi Gamma-ray Burst Monitor (GBM) has been a leading instrument in detecting such counterparts to GW events. While events above a certain detection threshold "trigger" the flight software upon observation, copious non-triggering short gamma-ray bursts (SGRBs) are instead uncovered through a subthreshold search that analyzes data in a time window for potential events once the full data is downlinked to the ground. A primary objective of this project is to apply and test several changes to this targeted sub-threshold search on both real events and background noise. This is done by running the search on previously observed, Swift-coincident GRBs and on 100 random ten-second windows of background. Such adjustments to the search include adding a blackbody spectral template-allowing for an expansion of discovery space for SGRBs-and adjusting the instrument's energy channels that are included in the search. By investigating which configuration maximizes the detection statistic for real events and minimizes it for background noise, the results of the project will contribute to more effective and confident future detections of gamma-ray counterparts in collaborations with LIGO/Virgo, IceCube Neutrino Observatory, etc.

**Author(s):** Collin Lewin, Adam Goldstein

**Institution(s):** University of Arizona, NASA Marshall Space Flight Center, Universities Space Research Association  
**Contributing Team(s):** The Fermi Gamma-ray Burst Monitor Team, NASA Marshall Space Flight Center

#### **248.03 - Gamma-rays as Gravitational Wave Counterparts: Testing Fermi-GBM's Limits(Nohely Miranda Colon)**

With the detection by the Gamma-ray Burst Monitor (GBM) of the first short gamma-ray burst (GRB) counterpart to a gravitational wave (GW) event, ground-based searches have gained a particular importance. Short GRBs are related to merger events involving at least one neutron star which produce gamma-rays as well as GWs. GBM has an on-board trigger that alerts when a GRB is detected. The threshold for a trigger is  $\sim 0.7$  photons  $\text{cm}^{-2} \text{s}^{-1}$ . However, some of these gamma-ray counterparts may be below this trigger threshold. GW detection range for neutron star mergers is 300 million ly, and most triggered short GRB detections are above 200 million ly. These GRBs can be recovered by ground-based searches of the data. One of these is the untargeted search. It looks continuously for time correlated counts above background with a valid geometry for a point source. In order to test the untargeted search we simulate GRBs with different spectral parameters, duration and fluences on different backgrounds. Knowing the sensitivity limits of this search allows us to explore the full extent of GBMs capabilities. Overall it was found that the minimum fluence recovered by the untargeted search is on the order of the faintest reported GRBs.

**Author(s):** Nohely Miranda Colon

**Institution(s):** University of Puerto Rico at Mayaguez  
**Contributing Team(s):** Gamma-Ray Burst Monitor Team at NASA MSFC

#### **248.04 - Gamma-Ray Bursts Light Curve Fitting with Swift XRT(Fatimah Hussein)**

Gamma Ray Bursts (GRBs) are extreme explosions that occur randomly in the Universe. They release more energy in seconds than what the sun emits in its entire lifetime. We present a study focusing on GRB afterglow flares; what are they? Why do they occur? How are they related to the prompt GRB itself? In order to begin the process of figuring this out, we fit  $\sim 350$  X-ray afterglow light curves collected by the Swift X-ray Telescope. The fitting procedure uses the superposition of two mathematical models; the Norris function and broken power laws. We minimized the fit residuals to establish a good fit, and search for a pattern in the residuals (Hakkila et al.2015) which may show a characteristic signature present in prompt GRB light curves. This residual signature may be related to details of the shock physics and provide a much better understanding of relativistic shocks.

**Author(s):** Jon Hakkila, Amy Lien, Fatimah Hussein, Judith

Racusin

**Institution(s):** University of the Virgin Islands, University of Charleston, NASA-GSFC

#### **248.05 - On to Off: Predictions for the Radio Afterglows of Neutron Star Mergers(Carlo Mario Esquivia)**

The Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo Observatory detect gravitational wave (GW) emission from neutron star mergers. When LIGO/Virgo detect a neutron star merger, fully characterizing the event is challenging due to fairly poor localizations of  $\sim 10$ - $100$ 's of square degrees, and relies on the detection of an electromagnetic signal. To potentially improve searches following GW events, we present a study to characterize the behavior of radio off-axis afterglows from neutron star mergers. Assuming that the properties of neutron star mergers are drawn from the same distributions as those of short gamma-ray bursts (GRBs), we used observations of on-axis short GRBs ( $\hat{l}, \text{obs}=0$ ) to predict the behavior of off-axis afterglows ( $\hat{l}, \text{obs}>0$ ) with BOXFIT. We sampled from the distributions of inferred kinetic energies and densities of on-axis short GRB afterglows for our simulation parameters. Overall, the light curves demonstrate that when we incorporate the distributions of energies and densities from short GRBs, there is a large diversity in expected light curve behavior. We find that for  $\hat{l}, \text{obs}=10^\circ$ , the light curves peak at or above  $10$ - $2$  mJy that can be detected by our most sensitive facilities; while for  $\hat{l}, \text{obs}=60^\circ$ , the light curves peak at or above  $10$ - $4$  mJy, which is beyond the reach of current facilities. Ultimately, our results show the critical role timing plays in our observations, as well as the limited return of deeper observations past a certain depth. This is a proof-of-concept study, and we have developed a multi-use tool that allows for adaptation to other electromagnetic counterpart models. Our results can be reproduced and also tested at other angles through user desired input.

**Author(s):** Carlo Mario Esquivia, Wen-fai Fong

**Institution(s):** Hamilton College, Northwestern University

#### **248.06 - Characterization of Silicon Photomultipliers(Kaylan Husband)**

Burstcube is a 6U CubeSat space research designed with the intention of detecting and localizing Gamma-ray Bursts (GRBs). GRBs are defined as "long", attributed to the collapse of massive stars, or "short", resulting from binary neutron star or binary black hole mergers. Burstcube is optimized to observe in the  $10$ - $1000$ keV range, where GRB prompt emission is detectable. Short Gamma-ray Bursts are of particular interest because they are predicted to be counterparts of gravitational wave sources that have now been detected by LIGO (The Laser Interferometer Gravitational-Wave Observatory) In the grand scheme, Burstcube will be a set of 5 CubeSats that are able to observe all aspects of the sky for a comparatively low cost.



Burstcube will be coupled with four Cesium Iodide (CsI) scintillator arrays that will be positioned to observe different portions of the sky to localize GRBs through the scintillator and the silicon photomultiplier (SiPM) arrays. Using Cesium Iodide, as opposed to lead and plastic based scintillators, allows for a better energy resolution when mapping these sources. With my research being centered around the analysis of the efficiency of the Hamamatsu Silicon Photomultiplier models, I assessed the upgrades made from the series 13 models to the series 14 model. Improvements to reduction to power need and increase to total efficiency was observed from the older models to the new. With these improvements made to the Silicon photomultipliers, energy resolution can see an increase through the arrays used in conjunction with the scintillator as well. These improvements will allow for technology to edge closer to wide-view, low-cost GRB analysis.

**Author(s):** Kaylan Husband,

**Institution(s):** University of the Virgin Islands, NASA

## **249 - Groups of Stars - Galactic & Extragalactic I Posters**

### **249.01 - A Comprehensive Abundance Analysis of the Open Cluster NGC 6940 from Optical and Infrared High Resolution Spectra(Catherine Pilachowski)**

We report the results of our analysis of 12 red giant stars in the intermediate-age open cluster NGC 6940, using high resolution, high signal-to-noise data gathered with McDonald Observatory IGRINS spectrograph (1.5-2.5 microns) and the Hobby-Eberly Telescope (5100-8800Å). Our combined, optical-infrared analysis of 30 species of 28 elements and the carbon isotopic ratio yields consistent results between the optical and infrared transitions. Often features in the infrared spectra yield more reliable results than those in the optical spectra. The reliability of the abundances of the CNO group received special emphasis, using multiple species of C and O. For 11 of our program stars we find good agreement with theoretical predictions for post-first-dredgeup abundances:  $[C/Fe] \sim -0.20$ ,  $[N/Fe] \sim +0.50$ ,  $[O/Fe] \sim -0.05$ , and  $^{12}C/^{13}C \sim 20$ . In contrast, the star MMU 152 shows evidence for a higher level of CNO processing:  $[C/Fe] \sim -0.50$ ,  $[N/Fe] \sim +0.60$ ,  $[O/Fe] \sim -0.10$ , and  $^{12}C/^{13}C \sim 6$ . These CNO abundances, combined with the overabundance of Na, argue for the presence of high-temperature hydrogen fusion products in the atmosphere of MMU 152 and suggest that this star may be contaminated by a more-evolved former companion. Our work has been supported by The Scientific and Technological Research Council of Turkey (TUBITAK, project No. 112T929), by NSF grants AST 12-11585 and 16-16040, and by the University of Texas Rex G. Baker, Jr. Centennial Research Endowment.

**Author(s):** Sergen Ozdemir, H. Kim, E. Strickland, G. N. Mace, D. T. Jaffe, Chris Sneden, Gamze Bâçcek Topcu, Catherine Pilachowski, Melike Afsar,

**Institution(s):** Indiana University, Ege University, University of Texas, Gemini Observatory

### **249.02 - VLA Limits on Ionized Gas in M81's Globular Clusters(J. M. Wrobel)**

As the stars in globular clusters (GCs) evolve, they shed gas into the potential wells of the GCs. Theory suggests that gas contents can be moderated by processes internal to the GCs, such as clearing by winds from compact objects; or external to the GCs, such as ram-pressure removal during passage through a galactic disk. We report the first gas-mass estimates for 206 GCs in M81, a nearby spiral galaxy. We used the NSF's Karl G. Jansky Very Large Array (VLA) to constrain the free-free continuum from ionized gas in the GCs. We then converted that continuum to gas masses using a simple model. We detected none of the 206 GCs and imposed a typical gas-mass upper limit of 550 solar masses (3-sigma). Notably, the GC with the highest stellar mass showed a gas-mass fraction below about 0.0002. These findings bear on GC evolution in M81. They can be improved with longer VLA exposures or similar exposures with a next-generation VLA. The NRAO is a facility of the NSF, operated under cooperative agreement by Associated Universities, Inc. K.E.J. is supported by NSF grant 1413231.

**Author(s):** J. M. Wrobel, K. E. Johnson

**Institution(s):** NRAO-NM, University of Virginia

### **249.03 - HII Region Morphologies of Young Star Clusters in 3 Nearby LEGUS Galaxies(Stephen Hannon)**

The study of HII morphology around young star clusters is important for understanding the timescales and thus the physical processes at work in the clearing of a cluster's natal gas. We present an analysis of 660 young clusters ( $\sim 10$  Myr) found in three nearby spiral galaxies (NGC 7793, NGC 4395, and NGC 1313) based on the Hubble Space Telescope (HST) multi-band imaging observations taken as part of the LEGUS survey. Clusters are examined in two parameters: 1) visually classified HII morphology stage (embedded, partially embedded, and exposed) and 2) whether they have neighboring clusters, which could affect the clearing timescale of a young cluster. We also present a promising method for quantitatively classifying clusters' stages based on HII concentration indices. Through visual inspection of each cluster, age estimation based on their spectral energy distribution (SED), and their position in (U-B) vs (V-I) space, we find the following: the vast majority (87%) of isolated clusters have at least started the clearing process (i.e. are no longer fully embedded) by 4 Myr, in agreement with previous works, while those that are older yet still embedded are of very low mass ( $< 500$  solar masses). It is important to note that  $\sim 93\%$  of our sample is of low mass clusters ( $< 5000$  solar masses) where the initial mass function is not fully sampled and the relationship between physical and photometric properties introduces stochastic effects and therefore may produce less reliable cluster ages. Adding to the uncertainty in the SED age-determinations, we also see that  $\sim 40\%$  of exposed, isolated clusters are actually paired with red supergiants, which makes them appear very red in color-color

space. In an effort to provide better constraints on the masses and ages, we remove the supergiant pairs and stack the flux of the sources in their respective bins and fields to form 36 composite clusters (6 fields by 6 bins). While stochasticity could certainly be an issue with our low-mass sample, the methods employed provide promising results for application to larger, more massive cluster samples.

**Author(s):** Janice Lee, Brad Whitmore, Rupali Chandar, Stephen Hannon,

**Institution(s):** University of California, Riverside, STSCI, Caltech/IPAC, University of Toledo Contributing Team(s): LEGUS

#### **249.04 - Spectroscopy of Known and Suspect Be Stars in Open Clusters(Steven Souza)**

In the course of our study of H $\pm$  emission variability in massive (primarily Be) stars in young open clusters using serial narrowband photometry (Souza, Davis and Teich 2013, BAAS.45, PM354.22; Souza, Beltz-Mohrmann and Sami 2014, JAAVSO, 42, 154) a number of stars of interest emerged. Some we suspected to be Be stars based on narrowband colors, or based on broadband colors plus apparent irregular variability; others exhibited possible emission or irregular variability, but lacked complete or recent spectral classification. We therefore obtained medium-resolution blue and red spectra of ~20 of these stars using the DIS spectrograph on the ARC 3.5-meter telescope at Apache Point Observatory, and used Gray (Gray, R.O. 2009, "A Digital Spectral Classification Atlas," V1.07) as a classification reference. In this manner we previously classified BD+35 1111 as B2Ve, the only confirmed Be star in the field of M38 (Souza, Kwitter, Sami and Beltz-Mohrmann 2013, BAAS.46, PM291.05). In the present work we classify 6 new Be stars previously lacking either known hydrogen emission, B or OB classification, or both. We also provide new or refined spectral classifications for 4 known Be stars and 6 non-Be early-type stars. We gratefully acknowledge support from Williams College. This work is based on observations obtained with Apache Point Observatory's 3.5-m Astrophysical Research Consortium Telescope.

**Author(s):** Karen Kwitter, Steven Souza

**Institution(s):** Williams College

#### **249.05 - Membership in the Globular Cluster NGC 6397 from Gaia DR2 Proper Motions(Richard Rees)**

We have used Gaia DR2 proper motions to derive membership probabilities for more than 13,000 stars brighter than  $G = 18$  within 15' of the globular cluster NGC 6397, reaching ~2 magnitudes fainter than the main-sequence turnoff. These proper motions provide excellent field-cluster separation. The results are highly consistent with independent membership probabilities derived from scans of good-focus photographic plates spanning 97 years in epoch. Preliminary extensions to larger radii find a significant number of likely cluster members

beyond the nominal tidal radius. This presumably reflects the difficulty of accurately determining structural parameters for a cluster in a low Galactic latitude field and/or is an effect of the cluster's recent passage through the Galactic disk.

This work has made use of data from the European Space Agency (ESA) mission Gaia, processed by the Gaia Data Processing and Analysis Consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

**Author(s):** Richard Rees, Kyle Cudworth

**Institution(s):** Westfield State University, Yerkes Observatory, The University of Chicago

#### **249.06 - Survivor: Protoplanetary disk edition(Megan Reiter)**

Stellar feedback permeates high-mass star-forming regions, fundamentally shaping the cradle of star and planet formation. Photoionizing radiation from high-mass stars may destroy the disks around still-forming low-mass stars. At the same time, fossil evidence in meteorites suggests that at least one supernova seeded the proto-Solar nebula with radioactive isotopes that play a central role in the geochemical evolution of Earth-like planets. Whether feedback helps or hinders planet formation depends critically on the morphology and dynamics of the natal cluster. This is because star formation is a fundamentally dynamic process where individual objects move (1 pc in 1 Myr at 1 km/s) through different environments during cluster formation. I will present first results from a new survey to measure radial velocities of low-mass stars in a truly high-mass star forming region, the Carina Nebula. Together with proper motions from Gaia, this will provide the first comprehensive study of the 3D kinematics in a truly high-mass star-forming region, allowing us to: -- constrain the time that low-mass stars spend subject to disk-destroying radiation from nearby high-mass stars and constrain the fraction polluted with supernova ejecta; -- determine the dynamical ages of both clusters; compare to the surviving disk fraction to test which environment is more hospitable; -- model the dynamical evolution of the clusters using new constraints; and -- compare cluster kinematics to older, post-supernova regions (e.g., Sco-Cen) to determine how typical Sun-like birth conditions are.

**Author(s):** Richard Parker, Aleksandra Kuznetsova, Lee Hartmann, Chris Evans, Nathan Smith, Megan Reiter

**Institution(s):** UK Astronomy Technology Centre, University of Arizona, University of Michigan, University of Sheffield

#### **249.07 - Gamma Ray Bursts from Black Hole - Star Collisions in Globular Clusters(Mitchell Lachat)**

In dense stellar environments such as globular clusters (GCs), close passages during dynamical interactions can lead to tidal disruptions or even physical collisions between stars. In this analysis, we use our Cluster Monte Carlo computer code to study collisions between BHs and stars in GCs. One of the most

impactful initial parameters for a GC is the initial virial radius. The virial radius determines the cluster density which, in turn, determines the collision rate. A smaller initial virial radius, which corresponds to a higher stellar density, results in earlier collisions compared to the systems with a larger initial virial radius. We perform cosmological rate calculations to estimate the rate of collisions between BHs and stars in a typical GC. Collisions of this type may connect to events that resemble gamma ray bursts. We estimate a collision rate of 15.4 Gpc<sup>-3</sup> yr<sup>-1</sup> for high-mass collisions out to a redshift of 3.5. For low-mass collisions, we estimate a rate of 30.2 Gpc<sup>-3</sup> yr<sup>-1</sup> within the same redshift. Within the uncertainties of this analysis, these rates are roughly consistent with the observed GRB rate.

**Author(s):** Mitchell Lachat,

**Institution(s):** Allegheny College, CIERA

#### **249.08 - Measuring Masses and Densities of Nuclear Star Clusters in the Nearest Galaxies(Renuka Pechetti)**

Galaxy nuclei contain both black holes (BHs) and nuclear star clusters (NSCs). Low-mass galaxies are typically dominated by NSCs. Measurements of NSC mass density suggest a scaling relation exists between them and their host galaxy mass, but very few NSC masses are dynamically estimated. We will present density profiles and dynamical masses for 29 nearby galaxies within 10 Mpc based on HST imaging and accompanying infrared spectroscopy from GNIRS and XSHOOTER. We quantify the NSC profiles by determining the effective radius and Sersic index. These profiles are then combined with their central velocity dispersions, derived using CO bandheads, to get dynamical mass density estimates for the NSCs and upper limits on any BHs. These measurements increase the number of dynamical measurements of NSCs by a factor of 3. The resulting scaling relations can be used to disentangle the formation scenarios of the NSCs. In addition, the measurement of central densities will help determine the expected rate of tidal disruption events by central BHs in galactic nuclei.

**Author(s):** Iskren Georgiev, Nikolay Kacharov, Renuka Pechetti, Nadine Neumayer, Anil Seth

**Institution(s):** University of Utah, Max Planck Institute for Astronomy

#### **249.09 - Effects of the Primordial Binary Fraction on the Evolution of Globular Clusters.(Thomas Macaulay Boudreaux)**

Despite over 150 confirmed globular clusters around the Milky Way, a generalized model of cluster expansion and mass evaporation rates has yet to be developed. Numerical studies have focused on the effects of external tidal fields and stellar evolution, two properties which models suggest play important roles in shaping long-term cluster evolution. Furthermore, there appears to be a correlation between the primordial binary fraction and a cluster's core radius expansion rate. However,

there has yet to be a firm quantitative relation. Using the publicly available Nbody6++GPU code, we integrate clusters of varying primordial binary fractions. We present the results of these simulations, which indicate possible relationship between the half-light radius and the expansion rate. Additionally, we present a set of models relating the half-light radius to cluster age for various primordial binary fractions. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST - 1659473, and by the Smithsonian Institution.

**Author(s):** Brad Barlow, Sownak Bose, Idan Ginsburg, Thomas Macaulay Boudreaux,

**Institution(s):** High Point University, Harvard Smithsonian Astrophysical Observatory

#### **249.10 - Stellar Rotation in the M35 Open Cluster Using K2 Data(Emma Turtelboom)**

The M35 open cluster is a relatively young (~150 Myr), nearby cluster, and we aim to investigate the relationship between rotation period and mass in its members. The K2 Mission conducted 70 days of high precision monitoring of a ~1 degree field centered on M35. We used K2 mission Campaign 0 data to determine the rotation periods of 968 cluster members, as identified in the GAIA second data release. We investigated several photometry methods to generate light curves for M35 objects, including aperture photometry, and point spread function (PSF) photometry using Kepler's modeled pixel response. Aperture photometry ultimately resulted in lower levels of long-term systematic light curves, and we used Lomb-Scargle periodograms to identify potential periods in the light curves of M35 Members. We investigate the relationship between rotation periods and (B-R) magnitude (as a proxy for mass), and find a slower-rotating arm with periods between 1 and 10 days for (B-R) < 1.8. These results echo those of previous studies of the similar age Pleiades cluster.

**Author(s):** Ann Marie Cody, Emma Turtelboom

**Institution(s):** MIT, NASA Ames Research Center

#### **249.11 - Know Your Neighbors: New Catalogs and Analysis of Star Clusters in the LMC, SMC, & M33(L. Clifton Johnson)**

Expanding on the success of the Andromeda Project citizen science project in identifying star clusters in Hubble Space Telescope (HST) imaging of M31, we present initial results from two new Zooniverse cluster identification projects. These projects analyze imaging from two Local Group surveys: HST imaging of the Triangulum galaxy obtained by the PHAT-M33 survey, a continuation of the Panchromatic Hubble Andromeda Treasury (PHAT) survey, and DECam imaging of the Large and Small Magellanic Clouds from the CTIO Blanco 4m telescope obtained by the Survey of Magellanic Stellar History (SMASH). These surveys produced wide-field, uniform optical imaging of the LMC, SMC, and M33 that surpass previous datasets in

depth and coverage, providing the data necessary to construct next-generation star cluster catalogs. The new crowdsourced cluster catalogs provide a well-characterized census of Local Group star clusters, enabling studies of star formation, stellar evolution, and more. We present initial catalog results from the citizen science searches and explore the population of massive star cluster across the Local Group.

**Author(s):** L. Clifton Johnson

**Institution(s):** Northwestern University Contributing Team(s): PHAT-M33 Team, SMASH Team

## **250 - Groups of Stars - Galactic & Extragalactic II Posters**

### **250.01 - Age Estimates of Open Clusters Using Gaia DR2(Chelen H Johnson)**

In a collaboration between students from three high schools, we present our preliminary results using Gaia DR2 data to refine age estimates of ten open clusters. We are following the basic approach presented by the Gaia collaboration (2018). We selected members based on proper motions. PARSEC isochrones (Bressen et al 2012) were matched to our color-magnitude diagrams to define the turn-off point for each cluster. In this preliminary study, we have not examined the effects of metallicity and/or reddening on our age calculations. This project is a collaborative effort of high school students and teachers from three states. They analyzed data individually and later collaborated online to compare results. This project is the result of many years of work with the NASA/IPAC Teacher Archive Research Program (NITARP).

**Author(s):** Rhiannon Gabrielsen-Shimp, Raymond Mathez, Grace Frey, Chelen H Johnson, Sabine Tronco, Alexandra Karos, Sierra Child, Thea Wallace, John Gibbs, Luc Bieri, Nathaniel Gong, Alexandra Bernstein, Luisa Rebull, Marcella Linahan, Meghan Taylor, Joseph Matusiew

**Institution(s):** Breck School, Carmel Catholic High School, Glencoe High School, IRSA, NITARP, SSC

### **250.02 - X-Ray Source Analysis In The Globular Clusters NGC 6341 and NGC 6541(Zachary Jones Carter)**

X-ray sources abound in globular clusters due to their high rates of stellar encounters. However, while X-ray telescopes such as the Chandra X-ray Observatory can determine the presence and location of these X-ray sources, determining their specific natures requires additional information from other wavebands. We present a joint Chandra and Hubble Space Telescope analysis of the globular clusters NGC 6341 and NGC 6541. We use DOLPHOT to analyze ACS observations in F435W, F625W, and F658N. We make color magnitude diagrams using the DOLPHOT photometry and look for CMD outliers. If any of these outliers is spatially coincident with an X-ray source, we consider it a possible counterpart. The combination of the X-ray and optical properties allows us to classify the sources in these clusters.

**Author(s):** David Pooley, Zachary Jones Carter

**Institution(s):** Trinity University

### **250.03 - WIYN Open Cluster Study: Photometry of the Open Cluster NGC 6603(Sarah E Popp)**

We present WIYN 0.9m HDI UBVR<sub>I</sub> photometry of open star cluster NGC 6603. We report values for cluster parameters such as age, distance, and reddening.

**Author(s):** Constantine P. Deliyannis, Dominique Cesario, Aaron Steinhauer, Rachel Farnsworth, Sarah E Popp, Shruti Giri, Anne Pellerin, Lucas Finn, Lydia Fillhart

**Institution(s):** State University of New York at Geneseo, Indiana University, Agnes Scott College

### **250.04 - H-alpha Index Observations of Open Clusters(Jacob Jensen)**

Joner and Hintz (2015) presented a new H-alpha photometric system as a companion to the classic H-beta photometric system. Using filters modeled after this H-alpha photometric system, we obtained data of a sample of open clusters which cover a wide age range. Data were obtained using 8" and 10" robotic telescopes located on BYU campus, as well as the 36" telescope located at the BYU West Mountain Observatory. We will present photometric data on a sample of 10-15 clusters with an age range of  $\log(t) = 6.85$  to  $\log(t) = 9.409$  and examine their color-magnitude diagrams using the H-alpha index for temperature. The H-alpha index was calibrated using a sample of stars from M67 and NGC 752, which were observed spectroscopically using the 1.2-m telescope of the Dominion Astrophysical Observatory.

**Author(s):** Jacob Jensen, Eric G Hintz, Michael Joner

**Institution(s):** Brigham Young University

### **250.05 - Was the first observed hypervelocity globular cluster, HVGC-1, accelerated by a supermassive binary black hole?(Sean Lewis)**

I investigate the possibility that the recently discovered hypervelocity globular cluster, HVGC-1, was accelerated by a close encounter with a supermassive binary black hole. By designing a 3-body Monte Carlo particle scattering experiment with a set parameters consisting of the physical properties of the black hole binary orbit and a test particle's closest approach distance, I determine the close encounter that will most likely allow a globular cluster to survive the ejection and possess a velocity similar to the value reported for HVGC-1. I apply the optimized path parameters to an extended globular cluster in an N-body integration using the software AMUSE. Ultimately, I find that neither a typical cluster of  $r_h = 6$  pc nor a compact cluster of  $r_h = 1$  pc survives the ideal interaction with the black hole system. Therefore, I am motivated to suggest that the extraordinarily high velocity of HVGC-1 is not due to a close

encounter with a supermassive binary black hole.

**Author(s):** Sean Lewis

**Institution(s):** Drexel University

#### **250.06 - Searching for Escaped Globular Cluster Stars in the Milky Way Galaxy.(Nicholas Cho)**

The GAIA Data Release 2 (DR2) on April 25th, 2018 opened new areas of focused research within the astronomical society. The unprecedented measurements specifically on proper motion and positional measurements of stars allowed my research to be possible. My goal was to identify escaped red giants in globular clusters contained in the Milky Way Galaxy Halo. I focused on set of criteria to identify outliers in globular clusters provided to be by my mentor. I calculated the six criteria (tidal radius, proper motion, right ascension and declination, color magnitude diagrams, radial velocity, and metallicity) with a Python program that I created. This simulation found outliers within a data set of around two hundred thousand stars for a selected seventy five globular clusters. Unfortunately, the information provided to me by GAIA DR2 was not complete with the measurements on metallicity and radial velocity which will be a goal for future work. This research aimed to identify escaped red giants to open up new information about the formation of the Milky Way Galaxy and also the origin of globular clusters in the galaxy. This research was performed at the University of Santa Cruz over the course of the summer of 2018 alongside my mentor Tiffany Hysu and Mike Bolte.

**Author(s):** Nicholas Cho

**Institution(s):** Bellarmine College Preparatory Contributing Team(s): SIP

#### **250.07 - The GeMS/GSAOI Galactic Globular Cluster Survey (G4CS)(Bryan W Miller)**

We present the first results from the GeMS/GSAOI Galactic Globular Cluster Survey (G4CS) of the Milky Way globular clusters (GCs) NGC3201 and NGC2298. Using the Gemini South Adaptive Optics Imager (GSAOI) behind the Gemini Multi-conjugate adaptive optics System (GeMS) on the 8.1-meter Gemini South telescope, we have collected deep near-IR observations of the clusters, resolving their stellar populations down to  $K_s = 21$  Vega mag. Point spread function (PSF) photometry was performed utilizing a spatially variable PSF to overcome AO correction variations across the field of view. The resulting near-IR photometric catalogs were augmented with optical and near-ultraviolet photometry from the Hubble Space Telescope (HST). We apply proper motion cleaning and differential reddening corrections before utilizing the characteristic color-luminosity difference between the lower main sequence knee (MSK) and main sequence turnoff (MSTO) to determine the ages. We find that the  $K_s$  vs. F606W- $K_s$  and F336W vs. F336W- $K_s$  filter combinations provide the most diagnostic power and we use them to derive the stellar

population ages, distances and reddening values for both clusters. We fit three sets of isochrone models to the two color combinations using a pseudo- $\chi^2$  approach. A weighted average of the results gives best-fit absolute ages of  $12.2 \pm 0.5$  Gyr and  $13.2 \pm 0.4$  Gyr for NGC3201 and NGC2298, respectively. Our derived parameters are in good agreement with recent age determinations of the two clusters, with our constraints on the ages ranking among the most statistically robust. These findings demonstrate the power of GeMS/GSAOI as a tool for the exploration of both cluster characteristics and their constituent stellar populations.

**Author(s):** Bryan W Miller, Stephanie Monty, Mirko

Simunovic, Thomas Puzia, Eleazar Rodrigo Carrasco Damele

**Institution(s):** Gemini Observatory, Pontificia Universidad Catolica de Chile, Australian National University Contributing Team(s): G4CS Team

#### **250.08 - The Efficacy of K Dwarf Abundance Derivations and the Implications for Chemical Tagging(Simon Schuler)**

We present the results of an abundance analysis of three G and two K dwarfs in the Praesepe Open Cluster based on high-resolution, moderate signal-to-noise ratio spectra obtained with the 3.5-m ARC telescope and ARC Echelle Spectrograph. Using a Principle Component Analysis and the BACCHUS automated spectral analysis code, we have determined stellar parameters and abundances of 20 elements for each star. Under the assumption that stars within an open cluster are chemically homogeneous, the abundances of the K dwarfs are compared to those of the G dwarfs to investigate the efficacy of using automated routines to derive the abundances of cool main sequence stars. The implications for large-scale stellar spectroscopic surveys and chemical tagging are discussed.

**Author(s):** Keith Hawkins, Brett M. Morris, Marwan Gerbran, Simon Schuler, Stephanie T. Douglas, Marcel Agüeros

**Institution(s):** University of Tampa, Notre Dame University-Louaize, Columbia University, University of Washington, University of Texas at Austin, Harvard-Smithsonian Center for Astrophysics

#### **250.09 - The Growth of Stars in Clusters: Simulations of Bondi-Hoyle-Lyttleton Accretion onto Discretized Potentials(Nick Omahen)**

This work examines the flow and accretion onto clusters of objects in the context of the Bondi-Hoyle-Lyttleton formalism. In our simulations, we initialize a uniform distribution of stationary, equal-mass accretors placed within a "wind tunnel" computational domain, where the incident gas is focused by the potential of the individual accretors and the self-gravity of the gas is neglected. We use a three-dimensional, cartesian geometry and employ an adiabatic exponent of  $\gamma = 5/3$  with a Mach 2 wind in all simulations. We vary the number of accretors and the mean separation between accretors, using our

results to determine their effect on the aggregate and individual accretion rate, which we compare to theoretical predictions and previous numerical results. We also study relevant astrophysical applications of our results.

**Author(s):** Nick Omahen, Andrea Antoni, Enrico Ramirez-Ruiz,

**Institution(s):** University of California, Santa Cruz, Niels Bohr Institute, University of Copenhagen, University of California, Berkeley

### **250.10 - Likelihood Analysis of Gamma-Ray Emission from the Massive Star Cluster Westerlund 1(Katie J. Chapman)**

A nexus of winds from massive stars self-interacts to become highly energized and capable of accelerating particles to high energies. The standing question is if this outflow can accelerate protons, or cosmic rays, to the point where they emit gamma rays. We performed a likelihood analysis using the Fermi Science tools on 10 years of Fermi Gamma-ray Space Telescope data of the most massive star cluster in our galaxy, Westerlund 1, to investigate its viability as a source of cosmic rays. Galactic cosmic ray origins still beg investigation: further analyses of Westerlund 1 and other massive star clusters could potentially contradict the current paradigm of supernovae remnants as the primary and only cosmic ray accelerators. This project was supported in part by the NSF REU grant AST-1757321 and the Nantucket Maria Mitchell Association.

**Author(s):** Katie J. Chapman, Theresa Brandt

**Institution(s):** Colgate University , NASA Goddard

## **251 - Laboratory Astrophysics Posters**

### **251.01 - Relativistic Image Doubling in Astronomical Cherenkov Detectors(Robert Nemiroff)**

A novel type of apparent relativistic kinematics may soon become detectable in Earth-based astronomical Cherenkov detectors. When a charged particle moving near the speed of light in vacuum enters a dense medium such as water, it not only creates Cherenkov light, but two diverging Cherenkov-emitting "images" of the particle. The two images will suddenly appear along the path of the particle, an event usually identified with a Cherenkov Ring. One particle image will subsequently proceed along the direction of motion of the particle, while the other image will appear to move backwards along the earlier path of motion. Capturing evidence of both Cherenkov-emitting images has not yet been done, to the best of the author's knowledge, but should be possible. Perceived pair events and image-doubled trajectories carry information about the charged particle's direction and deceleration beyond that of recording the time and location of a Cherenkov ring. Astrophysics-oriented observatories that monitor tanks and basins of water for Cherenkov radiation and might be adaptable to detecting relativistic and superluminal image doubling include Auger, HAWC, Ice-Cube and Super-Kamiokande.

**Author(s):** Robert Nemiroff

**Institution(s):** Michigan Technological University

### **251.02 - The first evidence of enhanced recombination in planetary nebulae and the implications on photo-ionized plasmas(Ahmad Nemer)**

There are two main types of photoionized gaseous nebulae that exist in the universe: H II regions and Planetary Nebulae (PNe). They mark the endpoints of stellar evolution and understanding their composition will lead to a better understanding of stellar evolution processes and galactic chemical nucleosynthesis. Elemental abundances are estimated through photo-ionization codes that include all relevant atomic processes for the plasma. Robicieux et al. proposed that the mechanism of Dielectronic Recombination (DR) which typically occurs in plasma through free electrons would extend to Rydberg states transitioning to below threshold doubly excited states. If enough Rydberg states overlap with the below threshold excited states, then we expect a transition between them, very similar to DR; we call this process Rydberg Enhanced Recombination (RER) and it is currently not considered in modeling codes. Furthermore, it is challenging to prepare an experiment for testing RER in a lab. We investigate the implications of this new process, while also searching for observational evidence of the mechanism in astrophysical spectra. We have identified many ions that should experience RER in low temperature environments, however most of their strong emission lines are in the UV. In the case of CII, one of the terms affected by RER will have emission in the optical. In this work we present the first evidence of RER through observed optical spectra from seven PNe. We found that 2 specific lines for CII which could have RER contributions were consistently detected in all PNe. After rigorously confirming their identifications, we checked for other mechanisms competing with RER to populate these lines. We found that cascade transitions from above to these levels is also likely in these PNe. We then simulated some of the observed PNe using the Cloudy radiation transport code. We found that the emission lines are populated by both cascades and RER, confirming the existence of the RER mechanism such plasmas. We also use Cloudy simulations to investigate the effects of RER on charge state balance and temperature in PNe

**Author(s):** Nicholas Sterling, Stuart Loch, Jorge Rojas, Ahmad Nemer, John Raymond

**Institution(s):** Auburn University, Harvard-Smithsonian Center for Astrophysics, University of West Georgia , Instituto de Astrofísica de Canarias Contributing Team(s): Ahmad Nemer

### **251.03 - Transition Probabilities of Sc I and Sc II, and Scandium Abundances in the Sun, HD 84937, and Arcturus(James Edward Lawler)**

New emission branching fraction and transition probability measurements are reported for 258 lines of Sc I and Sc II. A total of 25 new Fourier transform spectrometer (FTS) emission

spectra on hollow cathode lamps with currents ranging from 9 mA to 500 mA are used in this work. The earlier results from Lawler & Dakin (1989) (L89) are generally confirmed within one error bar for > 200 lines. However transition probabilities in L89 for the lines of Sc II near 17000 cm<sup>-1</sup> from the y<sup>3</sup>P levels are found to be low by several error bars. These new results are based on a combination of standard lamp calibrations and Ar I and Ar II branching ratio calibrations of the spectrometer response. Redundant techniques are employed to bridge between the optical (based on a W filament lamp) calibration and the ultraviolet (based on a deuterium lamp) calibration. This bridge is critical to the lines of Sc II near 17000 cm<sup>-1</sup>. New hyperfine structure (HFS) component patterns are generated for more than 250 lines in our work. These new lab data on Sc I and Sc II are applied to re-determine the Sc abundance in the Sun, in the metal-poor star HD 84937, and in the cool giant star Arcturus. Lawler, J. E. & Dakin, J. T. 1989, JOSA B 8, 1457 This work is supported by NASA grant NNX16AE96G (JEL), NSF grant AST-1516182 (JEL), NASA grant NNX17AE08I (GN), and by NSF grant AST-1616040 (C.S.). J.J.C. acknowledges support by the NSF under Grant No. PHY-1430152 (JINA Center for the Evolution of the Elements).  
**Author(s):** John Cowan, Gillian Nave, Michael Wood, James Edward Lawler, FNU Hala, Christopher Sneden  
**Institution(s):** Univ of Wisconsin - Madison, Univ of Texas, NIST, Univ of Oklahoma, StThomas Univ

#### **251.04 - Wavelengths, Energy Levels, Hyperfine Structure and Oscillator Strength Measurement of Sc I and Sc II(Fnu Hala)**

The precise observation of Sc-Ar, Sc-Ne and Sc-Ge hollow cathode emission spectrum have been made in the region 185 - 3500 nm (54,055 cm<sup>-1</sup> - 2857 cm<sup>-1</sup>) by Fourier transform (FT) spectroscopy, and in the region 80 - 410 nm (125,000 cm<sup>-1</sup> - 24,390 cm<sup>-1</sup>) using a 10.7 m grating spectrograph at NIST. We measured more than 1600 lines in Sc I and Sc II and used them to derive optimized values for 210 energy levels. The measurements using FT spectroscopy show significant hyperfine structure patterns (HFS) for more than 300 lines. These were fitted using the computer package XGREMLIN to determine the magnetic dipole hyperfine interaction constant A for 96 levels, of which 55 have no previous HFS constants. We also determine approximate electric quadrupole HFS constant B for several levels. The same spectra were used to measure the branching fractions and transition probabilities for 258 lines in Sc I and Sc II, as described in the companion poster [1]. This work was partially supported by NASA awards NNX17AE08I (GN) and NNX16AE96G (JEL), and NSF grant AST-1516182 (JEL). [1] J. E. Lawler, G. Nave, C. Sneden, Hala, M. P. Wood, and J. J. Cowan, "TRANSITION PROBABILITIES OF Sc I and Sc II, and SCANDIUM ABUNDANCES IN THE SUN, HD 84937, AND ARCTURUS", This meeting.[2] G. Nave, U. Griesmann., J. W. Brault, M. C. Abrams M. C, Astrophysics Source Code Library, record ascl:1511.004, 2015.  
**Author(s):** Gillian Nave, James Edward Lawler, Fnu Hala

**Institution(s):** NIST, University of Wisconsin

#### **251.05 - AtomDB in 2019: New models and features for modeling X-ray emission(Adam Foster)**

The AtomDB project provides a database of atomic data and a range of plasma models to allow modeling of a variety of astrophysical phenomena, focusing on the X-ray and EUV wavelengths. With both the currently available high resolution instruments on Chandra and XMM-Newton, and the upcoming microcalorimeter instruments on XRISM and Athena, accuracy and completeness of the database and models are of ever increasing importance. In addition, tools to access and manipulate the database are essential for the data. We present here recent updates to the AtomDB project to enable this. This includes the full release of the AtomDB Charge Exchange model, version 2, based on the Kronos database. This enables rapid modeling of velocity dependent charge exchange cross sections in an X-ray emitting plasma. We also use this as an example for discussing issues raised by converting atomic data into a model which can be readily used by astronomers: sometimes complexity must be reduced to obtain tractable models: what data we can usefully preserve depends on the model. In addition, we present new access and updating tools, allowing access to and modification of the AtomDB database and the models it contains using python 3.

**Author(s):** Nancy S Brickhouse, Adam Foster, Randall Smith  
**Institution(s):** Smithsonian Astrophysical Observatory

#### **251.06 - Transition Probabilities for lines from the z4P and z4D levels of Fe II(Elizabeth Den Hartog)**

We present new branching fraction measurements for transitions connected to the z4P and z4D levels of Fe II. These branching fractions, when combined with radiative lifetimes from the literature, result in transition probabilities for ~40 lines ranging in wavelength from 225 nm to 322 nm. We compare these data to those available currently in the NIST ASD. The branching fractions in the current study are determined from a combination of spectra from the University of Wisconsin high-resolution echelle spectrograph and archived spectra from the (now decommissioned) 1-meter Fourier transform spectrometer (FTS) at Kitt Peak National Solar Observatory. The strength of the echelle spectrograph lies in that, as a dispersive instrument, it is free from the multiplex noise of an FTS and thus can yield high signal-to-noise spectra at much lower source currents than an FTS. This means that the strong branches remain optically thin while still obtaining good signal-to-noise on much weaker branches. The current study of strong UV lines is preliminary to work on the weak optical lines from these upper levels. Weak optical lines of Fe-group species are desirable for stellar abundance determinations because, unlike the main branches in the UV, they will be optically thin even in metal-rich stellar photospheres. They also lie in a less congested part of the stellar spectrum, making blending and

continuum placement less problematic. We apply these new Fe II transition probabilities to the spectra of very metal-poor turnoff stars HD 84937 and BD+03 740. This work has been supported by NSF grant AST-1516182 to JEL and EDH and AST-1616040 to CS; and NASA grant NNX16AE96G to JEL.

**Author(s):** Christopher Sneden, James Edward Lawler, Elizabeth Den Hartog, John Cowan

**Institution(s):** University of Wisconsin - Madison, University of Oklahoma, University of Texas - Austin

#### **251.07 - Investigation of ThO Contamination in Th-Ar Hollow Cathode Lamps(Alexis Arsenault)**

Thorium Argon (Th-Ar) hollow cathode lamps (HCLs) provide optical wavelength calibration for high-resolution astronomical spectrographs on large ground-based telescopes. Thorium is an ideal element for the high-precision spectrometers used in exoplanet detection such as ESO's HARPS (R~100,000) and ESPRESSO (R~100,000 and 200,000) instruments because of its high atomic weight, and large density of lines in the visible wavelength range. In recent years regulations of the handling of radioactive material have been tightened, leading manufacturers to no longer use metallic Th in their HCLs and substitute Thorium Oxide (ThO) as the cathode material in Th-Ar calibration lamps. Molecular bands caused by this ThO substitution are present throughout the visible wavelength range. The molecular bands cause nearby atomic lines to be blended, and less intense atomic lines to be obscured completely. This contamination renders current standard Th-Ar HCLs inadequate for high precision calibration. However, if the wavelengths of the ThO features can be measured accurately, it will be possible to use them in addition to the atomic thorium lines for wavelength calibration. Previous laboratory measurements of the Th-Ar HCLs have been made with a Fourier Transform (FT) spectrograph. While this technique has set the standard for accurate wavelength measurements it suffers from multiplex noise, making it unsuitable for characterizing weak molecular features. Using the high-resolution Echelle spectrograph (R~250,000) at the University of Wisconsin-Madison these features have been characterized. The Echelle spectrograph is a dispersive instrument, and thus does not have the noise constraints of the FT spectrograph. This data will be added to the NIST Th-Ar atlas (<https://physics.nist.gov/cgi-bin/TH/site.cgi>) where it will provide an important resource for the wavelength calibration of high-resolution spectrographs at ESO and other observatories. This work has been supported by NSF REU grant AST-1560016 (AA) and NSF grant AST-1516182 (EDH).

**Author(s):** Gillian Nave, Alexis Arsenault, Florian Kerber, Elizabeth Den Hartog

**Institution(s):** Minnesota State University, National Institute of Standards and Technology, University of Wisconsin, European Southern Observatory

## **252 - Molecular Clouds, HII Regions and the ISM I -- Posters**

### **252.01 - High-Resolution Mid-Infrared Molecular Line Survey of the Orion Hot Core(Naseem Rangwala)**

Molecular line surveys provide a chemical inventory for star forming regions and are essential for studying their chemistry, kinematics and physical conditions. Previous high spectral resolution surveys have been limited to radio, sub-mm and FIR wavelengths. Mid-infrared missions such as ISO and Spitzer had low to moderate resolving power that were only able to link broad features with particular molecular bands and could not resolve the individual rovibrational transitions needed to identify specific molecules with certainty. Mid-infrared observations are the only way to study symmetric molecules that have no dipole moment and thus cannot be detected in the submillimeter line surveys from ALMA. We present results from an on-going high resolution (R ~ 60,000) line survey of the Orion hot core between 12.5 - 28.3 microns, using the EXES instrument on the SOFIA airborne observatory. SOFIA's higher-resolution and smaller beam compared to ISO allows us to spatially and spectrally isolate the emission towards the hot core. This survey will provide the best infrared measurements (to date) of molecular column densities and physical conditions - providing strong constraints on the current chemical network models for star forming regions. Specifically, we will present: (a) resolved rovibrational transitions of C<sub>2</sub>H<sub>2</sub>, detected in both the Ortho and Para states, transitions from its 13CCH<sub>2</sub> isotopologue and HCN. We find that the Ortho and Para C<sub>2</sub>H<sub>2</sub> clearly trace different temperatures with the C<sub>2</sub>H<sub>2</sub> Ortho to Para ratio (OPR) of  $1.7 \pm 0.1$ , which is far from its equilibrium value of 3. Additionally, the ortho and para VLSR values differ by about  $1.8 \pm 0.2$  km/s, while, the mean line widths differ by  $0.7 \pm 0.2$  km/s, suggesting that these species are not uniformly mixed along the line of sight to IRC2. These results could not be measured from previous, more limited observations of C<sub>2</sub>H<sub>2</sub>. (b) resolved line profiles for some of the atomic species that provide new information and constraints on the physical and chemical process associated with the hot core. (c) predictions for detecting new gas phase molecules with this survey.

**Author(s):** Eric Herbst, Kinsuk Acharyya, Xinchuan Huang, Timothy Lee, Curtis DeWitt, Sean Colgan, Naseem Rangwala

**Institution(s):** NASA Ames Research Center, Physical Research Laboratory, Universities Space Research Association, SETI, University of Virginia

### **252.02 - Improving [CII] as an SFR Indicator by Disentangling the Ionized AND Neutral Components of [CII] 158 $\mu$ m Emission(Jessica Sutter)**

The brightest observed emission line from most normal star-forming galaxies is the [CII] 158  $\mu$ m line, making it detectable in even z~6 galaxies. It is thus imperative that we have the tools to fully understand how this emission line could be utilized as an indicator of star formation rate. There are two main challenges to utilizing the [CII] 158  $\mu$ m line as a star



formation rate indicator: its multiphase origins and the so-called “[CII] deficit’. In order to better understand and quantify the [CII] emission as an indicator of star-formation rate, the relationship between the [NII] 205  $\hat{1}/4$ m emission and the [CII] 158  $\hat{1}/4$ m emission has been employed to determine the fraction of [CII] emission that originates from the ionized and neutral phases of the ISM. Sub-kiloparsec measurements of the [NII] 205  $\hat{1}/4$ m line in nearby galaxies have recently become available as part of the KINGFISH program. By using these two far-infrared lines along with the suite of KINGFISH data, an improved calibration of the [CII] emission line as a star formation rate indicator and a better understanding of the cause of the [CII] deficit have been determined. We find that the [CII] emission originating in the neutral phase of the ISM does not exhibit a [CII] deficit and is therefore preferred over the total [CII] as a star formation rate indicator for the galaxies included in this sample.

**Author(s):** Daniel Dale, Jessica Sutter

**Institution(s):** University of Wyoming Contributing Team(s): KINGFISH Team

### **252.03 - Isolated Molecular Clumps at the CO-boundary of a Diffuse Molecular Cloud(Amanda Stricklan)**

Defining the boundary of a molecular cloud is difficult given that different tracers of H<sub>2</sub> indicate different cloud borders or extent. Traditionally, the “edge” of a molecular cloud has been defined by the lowest CO(1-0) contour in maps with typical rms values of 0.1 K in antenna temperature. However, molecular gas extends beyond that boundary and may be traced by other means (dust, perhaps OH, the [CII] line, etc.). Recent work on dark molecular gas traces this CO-dark gas by using gamma-rays and infrared and submillimeter dust continuum emission. However, very sensitive CO(1-0) observations by Donate and Magnani (rms ~ 20 mK) reveal a larger CO extent for the diffuse molecular cloud, MBM 53. The deep CO survey consisted of averaging 13 one-arcminute beams to simulate a larger beam. By analyzing each CO(1-0) spectrum individually we can examine the structure of the emission on scales of 0.08 pc. We have identified four lines of sight in this data set where isolated CO clumps may be found. This molecular debris at the edges of a cloud may provide a way to study the structuring processes at the boundaries of these objects.

**Author(s):** Loris Magnani, Matthew Hummel, Amanda Stricklan

**Institution(s):** University of Georgia

### **252.04 - Sensitive OH 18 cm Observations at Boundary of MBM 03(Alejandro Garcia)**

We used low-rms OH observations at 18 cm of two strips in MBM 03 traversing from the center to the boundary of the cloud in two directions. The OH data were taken using the 305-m Arecibo radiotelescope with a resolution of ~3.3' equivalent

to 0.27 pc at the cloud distance. The aim of our observations was to see how the molecular edge of the cloud compared to the CO and dust boundaries. We find possible OH emission beyond the CO edge of the cloud and, possibly, the dust edge. The OH and previous CO data show two or three distinct velocity components. By examining the width of each component across the cloud edge we can diagnose the turbulence at the atomic-molecular interface. The observations also show that for typical CO maps (i.e., with rms ~0.1 K), OH observations of the main line at 1667 MHz can reveal the presence of molecular gas not traced by the CO(1-0) line.

**Author(s):** Elizabeth Wennerstrom, Loris Magnani, Raymond Chastain, Alejandro Garcia

**Institution(s):** University of Georgia, Louisville University

### **252.05 - The Excitation Temperature of the CH 3335 MHz Line(Jayne Dailey)**

We observed CH at 3.3 GHz with the Arecibo 305-m radio telescope along 3 lines of sight towards stars behind molecular clouds in an effort to determine the CH excitation temperature of the 3335 MHz line. By comparing the CH column density obtained from optical observations of the 4300 angstrom line in absorption to the velocity integrated antenna temperature of the CH 3335 MHz emission line we can solve for the excitation temperature of the  $\pi_{1/2} J=1/2, F=1-1$  transition. This is an important determination because radio studies of the 3335 MHz line assume  $|T_{ex}| \gg T_{bg}$ , permitting determination of the CH column density. We present preliminary results based on three lines of sight (HD21483, HD23180, HD26571) which produce excitation temperatures ranging from -1.5 K to 10 K. Thus, the common assumption that  $T_{ex}$  is a lot bigger than  $T_{bg}$  is not always warranted. In the absence of this assumption, the derived column density can differ by up to a factor of 4.

**Author(s):** Jayne Dailey, William Reach, B-G Andersson, Loris Magnani

**Institution(s):** University of Georgia, USRA

### **252.06 - Sensitive CO and OH observations of MBM 53(Emmanuel Donate)**

We observed a small region in the diffuse, high-latitude molecular cloud MBM 53 in the CO(1-0) transition at 115 GHz and the 1667 and 1665 OH main lines. Our goal was to determine which of the two tracers was more effective in detecting some portion of the so-called dark molecular gas. Both sets of observations detect more molecular mass than is revealed by conventional CO mapping (i.e., rms 0.1-0.5 K in main-beam antenna temperature). The sensitive CO observations in our study (rms 20-40 mK; 20 detections in 88 lines of sight) show approximately twice the molecular mass than is detected by previous, lower sensitivity CO observations (5 detections in 88 lines of sight). The OH observations reveal emission from 11 positions out of 50 lines of sight from the CO

sample. The rms noise level of the OH observations was in the 7-10 mK range in brightness temperature for integration times of 20-30 minutes. The CO observations we are presenting were of similar duration and indicate that, for similar on-source integration times, sensitive CO(1-0) observations trace more molecular gas than the OH main lines.

**Author(s):** Josh White, Emmanuel Donate, Loris Magnani

**Institution(s):** University of Georgia

### **252.07 - ALMA Observations of Nitrile Chemistry in the Massive Star-forming Region G10.6-0.4(Charles John Law)**

While massive star-forming regions are known to exhibit an extremely rich and diverse chemistry, few such sources have been mapped at high spatial resolution. Since the chemical structure of these sources displays substantial spatial variation among species on small scales (~104 AU), high spatial resolution observations are needed to test chemical evolution models of massive star formation. To remedy this, we present ALMA Band 6 observations toward the high-mass star-forming region G10.6-0.4 at a resolution of 0.14" (700 AU). In order to constrain the temperature distribution of the gas in the ultra-compact H II (UCHII) region around G10.6, we map the emission of methyl cyanide (CH<sub>3</sub>CN), a well-known thermometer in warm and dense regions of star formation. We fit the J=12-11, K-ladder transitions for each pixel in our image and derive rotational temperature and column density maps over a ~5" by 5" region around the UCHII region. Both temperature and column density span 2-3 orders of magnitude, allowing us to probe a wide range of physical and chemical conditions. We also analyze the spatial distributions of other prominent nitrogen-bearing molecules including HC<sub>3</sub>N and HNCO, which provide important constraints on chemical models of the hot regions around massive protostars.

**Author(s):** Roberto Galván-Madrid, Paul T P Ho, Eric Keto, Haoyu Baobab Liu, Ryan A Loomis, Qizhou Zhang, Karin I Åberg, Charles John Law

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Instituto de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México, National Radio Astronomy Observatory, Academia Sinica Institute of Astronomy and Astrophysics, East Asian Observatory

### **252.08 - Interstellar Glycolaldehyde, Methyl Formate, and Acetic Acid: Remarkably Bi-modal, Log-Linear Abundance Patterns in Star Forming Regions(Samer El-Abd)**

The relative abundances of the structural isomers methyl formate, glycolaldehyde, and acetic acid are derived for the MM1 and MM2 massive star-forming regions in the NGC 6334 I complex which are separated by ~4000 AU. When compared with the relative abundances of these molecules in 13 other sources, a clear bi-modal linear distribution is exhibited in the

glycolaldehyde abundance when plotted as a function of methyl formate. No such distribution is evident with acetic acid. The two linear trends in glycolaldehyde are comprised of star-forming regions with a variety of masses, suggesting that there must be some other common parameter that is heavily impacting the formation of the aforementioned isomers. The linear trends are indicative of some demonstrable differentiation in these cores; studying the abundances of these isomers may give a clue as to the integral chemical processes ongoing in a variety of protostellar environments.

**Author(s):** Eric Willis, Robin Garrod, Brett McGuire, Todd Russell Hunter, Samer El-Abd, Crystal Brogan

**Institution(s):** University of Virginia, NRAO

### **252.09 - Characterizing the cold, optically-thick ISM with convolutional neural networks(Claire Murray)**

A precise observational accounting of multiphase gas and dust in the Galactic interstellar medium (ISM) is vital both for correcting observations of extragalactic light and for resolving the bottleneck between mass reservoirs and star formation in galaxies. To differentiate between distinct thermal phases of neutral hydrogen (HI), we train a convolutional neural network using synthetic spectra from numerical simulations to predict the true HI column density and the fraction of cold, optically thick HI along the line of sight from 21cm brightness temperature spectra. We validate the model using 100s of HI absorption observations from the literature, finding excellent accuracy. With this model, we construct the highest-resolution all-sky map of optically thick HI in the local ISM using large-area 21cm emission data from the GALFA-HI and the HI4Pi surveys. This map will characterize the structure of neutral gas envelopes to molecular clouds, and to improve dusty Galactic foreground estimation for extragalactic surveys. Via comparison with tracers of dust reddening (E(B-V)), we demonstrate that E(B-V)/N(HI) increases with increasing cold gas fraction, which will be leveraged to produce the the highest-resolution, highest-fidelity E(B-V) map at high latitudes to date.

**Author(s):** Claire Murray, Joshua E. G. Peek,

**Institution(s):** Space Telescope Science Institute, Johns Hopkins University

### **252.10 - Analysis of Filamentary Molecular Cloud Candidates in the Southern Milky Way(Nathan Derenne)**

We aim to understand the formation of proto-stellar cores in filamentary, galactic molecular clouds. We will be using a catalog created by Hernandez et al., this is a complete cloud catalog and has both filamentary molecular cloud candidates as well as molecular clouds found in the Three-mm Ultimate Mopra Milky Way Survey (ThUMMS). Utilizing this catalog we will use a program called Network X, which is a data structure analysis algorithm, to estimate the medial axes (rachis), for the cataloged clouds in order to create a sub-

catalog of filamentary cloud candidates. The ThrUMMS radio survey of  $^{13}\text{CO}$  ( $1\hat{+}'\text{O}$ ) is in of the southern galactic plane and the range is:  $l = 300\hat{\text{A}}^\circ - 360\hat{\text{A}}^\circ$  and  $b = \hat{\text{A}}^\circ \pm 1\hat{\text{A}}^\circ$ . With the rachis of the sub-cataloged clouds located we will create a program that will analyze the aspect ratio of each cloud. The minimum aspect ratio needed for filament membership is 5. Any cloud that does not meet that requirement will be discarded from the sub-catalog. We will probe the velocity dispersion of each filament sub-candidate to determine if the molecular cloud has a cohesive velocity structure. Filament membership consists of having a cohesive velocity structure and meeting the minimum length to width ratio. If the cloud is found to have a cohesive velocity structure and meet the requirements of the ratio of length and width we will create a sub-catalog of these filamentary molecular clouds. We will present the filament sub-catalog, characteristics of the clouds such as location, orientation, and physical parameters. The physical parameters we will be assessing will be mass, size, distance, and velocity cohesiveness.

**Author(s):** Audra Hernandez, Nathan Derenne

**Institution(s):** University of Wisconsin Madison

#### **252.11 - Mapping Disk Thickness of Neutral Hydrogen in the Magellanic Clouds(Samuel Szotkowski)**

The spatial power spectrum (SPS) of the entire H I column density distribution of the Large Magellanic Cloud (LMC) can be fitted with two power-law functions, as shown in previous studies. We have applied the SPS analysis on sub-regions across the LMC and mapped the power-law slopes across this galaxy. In addition, we have mapped the physical scale of the break in the power spectrum, which corresponds to the thickness of the gas layer. We find significant spatial variation of the SPS slopes across the LMC, with significant steepening on large spatial scales in the outskirts of the galaxy. The H I disk is estimated to have a thickness of 200~300 pc in central regions and 100~200 pc along the outer edges. Similar analyses were performed on the Small Magellanic Cloud, showing more uniform turbulent properties across the galaxy. Understanding spatial variations of the disk thickness could illuminate turbulence driving processes such as gravitational collapse and star formation, while studying the turbulent properties in the outskirts of galaxies could also provide valuable insight into the surrounding circumgalactic medium.

**Author(s):** Lister Staveley-Smith, Katherine Jameson, Samuel Szotkowski, Delano Yoder, Snezana Stanimirovic, Naomi McClure-Griffiths, Alberto Bolatto, Brian Babler, Helga Denes

**Institution(s):** Astronomy Department, University of Wisconsin - Madison, Department of Astronomy, University of Maryland, Research School of Astronomy & Astrophysics, Australian National University, Mount Stromlo Observatory, ICRAR, University of Western Australia, C

#### **252.12 - Is The Milky Way A Grand Design Spiral?(Maryam Hami)**

It is difficult to decipher the structure of the Milky Way Galaxy since we reside within the Galactic disk. There is observational evidence that the Milky Way is a Grand Design, barred spiral galaxy with two symmetric spiral arms that are connected to the end of the bar. This is important since bars and spiral arms influence Galactic dynamics and star formation. If the Milky Way is a Grand Design spiral, we should expect to find an equal number and distribution of HII regions at both ends of the bar. We have produced a catalog of "all" Galactic HII regions in the Galaxy using the Wide Infrared Survey Explorer (WISE) and see a significant deficit in the number of HII regions at the end of the Southern bar (20) compared with the Northern bar (132). This is inconsistent with a Grand Design. The line-of-sight to the Southern bar is closer to the Galactic Center than the Northern bar and is more distant. Could opacity be an issue? Are the radio quiet WISE sources really HII regions? We use the Jansky Very Large Array (JVLA) to create a square degree mosaic of the thermal (free-free) emission at 8-10 GHz toward both ends of the bar to confirm this asymmetry and test the completeness of the WISE catalog.

**Author(s):** Thomas Bania, Loren Anderson, Dana Balser, Maryam Hami, Trey V Wenger

**Institution(s):** University of Rome Tor Vergata, Boston University, National Radio Astronomy Observatory

#### **252.13 - Search for Variability and Proper Motion of the OH (1720 MHz) Masers in Supernova Remnant IC443: VLBA, WSRT, and LWA Observations(Ian Hoffman)**

Hydroxyl (OH 1720 MHz) masers in supernova remnants are understood to arise in the interaction between a compression-type supernova shock and a molecular cloud. These masers may offer constraints on problems as wide-ranging as star formation and cosmic-ray acceleration. The masers in IC443 are unique among this class of maser in that they do not exhibit a Zeeman circular-polarization profile; rather, a single handedness at the level of approximately 10 percent was observed 1994--2001 using different instruments with interferometric baselines ranging in length from 4 km to 4000 km. One possible explanation for the atypical polarization signal is a line-of-sight confusion of numerous masers. The shock front with which the masers are suggested to be associated is moving transversely across the sky with a speed through the source of approximately 30 km/s. Since the masering volumes were measured in 2001 to have a transverse width of approximately 75 AU, by 2015 the shock is expected to have either (1) completely crossed into a new volume of gas or (2) swept the clump of masering gas transversely across the sky. Presumably, any line-of-sight coincidences that contributed to the atypical polarization signal observed in 2001 will have changed. However, we present WSRT observations from 2014 that are consistent with all previous observations in terms of flux density and polarization fraction---no variability is detected. In a search for proper

motion of the masers, we also present a 2015 VLBA observation that uses the same phase-reference source as was used in comparable 2001 observations. Another possible explanation of the atypical polarization signal is that the pumping of the masers is selective of magnetic sub-levels. In a search for additional constraints on the pumping mechanism and on the general environment, we present 2018 LWA observations at 54 MHz of the magnetic-dipole transitions that are associated with the 1720-MHz levels. Pumping models consistent with all three new observations are discussed.

**Author(s):** Ian Hoffman

**Institution(s):** Quest University Canada

#### **252.14 - Characterizing the Magnetic Field Properties of Nearby Molecular Clouds (Colin Sullivan)**

Researcher: Colin Sullivan Title: Characterizing the Magnetic Field Properties of Nearby Molecular Clouds Research Focus: Molecular Clouds Organization: National Radio Astronomy Observatory (NRAO) School: University of Virginia Presentation Type: Poster Presentation Abstract: Characterizing the Magnetic Field Properties of Nearby Molecular Clouds Laura Fissel, PhD, Patrick King, PhD, Juan Soler Diego, PhD, Zhi-Yun Li, PhD, Che-Yu Chen, PhD Of all the factors that influence star formation, magnetic fields are perhaps the least understood. This leaves a crucial gap in our ability to determine how, when, and how often stars will form. In this poster, we examine the magnetic field properties of nearby molecular clouds. We find evidence to support previous claims that the Giant Molecular Cloud, Vela C is highly inclined with respect to the plane of the sky. While investigating the relations between our clouds' magnetic field properties (Column Density (N), Polarization Fraction (p), Dispersion in Polarization Angles (S)) and previous studies of the change in relative orientation of cloud structure from parallel to perpendicular to the magnetic field, a distinctly positive correlation was discovered between the median S values and the slopes of the change in the relative orientation parameter. This result was unexpected, but can be explained by our understanding of magnetic field behavior and its effects on the observed dispersion. By investigating these relationships, we were able to lay the informational groundwork to estimate the magnetic field strength and orientation for each of the ten clouds. This in turn will be the instrumental in future studies as they further our understanding of the role magnetic fields play in the formation of stars.

**Author(s):** Che-Yu Chen, Laura Fissel, Colin Sullivan, Patrick King, Juan Soler, Zhi-Yun Li

**Institution(s):** University of Virginia, Max Planck Institute for Astronomy, National Radio Astronomy Observatory

## **253 - Molecular Clouds, HII Regions and the ISM II -- Posters**

### **253.01 - Mapping Water Ice and Silicates using Broadband Photometry of Background Stars (Melanie Jyll Rowland)**

The variation of extinction with wavelength is one of the best tracers of the nature and composition of dust grains. Particularly important is the nature of grains in dense molecular clouds since these environments are sites of star formation. The composition of these grains may be inferred from infrared spectra, but undertaking a spectroscopic survey is time intensive, and relevant space-based facilities are no longer operational. We have developed and calibrated a broadband photometric technique to estimate 3.0- $\frac{1}{4}$   $\mu$ m water ice and 9.7- $\frac{1}{4}$   $\mu$ m silicate optical depths utilizing archived imaging observations from the Wide-field Infrared Survey Explorer (WISE), Spitzer Space Telescope, and Two Micron All-Sky Survey (2MASS). The technique has the advantage of capitalizing on data already on-hand for thousands of stars behind more than a dozen nearby quiescent and star-forming molecular clouds. We will present this technique, discuss its benefits and limitations, characterize correlations of these optical depths with extinction, and investigate whether these correlations depend on cloud environment.

**Author(s):** Jeffrey S Bary, Tracy L. Huard, Melanie Jyll Rowland, Benjamin Scott Flaggs, A. C. A. Boogert, Lee Mundy

**Institution(s):** University of Maryland, University Hawaii, Colgate University

### **253.02 - Molecular Cloud Dust: Infrared Spectroscopic Study of a Large Sample of Background Stars (Benjamin Scott Flaggs)**

Archived mid-infrared spectra, obtained from the Spitzer InfraRed Spectrograph (IRS), of more than 100 stars behind molecular clouds were analyzed to constrain their spectral types as well as the extinctions and abundances of ices and silicates along the lines of sight. To help this analysis, ground-based infrared spectra for many of these background stars were also obtained. With this large sample, we characterize relationships between dust abundances and extinctions for all clouds as a group and investigate whether different cloud environments exhibit different relationships. We will present the spectra and abundance relationships, and discuss the implications of our findings.

**Author(s):** Jeffrey S Bary, Tracy L. Huard, Melanie Jyll Rowland, Benjamin Scott Flaggs, A. C. A. Boogert, Lee Mundy

**Institution(s):** University of Maryland, Colgate University, University of Hawaii

### **253.03 - Heat Conduction Versus Thermal Radiation of Halo Gas(Jerry Ortiz)**

For a warm gas cloud within hot halo gas, the internal energy of the warm gas cloud will be regulated by two primary processes: energy gained through thermal conduction with the surrounding gas, and energy lost due to thermal radiation; conduction between a cloud and the surrounding medium is not modeled in simulations, so the goal of this project is to determine the importance of conduction in regulating the cloud's structure. The warm cloud is assumed to have a temperature of  $1.5 \times 10^4$  K at its center. We tested a model with a spherical cloud, and a temperature of  $10^6$  K at the edge of the medium. For this scenario, the temperature, thermal conductivity, heat conduction, and thermal radiation will be calculated. Comparing the heat conduction with the thermal radiation will indicate which conditions are required for the warm gas cloud to heat up and eventually dissolve.

Understanding this interaction will inform observations of distant galaxies, as well as details about the interaction between warm gas and the surrounding hot gas.

**Author(s):** Ariyeh Maller, Jerry Ortiz,

**Institution(s):** CUNY College of Staten Island, CUNY City Tech, American Museum of Natural History

### **253.04 - The Perseus Illusion and Burton's Curse(Joshua E. G. Peek)**

The Milky Way provides our best view of star formation and its effects on the interstellar medium, but nearby and distant Galactic features are maddeningly difficult to disentangle. Historically, we have leveraged the fact that the Milky Way is a differentially rotating disk to relate radial velocities to distances, and thus find large scale structures in the interstellar medium, including a number of spiral arms and spurs. New precision observations, including maser parallaxes, Gaia parallaxes, and dust-tracing stellar photometry are allowing us to reconstruct the ISM with true distance information in the solar vicinity. These true distance measurements of the ISM are starting to show that some features may not be as real as previously thought; in particular, the low density component of the Perseus is largely an illusion. We show here how this illusion is generated by large-scale flows in the Milky Way disk and how it casts doubt on many distant spiral structures seen in Galactic longitude-velocity diagrams. We refer to this effect as "Burton's Curse" as it was predicted nearly 50 years ago by Butler Burton.

**Author(s):** Joshua E. G. Peek, Kirill Tchernyshyov

**Institution(s):** Space Telescope Science Institute, Johns Hopkins University

### **253.05 - Visualizing HII Regions in FIRE Galaxy Simulations(Mahlet Shiferaw)**

In this project, we analyze the spatial structure of HII regions in the interstellar medium of galaxy formation simulations from

the FIRE (Feedback in Realistic Environments) project. We focus on a simulation of a Milky Way-like galaxy at high resolution evolved with the time-dependent chemistry solver CHIMES. We compare the properties of HII regions around young, luminous stars to the spherical HII regions predicted by the Strömberg model. To do this, we used Firefly, an interactive web-based visualization application we developed for exploring particle-based data. In addition to zooming in, rotating around, and visually manipulating the particles, we have also implemented in Firefly the ability to apply a unique colormap to each particle type based on a certain attribute. Using this new feature reveals sharp boundaries between ionized and neutral hydrogen regions, similar to what is predicted by the Strömberg approximation. A more quantitative analysis, however, reveals that the Strömberg radius is systematically smaller than the true "ionized radius" measured from the simulation data. We find that this is because the Strömberg model assumes isolated stars, while in the more realistic simulations, young stars are clustered. The assumption of isolated stars underestimates the true ionizing luminosity of an HII region, causing the Strömberg radius to be generally smaller than the true ionized radius. In the future, we plan to use Firefly to further analyze how molecular clouds (traced by H<sub>2</sub>, CO, etc.) relate to HII regions in the simulations.

**Author(s):** Aaron Geller, Mahlet Shiferaw, Alexander

Richings, Claude-André Faucher-Giguère, Alexander Gurvich

**Institution(s):** Harvard College, Adler Planetarium, Northwestern University, Durham University Contributing Team(s): Mahlet Shiferaw

### **253.06 - Structure Function Analysis of Turbulent Properties in the Small and Large Magellanic Clouds(Delano Yoder)**

Turbulence plays a key role in the evolution of galaxies, but it is still uncertain which interstellar processes drive turbulence, and at what scales they dominate. Numerical simulations (e.g. Grisdale et al. 2017) show that star formation feedback can drive turbulence on small scales, while Krumholz & Burkhardt (2016) argue that large scale turbulence is mostly dominated by gravitational instabilities. We use the structure function analysis to search for turbulent drivers in neutral hydrogen (HI) observations of the Small and Large Magellanic Clouds (SMC and LMC). For the SMC we use new HI observations obtained recently with 16 ASKAP antennas, while for the LMC we use HI observations from a combination of the Parkes single dish telescope and ATCA. By incorporating a rolling kernel we have created a new structure function tool that applies a regional analysis to produce an image of the structure function slopes. We find uniform turbulent properties across the SMC, in agreement with previous studies. The structure function slope varies significantly across the LMC suggesting local stellar feedback enhancements, as well as large-scale effects caused by the geometry of the LMC disk. We compare the structure function slope image with the star-formation surface and stellar density distributions to search for turbulent drivers. The same method is applied on individual velocity channels and the

integrated intensity image to separately investigate turbulent fluctuations caused by either velocity or density fields.

**Author(s):** Lister Staveley-Smith, Katherine Jameson, Samuel Szotkowski, Delano Yoder, Snezana Stanimirovic, Naomi McClure-Griffiths, Alberto Bolatto, Brian Babler, Helga Denes

**Institution(s):** University of Wisconsin Madison, Research School of Astronomy & Astrophysics, Australian National University, Mount Stromlo Observatory, University of Maryland, CSIRO Astronomy & Space Science, ICRAR, University of Western Australia

### **253.07 - Flux Density Variations and Radio Recombination Line Emission at 7 mm and 3.6 cm in W49A(Christopher G De Pree)**

Numerical models first showed that detectable flux density variations in ultracompact (UC) HII regions could occur when accretion flows around young massive stars became unstable and clumpy. Observations show that some Galactic UC HII regions do indeed vary in radio flux density on timescales of 10-20 years, consistent with the predictions of these models. We have detected such variations in the Sgr B2 and W49A regions, most recently in W49A at 3.6 cm with the B-configuration at  $\sim 0.8''$  resolution. In these observations, taken between 1994 and 2015, W49A/G2 decreased by 20% in peak intensity (from  $71 \pm 4$  mJy/beam to  $57 \pm 3$  mJy/beam), and 40% in integrated flux (from  $0.109 \pm 0.011$  Jy to  $0.067 \pm 0.007$  Jy). We present new full-synthesis radio continuum radio images of the W49A region. In addition, we discuss explanations for the flux density decrease near the position of W49A/G2, and present new high-resolution radio recombination line (RRL) data at 7 mm and 3.6 cm associated with W49A/G2 and other sources in the region.

**Author(s):** Ralf Klessen, Roberto Galvan-Madrid, Christopher G De Pree, Theresa Melo, Mordecai-Mark Mac Low, Miller Goss, David Wilner, Thomas Peters, Sara Sloman, Rowen Webb-Forgus

**Institution(s):** Agnes Scott College, NRAO, Instituto de Radioastronomía y Astrofísica (IRyA), UNAM, Heidelberg University, Interdisciplinary Center for Scientific Computing, Heidelberg University, Center for Astronomy, Institute for Theoretical Astrophysics, Ameri

### **253.08 - A Catalog of Clouds in the Galactic Center with High Velocity Extent(Harrison Hall)**

Surveys of gas in our Galaxy's Central Molecular Zone have found structures with extreme velocity extent and low spatial extent. These structures are a point of theoretical interest in the kinematics of the central Milky Way. Called "vertical features," these structures are believed to represent gas flowing towards the center of the Galaxy colliding with slower moving gas. The astro dendro Python package was used to find these structures in CO data from the CfA 1.2 m telescope and the APEX telescope. A catalog of these structures was created,

documenting their distribution and properties, also using the astro dendro package.

**Author(s):** Harrison Hall, Cara Battersby

**Institution(s):** University of Connecticut

### **253.09 - Gas temperatures in the illuminated and shaded regions of IC63 using H<sub>2</sub> pure rotational line observations(B-G Andersson)**

The gas temperature in photodissociation regions (PDR) affect not only the chemistry and excitation of the gas, but also the interaction of the gas and dust. The rate and energy of gas-grain collisions affects many dust characteristics including the disalignment of the grains with respect to the magnetic field. In highly inhomogeneous PDRs the relative location of the gas, surrounding dense clumps, and the illumination source can cause the gas temperature to vary significantly on small scales. Indirect evidence for such small-scale variations in the reflection nebula/PDR IC 63 is provided by the observations of Thi et al. (2009) who used low spatial resolution ISO/SWS observations to show a two-temperature gas distribution in the region. Based on high resolution (CARMA and PdB) observations of HCO<sup>+</sup> we have hypothesized that this two-temperature structure arises from variable shadowing of the light from gamma Cas within the nebula. Because the large area of the Thi et al. aperture, the spatial dependence of the temperature structure is, however, not clear. We are pursuing high spatial resolution observations of the nebula using SOFIA/EXES and IRTF/TEXES, to resolve this issue and better understand the importance of internal structure on the physics of PDRs. Here we present SOFIA/EXES H<sub>2</sub> v=0 S(1) and S(5) measurements across the most intense H<sub>2</sub> emission ridge in the nebula to resolve the spatial structure. Combining these data with existing high-resolution HCO<sup>+</sup>, CO, [C II] and H I observations will allow us to analyze the PDR physics in detail.

**Author(s):** Thiem Hoang, Archana Soam, B-G Andersson, Matthew Richter, Curtis N DeWitt

**Institution(s):** SOFIA Science Center/USRA, Korea Astronomy and Space Science Institute, University of California, Davis

### **253.10 - ALMA CO absorption study - smallest structures in GMCs in the Milky Way(Jin Koda)**

We present an absorption study of the molecular ISM in the MW from ALMA. Two QSOs directly behind the MW mid-plane are observed at the rest frequencies of CO, <sup>13</sup>CO, and C<sup>18</sup>O J=1-0 & 2-1. Their lines-of-sight run through and sample several GMCs in the MW disk. This absorption study shows the smallest spatial and velocity structures within the typical GMCs: the spatial scales that this observations trace are determined by the apparent size of the QSOs (< 10 milliarcsec; or 10-100AU at 1-10 kpc) and ALMA permits significant detections at a high velocity resolution (below the sound speed of the cold ISM  $\sim 0.2$  km/s). We show the presence of

(roughly) thermally bound small molecular droplets within GMCs. Their temperatures, from the line ratios, are typically much lower than the often-adopted temperature of GMCs. The smallest structures in GMCs are important for understanding the dissipation scale of turbulent energy cascade and the trigger of star formation. We present a generalized picture of GMCs' internal structures from a synthesis of absorption features detected in this study.

**Author(s):** Seichi Sakamoto, Jin Koda, Nick Scoville, Tetsuo Hasegawa, Sachiko Onodera, Tsuyoshi Sawada

**Institution(s):** Stony Brook University, NAO Japan, Caltech, Meisei University

### **253.11 - A Catalog of the Southern Molecular Cloud Physical Properties from the ThrUMMS Survey.(Audra Hernandez)**

The Three-mm Ultimate Mopra Milky Way Survey (ThrUMMS) provides a uniform and unbiased mapping of a 60deg X 2deg region of our Galaxy's southern plane in three CO-isotopologues and CN. We present a new catalog of southern molecular clouds identified from the  $^{13}\text{CO}$  (1-0) data. We applied the dendrogram based algorithm SCIMES (Spectral Clustering for Interstellar Molecular Emission Segmentation; Colombo et al. 2015) on the data cubes using two different cloud extraction methods: A traditional intensity based cloud extraction (Iex) and a column density based extraction (Nex), inspired by current galactic disk and molecular cloud models that define cloud structures based on simulated mass or mass density data cubes. For the Iex extraction method we find a total of 1,296 molecular clouds, of which 407 are clusters (i.e., comprised of at least 2 dendrogram leaves). For the Nex extraction, we find a total of 4,532 molecular clouds, of which 2,397 are clusters. We present our initial estimates of the cloud physical properties, including their temperatures, column densities, velocity dispersion, elongation, and mass surface densities, as well as their distribution thought the Galactic plane. Since ThrUMMS provides simultaneous mapping for all three CO-isotopologues, excitation temperatures on the (l,b,v) pixel scale are measured directly from the  $^{12}\text{CO}$  for the  $^{13}\text{CO}$  based column density measurements. We derive the kinematic distances for all molecular structures using the Galactic rotation model of Reid et al. (2014). Additionally, we will present our analyses on the dynamical state of the clusters.

**Author(s):** Peter J. Barnes, Audra Hernandez

**Institution(s):** University of Wisconsin, University of Florida

### **254 - Progressing: Mentoring, Retention, Persistence, & Advancement -- Posters**

#### **254.01 - Overcoming the STEM Engagement Deficit in URM and Low-Income Students: A Bridge to the Stars High School-to-College Pipeline(Jaime S. Arnold)**

A Bridge to the Stars (ABtTS) is a pioneering high school-to-college pipeline that actively engages urban 10th and 11th grade students from all backgrounds in a high-impact exposure to

science through innovative experiential learning with Prof. McIntosh in a first-year astronomy course at UMKC, a public urban research university. Since 2012, this program has helped show students who traditionally do not identify with high-tech careers that they can succeed in a university setting - a promising way to build confidence and to help fortify positive STEM aspirations during the critical bridge between high school and college. To date, ABtTS has awarded 60 scholarships; 90% of participants passed their course satisfactorily with an average grade of 80%. Remarkably, the overall scholar performance is equivalent to that of 700 UMKC students enrolled in the same courses over 9 semesters. Owing to substantial improvements in the recruitment and application processes, Spring 2018 applications reached 40 (2x previous year record), with 16 new scholars (another new record) enrolled. Participation in the program has been nearly three-quarters female or transgender, 87% students of color, and the vast majority low-income. Long-term tracking of former scholars shows positive attitudes regarding ABtTS and persistence in STEM aspirations at promising rates based on small-number statistics. Our long-term mission is to see urban colleges and universities adopt similar pipelines in all STEM disciplines. As such, we provide a summary of the innovations that have led to the rapid increase in urban high-school student participation in the ABtTS pipeline over the last two years. Programs like ABtTS are a key step to overcoming the national deficit in URM and low-income STEM majors, and diversifying the high-tech workforce.

**Author(s):** Jaime S. Arnold, Daniel H. McIntosh

**Institution(s):** University of Missouri-Kansas City

#### **254.02 - Cal-Bridge and CAMPARE: Engaging Underrepresented Students in Physics and Astronomy(Alexander L Rudolph)**

We describe two programs, Cal-Bridge and CAMPARE, with the common mission of increasing participation of groups traditionally underrepresented in astronomy, through summer research opportunities, in the case of CAMPARE, scholarships in the case of Cal-Bridge, and significant mentoring in both programs, creating a national impact on their numbers successfully pursuing a PhD in the field. In 9 years, the CAMPARE program has sent 152 students, >80% from underrepresented groups, to conduct summer research at one of 14 major research institutions throughout the country. Of the CAMPARE scholars who have graduated with a Bachelor's degree, almost two-thirds (65%) have completed or are pursuing graduate education in physics, astronomy, or a related field, at institutions across the nation. Now in its fifth year, the Cal-Bridge program is a CSU-UC Bridge program comprised of physics and astronomy faculty from 9 University of California (UC), 16 California State University (CSU), and more than 40 California Community College (CCC) campuses throughout California. In the first five years, 59 Cal-Bridge Scholars have been selected, including 34 Latinos, 7 African-Americans and 25 women (15 of the 25 women are from underrepresented minority groups). Forty-four (44) of the 59 Cal-Bridge Scholars

are first-generation college students. In the first three years, 19 of 21 Cal-Bridge Scholars have begun or will be attending PhD programs in physics or astronomy at top PhD programs nationally. Five (5) of these 20 scholars have won NSF Graduate Research Fellowships and three more received an Honorable Mention. Cal-Bridge provides much deeper mentoring and professional development experiences over the last two years of undergraduate and first year of graduate school to students from this diverse network of higher education institutions. Cal-Bridge Scholars benefit from substantial financial support, intensive, joint mentoring by CSU and UC faculty, professional development workshops, and exposure to research opportunities at the participating UC campuses. Funding for these programs is provided by NSF-DUE SSTEM Grants #1356133 and #1741863, NSF-AST PAARE Grant #1559559, and NSF AST MSIP Grant #1564352.

**Author(s):** Alexander L Rudolph

**Institution(s):** Cal Poly Pomona Contributing Team(s): Cal-Bridge and CAMPARE Teams

### **254.03 - The Lowell Observatory Predoctoral Scholar Program(Lisa Prato)**

Lowell Observatory is pleased to solicit applications for our Predoctoral Scholar Fellowship Program. Now beginning its eleventh year, this program is designed to provide unique research opportunities to graduate students in good standing, currently enrolled at Ph.D. granting institutions. Lowell staff research spans a wide range of topics, from astronomical instrumentation, to icy bodies in our solar system, exoplanet science, stellar populations, star formation, and dwarf galaxies. Active collaborations, the new Ph.D. program at Northern Arizona University, and strong, cooperative links across the greater Flagstaff astronomical community create an exciting, multi-institutional locus in northern Arizona. Lowell Observatory's new 4.3 meter Discovery Channel Telescope is operating at full science capacity and boasts some of the most cutting-edge and unique instrumentation available in optical/infrared astronomy. Student research is expected to lead to a thesis dissertation appropriate for graduation at the doctoral level at the student's home institution. For more information, see <http://www2.lowell.edu/rsch/predoc.php> and links therein. Applications for Fall 2019 are due by May 1, 2019; alternate application dates will be considered on an individual basis.

**Author(s):** Larissa Nofi, Lisa Prato,

**Institution(s):** Lowell Observatory, Northern Arizona University

## **255 - The Solar System -- Posters**

### **255.01 - Hydromagnetic dynamo models of an ice giant planet(Dustin Hill)**

The topology of the magnetic field of a planet is determined by the internal dynamics of that planet. The difference between the dipolar magnetic field of Jupiter, for example, and the

multipolar magnetic fields of Uranus and Neptune indicate that there is also a difference between these planets in terms of physical composition. Over the past few decades, advances in both computational capabilities and understanding of the materials that constitute the giant planets have improved our ability to apply numerical models that are able to reproduce the physical conditions that exist at the outer planets. The properties of planets that consist of water have been investigated; however, these properties are expected to be sensitive to the relative abundance of other ices, such as ammonia and methane. Here we present a parameter study of Uranus- and Neptune-like dynamos in the magnetohydrodynamics code MagIC, including stratification of electrical conductivity based upon reasonable assumptions of the chemical composition of the interiors of ice giant planets.

**Author(s):** Dustin Hill

**Institution(s):** Drexel University

### **255.02 - Infrared Transmission and Reflection of Titan Aerosol Analogues Under Vacuum(Ashley L. Walker)**

Saturn's moon, Titan, is the only body in the solar system with a thick nitrogen atmosphere that may be similar to that of the Early Earth. Photochemistry in Titan's atmosphere, composed of mainly nitrogen and methane, produces incredibly complex organic materials. The purpose of this work is to understand the composition of these organic materials through the use of laboratory atmosphere simulation experiments. The Planetary HAZE Research Chamber (PHAZER) at Johns Hopkins University operated by the H<sub>2</sub> First Lab group has been used to simulate a variety of solar system and exoplanet atmospheres including that of Titan. In this chamber, nitrogen and methane gases flow past cold plasma in order to create aerosols called "tholins"; experiments such as these have been used to improve our understanding of the chemistry in Titan's atmosphere for decades. The particles generated in these experiments are deposited as thin films and then analyzed using Fourier transform infrared spectroscopy (FTIR). FTIR provides information regarding the chemical composition and optical properties of the particles and can be compared to remote sensing observations of Titan's atmosphere. We review and compare our spectral data to tholins from previous experiments to provide a better understanding on the habitability of Titan.

**Author(s):** Chao He, Ashley L. Walker, Sarah M Horst, Marcella Yant, Brynne Hadnott

**Institution(s):** Chicago State University, Johns Hopkins University

### **255.03 - Shape Model of Potentially Hazardous Asteroid (1981) Midas from Radar and Lightcurve Observations(Riley McGlasson)**

We report observations of potentially hazardous asteroid (1981) Midas, which passed 0.090 au from Earth (35 lunar distances) on March 21, 2018. During this close approach, Midas was



observed by radar both from Arecibo Observatory on March 21 through 25 (five nights), and from NASA's Goldstone Deep Space Communications Complex on March 19 and 21. These radar observations yielded one-dimensional continuous-wave spectra and two-dimensional delay-Doppler images. These data show a bilobed object with one lobe about 30% larger than the other. From these observations we also were able to find a circular polarization ratio of 0.8 at Arecibo's 13 cm wavelength, which implies a surface that is rough at decimeter scales (Benner et al. 2008). That ratio is consistent with Midas having visible and near-infrared spectral type V (Binzel et al. 2001, Binzel et al. 2004), which suggests a basaltic composition (Bus & Binzel 2002, and references therein). In addition, there have been optical lightcurve observations of Midas during four apparitions (1987, 1992, 2004, and 2018), which showed a rotation period of 5.22 hours (Wisniewski et al. 1997, Mottola et al. 1995, Muinonen et al. 2007, Franco et al. 2018). Midas has an absolute magnitude of  $H = 15.6$  (Wisniewski et al. 1997). By combining the lightcurves and radar data, we have constructed a shape model for Midas. This model shows that Midas has two lobes separated by a neck which, at its thinnest point, is about 60% of the width of the lobes. From our model, we also confirm the lightcurve-derived rotation period and show that Midas has dimensions of 4x2x2 km and a volume-equivalent diameter of about 2.3 km. The first author was supported by the Arecibo Observatory Research Experience for Undergraduates program, National Science Foundation grant 1559849. This research also was supported by NASA's Near-Earth Object Observations Program through grants NNX13AQ46G and 80NSSC18K1098. The Arecibo Observatory is a facility of the NSF, operated under cooperative agreement by the University of Central Florida in alliance with Yang Enterprises Inc. and Universidad Metropolitana.

**Author(s):** Jeff Tobak, Guy Wells, Daniel Bamberger, Shantanu Naidu, James Young, Betzaida Aponte, Flaviane Venditti, Marina Brozovic, Jon Giorgini, Sean Marshall, Riley McGlasson, Alan Harris, Lance Benner

**Institution(s):** Macalester College, Jet Propulsion Laboratory, California Institute of Technology, Arecibo Observatory, University of Central Florida, MoreData! Inc., Lunar and Planetary Institute, Universities Space Research Association, Northolt Branch Observatori

#### **255.04 - Taxonomic Ambiguous Asteroids(Tyler Linder)**

The Astronomical Research Institute presents the results of a study to identify and confirm the taxonomic classification of asteroids with possible heterogeneous surfaces. The target list was developed from ambiguous taxonomic asteroids identified by Linder et al. (2018). Observations were collected in B, V, R, I, g, r, i, z using SMARTS 1.0m telescope at Cerro Tololo Inter-American Observatory. The use of a combination of Johnson and Sloan filters provides additional data points across the visible wavelength. The Sloan Digital Sky Survey (SDSS) collected near-contemporaneous observations in five filters with central wavelengths from 468.6 to 893.2 nm (Ivezić et

al., 2001). Asteroids were serendipitously observed. The fourth release of the Moving Object Catalog (MOC4) contains 220,101 observations identified to 104,670 known asteroids (Ivezić et al., 2010). Analysis shows that a significant fraction of observations had higher errors than expected, therefore any analysis should be limited to 114,904 observations on 63,676 asteroids and the u filter should be excluded. (Linder et al., 2018). The set of 114,904 observations were analyzed and 23,403 asteroids were observed more than once. Of these asteroids, 12,710 have reflectance variations greater than 0.1 in a single filter. These asteroids are defined as taxonomic ambiguous because photometric based taxonomic classification is unable to identify a single taxonomic complex that describes that asteroid (Carvano, Hasselmann, Lazzaro, & Mothé-Diniz, 2010; Linder et al., 2018).

**Author(s):** Tyler Linder, Katya Gozman

**Institution(s):** Astronomical Research Institute, University of Chicago

#### **255.05 - Trans-Neptunian Object Search in the Dark Energy Survey(Tongtian Liu)**

Several algorithms have been designed for identifying minor planets in our solar system, more specifically asteroids and trans-Neptunian Objects (TNOs). However, such algorithms rely on back to back exposures that are taken within an hour to identify moving objects (transients) within a certain portion of the sky. We develop a method to identify trans-Neptunian objects in data where images contain gaps up to weeks or even months. We are able to cut down on the computational costs by initially considering partial orbits that are formed by the transient detections, then extending those partial orbits into longer chains. We applied our algorithm on the Dark Energy Survey wide survey and have identified approximately 50 new TNOs after running the pipeline through ~10% of the search area, including one with semi-major axis of ~460AU.

**Author(s):** Tongtian Liu, Aditya Inada Somasundaram, Masao Sako

**Institution(s):** University of Pennsylvania Contributing Team(s): Michigan TNO search

#### **255.06 - Finding moving objects below the single-image detection limit(Hayden Smotherman)**

**Title:** Finding moving objects below the single-image detection limit  
We present new results from the Kernel Based Moving Object Detection (KBMOD) pipeline, which detects moving objects that would be too dim to be detected in a single image. This pipeline takes a series of images of a given field, creates matrices of the likelihood of a source detection in a given pixel, and uses GPU-accelerated computing to "shift-and-stack" these likelihood matrices along a grid of position and velocity vectors, returning stacked maximum likelihood results over a given threshold. We then use a lightcurve filter followed by a image central moment filter to help eliminate false

positives. Unlike traditional linking algorithms which require source detections in a given image before linking can occur, KBMOD does not require a source detection in any individual image in a given field. Furthermore, KBMOD does not need any fixed image cadence in order to detect moving objects. The result is that we are able to use consumer-grade hardware to quickly search a stack of image and detect moving objects that may be too faint to be even detected as sources in a single image. Here, we follow up the work of Whidden et al. 2018 by applying KBMOD to a new 6.5 TB data set covering over 2000 square degrees of the sky. We now use difference imaging software from the LSST Software Stack on the data set prior to running KBMOD. This not only gives us a new data set in which to search for moving objects, but also allows us to avoid simply masking sources out of images, thereby increasing our effective searchable area for a given image.

**Author(s):** Colin Slater, Andrew Connolly, Joachim Moeyens, Dino Bektsev, John Bryce Kalmbach, Hayden Smotherman, Peter Whidden, Mario Juric

**Institution(s):** University of Washington Contributing Team(s): DIRAC Institute

### 255.07 - The Impossibility of Detecting Terrestrial Planetary Engulfment Events (Sydney Gilbert)

After the Sun's main sequence life, it will evolve up the red giant branch (RGB) and expand significantly. As it reaches the tip of the RGB, its stellar envelope will have expanded outward significantly, reaching the orbit of Venus, and engulfing the planet. Using the MESA Isochrones and Stellar Tracks (MIST) project, a Sun-like stellar isochrone was evolved until its outer stellar envelope reached Venus' orbit at  $A \approx 0.70$  AU or  $R \approx 155 R_{\odot}$ . As it is engulfed, Venus will generate orbital decay power via drag force as it falls through the Sun's outer envelope. This gas will have a very low density ( $\rho \approx 10^{-6}$  kg/m<sup>3</sup>) and Venus will fall inwards slowly, at an average rate of  $\dot{r} \approx 1.20 \text{ Å} - 10^{-7} \text{ m/s}$ , resulting in an orbit that is only minimally changed during the Sun's RGB lifetime. The peak drag power, or  $L_{\text{decay}}$  will be  $6.87 \text{ Å} - 10^{29} \text{ W}$ . At the tip of the red giant branch, the Sun will be cooler, with an effective surface temperature of 3100K, and brighter, with a luminosity of  $7.71 \text{ Å} - 10^{29} \text{ W}$ . As  $L \gg L_{\text{decay}}$ , this event would be very hard to observe, causing only minor perturbations in the Sun's luminosity. It would be near impossible to detect similar terrestrial planetary engulfment events in solar-type stars with planetary companions.

**Author(s):** Sydney Gilbert, Nathaniel E Q Paust

**Institution(s):** Whitman College

### 255.08 - Solar System Science with the Stratospheric Observatory For Infrared Astronomy (Arielle Moullet)

Now in its sixth cycle of observations, The Stratospheric Observatory for Infrared Astronomy (SOFIA) and its wide suite of instruments continue to offer a unique access to the far-IR sky in the 4-600 microns range. SOFIA observations of Solar System bodies have included varied topics such as chemical studies of terrestrial planets atmospheres, moons' exospheres and mineral characterization of asteroids. Thanks to its positioning flexibility, SOFIA has also been instrumental in occultations observation campaigns of Triton, Titan and Kuiper-Belt objects. This poster highlights some of the latest SOFIA Solar System results and new observational opportunities in the context of its latest instrumental developments.

**Author(s):** Kimberly Ennico, Arielle Moullet, William Reach

**Institution(s):** SOFIA/USRA, NASA Ames Research Center

### 255.09 - Examining Initial Conditions of Planetary Formation Simulations (Alexandra Elizabeth Detweiler)

Terrestrial planet formation simulations have consistently produced Mercury and Mars-like planets with too much mass (Raymond et al. 2009). Hansen (2009) showed that terrestrial planet analogues may be much more accurately reproduced when all mass is initially confined to a narrow annulus from 0.7-1.0 AU. However, these initial conditions also required 400 embryos spaced less than one mutual Hill radius apart: an extremely dynamically over-packed initial condition. This compression may have occurred due to the inward shepherding of material by Jupiter during the Grand Tack, but here we test whether it's possible to achieve this dynamical packing due to rapid pebble accretion. First, we showed that the over-packed nature of the truncated disk in Hansen (2009) is unrealistic but a necessary condition for re-creating the mass-orbit distribution of the terrestrial planets. In order to test the necessity of dynamical over-packing, we first varied the number of initial embryos in the annulus while keeping the total mass constant at two Earth masses and second varied the total mass (and therefore separation distance in mutual Hill radii) while keeping total embryos constant at 400. We found that simulations with 400 embryos were instantly unstable and therefore unrealistic initial conditions. When decreasing the number of embryos, a system without instantaneous instability did not occur until the total number of embryos dropped to approximately 8. Systems experienced instantaneous instability until the the separation distance was increased to approximately 4 mutual Hill radii. However, simulations without instantaneous instability did not reproduce the mass-orbit distribution of the terrestrial planets. Second, we investigated whether a truncated disk of embryos of this density could have been created through the process of pebble accretion. Over-packing can be achieved by shortening the distance between the embryos or by increasing embryo masses, since the relevant measure is the mutual Hill radius. However,

we find that even under extreme pebble fluxes (2000 Earth masses per Myr) there isn't enough growth to recreate the inner Solar System.

**Author(s):** Alexandra Elizabeth Detweiler,

**Institution(s):** Illinois Institute of Technology, Northwestern University

#### **255.10 - USING CASSINI VIMS STELLAR OCCULTATIONS TO INVESTIGATE GEOSTROPHIC WINDS IN SATURN'S STRATOSPHERE(Nicholas Ian Merritt)**

Using Cassini VIMS Stellar Occultation observations of Saturn's atmosphere, we calculated light-curves and 50% signal attenuation altitudes (half-light altitudes) for wavelength bands centered around 6 values: 1.37  $\mu\text{m}$ , 2.35  $\mu\text{m}$ , 3.40  $\mu\text{m}$ , 1.05  $\mu\text{m}$ , 2.75  $\mu\text{m}$ , 4.05  $\mu\text{m}$ , corresponding respectively to three hydrocarbon absorption features and three ranges free of molecular absorption. Our goal was to calculate a shape of the planet parameterized by the half-light altitudes for each wavelength range in order to examine deformation of Saturn's shape by global wind patterns at the altitudes probed by VIMS occultations (from 250 km to 550 km above the 1-bar level, corresponding to pressures from 3 mbar to 20  $\mu\text{bar}$ ). In each of the 6 wavelength bands, we found a significant latitude dependent increase in the radius of the atmosphere. The latitude range with largest increase of radius (150-200 km deviation from the oblate spheroid shape measured at 1 bar) matches the measured latitude range of the cloud-level equatorial jet. Our findings indicate that the general structure of global winds observed at the visible cloud layer persists up into the stratosphere.

**Author(s):** Nicholas Ian Merritt, Philip D Nicholson

**Institution(s):** Colorado College, Cornell University

Contributing Team(s): Cornell Astronomy Cassini VIMS group

#### **255.11 - LightSound: A Sonification Device for Eclipses(Soley Osk Hyman)**

On August 21, 2017, millions of people across North America turned their (protected) eyes to the Sun to witness a total solar eclipse. At the same time in Jackson Hole, Wyoming, LightSound, an Arduino device developed at Harvard University, streamed the event online for the blind and visually impaired around the world. In a process called "sonification," the device uses a light sensor that takes the measured intensity of light (in the IR band, visual band, or both) and converts it to a pitch so that the listener can experience the real-time darkening during an eclipse. In preparation for the 2019 and 2020 eclipses in Chile and Argentina, LightSound has been redesigned with a MIDI synthesizer to allow the user to choose a variety of sound outputs and to offer a more rugged and telescope-adaptable interface. The documentation and code for LightSound, which costs about \$70 to build, will be freely available online so that others may build their own (and modify

the code, if they wish).

**Author(s):** Wanda Diaz Merced, Daniel Davis, Soley Osk Hyman, Allyson Bieryla

**Institution(s):** Harvard University, IAU Office for Astronomy Development

#### **255.12 - Distribution and Energy Balance of Pluto's Nitrogen Ice, as seen by New Horizons in 2015(Briley Lynn Lewis)**

Pluto's surface is geologically complex, to a significant extent because of volatile ice frosts that are mobile on seasonal and longer time scales. Here, we analyze New Horizons LEISA spectral data to globally map the nitrogen ice, including nitrogen with methane diluted in it, in order to learn about the seasonal processes influencing ice redistribution, and to calculate the globally averaged energy balance. We take advantage of the shifted bands of methane in solid solution with nitrogen, which are much stronger than the 2.15-micron nitrogen band, to more completely map the distribution of the nitrogen ice. We present the resulting maps of the encounter-hemisphere distribution of nitrogen, as well as characterization of its average latitudinal dependence and an examination of how the distribution at the global scale depends on topography. We also use the encounter-hemisphere distribution of nitrogen ice to infer the latitudinal distribution of nitrogen over the rest of Pluto, allowing us to calculate the global energy balance. Under the assumption that Pluto's nitrogen-dominated 11.5 microbar atmosphere is in vapor-pressure equilibrium with the nitrogen ice, the ice temperature is  $37.18 \pm 0.10$  K. Combined with our global energy balance calculation, this implies that the average bolometric emissivity of Pluto's nitrogen ice is probably in the range 0.5 - 0.9, and that there is a significant reservoir of N<sub>2</sub> ice in the un-illuminated areas south of  $-38^\circ$  latitude. The global pattern of volatile transport at the time of the encounter was from north to south, with condensation of volatile ices likely occurring southward from approximately Pluto's equator (including in the un-illuminated regions south of  $-38^\circ$  latitude). The transition between condensation and sublimation within Sputnik Planitia is correlated with changes in the grain size and CH<sub>4</sub> concentration derived from the spectral maps. The low emissivity of Pluto's N<sub>2</sub> ice suggests that Pluto's atmosphere may undergo an extended period of constant pressure even as Pluto recedes from the Sun in its orbit.

**Author(s):** Leslie Young, Briley Lynn Lewis, Harold Weaver, Catherine Olkin, William Grundy, Bernard Schmitt, Kimberly Ennico, Bryan Holler, John Stansberry, S. Alan Stern, Silvia Protopapa

**Institution(s):** Columbia University, Space Telescope Science Institute, University of California, Los Angeles, Universite Grenoble Alpes, Lowell Observatory, Southwest Research Institute, University of Maryland, College Park, NASA Ames Research Center, Johns Hopk

### **255.13 - The Flyby Model for Chondrule and Chondrite Formation(William Herbst)**

We propose that chondrules and chondrites formed together during a brief heating event caused by the close encounter of a small (m to km-scale), primitive planetesimal (SPP) with incandescent lava on the surface of a large (100 km-scale) differentiated planetesimal (LDP). While a seemingly rare occurrence, such events may have been common enough during the brief epoch of chondrule formation to account for the known abundance of chondrules. In our scenario, chondrite formation occurs by hot isostatic pressing (HIP) simultaneously with chondrule formation. Mechanisms to form chondrules abundantly and independently of chondrites within the solar nebula are not required. Thermal models of LDPs formed near  $t=0$  predict that there will be a very narrow window of time, coincident with the chondrule formation epoch, during which crusts are thin enough to frequently rupture by impact, volcanism and/or crustal foundering, releasing hot magma to their surfaces. A radiative heating model is developed for heating the SPPs, which allows us to predict possible thermal histories within fairly tight constraints. The characteristically brief heating periods for chondrules of order 1 hour match the gravitational timescale for a close encounter with an LPD of mean density near 3 gm/cc. The SPP is, itself, a plausible source of the O and Na vapor pressures required by cosmochemical studies, levels that are inconsistent with a solar nebula composed mainly of H and He. We propose that lithification of the chondrite occurs simultaneously with chondrule formation so that, depending on the pore structure, at least some parts of the SPP may be expected to vaporize, melt and recondense to matrix as a closed system, potentially accounting for the phenomenon of complementarity. Preliminary laboratory experiments demonstrate that synthetic Type I and Type II chondrules with a range of observed textures can be made using heating and cooling curves predicted by the flyby model. It provides a potential framework for understanding a wide range of chondrule and chondrite properties, including challenging ones such as complementarity and the existence of cluster chondrites.

**Author(s):** James Greenwood, William Herbst

**Institution(s):** Wesleyan University

### **255.14 - Solar Wind Effects on Ion Temperature and Density in Mercury's Central Plasma Sheet(Kristin E. Brady)**

Mercury has a complicated, reconnection-dominated magnetosphere; understanding the areas where plasma is found will give insight to how this complex system works. We focus on Mercury's central plasma sheet (CPS), one of three main areas where plasma is found in the magnetosphere. Using data from the Fast Imaging Plasma Spectrometer (FIPS) on the MExury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft we analyze measurements of the solar wind and planetary ions over orbital observations from

March 2011 to April 2015. With MESSENGER's extensive observations of Mercury's plasma composition around the planet's space environment, we determine how the temperature and density of the ions in the CPS are connected to dynamics in Mercury's magnetotail and how they are affected by the solar wind. We find that proton density decreases linearly with solar wind speed while proton temperature increases linearly with solar wind speed, which is consistent with previous results (Gershman et al., 2014). The post-midnight side is hotter than the pre-midnight side, with average temperatures of 22.7MK and 20.04MK, respectively. This is also consistent with previous results (Sun et al., 2017). Proton density increases as the thickness of the plasma sheet increases, and decreases as you move further downtail. Proton temperature is greater closer to the planet.

**Author(s):** Jim M. Raines, Kristin E. Brady,

**Institution(s):** Whitman College, University of Michigan

### **256 - The Milky Way & The Galactic Center Posters**

#### **256.01 - The Effects of the Galactic Center on the Ionization of the Magellanic Stream(Elaine M Frazer)**

The Magellanic Stream is a large, filamentary system of gas that was created primarily through tidal interactions between the Large and Small Magellanic Clouds. The Stream was first discovered in surveys of neutral H I gas and has since been explored in ultraviolet and optical absorption, which has revealed that it contains multiple phases of ionized gas. In this project, we study whether the radiation from a flare in the Galactic Center can account for the over-abundance of high ions in the portions of the Stream directly below the Galactic Center. With a sample of 69 sightlines spread across the Stream with HST/COS FUV absorption spectra from Fox et al. 2014, we use Voigt-profile fitting techniques in Python to search for differences in the properties of the low- and high-ion phases. This allows us to explore the regional variation of the Stream's kinematics and whether a flare from the Galactic Center has left an imprint in its ionization state.

**Author(s):** Andrew J Fox, Joss Bland-Hawthorn, Kat Barger, Elaine M Frazer

**Institution(s):** STScI, Texas Christian University, University of Sydney

#### **256.02 - Supernovae Driven Winds from the Large Magellanic Cloud(Drew A Ciampa)**

Massive amounts of gaseous material are being ejected from the nearby Large Magellanic Cloud (LMC). Deciphering how baryons cycle in and out of galaxies is crucial for our understanding of how galaxies evolve and with the LMC at only one Milky Way diameter away, we are provided with an excellent opportunity to explore this cycle in detail. As this gaseous wind is being thrown outward, some of it may fall back into the grasp of the host galaxy while the rest will be sent hurtling into space directed toward the Milky Way. The star-

forming lifetime of a galaxy is dependent on the gas supply it has and therefore dependent on the galactic processes that occur. Galaxies losing gas will not be able to form as many new stars compared to those who can maintain a supply of gas. We have combined spectroscopically resolved ground based and space based observations to (1) fully map the near-side galactic wind of the LMC, (2) determine the properties of this gaseous outflow including its morphology, extent, mass, and outflow rate, and (3) estimate how much energy is needed to eject this gas and which regions within the LMC are driving this outflow. Understanding the properties of this galactic wind will provide invaluable information regarding galaxy evolution and surrounding environments, galactic feedback, and the LMC's possible influence on the Milky Way.

**Author(s):** Brianna Marie Smart, L. Matthew Haffner, Drew A Ciampa, Maddie Horn, Kat Barger, Michael Hernandez, Chris Howk, Sam Barber, Henry Boot, Nicolas Lehner

**Institution(s):** Texas Christian University, University of Wisconsin-Madison, Notre Dame, Burleson High School, Trinity Valley High School, Smith College

### **256.03 - Shielding the Leading Arm of the Magellanic Clouds during its infall onto the Milky Way(Kat Barger)**

The leading tidal arm of the Magellanic Cloud galaxies is punching through the disk of our galaxy. This gaseous stream is traveling through and interacting with the surrounding coronal medium, the interstellar medium of our galaxy, and the Galactic radiation field. These interactions heat, ionize, and strip away the outer layers the Leading Arm. In this study, we use UV absorption-line observations taken with the Hubble Space Telescope / Cosmic Origins Spectrograph to explore the properties of the high-ionization species in the Leading Arm and the source of its ionization. This will be accomplished by comparing the SiIII, SiIV, and CIV line ratios and line widths to determine if photoionization or collisional ionization is the dominant ionization process. We will further compare these line ratios with ionization models. These efforts will enable us to identify the mechanisms that influence gas that an advanced state of accretion onto an Lstar galaxy.

**Author(s):** Andrew J Fox, Kat Barger, Elaine M Frazer

**Institution(s):** Texas Christian University, Space Telescope Science Institute

### **256.04 - The Physical Nature of the Gas Stripped from Magellanic Cloud Galaxies as it Crashes into the Milky Way(Rachel Mochama)**

There is a cluster of gas clouds known as the Leading Arm that has been stripped from the nearby Magellanic Cloud galaxies. This gas cloud has traveled to our galaxy and is currently interacting with its disk. The gas that is absorbed by the Milky Way could be used to form new stars in the Galaxy. We determined the temperature, density, pressure, and ionization

fraction of the gas cloud by running radiative transfer simulations that were anchored with Hubble Space Telescope / Cosmic Origins Spectrograph observations. We compared these properties at different locations in the Leading Arm along background QSOs. The results from this study will enable us to better understand the processes that heat and ionize gas clouds as they travel onto large galaxies.

**Author(s):** Alec Creel, Andrew J Fox, Drew Ciampa, Kat Barger, Elaine Frazer, Rachel Mochama,

**Institution(s):** Scripps College, Space Telescope Science Institute, Texas Christian University

### **256.05 - Disentangling Stellar Streams using Gaia, SDSS and PanStarrs(Thomas Donlon)**

It has recently been proposed that there are several large streams crossing the north Galactic cap within 20 kpc of the Sun. In particular, the Parallel Stream and the Perpendicular Stream could cross each other in the region of the Virgo Overdensity/Virgo Stellar Stream at a heliocentric distance of 15 kpc. It has also been proposed that a significant merger is responsible for the Virgo Overdensity, the Hercules-Aquila Cloud, and the Gaia "sausage." At similar distances in the north Galactic cap the Lethe stream and an apparent stream associated with NGC 5466 have been identified. Using proper motions from Gaia and photometry from SDSS and PanStarrs, we attempt to disentangle and relate all of these proposed structures to each other. This research was supported by NSF grant AST 16-15688 and Rensselaer's Summer Undergraduate Research Program.

**Author(s):** Heidi Jo Newberg, Jeffery Thompson, Jake Weiss, Thomas Donlon

**Institution(s):** Rensselaer Polytechnic Institute, Southern Vermont College

### **256.06 - Kinematic Analysis of Stellar Streams in the Dark Energy Survey(Nora Shipp)**

In this poster I will present a kinematic analysis of the stellar streams recently discovered with the Dark Energy Survey (DES). The DES data, covering  $\hat{\sim} 1/45000$  sq. deg. to a depth of  $g > 23.5$  with a relative photometric calibration uncertainty of  $< 1\%$ , has allowed for unprecedented observations of the stellar density features in the southern sky, including the discovery of eleven new stellar streams, and improved observations of four previously known streams. I will present the proper motion measurements of these DES streams from Gaia DR2, as well the Southern Stellar Stream Spectroscopic Survey (S5), an ongoing survey to obtain radial velocity measurements of all known streams in the southern hemisphere. Together, this 6D phase space information for the DES streams will allow for stronger constraints on the formation of the Galactic stellar halo, the Milky Way gravitational potential, and the large- and small-scale distribution of dark matter around the Milky Way.

**Author(s):** Nora Shipp

**Institution(s):** University of Chicago

**256.07 - The Footprints of Formation: Analyzing the Milky Way's Stellar Halo using The Payne(Priscilla Elise Holguin West)**

The Milky Way is one of the greatest laboratories astronomers have for better understanding not only stellar formation and evolution, but the formation and evolution of galaxies as well. Constraining values for properties of the Galaxy, such as its mass, can be difficult due to the challenge that arises from studying a system within which we are contained. However, the stellar halo, which contains the oldest stars, is likely made up of dwarf galaxies and globular clusters that have been disrupted and joined our Galaxy, making it a fundamental building block of the Galaxy and a region that contains footprints of the Milky Way's evolutionary history. In particular, the metallicity and abundance patterns of halo stars should hold unique clues to their formation pathways. The Payne is a new stellar parameter pipeline that fits a star's spectrum and photometry self-consistently using ab-initio models that allow for the derivation of up to thirty parameters, including metallicity and abundance pattern. Before applying The Payne to large samples of stars we must determine the accuracy of the results by comparing to well-studied stars in open clusters. Preliminary analysis of data from M67 has shown that The Payne is capable of recovering well-constrained values for the temperature, surface gravity, metallicity, and  $[a/Fe]$ . Determining the accuracy of these values is done through comparing The Payne's derived parameters with accepted literature values for the stars in M67. **Author(s):** Charlie Conroy, Priscilla Elise Holguin West, Phillip Cargile

**Institution(s):** Cal Poly San Luis Obispo, Harvard Smithsonian Center for Astrophysics

**256.08 - The Smith Cloud: Past, Present, and Future(Nicolas Pichette)**

The Smith Cloud is a prominent high-velocity HI cloud with a well constrained distance that allows us to derive many of its physical properties. It contains several million solar masses of neutral and ionized gas, and is on a collision course with the Milky Way disk (Lockman et al. 2008, ApJ, 679, L2; Hill et al. 2009, ApJ 703, 1832; Hill et al. 2013, ApJ, 777, 55; Fox et al. 2016, ApJ, 816, L11). We have analyzed new 21cm HI data from the Green Bank Telescope (GBT) that cover hundreds of square-degrees around the Smith Cloud. They reveal previously unknown components of the Cloud that stretch out over a wide area. Compact HI features almost certainly associated with the Smith Cloud are found both trailing behind the Cloud's apparent direction of motion, and leading it. In all, the Cloud appears to extend more than 40 degrees across the sky, spanning Galactic latitudes from -40 degrees all the way through the Galactic plane to positive latitudes, with a continuity of velocity. We will discuss the results of fitting

trajectories to the Cloud components that establish limits on its total velocity and trajectory through the Milky Way halo: it's past, present and its future. The Green Bank Observatory is a facility of the National Science Foundation operated under a cooperative agreement by Associated Universities, Inc. N. Pichette was funded by the NSF through the REU program at the Green Bank Observatory.

**Author(s):** Nicolas Pichette, Felix Lockman, Toney Minter

**Institution(s):** University of South Florida, Green Bank Observatory

**256.09 - SOFIA FIFI-LS Observations of the PDR in Sgr B1(Janet P Simpson)**

Photodissociation regions (PDRs) are the interface between the H II regions ionized by hot stars and cold molecular clouds. In the Galactic Center (GC), since Sgr B1 is found with Sgr B2 in a common envelope of molecular gas and far-infrared (FIR) emission, it has been assumed that the two sources are physically related, even though the ionized gas of Sgr B1 is much more extended and the stars of Sgr B1 have a significantly greater age than the newly-forming stars of Sgr B2. We have mapped Sgr B1 with the FIFI-LS spectrometer on SOFIA in the FIR lines of [O I] 146 micron and [C II] 158 micron, along with the [O III] lines, which we published in Simpson et al. (2018, submitted). There, we suggested that the ionizing stars of Sgr B1 formed elsewhere in the GC and have orbited into positions close to Sgr B2, where they now light up the edges of somewhat dispersed molecular clouds, thereby forming Sgr B1. As a result, because Sgr B1 does not include the natal molecular cloud of the ionizing stars, its PDR may be cut-off as it extends into the neutral gas and dust, "density-bounded", so to speak. Here we compare our observed [O I] and [C II] intensity maps to the FIR intensity maps measured with the Herschel Hi-GAL program (Molinari et al. 2016, A&A, 591, A149) and the mid-infrared lines of [Si II], H2 S(0), and H2 S(1) taken from the Spitzer Infrared Spectrograph Archive (Simpson 2018, ApJ, 857, 59). We find that the PDR lines have almost no correlation with the [O III] H II region lines, but the [C II] 158 micron line correlates much better with the structure seen in the Herschel PACS Blue 60-85 micron image than it does with the Red 130-210 micron image, which is dominated by the massive molecular cloud seen at higher Galactic latitude. The [O I] line has a distinctly different appearance yet, from which we infer that there are large variations in the PDR parameters across the source. We will describe our estimates of the neutral gas density  $n_o$  and the far-ultraviolet photon intensity  $G_o$  and how they differ from ionized gas density  $N_e$  and inferred ionization parameter (extreme-ultraviolet photon density/ $N_e$ ).

**Author(s):** Sean Colgan, Angela Cotera, Susan Stolovy, Janet P Simpson, Michael Kaufman

**Institution(s):** SETI Institute, Nasa Ames Research Center, San Jose State University, El Camino College

### **256.10 - SOFIA FORCAST Observations of the Warm Dust in Sgr B1 (Angela Cotera)**

The central ~500 pc of the galaxy contains the most dense molecular clouds in the Galaxy; however, the measured star formation rate (SFR) is an order of magnitude lower than expected, seriously challenging theoretical models of star formation. Recent studies have suggested that star formation in the Galactic Center is episodic, with new episodes occurring when clouds, traveling on open, quasi-elliptical orbits, are tidally compressed during their pericenter passage by the supermassive black hole Sgr A\*. This should result in an identifiable age sequence along these streams of gas: starting with the youngest cores in the dense cloud such as Go.253+0.016 ("the Brick"), followed by Sgr B, then Sgr C. We have obtained images of Sgr B1 utilizing FORCAST on SOFIA. We obtained images at 19.7 micron and 31.5 microns in Cycle 3, and had partial observations at 37.1 micron in Cycle 5. We used the pipeline-processed images for the individual dither positions, but then used the IDL program IDP3, initially developed by the HST/NICMOS team, to shift, calibrate, and combine all of the images from both positions. Prior to combining, the images were re-sampled by a factor of 4 using bi-cubic interpolation. The result of these additional steps is a FWHM for the bright OH/IR star in the images of 2.6" at 19.7 micron, 3.0" at 31.5 micron, and 3.5" at 37.1 micron. Since we only received a portion of the planned data at 31.7 micron, we must contend with low signal-to-noise images at that wavelength, which makes the planned dust temperature maps of the entire region unreliable. We will present dust temperature maps for those regions where we can provide a robust measure. We will also provide comparisons of our observations with archival data from several other wavelengths. Preliminary results confirm our FIFI-LS results, indicating that there does not appear to be very recent or ongoing star formation in Sgr B1, which could necessitate a rethinking of how Sgr B1 fits into the proposed episodic star formation model.

**Author(s):** Angela Cotera, Janet P Simpson

**Institution(s):** SETI Institute

### **256.11 - Star Formation in the 3 Kiloparsec Arms of the Milky Way (Samantha Lucia Garza)**

A growing body of evidence suggests that the near and far 3 kpc arms of the Galaxy might be identified as a galactic ring by an outside observer. These arms were discovered kinematically due to their unusual Doppler shifts of - 50 km/s and +50 km/s of neutral hydrogen and molecular CO gas in the direction of Galactic center (where circular rotation would predict no Doppler shift.) However, because of the non-circular rotation mapping the 3kpc arms relies on model predictions of how gas would flow in the gravitational field of the barred Milky Way Galaxy. We present progress on mapping these arms using maser parallaxes and photometric distances to stellar clusters associated with star forming regions associated with the 3kpc

arms. Starting with a list of HII and maser regions from previous surveys, we visually inspected each direction, measured the angular sizes of associated star forming regions, and cataloged the ones that show stellar cluster candidates for future spectroscopic follow-up. We then re-examined a model for calculating the distance to these objects, refit the model parameters, and compared the distances between the model and our measured distances. We also found that the distribution for the radii of the star forming regions in the Near and Far 3kpc arm are approximately equal while the angular sizes of the Far 3kpc arm regions are smaller than the angular sizes of the Near 3kpc arm regions, as expected. This suggests that the model distances are correct.

**Author(s):** Samantha Lucia Garza, Robert Benjamin

**Institution(s):** University of Dallas, University of Wisconsin-Whitewater

### **256.12 - Science Goals, Data Management, and Early Results for the Blanco DECam Bulge Survey (BDBS) (Christian Johnson)**

The Blanco DECam Bulge Survey (BDBS) utilizes the Dark Energy Camera on the Blanco 4m telescope to obtain deep ugrizY images of the entire southern Galactic bulge. The survey spans approximately 200 square degrees in all filters, contains about 30 globular clusters, has identified over 1 billion unique point sources, and reaches at least 2 magnitudes below the bulge main-sequence turn-off. The final data set will be used to obtain detailed metallicity, reddening, and structural maps of the inner Galaxy, and will also promote synergistic investigations into the chemodynamical evolution of the bulge using velocity and proper motion information from various surveys (e.g., Gaia; BRAVA). We report on the severe technical and data management challenges that were overcome to complete BDBS, and also present the first results and color-magnitude diagrams from the project.

**Author(s):** Michael Rich, Andrea Kunder, William I Clarkson, Michael Young, Katherina Vivas, Christian Johnson, Catherine Pilachowski

**Institution(s):** Smithsonian Astrophysical Observatory, University of Michigan-Dearborn, University of California, Los Angeles, CTIO, Indiana University, St Martin's University  
**Contributing Team(s):** BDBS Team

### **256.13 - OCCAM: A Uniform Chemodynamical Evolution Study of the Milky Way (John Donor)**

We present the latest results from the Open Cluster Chemical Abundance and Mapping (OCCAM) survey. The OCCAM survey uses uniform chemical analysis (telescope + instrument + pipeline) of open clusters to explore the chemodynamical evolution of the Milky Way. We present improved Galactic abundance gradients, using the abundances from SDSS/APOGEE survey for 11 elements (Fe, O, Mg, Si, S, Ca, V, Cr, Mn, Co, and Ni) for sample of over 40 clusters, more than

double the OCCAM II sample. We find further evidence of a significant positive trend in  $d \alpha / d R_{gc}$ , confirming trends seen in Galactic chemical evolution models and some previous studies. We also find a significant negative trend for iron-peak elements, as first presented in Donor et al. (2018). We also explore the effects of various cluster distance determinations on the resulting gradient determinations.

**Author(s):** John Donor, Katia Cunha, Peter Frinchaboy, Gail Zasowski

**Institution(s):** Texas Christian University, University of Utah, Observat rio Nacional, S o Crist v o Contributing Team(s): The APOGEE team

#### **256.14 - Shooting for Open Cluster Chemical Abundances with The Cannon: Aiming for Signatures of Radial Migration(Amy Elaine Ray)**

Open clusters are key tracers of Milky Way, as both chemical and age tracers. The use of open cluster to provide significant constraints on galaxy evolution, however, has been limited due to discrepancies in measuring abundances from different studies. This work seeks to add additional southern open clusters into the SDSS/APOGEE metallicity system. We analyze medium resolution spectra of giant stars in 31 open clusters have been obtained and analyzed using *The Cannon* to determine [Fe/H] metallicities accurate to 0.15 dex. This uniform analysis is compared for roughly half of the clusters with previous results, and we present metallicities for the first time for 12 open clusters.

**Author(s):** Peter Frinchaboy, Amy Elaine Ray

**Institution(s):** Texas Christian University

#### **256.15 - Analyzing the formation of globular clusters in cosmological simulations(Youssef Eweis)**

Understanding the formation of globular clusters remains a challenge for cosmological models. In this work, we use fully cosmological simulations of Milky Way-mass galaxies to identify a method to tag particles as forming globular clusters. We identify both clusters created in the progenitor Milky Way, and in accreted dwarf galaxies. We trace the tagged particles to the present day to investigate whether they can reproduce the distribution of globular clusters observed in the Milky Way. We will also consider which clusters should be destroyed, in order to investigate the population of destroyed clusters in the Galactic Center.

**Author(s):** Elaad Applebaum, Alyson Brooks, Youssef Eweis, Ramon Sharma

**Institution(s):** Rutgers University

#### **256.16 - Escape Velocity Curves of Simulated Milky Way Analogues(Brendan Massey)**

The total mass and mass profile of the Milky Way are important to know but are still uncertain by a factor of two or more. One way to measure the mass of the Milky Way is by using halo stars to measure the escape velocity, something that is now possible with 3D space velocities from Gaia. In this project, we analyze the escape velocity curves of eleven Milky Way analogs from hydrodynamical cosmological simulations. We group the star particles according to their stellar metallicities into three subsets: low ( $\epsilon$ ), medium ( $\epsilon$ ) and high ( $\epsilon$ ). We compare the escape velocity curve computed from the spherically averaged total matter distribution with the maximum three-dimensional velocity profile ( $V_{3max}$ ) of stars in each of these metallicity subsets. We measure the difference between the escape velocity curve and  $V_{3max}$  as a function of radius for each subset and determine if any of them deviate significantly from the escape velocity curve. We also determine at what range of radii these deviations would lead to an incorrect estimate of the total mass. MV and BM acknowledge support from NASA-ATP award NNX15AK79G.

**Author(s):** Monica Valluri, Brendan Massey

**Institution(s):** University of Michigan Contributing Team(s): Eric Bell and Richard D'Souza

#### **256.17 - Probing the Dynamic Evolution of the Milky Way Using Stellar Substructures in the Galactic Anticenter(Anastasios Tzanidakis)**

In an attempt to understand the dynamic history of the Milky Way, the origins of stellar substructures in the Galactic anticenter reveal the remnants of perturbed stellar populations inhibited in the Galactic halo. In this joint analysis, we reveal both observational and theoretical frameworks on the origins of stellar substructures found at heliocentric distances of  $>7$  kpc. From the perspective of stellar populations, the number of M-Giants versus RR Lyrae stars ( $f_{RR}/f_{MG} \sim 0$ ) suggests a disk-like origin for the Monoceros/GASS and A13 substructures that have been identified as M-Giant overdensities. Conversely, through N-Body simulations of a Milky Way Galaxy, we identify that the dynamic collision between a Sagittarius-like dSph is enough to perturb the disk, "kicking out" stars from the disk into the Galactic Halo at large galactic radii consistent with fields where stellar substructures are observed. With the emergence of Gaia DR2, we now attempt to investigate the same fields for new structure utilizing M-giants as distance tracers and signatures of disk oscillations from the proper motions.

**Author(s):** Kathryn V. Johnston, Chervin Laporte, Anastasios Tzanidakis, Allyson Sheffield, Adrian Price-Whelan

**Institution(s):** Columbia University, LaGuardia Community College, University of Victoria, Princeton University



## **257 - Teaching College-Level, Gen. Ed.**

### **Astronomy: Practices & Resources**

#### **257.01 - Connecting Classroom and Sky: Helping Students Observe the Sky in Ways that are Meaningful, Modern, and Scientific(Jackson Steele)**

Introductory undergraduate astronomy courses have long aimed to familiarize students with the night sky. Through observations of objects such as globular clusters, the moons of Jupiter, the phases of Venus, students connect what they learn in class with observational evidence. At BYU, students complete several "Observing Projects" over the course of the semester. These projects have long centered on worksheets which included some form of observation to be made, data to be gathered (frequently through a hand-drawn picture) and follow-up questions for analysis. Although these projects were useful in allowing students guided opportunities to look through telescopes, they were badly outdated, and many students viewed them as busy-work instead of useful learning opportunities. We have updated and expanded the Observing Projects to facilitate greater understanding of astronomy and the scientific method in the modern world. We have removed mentions of floppy disks and have instead added opportunities to participate in online citizen science, use cell phone apps to make quantitative measurements, use CCD data (taken in three different filters) to create a combined RGB image, and understand galaxy classifications using archival data from SDSS. Students still have extensive access to telescopes for the duration of this course, but the Observing Projects now introduce them to resources that they will have after this course as well. We have given students increased flexibility when choosing which projects they will do. Students are more engaged in the scientific process, with the addition of a formal-write up that further encourages students to analyze their data, draw meaningful conclusions, and communicate their results. The new Observing Projects boast flexibility, modernity, and greater potential for analysis and learning, and they represent a significant improvement over the former observing projects.

**Author(s):** J. Moody, Denise Stephens, Eric G Hintz, Darin Ragozzine, Maureen Hintz, Jackson Steele

**Institution(s):** Brigham Young University

#### **257.02 - Online Astronomy Education at the University of Wisconsin-Madison(Dhanesh Krishnarao)**

The Department of Astronomy at the University of Wisconsin-Madison has developed a new introductory astronomy course taught entirely online. Following a backwards design model, the course set learning goals to focus on three overarching questions:1. What are the natural lights in the sky - the Sun, the Moon, the Stars, and the Planets?2. How do these lights inform us about the past, present, and future of the Universe?3. How do these lights, and our quest to understand them, impact our everyday life here on Earth?Core course content is presented via "2-Minute Universe" videos, where the instructors construct a single page slide or graphic with narration on a specific topic, with the intention of students printing out the

page and compiling a set of notes to recall the material. These mini-lectures would supplement reading material from the free "Astronomy" textbook by the OpenStax project. Some longer videos (~10 minutes) provide more in-depth coverage through virtual planetarium shows, digital whiteboard drawings, and guest lectures by graduate students. A core aspect of the course is designed around the use of the educational video game, "At Play in the Cosmos" by Gear Learning. Students complete the primary missions of this game and work on extra assignments based on gameplay, with the help of narrated walkthrough videos made by the instructors. Student's learning and understanding outcomes are tested with weekly written assignments, discussion board postings, quizzes, and several in-depth projects. Projects are constructed to encourage many skills, such as artistic design, descriptive writing, trip planning, and budget management, and often require analyzing political and socio-economic impacts. The introductory course was debuted over 8-weeks in the Summer of 2018, with plans to continue to grow into future summers and be adopted into hybrid style courses during the standard academic year.

**Author(s):** Dhanesh Krishnarao, Richard H. D. Townsend, Sebastian Heinz

**Institution(s):** University of Wisconsin-Madison

#### **257.03 - Open Educational Resources for a Life in the Universe Course(Noella Deruz)**

The interdisciplinary field of astrobiology has become very popular because of the constant stream of exciting new results from astronomy, geology and biology. Due to the popularity of this topic, a number of colleges and universities now offer a general education "Life in the Universe" course for non-science majors. However, unlike introductory astronomy courses, there is limited choice in textbooks and active learning materials for the "Life in the Universe" course. In addition, the cost of textbooks keeps increasing. Hence, we would like to explore possible open educational resources for this course. Some of these materials are available from NASA's astrobiology institute website, from physics and astronomy education websites, from geology education websites and biology education websites. In this presentation, we will review textbooks, active learning materials and open educational resources for this interdisciplinary course. The materials presented here are not meant to be an exhaustive list but an initial collection of materials that can be added to over time.

**Author(s):** Noella Deruz

**Institution(s):** Joliet Junior College

#### **257.04 - Introduction to the Solar System in a medium security prison(Elisabeth Newton)**

There were 1.5 million men and women incarcerated in state and federal prisons in the United States in 2016 (Kaeble & Cowhig, 2018). 700,000 of these individuals are released each year, of which 40% will return to prison within 3 years (Gelb &

Valazquez, 2018). Educational programs have been shown to reduce recidivism and increase employment rates (Davis et al., 2016). The Metropolitan College at Boston University operates a prison education program (BUPEP) at Massachusetts state correctional facilities. We developed an introductory astronomy course for BUPEP that utilized active learning strategies and peer instruction. We taught the course twice in a medium security men's prison in which BUPEP has an established community college program. The course, "Introduction to the Solar System," served approximately 20 students each of the two semesters it was taught. In this contribution, we discuss the need for programs such as this, our course structure, and recommendations for future instructors. This work was supported by a National Science Foundation Astronomy & Astrophysics Postdoctoral Fellowship awarded to E. Newton under award #1602597

**Author(s):** Elisabeth Mills, Elisabeth Newton,

**Institution(s):** Massachusetts Institute of Technology, Brandeis University, Dartmouth College, Boston University

### **257.05 - The Red Thumbs: Growing Plants on Martian Regolith Simulant(Giannina Guzman)**

Having humans reach Mars has recently become one of the most popular upcoming space missions and in order to ensure a healthy colony in a cost-effective, self-sustainable way colonies will need to cultivate food. Since the cost of a rocket correlates to its weight, loading rockets with Earth soil would be cost-ineffective and not self-sustainable, especially if it is possible to farm in Martian regolith. This project, then, explores the extent to which we can grow and harvest plants in a controlled environment using Martian regolith simulant. Due to its popularity, the experiment naturally garners a lot of attention, making it an excellent tool for teaching. Although it was originally applied to a college-level class, it can also be adapted to many levels of education by simplifying certain aspects within the experimental process in order to make it more qualitative. We obtained our regolith from the company The Martian Garden, and we experimented with vermiculate, organic soil builder, acidifiers, and a variety of plants to observe which seemed to thrive the most in which conditions. There are many facets which we explored that can be implemented in order to reach the desired effect on the class. The experiment provides a way to show the difficulties of growing plants on Martian regolith, which opens a door to discussions on challenges for future missions, composition of the Martian surface, the Martian environment, and the astrophysical history that led to such conditions on Mars.

**Author(s):** Edward Francis Guinan, Scott Engle, Giannina Guzman

**Institution(s):** Villanova University

### **257.06 - Introductory Astronomy Interactives developed with Undergraduates(Juan Cabanela)**

Many introductory astronomy service courses incorporate labs or other interactive components which use web-based activities. Much of the currently available software, either from textbook publishers or astronomy educators such as the Nebraska Astronomy Applet Project, was written using Adobe Flash. Adobe Systems is dropping support for Flash at the end of 2020. This problem hit our service courses particularly hard, with approximately half of our lab activities requiring updates. Faced with this challenge, we exploited the fact that our department has incorporated Python programming into our curriculum for physics majors to come up with a solution. For 10 weeks in Summer 2018, two undergraduates collaborated with a professor to develop 16 replacement web-based activities for these labs. The interactives were written in Python running in Jupyter notebooks and have been made available as open source software. We deployed the interactives to students using The Littlest JupyterHub server. Students simply log into the server and the interactives are executed automatically. We are presenting our interactives as well as a discussion of what we learned to help make this collaboration so productive.

**Author(s):** Samuel Holen, Juan Cabanela, Andrew Lowagie Gordon

**Institution(s):** Minnesota State University Moorhead

### **257.07 - Peer Instruction in Introductory Astronomy(Windsor A. Morgan)**

Think-Pair-Share (TPS) questions help both stakeholders in education: the students who become more invested in their own in-class learning, and the instructors who can gain insight into what their students' understanding is. Also known as "clicker questions" and "ConceptTests", they have come into widespread use in both astronomy and physics classes across the country. They encourage intellectual engagement as well as peer instruction. We have compiled a library of TPS questions that are designed to be used with the OpenStax textbook Astronomy but may also be used for any introductory astronomy course and in conjunction with any textbook. We describe the TPS library, tell you how to access it, and how to implement the library in your classes.

**Author(s):** Windsor A. Morgan, Timothy F. Slater,

**Institution(s):** Dickinson College, Center for Astronomy & Physics Education Research, University of Wyoming

### **258 - Supernovae -- Posters**

#### **258.01 - Investigating Hydrogen Loss Preceding Type Ib/c Supernovae(Madelaine Griesel)**

Because the most massive stars show no signs of hydrogen when they explode, they must have lost their outer envelope of hydrogen prior to the explosion. If it was expelled, we expect to see late-time emission when the explosion shock wave catches up with the ejected material. The interaction of the supernovae

shock wave and this material would excite the material, which would then emit radiation, some of which would be detectable in the form of an H $\beta$  emission line. As a continuing effort in a long-term observational survey, we use the Harlan J. Smith 2.7m telescope at the McDonald Observatory in Fort Davis, Texas, to observe supernovae that were discovered as hydrogen-poor. Our observations take place years to decades after the supernovae were discovered, and we look for late-time hydrogen emission, which would signal that interaction between the shock wave and previously cast-off hydrogen is taking place. Gathering data about the frequency of occurrence and the time scale of interaction will help us to better understand the end of a massive star's life and the mechanism of mass loss in a star prior to the supernova explosion. We present results from our ongoing survey.

**Author(s):** David Pooley, Jozsef Vinko, Craig Wheeler, Madelaine Griesel

**Institution(s):** Trinity University, University of Texas at Austin, Konkoly Observatory

### **258.02 - Evidence of Helium Emission Provides Progenitor Constraints in Type Iax Supernovae(Wynn Vicente Jacobson-Galan)**

Type Iax supernovae (SNe Iax) are thermonuclear stellar explosions involving a white dwarf star in a binary system. Similar their common cousins, Type Ia supernovae, SNe Iax are distinguished by lower energy output and observed luminosities. Of the ~ 50 known objects in this subclass, prominent helium emission lines have been detected in the spectra of two SNe Iax: SN 2004cs and SN 2007J. The presence of He I in these objects supports a single degenerate model involving a white dwarf star accreting mass from a larger, helium star companion. In an effort to validate such a model, we have performed direct spectroscopic modeling of 25 SNe Iax using spectral synthesis code SYNAPPS. However, based on the spectral modeling of the rest of the sample, we find no obvious helium features in other SNe Iax at early times. We have examined the late-time (> 100d) spectra of 10 SNe Iax for evidence of helium emission, and have placed limits on the amount of stripped helium mass remaining in the system. The lack of prominent helium emission in a fraction of sampled SNe Iax may be the result of helium luminosities below the level of spectral detection. Furthermore, the limited presence of helium in observed SNe Iax could potentially be explained by helium novae eruptions, which only occur in a fraction of binary systems comprised of a white dwarf and helium star.

**Author(s):** Wynn Vicente Jacobson-Galan, Rollin Thomas, Charles Kilpatrick, Ryan Foley, Shawfeng Dong, Josiah Schwab  
**Institution(s):** University of California, Santa Cruz, Lawrence Berkeley Labs

### **258.03 - Evolution of Helium Star - White Dwarf Binaries Leading up to Thermonuclear Supernovae(Tin Long Sunny Wong)**

We perform binary evolution calculations on helium star - carbon-oxygen white dwarf (CO WD) binaries using the one-dimensional stellar evolution code MESA. This channel may contribute significantly to thermonuclear supernovae at short delay times. We examine the thermal-timescale mass transfer from a 1.1 - 2.0  $M_{\odot}$  helium star to a 0.90 - 1.05  $M_{\odot}$  CO WD for initial orbital periods in the range 0.05 - 1 day, which may produce a thermonuclear supernova, helium novae, a helium star - oxygen-neon WD binary, or a detached double CO WD binary. Our time-dependent calculations resolving the stellar structures of both binary components allow accurate distinction between the eventual formation of a thermonuclear supernova and that of an ONe WD. Furthermore, we investigate the effect of a slow WD wind which implies a specific angular momentum loss from the binary that is larger than typically assumed. We find that this does not significantly alter the region of parameter space over which systems evolve toward thermonuclear supernovae. Our determination of the correspondance between initial binary parameters and the final outcome informs population synthesis studies of the contribution of the helium donor channel to thermonuclear supernovae. In addition, we constrain the orbital properties and observable stellar properties of the host binaries of thermonuclear supernovae and helium novae.

**Author(s):** Tin Long Sunny Wong, Enrico Ramirez-Ruiz, Josiah Schwab

**Institution(s):** University of California, Santa Cruz, Niels Bohr Institute

### **258.04 - Solving a Simple Model for Self-Similar Stellar Collapse(David Pochik)**

The iron core of a massive star is supported by degenerate relativistic electron pressure. As a result, the collapse of the core, initiating a core collapse supernova, exhibits the behavior of a simpler, model system: the self-similar, homologous collapse of an ideal fluid with a polytropic equation of state  $P = \hat{\rho}^{\hat{\gamma}}$  and adiabatic index  $\hat{\gamma} \sim 4/3$ , whose solution can be obtained semi-analytically. In turn, this solution provides a significant test for supernova codes. Nonetheless, despite the simplifications, obtaining the solution for such a relevant model problem is nontrivial. We solve the Euler equations of continuity and momentum in spherical symmetry using the polytropic equation of state  $P = \hat{\rho}^{\hat{\gamma}}$ , the hydrodynamic variables, and the non-inertial frame of reference defined by Amos Yahil (1982). The effective adiabatic index  $\hat{\gamma}$  for this homologous solution set lies within the range of  $6/5$  to  $4/3$ . The hydrodynamic variables are functions of the unitless parameter  $X$  only, so the equations of continuity and momentum are reduced to two, coupled ordinary differential equations. Moreover, the wind velocity, which is defined in the non-inertial reference frame, propagates at subsonic speeds until  $X \sim 2.39$ , where it becomes supersonic. This sonic point generates

a singularity in the coupled ODE's during numerical integration, so the data is linearly approximated around this region to allow calculations through the sonic point, avoiding an indeterminate form. Implementing the forward Euler method for numerical integration and using a linear approximation around the sonic point yields a smooth solution set that models stellar collapse in one dimension. As intended, these solutions agree with Yahil's and they hold for various values of  $I^3$ . Given these 1D homologous collapse solutions, we use them to benchmark our Thornado core collapse supernova development test suite.

**Author(s):** Anthony Mezzacappa, Nick Roberts, Eirik Endeve, David Pochik, Kristopher Andrew

**Institution(s):** University of Tennessee, University of Kentucky, Oak Ridge National Laboratory

### **258.05 - Signatures of Bi-Modality in Nebular Phase Type Ia Supernova Spectra: Indications of White Dwarf Collision Progenitors(Patrick J Vallely)**

We present spectroscopic observations of 16 nebular phase SNe Ia, and after an exhaustive search of available archival data for comparable events, include an additional ~70 SNe in our sample. We identify compelling evidence for bi-modal velocity distributions among  $^{56}\text{Ni}$  decay products in ~10 of these spectra, indicative of explosions generated through the collision (not merger!) of two white dwarfs. We find that the peak  $M_V$  of events with bi-modal velocity components are systematically lower than events without these signatures by approximately -0.3 mag. This provides enticing evidence that the WD-WD collision progenitor channel may be responsible for producing a considerable fraction of the observed low-luminosity SNe Ia population, and merits further theoretical and observational work.

**Author(s):** Subo Dong, Benjamin Shappee, Patrick J Vallely, Michael Tucker, Krzysztof Stanek

**Institution(s):** The Ohio State University, University of Hawaii, Kavli Institute for Astronomy and Astrophysics

### **258.06 - Spectral divergence of the Type Iax Supernova SN 2014dt(Yssavo Camacho-Neves)**

Type Ia Supernovae (SN Ia) have been instrumental cosmological standard candles that led to the discovery of the accelerated expansion of the Universe. Yet, the progenitors and explosion mechanism of these important and powerful transient events remain elusive. Members of the recently categorized Type Iax (SN Iax) class may be able to constrain the models and aid in the physical interpretation of SN Ia observables. We present optical spectroscopy of SN 2014dt, a SN Iax in the nearby galaxy M61 that was the focus of extensive observations. Using a wide range of epochs, we analyze the spectral evolution of SN 2014dt and compare it to the evolution of normal SN Ia. We find that the spectral evolution of SN 2014dt begins a "divergence phase" from normal SN Ia around

100 days after peak brightness. We also generate synthetic spectra of SN 2014dt using TARDIS and SYNAPPS for a more quantitative analysis of this "divergence phase".

**Author(s):** Saurabh Jha, Curtis McCully, Barnabas Barna, Ryan Foley, Yssavo Camacho-Neves

**Institution(s):** Rutgers, The State University of New Jersey, European Southern Observatory, University of Szeged, Las Cumbres Observatory, University of California, Santa Cruz, University of California, Santa Barbara

### **258.07 - The relationship between photospheric velocity and color in type-Ia supernovae(Kyle Dettman)**

We search for a "velocity-color relationship" for type-Ia supernovae (SN Ia) using data from the Foundation Supernova Survey. We re-analyze previously published data using new methods and confirm the original results showing that SN Ia with high ejecta velocities (Si II line velocity more than 11800 km/s) are intrinsically redder than those with lower ejecta velocities. However, we do not reproduce this finding in the new Foundation SN Survey data. We reconcile these seemingly contradictory conclusions by investigating the velocity-color relationship in different passbands. We conclude that the choice of filters observed or included in the light curve fit has a significant effect on derived SN Ia parameters, with potentially important impacts on future SN surveys.

**Author(s):** Charles Kilpatrick, Ryan Foley, Angela Schultz, David Jones, Elizabeth Johnson, Matthew Siebert, Armin Rest, Daniel Scolnic, Saurabh Jha, Yen-Chen Pan, Kyle Dettman, Dave Coulter, Robert Kirshner

**Institution(s):** Rutgers University, University of Chicago, University of California, Santa Cruz, Villanova University, Space Telescope Science Institute, National Astronomical Observatory of Japan, Harvard-Smithsonian Center for Astrophysics, Institute for Astrono

### **258.09 - The double-peaked radio light curve of supernova PTF11qej- Evidence for an off-axis jet?(Nipuni Palliyaguru)**

We present continued radio and X-ray follow-up observations of PTF11qej, a highly energetic broad-lined Type Ic supernova (SN), with a radio peak luminosity comparable to that of the gamma-ray burst (GRB) associated SN 1998bw. The latest radio observations, carried out with the Karl G. Jansky Very Large Array (VLA), extend up to ~5 years after the PTF11qej optical discovery. The radio light curve shows a double-peak profile, possibly associated with density variations in the circumstellar medium (CSM), or with the presence of an off-axis GRB jet. Radio modeling of the second peak within the CSM interaction scenario requires a flatter density profile and an enhanced progenitor mass-loss rate compared to the first peak. While radio data alone cannot rule out an off-axis GRB powering the second radio peak, the derived GRB parameters are somewhat

unusual compared to typical values found for cosmological long GRBs. Our Chandra X-ray observations carried out during the second radio peak are compatible with the off-axis GRB hypothesis, within the large measurement errors. We further discuss the possibility of unambiguously confirming or ruling out the off-axis GRB jet scenario with VLBI direct size measurements and the possibility of utilizing polarization observations to probe the post-shock magnetic field structure.

**Author(s):** Nipuni Palliyaguru, Alessandra Corsi

**Institution(s):** Arecibo Observatory, Texas Tech University

### **258.11 - The Luminosity Comparison between Type Ia Supernovae 2011by and 2011fe(Xiaosheng Huang)**

Type Ia supernovae (SNe~Ia) that are spectrophotometric “twins” - with spectral features and colors well-matched during the photospheric phase - have been shown to have a per-object RMS scatter of their peak luminosity in the 0.07 - 0.08 mag range (Fakhouri et al. 2015), or ~0.11 mag for a pair of SN twins. Foley et al. (2018) reported that the spectral features of SN 2011by are well matched to SN 2011fe but that the peak luminosities of these two SNe Ia differ by ~0.34 mag. Using the self-consistent, multi-epoch, spectrophotometric observations of these two SNe spanning 3300 - 9200 Å by the Nearby Supernova Factory (SNfactory), we carry out a phase-matched comparison across seven epochs of SN 2011by and SN 2011fe (which has almost no host galaxy extinction and is treated as the template), after Milky Way (MW) extinction correction. We find that for SN 2011by 1) the host galaxy total-to-selective extinction ratio  $R_V$  is unusually, but not unacceptably, high, compared with observations of dust extinction in the MW and other galaxies; and 2) the color excess  $E(B-V)$  varies between zero and ~0.035 mag. In contrast to the small  $E(B-V)$ , strong host galaxy sodium absorption has been identified across multiple epochs, as well as a possible interstellar diffuse band feature for at least one epoch. It is not clear whether the source for the difference in color evolution between these two SNe is intrinsic or due to the effects of dust, although given the power spectrum of interstellar medium the latter is highly improbable (Huang et al., 2017). However, empirically, such a pair is rare and is identifiable. Even though the color difference between these two SNe may not be constant, taking into account the dust extinction, we find their luminosity difference to be consistent with the expectation for spectrophotometric “twins.”

**Author(s):** Xiaosheng Huang,

**Institution(s):** University of San Francisco, Lawrence Berkeley National Laboratory Contributing Team(s): Nearby Supernova Factory

### **258.12 - I Ib or Not I Ib: The Photometry of Type I Ib Supernovae(Katya Leidig)**

Type I Ib supernovae (SN I Ib) are a type of core-collapse supernova, meaning they result from the explosion of massive stars, and are classified by their spectra, which evolve from

being dominated by Balmer hydrogen lines to helium lines. This unique spectral evolution is thought to be due to partial stripping of a hydrogen rich envelope from the event's progenitor. With the rapid increase of supernova detections in the past decade, more multi-wavelength photometric data is available than ever before, including data from the Swift Ultra Violet Optical Telescope (UVOT) in six ultraviolet and optical filters. Here we analyse the photometric light curves of type I Ib supernovae, focusing on the UV and visible bands. This analysis will be able to aid astronomers in predicting the detectability of supernovae at large distances where the UV bands are redshifted to optical wavelengths, as well in the classification of type I Ib supernovae.

**Author(s):** Katya Leidig, Peter Brown

**Institution(s):** Boston University, Texas A&M University

### **258.13 - A Circumstellar Shell around a Superluminous Supernova Revealed in a Light Echo(Ragnhild Lunnan)**

Superluminous supernovae (SLSNe) are a rare class of transients with peak luminosities 10-100 times those of normal core-collapse and Type Ia SNe, and whose progenitors and energy sources are still debated. I will report on a surprising result from a late-time spectroscopic survey of SLSNe: the discovery of a shell of circumstellar material (CSM) around a superluminous supernova, revealed by both absorption and subsequent re-emission in Mg II from the shell, in an “echo” of the SN light. The blueshift of the absorption lines allows us to measure the velocity of the CSM shell, while the evolution (and eventual fading) of the emission lines directly constrains the size of the shell. While pre-supernova mass loss is not uncommon in massive stars, this kind of observation is nearly unique, with the closest observed analogue being the ionization of the ring around SN1987A by the supernova flash. I will discuss both the circumstances that made it observable in this particular instance, and the implications for superluminous supernova progenitors and mass loss mechanisms. In this case, the high shell velocity (~3000 km/s) and implied time of the eruption (~30 years prior to explosion) may point to a pulsational pair-instability origin.

**Author(s):** Ragnhild Lunnan, Claes Fransson, Paul Vreeswijk, Stan Woosley

**Institution(s):** Stockholm University, UC Santa Cruz, Weizmann Institute of Science Contributing Team(s): Intermediate Palomar Transient Factory Collaboration

### **258.14 - The Age Evolution of the Radio Morphology of Supernova Remnants(Jennifer Nicole Stafford)**

Recent hydrodynamical models of supernova remnants (SNRs) demonstrate that their evolution depends heavily on the inhomogeneities of the surrounding medium. As SNRs expand, their morphologies are influenced by the non-uniform and turbulent structure of their environments, as reflected in their

radio continuum emission. In this paper, we measure the asymmetries of 22 SNRs in 1.4-GHz images of the Galactic plane from the Karl G. Jansky Very Large Array and compare these results to the SNRs' radii, which we use as a proxy for their age. We find that larger (older) SNRs are more elliptical/elongated and more mirror asymmetric than smaller (younger) SNRs, though the latter vary in their degrees of asymmetry. This result suggests that SNR shells become more asymmetric as they sweep up the interstellar medium (ISM), as predicted in hydrodynamical models of SNRs expanding in a multi-phase or turbulent ISM.

**Author(s):** Jennifer Nicole Stafford, Laura A. Lopez

**Institution(s):** The Ohio State University

### **258.15 - Investigating the Sample-Dependence of the Host Galaxy Bias with $\sim 1500$ Nearby Type Ia Supernovae Used for Cosmological Analyses(Ravi Gupta)**

It is now well-established that conventional Type Ia supernova (SN Ia) light-curve standardization techniques leave residual correlations with properties of the host galaxy. However, various studies have shown that the strength and direction of these correlations depend on the method used and SN sample being analyzed. We collect a large sample of  $\sim 1500$  spectroscopically-confirmed, nearby (median  $z \approx 0.03$ ) SNe Ia that have been used in the past for cosmological analyses in order to gain a coherent understanding of these effects and how their appearance is influenced by sample selection and methodology. We assemble a large set of multi-wavelength imaging around each SN spanning the ultraviolet to infrared, identify the host galaxy in optical images, and perform matched-aperture photometry to obtain global magnitudes of these SN hosts. We generate a custom set of 150,000 Flexible Stellar Population Synthesis models which we use to fit this photometry and derive properties such as host-galaxy stellar mass, specific star formation rate, and massed-weighted age. We examine correlations between these properties and SN properties in an effort to better understand the nature of the host galaxy bias on SN luminosities. As there is evidence that environmental effects are stronger closer to the SN, in a future study we will extract physical properties of the region within a few kiloparsecs of the SN location and investigate their effects on these same SNe. We also intend to expand the range of methods used to infer host galaxy properties.

**Author(s):** Greg Aldering, Brian Hayden, Saul Perlmutter, David Rubin, Jakob Nordin, Mickael Rigault, Marek Kowalski, Ravi Gupta, Alex Kim, Yannick Copin

**Institution(s):** Lawrence Berkeley National Laboratory, CNRS - INP3, Space Sciences Laboratory, Université Claude Bernard Lyon, Humboldt Universität zu Berlin, Space Telescope Science Institute

### **258.16 - The Global Supernova Project(Dale Howell)**

The Global Supernova Project (GSP) is a three year program to obtain lightcurves and spectra for 500 supernovae of all types. It is a Key Project at Las Cumbres Observatory, a global network of 21 robotic telescopes, placed around the globe, distributed in longitude and hemispheres so that it is always dark somewhere. Supplemental data is obtained at Keck, Gemini, Swift, and other facilities. Here we present some of the latest results relating to the progenitors of Type Ia and core-collapse supernovae.

**Author(s):** Dale Howell

**Institution(s):** Las Cumbres Observatory / UCSB

Contributing Team(s): The Global Supernova Project

### **258.17 - Explosions in our Back Yard: A Nearby Supernova Search at the Thacher Observatory(Yao Yin)**

We are conducting a new supernova survey at the Thacher observatory toward  $\sim 1200$  galaxies closer than 40 Mpc selected from the GLADE catalog. Template and science images have been collected nightly since the summer of 2018. We present the details and strategy of the search, and also the preliminary results of our automated search. We use a machine learning algorithm trained on a hybrid dataset including images from our survey and simulated detections so that candidate transient events can be identified in an automated fashion. We report on the efficiency and accuracy of our search, which is improving as we accumulate ever more images and training data.

**Author(s):** Charles Kilpatrick, Ryan Foley, Jon Swift, Yao Yin, César Rojas-Bravo, Dave Coulter, Draco Reed

**Institution(s):** The Thacher School, UC Santa Cruz

### **258.18 - Survey Statistics for the Nearby Supernova Factory Data Release(Kara Ponder)**

The Nearby Supernova Factory (SNfactory) began taking integral field spectroscopy of transients in 2004. Since then we have gathered at least one spectrum of over 1000 supernovae and have spectrophotometric time series of over 300 Type Ia Supernovae (SNe Ia). This effort has produced a rich dataset of thousands of spectra and over 300 reconstructed light curves in 5 passbands. A self-consistent reduction of our hundreds of spectrophotometric standard star observations achieves an RMS with respect to CALSPEC of 3-7 mmag, consistent with the calibration accuracies of well-calibrated imaging surveys such as SDSS and PanSTARRS. The spectrophotometric time series have already been used to discover that SNe Ia can be "twinning" to reduce statistical and systematic errors in cosmological distances and have been integral in detecting that conventional SN Ia standardization fails to remove systematic errors related to the SN natal environment and other characteristics important for cosmology and supernova physics. We will show statistics from our latest data reduction, which includes improvements from implementing the Binary Offset Effect, and

examples of our data with some illustrative validation tests. We plan to release this improved and expanded dataset on our own website in mid-2019 and help integrate them into other popular websites that aggregate supernova data. The supernova surveys from SNfactory are complete; however, the integral field spectrograph built for this project (SNIFS) continues to be used by the community to further other research such as asteroids, variable stars, exoplanets, tidal disruption events, and binary active galactic nuclei.

**Author(s):** Kara Ponder

**Institution(s):** University of California Berkeley  
**Contributing Team(s):** The Nearby Supernova Factory

### **258.19 - Neutrino Driven Convection in 15 M $\odot$ Supernova Models at Different Spatial Resolutions(Chloe Keeling)**

Neutrino driven convection is an essential process in reviving the stalled shock in core-collapse supernovae. We analyze the convective properties of a 15 M $\odot$  core-collapse supernova in 3D at 3 different spatial resolutions simulated using the neutrino radiation hydrodynamics code CHIMERA. We seek to understand the impact of spatial resolution on neutrino-driven convection in the gain region before the shock is revived. We examine the relationship between spatial resolution and convective energy transport properties such as convective flux, kinetic flux, buoyant work, and expansion work at various times during the shock revival period. We compare and contrast the convection profiles generated with those produced by other codes with different neutrino transport schemes.

**Author(s):** Eric J. Lentz, Chloe Keeling, Stephen W. Bruenn, J. Austin Harris, William Raphael Hix, Konstantin Yakunin, Eirik Endeve, O. E. Bronson Messer, Anthony Mezzacappa, Jordi Casanova, Pedro Marronetti, John M Blondin

**Institution(s):** University of Tennessee-Knoxville, North Carolina State University, Oak Ridge National Lab, National Science Foundation, Florida Atlantic University

### **258.20 - Extending Core-Collapse Supernova Simulations: from the Onset of Explosion to Shock Breakout(Michael Alexander Sandoval)**

As well as contributing to star formation, core-collapse supernovae (CCSNe) are the richest astrophysical producers of heavy elements. As the explosion progresses, the evolution of the nuclear species synthesized in the early-time of the explosion is strongly coupled with the hydrodynamics. Hydrodynamic instabilities, specifically Rayleigh-Taylor instabilities, affect the distribution of material most strongly. Our aim is to understand how the instabilities in the central engine drive inhomogeneities in the ejecta, leading to the observed elemental distribution. To achieve this understanding, and to accurately replicate the observed asymmetries, multi-dimensional simulations of the supernova explosion must be carried beyond the initial seconds where the central engine

operates and the nucleosynthesis occurs. We have therefore performed simulations with the FLASH code that follow the progression of the explosion throughout the entire star, starting from neutrino-radiation hydrodynamic simulations of the first seconds performed with the CHIMERA code. At present, we have performed two-dimensional and three-dimensional FLASH simulations starting from two-dimensional CHIMERA models of a 9.6 M $\odot$  zero-metallicity progenitor, and a 10 M $\odot$  solar metallicity progenitor, all simulated until shock-breakout while tracking the 160 nuclear species evolved in the CHIMERA models. We are presently exploring differences that result when three-dimensional CHIMERA models are used as the initial conditions.

**Author(s):** William Raphael Hix, Eric J. Lentz, J. Austin Harris, O. E. Bronson Messer, Michael Alexander Sandoval

**Institution(s):** University of Tennessee, Oak Ridge National Laboratory

### **258.21 - Using SNEMO to Simulate Surveys for Supernova Cosmology(Samantha Dixon)**

Type Ia supernovae continue to be one of the best tools for measuring cosmological distances. However, photometric studies of supernovae are currently limited in their use for cosmology by as yet unmodeled dispersion in standardized magnitudes. Recent work by Saunders et al. has developed SNEMO, a new empirical model of Type Ia supernova spectral time series that captures more of the spectral diversity responsible for this remaining dispersion than can be captured by traditional light-curve-based SED models. We present a continuation of this work, introducing software tools that can be used to fit both photometric and spectroscopic observations, as well as to simulate these types of observations using SNEMO as the underlying SED model. Using these tools, we explore new analyses that are uniquely enabled by this model, including evaluations of our ability to find spectroscopic twins and to probe population evolution with redshift. These analyses will be an important piece of the puzzle in assessing the cosmological impact of various survey strategies for upcoming projects like WFIRST and LSST.

**Author(s):** Samantha Dixon,

**Institution(s):** University of California, Berkeley, Lawrence Berkeley National Lab  
**Contributing Team(s):** Nearby Supernova Factory, Perlmutter+ WFIRST Supernova Science Investigation Team

### **258.22 - SNEMO: Demonstration and Applications of a New Empirical Model for Type Ia Supernovae(Clare Myers Saunders)**

SNEMO is an empirical model for Type Ia supernovae based on a set of spectral time series templates. It aims to improve upon the models that are currently standard by increasing the diversity of supernova behavior explained by the model, and also by being trained on a large set of spectrophotometric

spectral time series from the Nearby Supernova Factory. Its capability when used to fit spectral time series was shown in Saunders et al. 2018. Here we demonstrate its performance on outside data sets, using either spectral or photometric data. The potential of SNEMO for improving standardization of the supernova peak magnitude is shown. We also discuss perspectives for using machine learning or other non-linear techniques to standardize supernova magnitudes, utilizing the increased feature space of the model.

**Author(s):** Clare Myers Saunders

**Institution(s):** Laboratoire de Physique Nucléaire et de Hautes Énergies  
**Contributing Team(s):** The Nearby Supernova Factory

### **258.23 - Classification of Supernova Spectra Using Machine Learning Techniques(Ouail Kitouni)**

Type Ia supernovae are transient astronomical events caused by the explosion of a white dwarf star. They are extremely bright "standard candles;" their intrinsic luminosity can be estimated and used to measure distances on cosmological scales. Although most Type Ia supernovae are found with imaging surveys, it is very important to also measure their spectra (and redshifts) in order to calibrate their estimated distances. I have investigated machine learning techniques to search for Type Ia supernovae in spectroscopic data from SDSS as part of a larger search for unusual transient events. I will report on the relative merits of different types of neural networks and discuss their suitability for finding Type Ia supernovae (as well as other unusual transients) in the next generation of spectroscopic surveys.

**Author(s):** Ouail Kitouni

**Institution(s):** University of Rochester

### **258.24 - RAPID: Deep-learning for Prompt Transient Discovery(Gautham Narayan)**

RAPID (Real-time Automated Photometric Identification) is a cutting-edge deep learning algorithm capable of automatically classifying transients independent of the phase coverage of the light curve. Unlike traditional feature-based classifiers, RAPID has been designed as a Recurrent Neural Network (RNN) with Long-Short Term Memory (LSTM) gates. This enables it to be competitive with techniques such as random forests and gradient boosting when several observations are available, but critically, RAPID can utilize sparse early-time information to classify transient sources as they rise towards maximum. This novel technique enables automated discovery and prioritized follow-up of novel events within a day of explosion. We describe its application to Zwicky Transient Facility data, and quantify its performance on the simulated Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC) dataset.

**Author(s):** Gautham Narayan, Daniel Muthukrishna, Kaisey Mandel

**Institution(s):** Space Telescope Science Institute, University

of Cambridge

### **258.25 - SuperNovae Analysis aPplication (SNAP): Identifying and Understanding the Physics of Supernovae(Amanda Jo Bayless)**

The explosive death of massive stars, known as supernovae (SNe), are responsible for chemically enriching the universe in heavy elements. Presently, we discover ~300 SNe per year. In the 2020s new all sky surveys will be on-line and this will increase to at least 100,000 discovered annually. We will need rapid ways to identify these new transients. Using a decision tree-based machine learning classifier and photometry from the Supernovae Photometric Classification Challenge, we demonstrate that supernovae can be typed as Ia or core-collapse using as few as 5-data points. Additionally, the mechanics and physics of the explosion itself are not solved problems. We need a rapid way to determine the properties of new SNe and a way to compare new models to observations. SNAP is a comparative data base system that contains archived observations, light curve models, and correlation software. We will be able to study SNe events to determine degeneracies in parameters and determine the important physics needed to describe these catastrophic events.

**Author(s):** Jonathan Markel, Amanda Jo Bayless, Chris Fryer, Pete Roming,

**Institution(s):** Southwest Research Institute, UT Austin, UTSA, LANL

### **258.26 - Using Manifold Learning to Improve Cosmological Distance Measurements with Type Ia Supernovae(Kyle Robert Boone)**

With the Nearby Supernova Factory dataset of hundreds of Hubble-flow type Ia supernovae, we showed that we can identify "twin" Type Ia supernovae by matching their spectral data (Fakhouri, Boone et al. 2015). These pairings provide cosmological distance measurements that are significantly better than traditional lightcurve based alternatives. In this poster, we extend the twins method to embed Type Ia supernovae in a low dimensional parameter space that preserves the twins pairing. We first measure the relative apparent brightnesses among Type Ia supernovae from their spectra near maximum light using a novel Bayesian modeling technique that we call "Reading Between the Lines". We then apply an adapted twinning method to measure pairwise spectral distances between these supernovae, and we use manifold learning techniques to embed the supernovae into a lower dimensional parameter space. This embedding captures the diversity of Type Ia supernovae with fewer components than traditional linear analyses, and we find that it preserves the pairwise spectral distances of the twins method in the embedded space. After determining a supernova's location in the embedded space, we compare it to supernovae which are nearby in that space to estimate both its absolute luminosity



and its effectiveness as a standard candle. We discuss how future surveys such as LSST or WFIRST can take advantage of this method to improve both the statistical and systematic uncertainties of their cosmological distance measurements for Type Ia supernovae.

**Author(s):** Kyle Robert Boone,

**Institution(s):** UC Berkeley, Lawrence Berkeley National Laboratory  
Contributing Team(s): The Nearby Supernova Factory

## **259 - Stars, Cool Dwarfs, Brown Dwarfs -- Posters**

### **259.01 - Is TRAPPIST-1 a Unique M-dwarf Host Star?(Eileen Gonzales)**

TRAPPIST-1 is an M7.5 dwarf that hosts seven rocky earth-size planets, three of which are in its habitable zone. Given the abundance of M dwarfs throughout the Galaxy as well as the ease by which rocky planets might be uncovered around low mass stars with future studies like TESS, an inquiry into the uniqueness of the nature of the TRAPPIST-1 system is particularly relevant today. TRAPPIST-1 is classified as a field dwarf with kinematics that suggest it is an “old disk” star. However, the near infrared spectrum of TRAPPIST-1 exhibits a subtle peculiarity that causes it to be classified as an intermediate gravity (INT-G) object using spectral indices. To understand this subtle peculiarity as well as to place TRAPPIST-1 in context with other nearby M dwarfs, we have created a distance-calibrated spectral energy distribution (SED). Combining the most recent parallax measurement with optical and infrared spectra and all available photometry, we re-evaluate bolometric luminosity and effective temperature. We compare the resultant SED to a sample of old, young, and field age objects of similar properties. Using a FIRE echelle spectrum, we also investigate the near-infrared Y, J, H, and K bands to compare observables linked to gravity, atmosphere, metallicity and age effects.

**Author(s):** Eileen Gonzales, Jacqueline K Faherty, Andrew McWilliam, Johanna Teske, Jonathan Gagné

**Institution(s):** CUNY Graduate Center, American Museum of Natural History, Hunter College, Carnegie

### **259.02 - Binaries or Variables? Disentangling the signatures of blended-light spectra(Daniella Bardalez Gagliuffi)**

Time-resolved photometry and spectroscopy of brown dwarfs has revealed variability in their atmospheres, caused by heterogeneous cloud coverage across different pressure levels in their photospheres. Characterizing the vertical structure of brown dwarf atmospheres and its temporal variability is an essential stepping stone towards understanding the atmospheric processes occurring in exoplanets. The spectral signatures arising from heterogeneous cloud coverage are similar to those caused by unresolved binarity from components with different spectral types in blended-light

spectral binary systems. False positives in our search for spectral binaries have been identified as single, photometrically variable objects, yet currently there is no technique to identify variable objects without photometric monitoring. We present a status update on our optimization of the spectral binary technique to identify the statistical signatures of single, photometrically variable objects from a single low-resolution, near-infrared spectrum.

**Author(s):** Kelle Cruz, Daniella Bardalez Gagliuffi, Jacqueline K Faherty, Rebecca Oppenheimer, Emily Rice, Elena Manjavacas

**Institution(s):** American Museum of Natural History, College of Staten Island, University of Arizona, Hunter College

### **259.03 - The POKEMON Speckle Survey of Nearby M-dwarfs(Catherine Clark)**

The POKEMON (Pervasive Overview of Companions of Every M-dwarf in Our Neighborhood) survey of nearby M-dwarfs intends to inspect, at diffraction-limited resolution, every low-mass star out to 15pc, along with selected additional objects to 25pc. The primary emphasis of the survey is the detection of low-mass companions to these M-dwarfs for refinement of the low-mass star multiplicity rate. Given the priority these targets will have for upcoming exoplanet studies using TESS and JWST - and the degree to which initially undetected multiplicity has affected Kepler results - a comprehensive survey of our nearby low-mass neighbors will produce a homogenous, complete catalog of fundamental utility. Prior knowledge of those secondary objects - or robust non-detections, as will be captured by this survey - will help immediately clarify the nature of exoplanet transit detections from these current and upcoming missions. POKEMON is using Lowell Observatory's 4.3-m Discovery Channel Telescope (DCT) with the Differential Speckle Survey Instrument (DSSI) speckle camera, along with the NN-Explore Exoplanet Stellar Speckle Imager (NESSI) speckle imager on 3.5-m WIYN; the survey takes advantage of the extremely rapid observing cadence rates possible with WIYN and (especially) DCT. The current status and results are from the first 20+ nights of observing.

**Author(s):** Elliott Horch, Gerard van Belle, Catherine Clark, Kaspar von Braun

**Institution(s):** Northern Arizona University, Southern Connecticut State University, Lowell Observatory

### **259.04 - The Backyard Worlds: Planet 9 Citizen Science Project -- Status and Discoveries(Dan Caselden)**

For very cold substellar and planetary mass objects, the immediate solar neighborhood and outer reaches of our own solar system have yet to be fully explored. To complete our census of the Sun's closest and coldest neighbors, the Backyard Worlds: Planet 9 citizen science project is searching for previously unnoticed nearby objects via a crowdsourced full-sky

motion survey. Launched in early 2017 through the Zooniverse platform, Backyard Worlds displays time-series blinks of Wide-field Infrared Survey Explorer (WISE) images to online volunteers. With its unique full-sky sensitivity at 4.6 microns, WISE provides an unrivaled capability to pinpoint the coldest brown dwarfs and even hypothetical distant planets potentially orbiting the Sun. By visually inspecting a set of coadded mid-infrared images spanning the entire WISE operational lifetime, Backyard Worlds participants can detect moving objects to depths far fainter than was possible with previous WISE-based motion searches. Backyard Worlds now counts over 50,000 registered volunteers and has received contributions from more than 100,000 unique participants representing all 50 US states and 167 countries worldwide. As a result, Backyard Worlds is delivering a trove of exciting discoveries: over 1,000 new motion-confirmed brown dwarf candidates later than type M have been identified. A wide-ranging Backyard Worlds follow-up program is underway, including Spitzer, HST, and Keck observing campaigns. To date, ~50 newly discovered brown dwarfs have been spectroscopically confirmed, with a near 100% true positive rate. Backyard Worlds is forecast to roughly double the number of known brown dwarfs later than type L5, and photometric follow-up thus far indicates that Backyard Worlds will ultimately yield an order unity increase in the sample of known Y dwarfs.

**Author(s):** Aaron Michael Meisner, John Wisniewski, Sarah E. Logsdon, Jonathan Gagné, Adam Schneider, Jacqueline K Faherty, Laura Trouille, Daniella Bardalez Gagliuffi, Adam Burgasser, Katelyn Allerso, Michaela Beth Allen, Dan Caselden, Steven Silverberg, Joseph Fil

**Institution(s):** University of California, San Diego, oBucknell University, University of Oklahoma, Backyard Worlds, NASA/GSFC, National Optical Astronomy Observatory, Arizona State University, American Museum of Natural History, The Adler Planetarium, Zooniverse, &

### 259.05 - Forward-Modeling Analysis of Late-T Dwarf Atmospheres(Zhoujian Zhang)

Understanding the appearance and evolution of giant planets and brown dwarfs requires characterization of ultracool atmospheres. Late-T dwarfs provide convenient laboratories for atmosphere characterization, given that their clouds condensed below the photospheres at such cold temperatures (~500-1000 K). We are performing a uniform forward-modeling analysis for over 20 late-T ( $T_{\text{eff}} \leq 700$  K) dwarfs with parallaxes using the Sonora models (Marley et al. in prep) and the Starfish code (Czekala et al. 2015). We present the derived effective temperatures, surface gravities, and temperature-pressure profiles of our sample and comparisons with retrieval analysis and evolutionary models. Combining the answers from atmospheric models with both forward-modeling and retrieval techniques, as well as the evolutionary models, will lead to a better understanding of planetary and brown dwarf atmospheres.

**Author(s):** Zhoujian Zhang, William M J Best, Mark Marley, Michael R. Line, Michael C. Liu

**Institution(s):** Institute for Astronomy, University of Hawaii at Manoa, Arizona State University, NASA Ames Research Center

### 259.06 - Data-driven Physical Parameters for 10,000+ M dwarfs in APOGEE(Jessica Lua Birky)

The Cannon is a flexible, data-driven spectral-modeling and parameter-inference framework, demonstrated on high-resolution, near-infrared SDSS-IV APOGEE spectra of giant stars to estimate stellar labels (Teff,logg,[Fe/H], and detailed abundances) to precisions higher than the APOGEE model-grid pipelines. The lack of reliable atmospheric models in the near infrared for temperatures cooler than ~3550 K motivates the extension of this approach to M-dwarf stars, but with calibrated training labels from optical surveys that overlap with APOGEE. Training two models (one for temperature/metallicity and one for spectral type) spanning temperatures  $2860 < T_{\text{eff}} < 4130$  K, metallicities  $-0.5 < [\text{Fe}/\text{H}] < 0.5$  dex, and classifications Mo to M9, we demonstrate predictive accuracies (in cross-validation) of 77 K, 0.09 dex and 0.9 subtypes, respectively. We apply our models to 10,311 sources selected from the overlap of APOGEE and Gaia DR2, and compare our Cannon-derived Teff against color-temperature relations, finding better agreement than pipeline measurements, and compare [Fe/H] against isochrone models in Gaia color-magnitude space. Finally we use empirically-calibrated relations to estimate radii from K-band absolute magnitudes and Cannon temperatures.

**Author(s):** Andrew Mann, Adam Burgasser, David W Hogg, Jessica Lua Birky,

**Institution(s):** UC San Diego, New York University, Max Planck Institute for Astronomy, University of North Carolina, Chapel Hill

### 259.07 - VALIDATING THE C I 5052 Å / Mg II 4481 Å EQUIVALENT WIDTH RATIO AS A DIAGNOSTIC FOR F-TYPE LAMBDA BOO STARS(Kwang-Ping Cheng)

The Lambda Boo-type stars are chemically peculiar with up to 2 dex deficiencies of iron-peak elements but near-solar C, N, O, and S abundances. Although a detailed abundance analysis that reveals this abundance pattern is the definitive confirmation of the Lambda Boo characteristic, the rapid rotation of many Lambda Boo stars generally limits how much detail can be derived from an abundance analysis. We have established a straightforward yet reliable way to identify Lambda Boo-type stars using high-resolution spectra. We found that between 6000 K and 8000 K, the C I 5052 Å/Mg II 4481 Å equivalent width ratios of Lambda Boo stars are very different from the C I/Mg II ratios of normal stars and other metal-poor stars. We carried out a detailed abundance analysis of HD 81290, an F2 star with a C I 5052 Å/Mg II 4481 Å equivalent width ratio in the range expected for Lambda Boo-type stars. Our elemental abundance analysis results confirm HD 81290's Lambda Boo-like abundance pattern and demonstrate the utility of our

equivalent width ratio as a diagnostic for cooler F-type Lambda Boo stars.

**Author(s):** James E Neff, Christopher A Romo, Anthony J Giacinto, Dustin M Johnson, Richard Gray, Kwang-Ping Cheng, Erik S Tarbell, Christopher Corbally

**Institution(s):** California State University, Fullerton, Appalachian State University, National Science Foundation, Vatican Observatory

### **259.08 - Backyard Worlds: Planet 9 --- The Coldest Discoveries (Michaela Beth Allen)**

The Backyard Worlds: Planet 9 citizen science project is discovering hundreds of brown dwarfs and low-mass stars in the solar neighborhood by visually identifying moving objects in images from NASA's Wide-field Infrared Survey Explorer (WISE) mission. Among our ~1,000 brown dwarf candidates submitted by citizen scientists at [www.backyardworlds.org](http://www.backyardworlds.org), several dozen are extremely red, appearing in only the WISE 4.6 micron (W2) channel. These reddest candidates may be newly identified members of the Y-dwarf population, the coldest known class of brown dwarfs, which are valuable giant exoplanet analogs and may reside relatively nearby the Sun despite their faint appearance. Using the Gemini, HST, and Spitzer facilities, Backyard Worlds has recently acquired follow-up imaging for many of our latest-type, highest priority brown dwarf candidates which lack near-infrared photometry in the literature. In particular, we obtained J and K band photometry of twelve Y-dwarf candidates and J band only for another five candidates from Gemini North with the NIRI instrument to measure near-infrared colors and to provide improved astrometry. The data will also allow us to rank future spectroscopic targets by how faint they are in the near-infrared relative to the WISE bandpasses. We analyzed the data in IRAF both with the NIRI pipeline provided and via manual reductions; the manual reduction was a better alternative as it allowed more control over input parameters and thus produced cleaner images. This Gemini photometry, as well as our HST and Spitzer imaging data, represent critical steps in confirming and prioritizing the coldest Backyard Worlds discoveries that will likely become targets for future spectroscopy with facilities like HST and JWST.

**Author(s):** Aaron Michael Meisner, John Wisniewski, Sarah E. Logsdon, Adam Schneider, Jacqueline K Faherty, Katelyn Allers, Laura Trouille, Daniella Bardalez Gagliuffi, Adam Burgasser, Jonathan Gagne, Michaela Beth Allen, Dan Caselden, Steven Silverberg, Joseph Fili

**Institution(s):** Backyard Worlds, University of California, San Diego, The Adler Planetarium, Zooniverse, & Northwestern University, Angelo State University, University of Oklahoma, NASA Goddard Space Flight Center, American Museum of Natural History, Arizona State U

### **259.09 - Multi-Resolution Spectral Fitting of T dwarfs (Emily Rice)**

T dwarfs are the coolest fully-populated spectral class (~1300-500 K) and are optimal analogs for the lowest mass directly-imaged exoplanets, like 51 Eridani b. The physical and atmospheric properties of these objects can be inferred via comparison to synthetic spectra from atmospheric models, which provide parameters like temperature, gravity, and metallicity without relying on fraught measurements or estimates of distance, age, or radius. While more amenable to direct observations than exoplanets, T dwarfs are still intrinsically cool and faint and are thus challenging targets for high-resolution spectroscopy, even at infrared wavelengths where their emitted flux peaks. Therefore we are motivated to conduct multi-resolution spectral fits to determine how the precision, accuracy, and consistency of inferred parameters depend on the resolution and wavelength coverage of the observed spectra and to establish optimal procedures for estimating reliable physical and atmospheric properties. The sample will span the T dwarf spectral class to test how dust, which is expected to be a larger contributor to opacity for earlier spectral types, may further complicate the results. This poster presents an overview of the sample, existing observations, atmosphere models, and preliminary results for selected objects.

**Author(s):** Sarah E. Logsdon, Kelle Cruz, Emily C. Martin, Jacqueline K Faherty, Ian S. McLean, Evan Morris, Paige Godfrey, Stephanie T. Douglas, Emily Rice,

**Institution(s):** CUNY College of Staten Island, Slooh, American Museum of Natural History, Harvard-Smithsonian Center for Astrophysics, UC Santa Cruz, UCLA, NASA Goddard Space Flight Center, CUNY Hunter College  
Contributing Team(s): BDNYC, BDSS

### **259.10 - Measuring Rotation Periods and Flare Rates for K2 M Dwarfs (Mark Popinchalk)**

Young stars are usually rapidly rotating and typically have strong magnetic fields. As a star ages it loses angular momentum, in turn decreasing the strength of the magnetic field. The interaction of the magnetic field with the photosphere of a star can lead to dark star spots forming. This can be detected as photometric variability in time series data, allowing for measurement of rotation rates. Additionally, the magnetic fields of M dwarfs also lead to stellar flare activity as rapid bursts of electromagnetic radiation are created by magnetic field lines when they reconnect. These flares are more frequent in M dwarfs due to their long lived magnetic fields while also being more noticeable in the optical as the bright blue emission contrasts with the red cooler photosphere. Rotation is a strong age indicator for solar-type stars as they spin down following a Skumanich decay, however this relationship has not been precisely calibrated for M dwarfs. Additionally, the relationship between flare rate and age should be strong, although it hasn't been studied in detail. We present preliminary measurements of rotation periods and flare rates for a sample of K2 M dwarfs.

We compare rotation period measurements from different detrending pipelines, consider multiple measurement methods, and present our efforts to measure flare distribution. This work is part of a larger project to combine three other age diagnostic indicators to both calibrate the spin-down relation and estimate ages for all objects.

**Author(s):** Kelle Cruz, Ellianna Schwab, Sarah J Schmidt, Jacqueline K Faherty, Rocio Kiman, Ruth Angus, Emily Rice, Mark Popinchalk,

**Institution(s):** CUNY Graduate Center, Leibniz Institute for Astrophysics - Potsdam, American Museum of Natural History, CUNY Hunter College, Center for Computational Astrophysics, UC Berkeley, CUNY College of Staten Island

#### **259.11 - Orbital Architectures of Stellar, Brown Dwarf, and Planetary Companions around Nearby M Dwarfs(Eliot Halley Vrijmoet)**

We present a comprehensive survey of ~300 nearby M dwarf stars in a search for companions of stellar, brown dwarf, and planetary nature orbiting within 10 AU of their hosts. By characterizing the orbital parameters of these solar systems, we will gather clues regarding their construction and evolution. To this end, we seek to identify systems with periods short enough to allow accurate determinations of their orbital periods and companion masses by, for example, defining criteria to identify likely stellar binaries in Gaia Data Release 2. We establish these criteria by first considering the Gaia astrometric parameters and parallax errors for binaries observed with long-term astrometry by the RECONS program at the CTIO/SMARTS 0.9m. We find that an unseen stellar companion is suggested in the DR2 data when the `parallax_error` > 0.40, or when one or more of the following astrometric parameters are fulfilled: `astrometric_gof_al` > 140, `astrometric_excess_noise` > 2.0, and `astrometric_chi2_al` > 10,000. Already, we have found that ~20% of our M dwarfs have stellar companions and ~1% have brown dwarf companions. This effort has been supported by the NSF through grants AST-09008402, AST-1412026, and AST-1715551 and via observations made possible by the SMARTS Consortium.

**Author(s):** Wei-Chun Jao, Todd Henry, Eliot Halley Vrijmoet

**Institution(s):** Georgia State University, RECONS Institute Contributing Team(s): RECONS

#### **259.12 - Carbon Isotopic Ratios in M Dwarfs(Becky Esmeralda Flores)**

M-Dwarf stars are the most abundant stars in the universe, yet their ages, chemical abundances, and other properties are not well known due to their intrinsic faintness and complicated spectra dominated by molecular lines. Determining the formation conditions of M dwarfs could lead to a better understanding of their ages, their evolution, their host planets, and Galactic chemical evolution. We worked to measure the abundance ratio of carbon-12 to carbon-13 ratios to help answer

these problems. With data from the high-resolution IRTF/iSHELL spectrograph (R=75,000), we aim to directly detect carbon 13 in several M dwarf stars. We focus on CO absorption lines in the M band, where carbon monoxide features are 100 times stronger compared to the K band. We do this by comparing to high-resolution model spectra to locate the presence of carbon 12 and carbon 13. From our results, we robustly detect carbon-13 in the M band for the first time in any dwarf star beyond the Sun. Further steps include measuring the carbon ratios and apply them to obtain the ages of our sample and then apply this to a larger sample of M dwarfs to reveal possible trends with other stellar parameters. This study suggests that with higher resolution spectroscopy, carbon isotopic ratios can be detected in M dwarfs and could be used to understand their ages, evolution and the make-up of the universe.

**Author(s):** Becky Esmeralda Flores, Ian Crossfield

**Institution(s):** California State University, Northridge, Massachusetts Institute of Technology

#### **259.13 - Searching for Near-Infrared Spectral Variability of early-L type Brown Dwarfs(Samantha Hudson)**

Near-infrared spectra for five brown dwarfs were obtained by the SOFI instrument on the New Technology Telescope (NTT) in April of 2002 as part of the CLOUDS survey to look for variability in brown dwarf atmospheres (Goldman et al. 2008). This data was not reduced or analyzed for spectral variability at that time. For my REU project, I took this data and created a procedure to reduce the spectra and prepare the data for variability studies. The European Southern Observatory (ESO) provides a data file organizer called Gasagano and a common pipeline library of recipes to facilitate reduction of SOFI data. However, these tools are not maintained and failed halfway through the data reduction, so packages from IRAF were used instead. We present here the data reduction procedure and the future work that could be done on the extracted spectra to search for spectral variability. If successful, this work will add to the growing body of data for brown dwarfs with variable behavior and ultimately help resolve uncertainty regarding general patterns and causes of variability in brown dwarfs across spectral classes.

**Author(s):** Ian Clark, Denise Stephens, Samantha Hudson

**Institution(s):** Hiram College, Brigham Young University

#### **259.14 - Gemini Planet Imager Spectroscopy of the Extremely Red Brown Dwarf Companion HD206893 B(Kimberly Ward-Duong)**

From the Gemini Planet Imager Exoplanet Survey, we present new near-infrared spectroscopy of the brown dwarf HD206893 B, a substellar companion orbiting within the debris disk of an F5V star. New H, K1, and K2 spectra with GPI demonstrate the extraordinary red color of the object, presenting a challenging

atmosphere to model with existing model grids. We present comparison with field and young L-dwarfs to assess whether the NIR spectra are consistent with upper atmosphere sub-micron hazes. Multi-epoch astrometric monitoring of the system suggests a probable semimajor axis of 10 au, well within the estimated disk inner radius of ~50 au. As the second brown dwarf imaged within the innermost region of a debris disk, the properties of this system offer important dynamical constraints for companion-disk interaction and a useful benchmark for brown dwarf and giant planet atmospheric study.

**Author(s):** Kimberly Ward-Duong, Robert De Rosa, Abhijith Rajan, Katherine Follette, Julien Rameau, Jennifer Patience, Alexandra Z Greenbaum, Mark Marley

**Institution(s):** Five College Astronomy Department, Amherst College, Stanford University, Arizona State University, Université de Montréal, Space Telescope Science Institute, NASA Ames Research Center, Amherst College, University of Michigan Contributing Team(s): GPIE

#### **259.15 - Finding age relations for low mass stars using magnetic activity and kinematics(Rocio Kiman)**

M and early-L dwarfs are the coolest and most abundant stars in the Milky Way. They have main sequence lifetimes longer than the current age of the Universe, so they are an ideal group to study stellar population properties across a wide range of ages. Ages of M dwarfs cannot be obtained with the same methods used for solar type stars because stellar evolution models break down for fully convective stars. Therefore, empirical and statistical methods are required. With the Gaia-Cupid project, we seek to obtain ages for M and L dwarfs using multiple age indicators, including magnetic activity, full kinematics and, eventually, rotation periods. We first examine the relationships between these indicators, but plan to ultimately, use hierarchical Bayesian analysis to combine them. We compiled a catalog of over 70,000 M and L-dwarfs based on SDSS spectroscopy that contains spectral type,  $H\delta$  strength, and radial velocities, and is cross-matched to Gaia DR2 for high quality proper motions and parallaxes. The relationship between dispersion in vertical action and magnetic activity shows a monotonically decreasing curve meaning active stars have small vertical action dispersion and inactive stars have high dispersion. This result shows both parameters are correlated with age. By studying this relation for different spectral types, we do not find a dependence with mass. Consequently, we hope to extend the kinematics-age relations to constrain ages of brown dwarfs, a notoriously difficult group of objects to age-date.

**Author(s):** Kelle Cruz, Jacqueline Faherty, Sarah J Schmidt, Rocio Kiman, Ruth Angus, Emily Rice,

**Institution(s):** Graduate Center, CUNY, Leibniz-Institut für Astrophysik - Potsdam (AIP), AMNH, College of Staten Island, Hunter College, Center for Computational Astrophysics, Flatiron Institute Contributing Team(s): BDNYC

#### **259.16 - The Time-Domain Spectroscopic Survey: Orbital Separations of Dwarf Carbon Stars(Benjamin Richard Roulston)**

Dwarf carbon (dC) stars, main sequence stars showing carbon molecular bands, are an oxymoron since only AGB stars can dredge carbon into their atmospheres from their cores. However, long-dead AGB stars may have enhanced their companion stars via mass transfer creating the main sequence dwarf carbon stars. Indeed, this is known to be the case for several types of giants showing anomalous abundances, like the CH, Ba, and CEMP-s stars, all of which have a suspiciously high binary frequency. The dC stars may be the enhanced-abundance progenitors of most of these systems, but this requires a demonstrated high binary frequency for dCs. Our Time Domain Spectroscopic Survey, part of the Sloan Digital Sky Survey IV, targeted a large sample of dC stars for repeat spectroscopy to constrain the binary frequency and orbital properties. We analyzed radial velocity shifts ( $\dot{r}$ RV) between spectral epochs for a sample of 240 dC stars with a total of 540 spectra. We then compared this dC  $\dot{r}$ RV distribution to that of a control sample of objects with similar distributions of magnitude, color, and proper motion. Our results show a distinctly wider distribution in  $\dot{r}$ RV in the dC stars compared to a well-chosen control sample. Using MCMC methods, we fit model separation distributions to this  $\dot{r}$ RV distribution. We find that these separation distribution for the dCs corresponds to close binaries with mean periods on order of 1 year. Follow-up observations are planned for the dCs with the largest  $\dot{r}$ RVs to fit orbits.

**Author(s):** Paul Green, Carlos Badenes, Benjamin Richard Roulston

**Institution(s):** Boston University, University of Pittsburgh, Harvard-Smithsonian Center for Astrophysics

#### **259.17 - The Mini-MUSCLES Treasury Survey: Measurements of the Ultraviolet Stellar Characteristics of Low-mass Exoplanetary Systems(Steve Anusie)**

Astronomers are becoming more interested in finding an Earth-like planet in the liquid water, or habitable, zone of the star it is orbiting. With today's methods for finding exoplanets (transit, radial velocity) being more efficient when observing smaller stars with planets closer to them, the best targets for modern instruments are M-dwarf stars. M-dwarf stars are also known to have intense flares that must be considered when determining if stars of this type can host a planet with an atmosphere, let alone sustain life. More information about the star's ultraviolet characteristics is needed to understand the effects of heating and photochemistry on the exoplanet's atmosphere. Contemporaneous optical light curves also provide information on the flare chromospheric continuum emission and serve as proxy tracers of high energy behavior. The Mini-MUSCLES Treasury Survey focuses on observations of two M-dwarf stars from the target list of the ongoing Mega-MUSCLES Treasury

Survey: GJ 674 and GJ 729. Using U-band photometric observations from the Los Cumbres Observatory, Mini-MUSCLES created light curves of the stars and compared them to simultaneous UV spectroscopic observations from HST. The LCO observations of GJ 674 missed a large flare seen by HST but was able to trace the post-flare light curve of the star. For GJ 729, a simultaneous flare observation was successfully observed. In this poster, we present the ongoing analysis of the light curves and the correlation between the UV and optical activity.

**Author(s):** Cynthia S. Froning, Allison Youngblood, Steve Anusie, David Wilson,

**Institution(s):** Howard University, McDonald Observatory, University of Texas at Austin, NASA Goddard Space Flight Center

### **259.18 - Modeling Brown Dwarf Atmospheres at the L/T Transition(Laci Shea Brock)**

Substellar evolutionary models, dependent upon mass and age, predict cooling rates for brown dwarfs. Binary systems with directly measured quantities of dynamical mass and luminosity can be used to infer age and test the predictability of such evolutionary models. We are conducting a photometric and spectroscopy survey of the individual components in a sample of brown dwarf binaries by using adaptive optics and near-infrared instruments at the Keck Observatory. We use the PHOENIX atmosphere code to model the atmospheres of these objects in order to better characterize their properties (e.g., temperature, gravity, metallicity, and clouds). Traditional PHOENIX cloudy (Dusty) and cloud-free (Cond) model grids provide useful limits for the photometric and spectroscopic properties of brown dwarfs while also capturing some of the observed trends; however, these two limiting cases avoid most of the challenges associated with modeling the cloudy atmospheres of substellar objects. Clouds strongly influence the relationship between spectral morphology and effective temperature, and the L/T transition objects are notoriously difficult to interpret with overly restrictive and generalized assumptions about clouds. We are constructing individualized model grids for each of the brown dwarf binaries with a particular focus on cloud properties for objects having effective temperatures between 1200 and 1400 K. We present new comparisons between predictions from evolutionary models and properties determined solely from atmosphere model fitting.

**Author(s):** Travis Barman, Laci Shea Brock, Quinn Konopacky

**Institution(s):** University of Arizona, University of California, San Diego

### **259.19 - Binary Red Supergiants: A New Method for Detecting B-type Companions(Kathryn Neugent)**

With the exception of a few well-known and studied systems, the binary population of red supergiants (RSGs) remains relatively uncharacterized. Famous systems such as VV Cep, 31 Cyg and zeta Aur contain RSG + B star binaries and here we explore whether B stars are the main type of companion we expect from an evolutionary point of view. Using the Geneva evolutionary models we find that this is indeed the case. However, few such systems are known, and we use model spectra to determine how easy such binaries would be to detect observationally. We find that it should be quite difficult to hide a B-type companion given a reasonable signal-to-noise in the optical / blue portion of the spectrum. We next examine spectra of Magellanic Cloud RSGs and newly acquired spectra of Galactic RSGs looking for new systems and refining our conclusions about what types of stars could be hidden in the spectra. We finally develop a set of photometric criteria that can help select likely binaries in the future without the overhead of large periodic or spectroscopic surveys. We also recently observed spectra of a sample of candidate RSG+B star binaries in M31 and M33, confirming that our photometric criteria can indeed be used to select RSG+B star binaries.

**Author(s):** Emily Levesque, Phil Massey, Kathryn Neugent,

**Institution(s):** University of Washington, Lowell Observatory

### **259.20 - Predicting the UV Emission of M dwarfs with Exoplanets from Ca II and H-alpha(Katherine Melbourne)**

Given the current capabilities of exoplanet detection methods, M dwarf stars are excellent candidates around which to search for temperate, Earth-sized planets. To evaluate the photochemistry of the planetary atmosphere and therefore the planet's potential habitability, it is essential to characterize the UV spectral energy distribution of the planet's host star. This wavelength regime is important because molecules in the planetary atmosphere such as molecular oxygen and ozone have highly wavelength dependent absorption cross sections that peak in the UV (90 - 320 nm). M dwarfs present a particular challenge to the interpretation of atmospheric chemistry as they are highly active stars with unique spectra that can produce key biosignatures abiotically. In this study, we seek to provide a broadly applicable method of estimating the UV emission of an M dwarf, without direct UV data, by identifying a relationship between non-simultaneous optical and UV observations. Our sample comprises 107 M dwarfs, including data from the MUSCLES and Mega-MUSCLES Treasury Surveys (Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems) and the FUMES survey (Far Ultraviolet M-dwarf Evolution Survey). We prioritize optical chromospheric activity indices that have been well-calibrated in past research, and measure H-alpha equivalent widths and the Mount Wilson CaII H&K S and R'HK indices using ground-based optical spectra from the HARPS, UVES, and HIRES archives. Archival and new Hubble Space Telescope COS and

STIS spectra are used to measure line fluxes for a variety of chromospheric and transition region emission lines between 1200-2800 Å.... Our preliminary results show a correlation between UV line luminosity and Ca II R'HK with a standard deviation of approximately 0.40 dex about the best-fit line. Correlations between UV luminosity and H-alpha or the S index are weak. These relationships allow one to estimate the UV emission from M dwarfs when UV data are not available, supporting the development of photochemical models of exoplanet atmospheres.

**Author(s):** Allison Youngblood, Sarbani Basu, David Wilson, Joshua Schlieder, Kevin France, Cynthia S. Froning, J. Sebastian Pineda, Elisabeth Newton, Aki Roberge, Katherine Melbourne

**Institution(s):** Yale University, University of Colorado Boulder, NASA Goddard Space Flight Center, Massachusetts Institute of Technology, University of Texas at Austin

### **259.21 - Searching for Stellar Flares in High Cadence ZTF Observations(Courtney Klein)**

We present a search for stellar flares using high-cadence observations from the Zwicky Transient Facility (ZTF). Stellar “white light” flares are caused by violent reconnection of magnetic fields that release large amounts of energy at all wavelengths. We observe these events as bright spikes in time series observations, such as those obtained by ZTF. Observations have been taken at a 90 second continuous cadence for three hours near the galactic plane. Here we demonstrate an ensemble estimation of the flare rate from observations of many stars within a single ZTF pointing. This rate enables the prediction of flare rate and event energies as a function of galactic location. This will be used to predict flare rate in the full ZTF survey as well as future missions like LSST.

**Author(s):** Courtney Klein, Eric Bellm, James Davenport

**Institution(s):** University of Washington

### **259.22 - Rotation in Taurus with K2(Luisa Rebull)**

K2 observed stars in the Taurus star forming region in their Campaign 13 in Spring 2017. At ~2 Myr, many of the stars still have circumstellar disks and/or active accretion, which complicate the light curves. Nonetheless, we are able to derive rotation periods for more than half of the members. We can compare USco with similar stars in Rho Oph (~1 Myr), USco (~20 Myr), the Pleiades (~125 Myr), and Praesepe (~700 Myr), all with K2 light curves.

**Author(s):** Luisa Rebull, John Stauffer

**Institution(s):** Caltech-IPAC/IRSA, Caltech-IPAC  
Contributing Team(s): K Clusters Team

### **259.23 - Telluric-Calibrated M Dwarf Radial Velocity Measurement with Low-Resolution Near-Infrared Spectra(Yingqi Ding)**

M dwarf stars comprise about three-quarters of the stars in the Milky Way and nearby M dwarfs constitute a rich population for surveys of exoplanets. Radial velocity (RV) reconnaissance of these stars is essential to determine their multiplicity, their kinematics and ages, and to better understand the properties of their planets. However, for many nearby M dwarfs we do not have precise multi-epoch RV measurements. We present here absolute RV measurements for 900 M dwarfs based on a large low-resolution spectral catalog. We improved and implemented a telluric line fitting algorithm presented in Newton et al. (2014), in which the absolute wavelength calibration is improved using the known wavelengths of observed telluric lines. A Monte Carlo analysis suggests that these updated wavelength solutions enable a typical RV precision of 3.9 km/s. We also considered the effects of different choices of RV template spectra, and chose final templates based on SNR and resulting consistency with external catalogs. To verify our RV measurements, we compared our absolute RV measurements to those measured in Gaia (2018) and Chubak et al. (2012). For 150 stars in common, we found a median offset of +1.6 km/s with a standard deviation of 3.7 km/s. These RV measurements will provide useful constraints on the RV variability, kinematics and ages of nearby M dwarfs.

**Author(s):** Elisabeth Newton, Ryan Terrien, Yingqi Ding

**Institution(s):** Carleton College, Massachusetts Institute of Technology

### **259.24 - A Uniform Retrieval Analysis on a Sample of 16 T-dwarfs**

**Authors:** Kezman Saboi (Arizona State University), Michael R. Line (Arizona State University), Michael C. Liu (University of Hawaii), Zhoujian Zhang (University of Hawaii), Will Best (Univ

The spectra of brown dwarfs are key to exploring the chemistry and physics that takes place in their atmospheres. T-dwarf spectra are particularly diagnostic due to their relatively cloud free atmospheres and deep molecular bands. With the use of powerful atmospheric retrieval tools, these properties permit relatively precise constraints on the molecular/atomic abundances and temperature profiles. Constraints on these properties can be used to derive the elemental abundances (metallicity, C/O), chemical disequilibrium, and non-radiative-convective equilibrium temperature perturbations. Previous analyses on T- and Y-dwarfs (Line et al. 2017; Zalesky et al. 2018) have begun to obtain such properties. Here we present a uniform retrieval analysis on a sample of 16 recently observed T-dwarf spectra from the IRTF SPeX instrument. This analysis more than doubles the sample of retrieved properties of T-dwarfs. We present updates on current compositional trends and thermal profile constraints amongst the T-dwarf population.

**Author(s):** Zhoujian Zhang, Michael R. Line, Kezman Saboi, Michael C. Liu, William M J Best, Mark Marley  
**Institution(s):** Arizona State University, NASA Ames, University of Hawaii

#### **259.25 - A USNO Search for Astrometric Companions to Brown Dwarfs V(Jennifer Lynn Bartlett)**

Preliminary analyses of eight brown dwarfs observed by the U.S. Naval Observatory infrared parallax program show no clear indication of astrometric perturbations due to low mass companions. The data were collected using ASTROCAM on the 1.55-m (61-in) Kaj Strand Astrometric Reflector from 2000 September through 2006 June over periods from 5.0 to 5.3 years. After our standard solution for parallax and proper motion, the residuals were subjected to a time-series analysis using the Lomb-Scargle periodogram method. The multiplicity fraction for brown dwarfs constrains theories of brown dwarf formation and evolution. Binary systems, especially those that straddle the transition between L and T spectral types, are also significant tests of atmospheric models. In addition, the identification of companions would have enabled the eventual measurement of the associated masses. This search for astrometric companions is an extension of the initial infrared parallax program. When finalized, the trigonometric parallaxes for these brown dwarfs will provide accurate distances for use in determining their luminosities and temperatures. The brown dwarfs in this subsample have spectral types that range from early L through mid-T. None of them are known binaries. Distance estimates place five of these objects within the 25-pc limit of the Solar Neighborhood, and a preliminary parallax places another within 30 pc. These substellar objects are located north of  $-2^{\circ}$  Dec. The brown dwarfs evaluated are SDSS J010752.33+004156.1 (2MUCD 20052), SDSS J053951.99-005902.0, SDSS J083008.12+482847.4 (2MUCD 20301), SDSS J125453.90-012247.4, SDSS J143517.20-004612.9, SDSS J143535.72-004347.0, SDSS J175032.96+175903.9, and 2MASS J22244381-0158521 (2MUCD 12128). Analyses of another 40 brown dwarfs were presented earlier and the analyses of 11 more brown dwarf systems are planned.

**Author(s):** Jennifer Lynn Bartlett, Trudy Tilleman, Frederick Vrba, Arne Henden, Christian Luginbuhl, Jeffrey Munn  
**Institution(s):** U.S. Naval Observatory, American Association of Variable Star Observers, U.S. Naval Observatory, Dark Sky Partners

#### **259.26 - Chemical abundance anomalies in twin-star binary systems.(Sawyer Lichon)**

We conducted analysis of data from 11 high-precision elemental abundance analyses of twin-star binary systems from previously published studies and included our own data for one additional pair. The goal of the analysis was to see if there were any new trends related to the differential abundances ( $\epsilon^{\circ}[X/H]$ ) versus

other common parameters in addition to condensation temperature. We did not find significant trends for surface gravity or effective temperature, but there is a weak correlation between the differential abundances and separation between the binary stars. As the separation between the stars increases, the absolute value of the difference in abundance increases for all chemical species. This suggests that less abundant chemical species tend to show higher star-to-star differences in abundance. This weak correlation could suggest inhomogeneity in the molecular clouds from which the binary star systems had formed.

**Author(s):** Ivan Ramirez, Sawyer Lichon  
**Institution(s):** Tacoma Community College

#### **259.27 - What Causes the Rotation Period Gap in Young Clusters?(Sean Matt)**

The angular momenta of sun-like and low-mass stars are observed to decrease with time in a systematic and mass-dependent way. Observations of stars in young clusters reveal the formation of a rotation period “gap” in their period-mass diagrams, where stars transition from being rapid rotators to converging onto a common slow-rotator sequence. A number of explanations for this gap have been put forward in the past few years. These explanations propose either dramatic transitions in stellar magnetism or wind driving, or they require that a substantial amount of angular momentum is hidden in the radiative core (due to “core-envelope decoupling”). It has not yet been shown whether any of these ideas can explain the morphology of the gap over its full mass range from  $\sim 0.1$ - $1.0$  solar masses. To address this, we develop our own spin-evolution models to predict period distributions across this mass range. We show that the gap seen in young clusters is well explained by a relatively subtle flattening of the stellar wind torque as a function of rotation rate. Such a flattening could be caused by a systematic deficit in magnetic field strength and/or mass loss rate, for faster rotators. Also, this flattening may be related to the phenomenon of “super-saturation” seen in some magnetic activity indicators, which is still poorly understood. Finally, since our model reasonably matches the spin-distributions for stars with and without radiative cores, it suggests that significant core-envelope decoupling may not be needed.

**Author(s):** Angela Breimann, Sean Matt, Victor See, Tim Naylor, Eric E Mamajek, Marcel Agüeros  
**Institution(s):** University of Exeter, JPL, Columbia University

#### **259.28 - Radial and Rotational Velocities for 300+ Ultracool Dwarfs from NIRSPEC High-Resolution Spectroscopy(Chih-Chun Hsu)**

Precise measurements of radial (RV) and rotational (vsini) velocities of stars are essential for studying stellar kinematics (space velocities and dispersions), binary orbits, and rotational



dynamics (angular momentum evolution). However, the high-resolution spectroscopic observations necessary to make these measurements is challenging for the intrinsically faint ultracool dwarfs, stellar or sub-stellar objects with effective temperatures less than 3,000 K. Velocity samples of these objects are correspondingly small. To address these limitations, we are conducting a velocity survey of over 300 late-M, L, and T dwarfs, drawing from nearly twenty years of observed and archival high-resolution data from the Keck NIRSPEC near-infrared spectrometer reduced by the NIRSPEC Data Reduction Pipeline. We determine RV, vsini, and atmospheric parameters using a Markov Chain Monte Carlo forward modeling method. Here we present our initial analysis of the sample. We compare our RV and vsini measurements to prior measurements, examine the distributions in atmospheric parameters (Teff,logg), and search for radial velocity variables.

**Author(s):** Jessica Lua Birky, Christopher Gelino, Chih-Chun Hsu, Adam Burgasser, Christopher Theissen, Cullen Blake

**Institution(s):** UC San Diego, Caltech, Infrared Processing and Analysis Center, University of Pennsylvania

#### **259.29 - Photometric Characterization of Late-Type Brown Dwarfs with MOSFIRE at Keck(Sarah E. Logsdon)**

The MOSFIRE instrument on the Keck I telescope at the W. M. Keck Observatory provides single- and multi-object spectroscopy and imaging over a 6.14 arcmin x 6.14 arcmin field of view with a 0.18 arcsec plate scale in imaging mode. MOSFIRE includes a suite of custom broad-band, near-IR filters (Y, J, H, Ks) and four medium-band filters that subdivide the traditional J and H bands (J2, J3, H1, H2). While predominantly used for spectroscopy, MOSFIRE's imaging mode is extremely sensitive and capable of reaching a J-band magnitude of ~19.5 with a S/N ~600 in 9 minutes (see Mace et al. 2013b). Brown dwarfs within 25 pc of the Sun and as cold as ~250 K are prime targets for JWST, and MOSFIRE's imaging sensitivity makes it a powerful tool for prioritizing these nearby, cold brown dwarfs for JWST spectroscopic follow-up. In order to characterize MOSFIRE's imaging mode we have observed more than 40 late-type T and Y dwarfs and over 20 brown dwarf candidates using MOSFIRE's Y, J, H, H1, and H2 filters. The H2 filter is sensitive to the methane absorption in late-T and Y dwarf atmospheres. Here we outline our observing strategy, data reduction, and preliminary photometric results. We also compare our photometry to the literature, when available. Finally, we discuss the utility of MOSFIRE for further photometric follow-up of late-type brown dwarfs.

**Author(s):** Sarah E. Logsdon, G. N. Mace, Ian S. McLean, Emily C. Martin, Michael McElwain

**Institution(s):** NASA Goddard Space Flight Center, University of California, Santa Cruz, University of California, Los Angeles, University of Texas at Austin

#### **259.30 - Tuning Into Brown Dwarfs: Long-Term Radio Monitoring of Two Ultracool Low-Mass Binaries(Russell Van Linge)**

The very lowest-mass (VLM) stars and brown dwarfs, with effective temperatures  $T < 3000$  K, exhibit mixed magnetic activity trends, with H-alpha and X-ray emission declining rapidly beyond type M7/M8, but persistent radio emission in roughly 10-20% of sources down to the T spectral class. The dozen or so VLM radio emitters known show a broad range of emission characteristics and time-dependent behavior, including steady persistent emission, periodic oscillations, periodic polarized bursts, and aperiodic flares. The origins of these emissions remain poorly understood and little data exists on long-term timescales. We report the results of a long-term JVLA monitoring program of two magnetically-active VLM dwarf binaries, the young M7 2MASS 1314+1320AB and older L5 2MASS 1315-2649AB. On long timescales, 2MASS 1314 shows repeated flaring while 2MASS 1315 appears to be a steady quiescent emitter. On short-term timescales, 2MASS 1314 displays some unique behaviors, including rapid (~ few minutes) transitions from low to high emission states. These results suggest long-term radio behavior in radio-emitting VLM dwarfs is just as diverse and complex as short-term behavior, potentially obfuscating signatures of magnetic cycling.

**Author(s):** Adam Burgasser, Peter Kelsey George Williams, Russell Van Linge, Carl Melis

**Institution(s):** University of California San Diego, Harvard-Smithsonian Center for Astrophysics

#### **259.31 - Using the I-band Sodium Doublet to Characterize M Dwarfs(Jiaqi Huang)**

M dwarfs are the most common stars in the Galaxy and present an exciting frontier for exoplanet missions and studies of stellar physics. An array of empirical techniques has been established for approximating the physical properties of M dwarfs, but the precise characterization remains challenging. We consider here potential refinements of these techniques based on the 820nm sodium doublet. Combined with measurements of stellar metallicity and effective temperature, we explore whether the pressure-sensitive sodium doublet could be used to refine the radius predictions of the MIST and Dartmouth isochrones for M dwarfs. We describe here the mixed performance of this potential radius indicator and how it can provide insight into other fundamental properties of M dwarfs.

**Author(s):** Ryan Terrien, Jiaqi Huang

**Institution(s):** Carleton College

#### **259.32 - RECONS and Gaia Discoveries in the Solar Neighborhood(Todd Henry)**

The solar neighborhood is much like the environs in which we live --- we know a lot about our closest neighbors, but the realm becomes less familiar the further we venture from home. To understand the local population, we will discuss solar

neighborhood samples within two horizons: 10 pc and 25 pc. On the most local level, the sample of stars, brown dwarfs, and exoplanets known within 10 pc of our Solar System as of January 1, 2019 is presented. An initial census incorporating results from Gaia Data Release 2 includes 418 objects in 305 systems, of which 40 systems were first revealed to be within 10 pc by the RECONS (REsearch Consortium On Nearby Stars, [www.recons.org](http://www.recons.org)) team. The sample contains 366 stars (including the Sun and white dwarfs) and 52 brown dwarfs. So far, Gaia has added only 8 systems to the 10 pc sample, while missing 47 systems (15%), roughly split between stellar (24) and brown dwarf (23) primaries. Continuing assessment of DR2 data will yield more true members, but of the 1722 objects with parallaxes of 100 milliarcseconds or more, we estimate that at least 80% are phantoms ... only careful vetting will reveal the real members. Further afield, we are exploring the Gaia DR2 results for new systems out to 25 pc that are being incorporated into the RECONS 25 Parsec Database. While the effort to vet several thousand known systems as well as several thousand new systems with first parallaxes in Gaia will take some time, it is clear that between 10 and 25 pc Gaia has made a significant impact. Many of the new entries are previously known red dwarfs that did not yet have parallaxes, and the new results expand upon our previous discovery from the 10 pc sample --- the solar neighborhood is dominated by red dwarfs that account for three of every four stars. Through the combination of long-term astrometric work done by ground-based teams and Gaia results, for the first time we know the names and addresses of most of our stellar neighbors. This effort has been supported by the NSF through grants AST-0507711, AST-0908402, AST-1412026, and AST-1715551 and via observations made possible by the SMARTS Consortium.

**Author(s):** Wei-Chun Jao, Jennifer Winters, Adric R. Riedel, Kenneth J. Slatten, Todd Henry

**Institution(s):** RECONS Institute, Space Telescope Science Institute, Georgia State University, Harvard-Smithsonian Center for Astrophysics

**Contributing Team(s):** RECONS

### **259.33 - Radio Bright High Proper Motion Stars (Montana Williams)**

A collection of candidate radio stars was found through matching of two all-sky radio catalogs, (NVSS and FIRST) and an optical catalog of high proper motion stars (LSPM). High proper motion was required because late-type stars are the most likely to have the observable radio emission, which would have to be nearby and have high proper motions ( $> .15''/\text{yr}$ ). Two radio catalogs were used to increase the chances of areal match. From the combination of all three catalogs 13 candidate radio stars were found. We investigated these sources, focusing on the three with the highest flux density. These three had a flux density greater than 35 mJy/beam in FIRST. We will discuss these sources to determine if they were in fact radio stars.

**Author(s):** Montana Williams, Thomas J. Maccarone, Amy Kimball, Sebastien Lepine

**Institution(s):** Texas Tech University, Georgia State

University, National Radio Astronomy Observatory

### **259.34 - K-KIDS: Radial Velocity Search of Closest Companions to K Dwarfs within 25 pc with the CHIRON Spectrograph at the CTIO/SMARTS 1.5m (Leonardo Paredes)**

The K-KIDS project is a large effort to study comprehensively a sample of nearby K dwarfs and their companions. We have carefully vetted an equatorial sample (+30 to -30 declination) up to an horizon of 50 pc away, aiming to detect companions of stellar, sub-stellar and planetary nature, in separations ranging from 10 000 AU to 0.2 AU with four different techniques. In this work, we present the results of the companion search on the K dwarfs up to 25 pc. A total of 304 K dwarfs have been compiled, using astrometric data from Gaia DR2, and photometric data from Tycho-2, Gaia DR2 and 2MASS, to search for their closest companions using the radial velocity time series technique. We have used CHIRON Spectrograph at CTIO 1.5m Telescope to monitor 104 K dwarfs that did not have high precision radial velocity coverage before, which up to date, corresponds to the remaining third not covered by other surveys conducted with similar precision capabilities. Within one year ongoing survey, we have obtained radial velocities measurements with a precision down to 5 m/s for K dwarfs between V magnitudes 7.0-11.5, and we have found 35 K dwarfs with radial velocity perturbations consistent with companions. We add to our work, results from previous searches published until now, to evaluate the current status of K dwarf systems within 25 pc. In addition, we highlight the exceptional efficiency and stability of CHIRON Spectrograph to carry our reconnaissance survey as well as for precise follow up for planet confirmation. Ultimately, the combination of the ongoing radial velocity survey and other three imaging surveys will provide an unprecedented portrait of K dwarfs and their kids. This effort has been supported by the NSF through AST-1517413 grant, and via observations made possible by the SMARTS Consortium.

**Author(s):** Hodari-Sadiki James, Daniel A Nusdeo, Leonardo Paredes, Rodrigo Hinojosa, Todd Henry

**Institution(s):** Georgia State University, Cerro Tololo Inter-American Observatory, RECONS Institute

### **259.35 - The Search for Low-mass Dwarfs in the Southern Skies (Roberto Alexander Tejada Arevalo)**

Low-mass dwarfs are sub-stellar objects (objects with less than half the mass of our Sun) that are ubiquitous throughout our galaxy. On average, low-mass dwarfs have been found to host three terrestrial planets, and there may be evidence that lower-mass dwarfs host an increasing number of planets (e.g., TRAPPIST-1). Therefore, these objects are important targets for current and future missions designed to find habitable planets (e.g., Transiting Exoplanet Survey Satellite, TESS; Transiting Planets and Planetesimals Small Telescope, TRAPPIST; Search for habitable Planets Eclipsing Ultra-cool Stars,

SPECULOOS). Since most of the deep-field digital surveys, such as the Sloan Digital Sky Survey (SDSS), hold prominence in the northern hemisphere, our project studies large-area digital survey data in the southern hemisphere from SkyMapper to search for new low-mass dwarfs. We aim to find new low-mass dwarfs by first extracting all known objects of spectral types M and L (giants and dwarfs) from known sky surveys, such as SDSS, the Wide-field Infrared Survey Explorer (WISE), the 2-Micron All-Sky Survey (2MASS), and Gaia. From this dataset of known dwarfs and giants, we will train a machine learning algorithm, known as a classifier, to recognize key distinct features that separate giants from dwarfs. When this algorithm fully recognizes the patterns, we will run the entire SkyMapper survey through the trained classifier to find the new low-mass dwarfs. Our preliminary estimates show SkyMapper dataset contains approximately 4000 low-mass dwarfs not previously identified or contained within Gaia Data Release 2.

**Author(s):** Dennis Henry Calderon-Madera, Russell Van Linge, Quinn Konopacky, Adam Burgasser, Christopher Theissen, Roberto Alexander Tejada Arevalo,

**Institution(s):** California State University, Los Angeles, California State University, East Bay, University of California, San Diego  
**Contributing Team(s):** DrSusan Terebey

#### **259.36 - Rotation Periods of Stars in Wide Binary Systems(Kenneth Janes)**

While it is well-known that the cooler main sequence stars spin down as they age, there is still considerable uncertainty as to how fast and how uniformly that process proceeds. To explore stellar rotations, particularly as a function of spectral type, I have searched the Gaia DR-2 catalog for wide binary systems (common proper motion stars) located in the Kepler spacecraft original field of view. Because of the exquisite precision of the parallax and proper motion data in the DR-2 database, I have been able to identify almost 400 wide binaries that also have Kepler photometric data. The actual ages of these binaries are not known, but assuming that the two components are physically connected, coeval stars, a comparison of their rotation periods as determined from starspot-induced photometric variations in the Kepler data can provide information about the regularity of the spin down and its effectiveness as a function of spectral type. In my analysis to date, I have confirmed that while there is a general "gyrochronology" relation of period vs. age, there are individual and systematic deviations from the typical behavior.

**Author(s):** Kenneth Janes

**Institution(s):** Boston University

#### **259.37 - Kinematics of fast-rotating, low-mass stars in K2: how groups of young stars dissolve into the field.(Sebastien Lepine)**

We present an analysis of the kinematics of ~1,000 low-mass stars with fast rotation (period < 4 days) identified through their starspot modulation in the Kepler K2 survey. These fast-rotators are assumed to represent the nearby ( $d < 250$  pc) populations of relatively young ( $< 1$  Gyr) low-mass stars. Using parallax and proper motion data from the GAIA second data release (DR2), we isolate fast-rotators from nearby star clusters and star forming regions (Hyades, Pleiades, Beehive, Upper Sco), and identify hundreds of fast-rotators that are scattered through the local field population. We then show that those field fast-rotators can be further split into: (1) groups that display significant clustering in space and/or velocity space, and (2) other stars that are more uniformly scattered. Based on the distribution of rotation rates, we find that the more clustered fast-rotators appear to be significantly younger (~100 Myr) than the more scattered ones (~500 Myr); this is consistent with the idea that young stars form in loose associations that slowly "dissolve" into the field, first showing up as relatively compact young moving groups (YMGs), that later disperse over larger volumes, losing their cohesiveness.

**Author(s):** Dicy Ann Saylor, Sebastien Lepine

**Institution(s):** Georgia State University

#### **259.38 - Stars on FIRE: Classifying Nearby M Dwarfs(Alana R Sanchez)**

M dwarfs comprise about 70% of the stars in our solar neighborhood and are some of the most exciting candidates for exoplanet research due to their small size and relative abundance, which both aid in exoplanet detection. Classification of spectral features, such as stellar radial velocities and metallicities, highlight specific characteristics of these stars and contribute to known information on M dwarfs. Classification can also be used to pinpoint stars of interest, which can be examined further using higher resolution data. We present stellar parameters for approximately 280 nearby M dwarfs determined with moderate resolution ( $R \sim 6000$ ) infrared spectra taken with the FIRE Spectrometer. The majority of our data is comprised of M dwarfs located in the southern hemisphere, the first area of interest for TESS and a source of understudied stars. Therefore, our contribution to the classification of these stars is integral to exoplanet and stellar research in this area. The MEarth team is grateful for support from the David and Lucile Packard Fellowship for Science and Engineering, the John Templeton Foundation (awarded to D.C.), and the NSF under grant numbers AST-1616624, AST-0807690, AST-1109468, and AST-1004488 (Alan T. Waterman Award). E.R.N. acknowledges support from the NSF through the GRF and the AAPF programs (award AST-1602597). N.M. acknowledges support from the NSF through the GRFP, and the LSSTC Data Science Fellowship program. A.R.S acknowledges support from the UROP department through MIT.

**Author(s):** Ian Crossfield, Nicholas Mondrik, Zachory Berta-

Thompson, Alana R Sanchez, Elisabeth Newton, Jason Dittmann, Jonathan Irwin, Carissa S Skye, David Charbonneau  
**Institution(s):** Massachusetts Institute of Technology, University of Colorado Boulder, Dartmouth College, Harvard University

#### **259.39 - Investigating Brown Dwarf Candidates from the M-dwarfs in Multiples (MinMs) Survey (Sebastian Gameros)**

For solar type stars, observations have shown a large deficit of brown dwarf companions as opposed to planetary and binary star companions. However, whether brown dwarf companions are more or less common around lower-mass M-dwarf stars is currently uncertain. From the M-dwarfs in Multiples (MinMs) Survey, consisting of 245 M-dwarf stars within 15 pc, we conduct a deep search for lower-mass brown dwarf companions, and present preliminary results from a southern hemisphere subsample of 54 MinMs targets observed with near-infrared, adaptive optics imaging using VLT/NaCo. Of the 54 southern targets, 6 systems were found to have companion candidates, at separations ranging from 0.2" - 14" (2-150 au in projected separation), and include star-to-companion magnitude ratios consistent with substellar luminosities ( $10^{-5}$  K $\sim$ 5). Of the candidates, 5 are newly discovered and 1 shares potential common proper motion with its host star, which will be confirmed with additional astrometric epochs. We combine the results from the southern survey with deep high-resolution infrared imaging data on 55 MinMs targets with MMT/ARIES to complement the substellar companion survey in the Northern hemisphere. We also describe new applications of point spread function subtraction algorithms to search VLT and MMT adaptive optics images for companions interior to  $\sim 3$  au.

**Author(s):** Kimberly Ward-Duong, Richard Parker, Don McCarthy, Robert De Rosa, Simon Goodwin, Katherine Follette, Jennifer Patience, Sebastian Gameros, Craig Kulesa

**Institution(s):** University of Massachusetts Amherst, Stanford University, Amherst College, University of Arizona, Arizona State University, University of Sheffield

#### **259.40 - Determining the surface gravity of APOGEE solar-type dwarf stars using line-depth ratios (Jessica Galbraith-Frew)**

Determination of stellar atmosphere parameters such as a star's surface gravity is essential in modelling its spectrum and determining chemical compositions. Historically, line-depth ratios (LDR) have provided estimates of the star's effective temperature. Here, we have applied the line depth ratio technique to derive stellar surface gravity. We analyzed over 100 iron lines in the H-band (15400Å-16800Å), seeking ratios that are sensitive to surface gravity for F and G type dwarf stars with metallicities  $\pm 0.5$  dex from the Sun. These LDRs were calibrated using  $\sim 90$  sets of spectroscopic stellar parameters

from the PASTEL catalog (Soubiran et al 2016) that matched with APOGEE-2 data ( $R \sim 22,500$ ). The resulting relations were then tested by measuring the LDRs in  $\sim 200$  APOGEE-2 dwarf stars. Finally, we will apply the LDR relations to the F and G dwarfs in the APOGEE-2 data set in order to provide a new estimate of their surface gravities.

**Author(s):** Szabolcs Meszaros, Nicholas Troup, Keivan G Stassun, Jennifer Sobeck, Maria Tsantaki, Matthew Shetrone, Jennifer Johnson, Jessica Galbraith-Frew, Inese Ivans, Suvrath Mahadevan

**Institution(s):** University of Utah, University of Texas, Ohio State University, Vanderbilt University, Salisbury University, Pennsylvania State University, University of Washington, Eötvös Loránd University, Universidad Nacional Autónoma de México

#### **259.41 - Stellar Radius Measurements of the Young Debris Disk Host AU Mic (Russel White)**

We present results from our on-going program to directly measure the sizes of nearby young stars using the CHARA Array interferometer. Here we highlight new diameter measurements of AU Mic (GJ 803), an M1 spectral type star that harbors a debris disk and is a member of the Beta Pictoris Moving Group. The star is spatially resolved with an angular diameter of just over 0.7 milli-arcseconds, corresponding to a physical radius of about 0.75 solar radii. We describe our observational strategies for calibrating measurements of this low elevation star ( $\text{DEC} = -31$  degrees), and present new high dispersion spectra and high spatial resolution images of the calibrators that aided in this. This size is roughly 60% larger than the average size of similar temperature main sequence stars; it is a bona-fide pre-main sequence star, and the first such low mass star ever spatially resolved. The size measurement is combined with AU Mic's bolometric flux to directly determine its effective temperature for more accurate placement on the HR diagram. The results provide an independent age estimate of the Moving Group, a temporal stamp on the evolutionary state of the debris disk, and offer a benchmark for theories of how low mass stars gravitationally settle toward the main sequence.

**Author(s):** Trent Dupuy, Kaspar von Braun, David W Latham, Theo ten Brummelaar, Allyson Bieryla, Tabet Boyajian, Russel White, Gail Schaefer

**Institution(s):** Georgia State University, Louisiana State University, Georgia State University / CHARA, Harvard-Smithsonian Center for Astrophysics, Lowell Observatory, GEMINI Observatory

#### **259.42 - Searching for New Ultracool Dwarfs in the Southern Skies (Dennis Henry Calderon)**

Low-mass dwarfs are subsolar objects with less than 50% the mass of the Sun (spectral types M and later). These dwarfs make up the peak of the mass function, cross the boundary between stellar and substellar objects, and have extremely long

lifetimes on the main sequence. Low-mass dwarfs are important tracers of galactic evolution, and prime candidates for exoplanets searches (e.g., TRAPPIST-1). Low-mass dwarfs in the Northern hemisphere have been thoroughly cataloged with the help of several surveys such as the Sloan Digital Sky Survey (SDSS). However, the Southern hemisphere is still extremely incomplete due to the lack of an SDSS equivalent. The SkyMapper Southern Sky Survey serves to rectify the problem and aims to be as comprehensive as SDSS. We aim to use existing samples of known low-mass dwarfs and red giants to find the essential criteria for classification and separation (e.g., color, magnitude, morphology) using machine learning algorithms. Using machine learning algorithms, we then apply our criteria to the SkyMapper survey data to classify new low-mass dwarfs.

**Author(s):** Russell Van Linge, Quinn Konopacky, Dennis Henry Calderon, Adam Burgasser, Christopher Theissen, Roberto Alexander Tejada Arevalo

**Institution(s):** CSU East Bay, UCSD, CSU Los Angeles

#### **259.43 - Asymmetric Shapes of Radio Recombination Lines from Ionized Stellar Winds(Richard Ignace)**

Recombination line profile shapes are derived for ionized spherical stellar winds at radio wavelengths. It is assumed that the wind is optically thick owing to opacity that scales as density squared. Recombination lines that also scale with square of density, and of arbitrary optical depth, are obtained assuming that the photosphere forms in the outer, constant expansion portion of the wind. Previous work has derived analytic results for isothermal winds when the line and continuum source functions are equal. Here, semi-analytic results are derived for when the source functions are not equal to reveal that line shapes can be asymmetric about line center for spherical outflow. A parameter study is presented and applications discussed.

**Author(s):** Richard Ignace

**Institution(s):** East Tennessee State University

#### **259.44 - Multi-scale Reconnection in a Turbulent Medium(Amir Jafari)**

We look for the spontaneous occurrence of magnetic reconnection events in the Johns Hopkins Turbulence Database. We discuss an intriguing example of a large Sweet-Parker type current sheet which shows outflows in the direction of the local mean field and inflows normal to the current sheet. At a fine-grained level, the reconnecting electric field is supplied by the Ohmic resistivity in the thin current sheet although with a number of unexpected features. Richardson diffusion occurs everywhere in the vicinity of the current sheet and the outflows are anomalously broad and not confined to the current sheet. In a coarse grained picture, "turbulent EMF", and not the resistivity, provides the majority of the reconnecting electric field. At this scale, reconnection is driven

by turbulent effects rather than any mechanism associated with small scale physics. We argue that reconnection is driven by different processes at different scales and compare the interpretation of this event in terms of the Sweet-Parker model with an interpretation based on Stochastic Reconnection.

**Author(s):** Amir Jafari

**Institution(s):** The Johns Hopkins University  
Contributing Team(s): EVishniac, GEyink, CLalescu, YShi, TDrivas, ALazarian

#### **259.45 - Poster Winner of the 2018 Beth Brown Memorial Award: Finding Flares on M Dwarfs with ASAS-SN(Romy Rodr  guez-Mart  nez)**

Stellar flares are sudden, rapid events on the atmospheres of stars that can generate copious amounts of radiation across the electromagnetic spectrum. They occur when charged particles interact with the plasma in the stellar surface and are accelerated by internal magnetic fields. Modern astronomical surveys have revealed that stellar flares are prevalent, particularly on M dwarfs - low-mass stars that display a high frequency of flare events. Magnetic phenomena such as flares, star spots and coronal mass ejections can complicate the detection of exoplanets and can erode the biosphere of potentially habitable planets. Our research aims to quantify the flare frequency and energy of a sample of ~1,300 mostly bright M dwarfs using data from the All-Sky Automated Survey of SuperNovae (ASAS-SN). Our preliminary results show that about 450 M dwarfs have had potential flares in the last 6 years and we confirm ~60 stars with at least one bona fide flare event. As one of the first systematic study of M dwarf flares in a large sample, our findings suggest that these events are common across a wide range of spectral types and have a wide distribution of amplitudes and energies.

**Author(s):** Laura A. Lopez, Romy Rodr  guez-Mart  nez, Benjamin Shappee, Sarah Jane Schmidt

**Institution(s):** The Ohio State University, Leibniz Institute for Astrophysics, Hawaii University

#### **260 - Spiral Galaxies -- Posters**

##### **260.01 - Examining the Limits of an Artificial Neural Network in Predicting the HI Content of Galaxies(David G Rea)**

The neutral hydrogen (HI) in galaxies provides the gas reservoir out of which stars are formed. The ability to determine the HI masses for statistically significant samples of galaxies can provide information about the connection between this gas reservoir and the star formation that drives galaxy evolution. However, there are relatively few galaxies for which HI masses are known because these measurements are significantly more difficult to make than optical observations. Artificial neural networks are a type of nonlinear technique that have been used to estimate the gas masses from their optical properties (Teimoorinia et al. 2017). We present HI observations of 51 galaxies with gas and stellar properties that are rare in the

Arecibo Legacy Fast ALFA Survey (ALFALFA, Haynes et al. 2018) which was used to train the Artificial Neural Network developed by Teimoorinia et al. (ANN, 2017). These sources provide a test of the Artificial Neural Network predictions of HI mass and include some rare and interesting systems including galaxies that are extremely massive in both stellar mass ( $\log M_* > 11.0$ ) and HI mass ( $\log M_{\text{HI}} > 10.2$ ) with large HI line widths ( $w_{50} > 500$  km/s). We find that this Artificial Neural Network systematically overestimates the gas fraction of the galaxies in our selected sample, suggesting that care must be taken when using these techniques to predict gas masses for galaxies from a broad range of optical properties.

**Author(s):** Hossen Teimoorinia, David G Rea, Sara L Ellison, Jessica Rosenberg

**Institution(s):** George Mason University, University of Victoria

### **260.02 - Regularly Spaced Infrared Peaks in the Dusty Spirals of Messier 100 (Debra Elmegreen)**

Spitzer Space Telescope InfraRed Array Camera (IRAC) images of M100 show numerous long filaments with regularly-spaced clumps, suggesting the associated cloud complexes formed by large-scale gravitational instabilities in shocked and accumulated gas. Optical images give no hint of this underlying regularity. The typical spacing between near infrared (NIR) clumps is  $\sim 410$  pc, which is  $\sim 3$  times the clump diameter, consistent with the fastest growing mode in a filament of critical line density. The IRAC magnitudes and colors of several hundred clumps are measured in the most obvious 27 filaments and elsewhere. The clump colors suggest that the dust is associated with diffuse gas, PAH emission, and local heating from star formation. Neighboring clumps on the same filament have similar magnitudes. The existence of many clumps all along the filament lengths suggests that the ages of the filaments are uniform. The observations support a model where interstellar gas is systematically accumulated over lengths exceeding several kpc, forming spiral-like filaments that spontaneously collapse into giant clouds and stellar complexes. Optical wavelengths show primarily the irregular dust debris, HII regions, and lingering star formation downstream from these primal formation sites.

**Author(s):** Debra Elmegreen, Bruce G. Elmegreen, Yuri Efremov

**Institution(s):** Vassar College, Sternberg Astronomical Institute of the Lomonosov Moscow State University, IBM T.J.Watson Research Center

### **260.03 - Cold gas content in two-arm and multi-arm spiral galaxies (Esther Chen)**

In this research, we study the difference in galaxies' gas content based on their number of spiral arms. Based upon citizen scientist classifications from Galaxy Zoo 2, we divide our sample into two-arm galaxies and multi-arm galaxies. Using

molecular gas ( $\text{H}_2$ ) masses from the xCOLD GASS survey and atomic hydrogen (HI) masses from the xGASS survey, we compare the gas content with respect to these two categories. We find a significantly higher HI gas content for the multiple-arm spiral population compared to that of the two-arm spirals, confirming the result established in Hart et al. 2017. For the  $\text{H}_2$  gas content, we see a trend with stellar mass such that the offset (higher gas content for multiple-arm galaxies) is most significant at the highest stellar masses. Furthermore, we see a much steeper slope for the decreasing specific HI content versus stellar mass compared to the specific  $\text{H}_2$  content versus stellar mass.

**Author(s):** Helen Zhang, Alison Crocker, Esther Chen

**Institution(s):** Reed College

### **260.04 - Using VLA/GBT Data Combined with a New Interferometer and Single-Dish Joint Deconvolution Technique to Model Radio Halos of Galaxies (Timothy T. Braun)**

We present preliminary results from a new joint deconvolution algorithm we use to combine wideband On-The-Fly (OTF) Robert C. Byrd Green Bank Telescope (GBT) data with Karl G. Jansky Very Large Array (JVLA) data from the Continuum Halos in Nearby Galaxies - an EVLA Survey (CHANG-ES). This technique feathers wideband single-dish (SD) data with interferometric (INT) data within an iterative image reconstruction scheme and solves the missing short-spacings problem, while also supporting imaging options such as multi-term multi-frequency synthesis, multi-scale modeling, and joint mosaicing. By jointly deconvolving SD and INT data, we avoid burning in negative bowls and we retain the absolute flux density at zero spacing in the uv-plane, both of which are problematic when imaging INT-only observations of large-scale diffuse emission. We apply this combination technique to create a Stokes I C-band (6 GHz) continuum image and a spectral index map of the nearby edge-on galaxy NGC 891 using data from the CHANG-ES project. This galaxy features a well characterized lagging gaseous halo, where the rotation velocity of the gas decreases with increasing height from the midplane. We use these images to model nonthermal halo radial pressure gradients, with the goal of understanding whether such pressure gradients can explain the amplitude of the lag. In the future, we plan to extend our analysis to a subsample of CHANG-ES galaxies with measured lags.

**Author(s):** Timothy T. Braun, Richard J. Rand, Amanda Kepley, Urvashi Rau

**Institution(s):** University of New Mexico, National Radio Astronomy Observatory, National Radio Astronomy Observatory Contributing Team(s): CHANG-ES

### **260.05 - Tracing Star Formation and Galaxy Evolution with Multi-Pixel Cameras on the GBT(Karen O'Neil)**

The power of large, sensitive images of the radio sky to advance our understanding of the Universe is profound. This is true for most fields of astronomy, including star formation and evolution, astrochemistry, and fundamental physics to galaxy and cluster formation and evolution and mapping the cosmic web in hydrogen. The GBT has a program in place to develop radio cameras across all frequency bands, dramatically increasing the mapping speed and scientific output of the telescope. Four multipixel instruments are already in use on the GBT. The next step in this program will be Argus+, a 144-pixel replacement for the existing 75-116 GHz array. Cooled, high performance phased array feed systems will then be developed for the lower frequencies, to enable deep HI surveys, pulsar searches, etc., while multi-pixel heterodyne receivers will be developed at the higher frequencies, starting with a 48 pixel system at 18-27 GHz and then moving upward to cover the 30-50 GHz range.

**Author(s):** Tapasi Ghosh, Chris Salter, Joy Skipper, Amber Bonsall, Ryan S Lynch, Anthony Minter, Ronald Maddalena, David Frayer, Felix Lockman, Andrew Seymour, Frank Ghigo, William Armentrout, Karen O'Neil, Natalie Butterfield

**Institution(s):** Green Bank Observatory

### **260.06 - Green Bank Telescope Studies of HI in the Circumgalactic Medium of M31(Stanley Lucas Denny)**

Project AMIGA is a study of the circumgalactic medium of M31 through the combination of HST UV spectroscopy toward background AGN with Green Bank Telescope (GBT) measurements of HI from the 21cm line along the same sight lines. The first results of the GBT observations from single pointings toward the AGN yielded only 5-sigma upper limits on log(NHI) of 17.60 (Howk et al. 2017, ApJ, 846, 141), that were in some tension with expectations from the COS-Halos survey (Prochaska et al. 2017, ApJ 837, 169). We have now continued our study of the neutral gas around M31 by expanding the GBT 21cm measurements to cover areas typically 1x1 degree around 12 AGN that probe M31 impact parameters out to 200 kpc. With 3-sigma detection limits around log(NHI) of 17.60 and ~10 square-degrees of coverage, we find HI emission in some directions at a log(NHI) of 18.3. This poster will describe the observations and details of the results, with their implications for our understanding of neutral gas in the circumgalactic medium of M31.

**Author(s):** Stanley Lucas Denny, Felix Lockman

**Institution(s):** Florida State University, Green Bank Observatory

### **260.07 - Chemical Abundances Of Spirals: Understanding Gas Content and ISM Conditions through CHAOS(Danielle Berg)**

Accurate and robust measurements of extragalactic metallicities are essential to constrain models of chemical enrichment, chemical evolution, and the cycle of baryons in the cosmos. Despite this strong dependence on chemical abundances, an absolute calibration of gas-phase abundances from nebular emission lines has not been definitively established. The Chemical Abundances of Spirals (CHAOS) project leverages the combined power of the Large Binocular Telescope (LBT) with the broad spectral range and sensitivity of the Multi-Object Double Spectrographs (MODS) to uniformly measure "direct" (Te-based) abundances in large samples of HII regions in spiral galaxies. Thus far, CHAOS has increased, by more than an order-of-magnitude, the number of H II regions with high-quality spectrophotometry to facilitate the first detailed measurements of the chemical abundances of a statistically significant sample of nearby disk galaxies. These observations, which include a large number of low excitation H II regions, have led to several unexpected results, challenging our current understanding of the trends in gas conditions, ionization correction factors, relative abundances, and more.

**Author(s):** Evan Skillman, John Moustakas, Richard Pogge, Kevin Croxall, Danielle Berg

**Institution(s):** Ohio State University, Expeed Software, University of Minnesota, Sienna College

### **260.08 - HI Balmer Jump Temperatures for Extragalactic HII Regions in the CHAOS Galaxies(Ness Mayker)**

The Chemical Abundances of Spirals (CHAOS) project has measured an unprecedented number of "direct" abundances (based on observations of the temperature-sensitive auroral lines) in HII regions of spiral galaxies. However, by comparing temperatures derived from multiple ions, we found two surprising results: (1) a strong correlation between temperatures based on [SIII] 6312 and [NII] 5755 and (2) large discrepancies for some temperatures based on [OIII] 4363 that resulted in large dispersions in the O/H gradients. Fortunately, the large number of sensitive diagnostics in the rich CHAOS dataset allows for other approaches to investigate these issues. Here we present robust measurements of the Balmer Jump electron temperature in our best CHAOS spectra as a tool to investigate temperature anomalies. Determining the best nebular temperature measurement in HII regions has important implications for abundance determinations and properly calibrating empirical diagnostics.

**Author(s):** Richard Pogge, Ness Mayker, Danielle Berg

**Institution(s):** Ohio State University

### **260.09 - Clues to the formation of spiral structures in the Flocculent Galaxy M83(Bradley Malko)**

Structures of spiral arms in disk galaxies are well studied, both through observations and theories, in the late twenty centuries (e.g. Toomre 1964, Lin & Shu 1985, Elmegreen 1991). However, with the Hubble Space Telescope (HST), high-resolution observations have shed some new light on a less-understood type of spirals, the flocculent galaxies. These galaxies have multiple (more than four) short arms and “feathers”, seen as stellar structures extending outwards from the arms. The formation of such structures is still not well understood. For this project, we will be focusing on M83, a well-known flocculent galaxy. We will use its HST multi-band images to first determine the spatial distributions of star clusters at different ages. We will then combine with data of molecular gas and dust distribution, to study their correlation with the clusters at different ages. We hope to further understanding the formation of feathers in M83, and thus provide crucial information in understanding the structures in the flocculent galaxies.

**Author(s):** Bradley Malko

**Institution(s):** Northern Arizona University

### **260.10 - Investigating the origins of oxygen abundance gradient anomalies with MaNGA(Jalyn Nicole Krause)**

It is known that a large majority of disk galaxies show a linear, radial, nebular, oxygen abundance gradient. However, we have observed a small fraction of galaxies that exhibit distinct breaks in their abundance profile between 0.5 and 2 effective radii. We find that ~5% of star-forming galaxies from the Sloan Digital Sky Survey IV Mapping Nearby Galaxies at Apache Point Observatory show a change in slope in their gas-phase metallicity profile. We investigate if these deviations from normality are due to error in the strong-line abundance calibrator, or whether the presence of bright star-forming regions convolved with the point spread function could produce these anomalous observed metallicity profiles. Alternatively, these breaks in the oxygen abundance profile may result from abrupt changes in the stellar mass surface density or gas fraction. In addition, we explore the association of these breaks with morphological features such as bars, bulges, spiral structure, and minor mergers.

**Author(s):** Adam Schaefer, Jalyn Nicole Krause, Cameren Swiggum, Christy Tremonti, Celeste Keith

**Institution(s):** University of Wisconsin-Madison

### **260.11 - Dissecting the Chemodynamics of Stellar Populations in M31 with APOGEE-2(Olivia Cooper)**

Just as petroglyphs on a rock face preserve details about the history of ancient peoples, the chemodynamics of a galaxy's stars provide a fossil record of the evolution of that galaxy. For example, the Milky Way's stars show correlations between alpha enhancement and kinematics that may hold clues to the formation of the thin and thick disks. Using high resolution

(R~22,500) infrared spectroscopy from SDSS IV's APOGEE-2 project, we investigate these properties and the presence of this correlation in our closest neighbor, the Andromeda Galaxy (M31). Using template-fitting with a custom library of simple stellar population spectra, we map the stellar dynamics throughout the galaxy's inner region. We also present results from an analysis of composite populations in M31's disk, including of kinematic differences between populations with different mean metallicity and alpha enhancement. This study provides insight into the uniqueness of M31 and the Milky Way's evolutionary histories.

**Author(s):** Aishwarya Ashok, Nicholas Boardman, Galen Bergsten, Anil Seth, Gail Zasowski, Olivia Cooper, Dmitry Bizyaev

**Institution(s):** Smith College, New Mexico State University, University of Utah

### **260.12 - An APOGEE-2 Survey of the Stellar Populations in the M31 Group(Galen Bergsten)**

The Milky Way and Andromeda Galaxies present opportunities to study galaxy formation and evolution processes at a unique level of detail. We present initial results from a study of Andromeda group galaxies and globular clusters with high-resolution, integrated-light infrared spectroscopy from the SDSS-IV APOGEE-2 survey. We construct semi-empirical simple stellar population (SSP) spectra using APOGEE stellar templates and demonstrate their effectiveness in recovering fundamental parameters of composite stellar populations, including in M31 and some of its companion galaxies. The SSP library will be made publicly available for the community to use.

**Author(s):** Aishwarya Ashok, Galen Bergsten, Dmitry Bizyaev, Gail Zasowski, Olivia Cooper, Anil Seth

**Institution(s):** University of Utah, Apache Point Observatory, Smith College

### **260.13 - Deep Chandra observations of the Grand Design Spiral M81: A First Look(Mihoko Yukita)**

We present a deep Chandra ACIS-I survey of M81 (4 fields, ~200 ks each, total 800 ks) sampling the entire optical, and a large fraction of the extended UV, disks. We detected about 600 point sources down to a sensitivity limit of  $\sim 6 \times 10^{-35}$  erg/s. Our X-ray point sources comprise X-ray binary stars, background active galactic nuclei, foreground stars, and supernova remnants (SNRs). We classify the detected X-ray point sources by cross-correlating with several multi-wavelength source catalogs (IR: WISE, Spitzer; optical: Pan-STARRS), as well as published SNR and globular cluster catalogs. We construct X-ray binary luminosity functions for galactic substructures such as the bulge, disk, spiral arms, halo, extended UV disk and globular clusters, which can then be compared to state-of-the-art X-ray binary population synthesis models.



**Author(s):** Andreas Zezas, Doug Swartz, Panayiotis Tzanavaris, Paul Sell, Kristen Lackeos, Andrew Ptak, Mihoko Yukita, Ann Hornschemeier  
**Institution(s):** Johns Hopkins University, USRA, NASA Goddard, University of Crete, NASA MSFC, UMBC

#### **260.14 - The X-ray Binary Populations of M81 and M82(Paul Sell)**

We present a detailed study of the X-ray point source populations of the nearby, star-forming, spiral galaxy M81. Using deep HST data, we uniquely classify the X-ray binary (XRB) populations on the basis of their donor stars and local stellar populations. While this analysis is focused on Chandra observations most sensitive to the central galactic regions, we also include preliminary analysis of new Chandra observations probing the outer disk regions. These new observations importantly enable us to study XRBs across the entire disk at a range of ages. We measure the X-ray luminosity functions (XLFs) of the different XRB sub-populations (early-type main sequence, supergiant, low-mass, globular cluster), and we compare these results with predictions from XRB population synthesis models. This more robust classification (than the common, simple bulge/disk spatial separations) of XRBs minimizes contamination between different sub-populations, and it shows that high-mass XRBs have steeper XLFs than the “canonical” star-forming galaxy XLF commonly used. In the case of globular clusters, we find that more massive and denser globular clusters are more likely to be associated with XRBs. We also compare these results with the XRB populations of the prototypical starburst galaxy, M82, for which we present the deepest XLF reported for a starburst galaxy. We discuss the variations of the XRB populations in regions of M82 dominated by star-formation episodes at different ages, and in the context of predictions from XRB formation and evolution models.

**Author(s):** John Gallagher, Jeff Andrews, Andreas Zezas, Doug Swartz, Paul Sell, Andrew Ptak, Mihoko Yukita, Stephen Williams

**Institution(s):** University of Crete, NASA GSFC, US Naval Observatory, NASA Marshall, University of Wisconsin-Madison, Johns Hopkins University

#### **260.15 - The Spatially Resolved Star Formation History in M81(Douglas Swartz)**

The Markov Chain Monte Carlo version of the publicly available code CIGALE (Code Investigating GALaxy emission) is used to investigate the star formation history of the nearby SA(s)b galaxy NGC 3031 (M 81) on sub-kpc spatial scales. Sub-kpc regions are defined using the contour binning algorithm of Sanders (2006). This algorithm bins imaging data using contours on an adaptively smoothed UV image to define a map that closely follows the Grand Design spiral arm structure of M 81; effectively separating regions of recent star formation activity from older disk and bulge structures. CIGALE generates

theoretical Spectral Energy Distribution (SED) models and fits to UV-to-far-IR photometric data from each map region to constrain local star formation histories. We find a local peak star formation rate (SFR) near the spiral arms between 100 and 300 Myr ago consistent with estimates of the time of recent encounters with the M81 companion galaxies M 82 and NGC 3077.

**Author(s):** Andreas Zezas, Panayiotis Tzanavaris, Paul Sell, Kristen Lackeos, Andrew Ptak, Mihoko Yukita, Ann Hornschemeier, Douglas Swartz

**Institution(s):** USRA, Johns Hopkins, NPP, University of Crete, NASA/GSFC

#### **260.16 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC 4088, 4085, and 4369(Frederick A Slane)**

New deep ugr imaging was obtained on the Wyoming Infrared Observatory 2.3 meter telescope for NGC4088, NGC4085, and NGC4369, three galaxies in the Extended Disk Galaxy Exploration Science survey. These data are coupled with deep GALEX ultraviolet, Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461 and PAARE grant AST 1559559.

**Author(s):** Carolyn Drake, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Louis Marlon Bran, Nathan Lee, Jordan Turner, Henry Kobulnicky, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Frederick A Slane, Kristin Anderson

**Institution(s):** University of Wyoming, Cal State U Channel Islands, Cal State U Long Beach, Whitman College, East Tennessee State University, Cerritos College, Colgate University

#### **260.17 - EDGES: Radial Star Formation Histories in Nearby Galaxies UGC07408 and IC4182(Carolyn L Drake)**

New deep ugr imaging was obtained on the Wyoming Infrared Observatory 2.3-meter telescope for UGC07408 and IC4182, two galaxies in the Extended Disk Galaxy Exploration Science survey. These data are coupled with deep GALEX ultraviolet and Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461.

**Author(s):** Carolyn L Drake, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Louis Marlon Bran, Nathan Lee, Jordan Turner, Henry Kobulnicky, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Frederick A Slane, Kristin Anderson

**Institution(s):** Whitman College, CalState UChannel Islands, CalState ULong Beach, University of Wyoming, East Tennessee State, Cerritos Community College, Colgate University

**260.18 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC4143 and UGC07639(Jacob Pilawa)**

New deep u, g, and r imaging was obtained on the Wyoming Infrared Observatory 2.3 meter telescope for NGC4143 and UGC07639, two galaxies in the Extended Disk Galaxy Evolution Science survey (EDGES). These data are coupled with deep GALEX ultraviolet and Spitzer/WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE spectral energy distribution (SED) modeling software are presented, including trends in the star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461.

**Author(s):** Carolyn Drake, F. Alexander Slane, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Louis Marlon Bran, Nathan Lee, Jordan Turner, Henry Kobulnicky, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Kristin Anderson

**Institution(s):** Colgate University, Cal State UChannel Islands, Cal State ULong Beach, Whitman College, East Tennessee State University, Cerritos College, University of Wyoming

**260.19 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC4096 and UGC7577(Louis Marlon Bran)**

New deep optical and near-infrared imaging was obtained on the Wyoming Infrared Observatory 2.3 meter telescope for NGC4096 and UGC7577, two galaxies in the Extended Disk Galaxy Exploration Science (EDGES) survey. These data are combined with deep GALEX ultraviolet and Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions (SED). Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461 and PAARE grant AST 1559559.

**Author(s):** Carolyn Drake, F. Alexander Slane, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Louis Marlon Bran, Nathan Lee, Henry Kobulnicky, Jordan A. Turner, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Kristin Anderson

**Institution(s):** California State University Channel Islands, East Tennessee State University, California State University Long Beach, University of Wyoming, Whitman College, Cerritos College, Colgate University

**260.20 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC4138 and NGC4460(Susana Soto)**

New deep u'g'r' imaging was obtained on the Wyoming Infrared Observatory 2.3-meter telescope for NGC4138 and NGC4460, two galaxies in the Extended Disk Galaxy Exploration Science survey. These data are coupled with deep GALEX ultraviolet and Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461 and PAARE grant AST 1559559.

**Author(s):** Susana Soto,

**Institution(s):** Cerritos Community College, University of Wyoming Contributing Team(s): Kristin RAnderson (Cal State ULong Beach), Louis MBran (Cal State UChannel Islands), Isaiah SCox (East Tennessee State U.), Carolyn LDrake (Whitman College), Nathan JLee (UWyoming), Jacob

**260.21 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC4214 and IC3687(Nathan Lee)**

New deep ugr imaging was obtained on the Wyoming Infrared Observatory 2.3 meter telescope for NGC4214 and IC3687, two galaxies in the Extended Disk Galaxy Exploration Science survey. These data are coupled with deep GALEX ultraviolet and Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461.

**Author(s):** Carolyn Drake, F. Alexander Slane, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Nathan Lee, Henry Kobulnicky, Jordan A. Turner, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Kristin Anderson, Louis Bran

**Institution(s):** University of Wyoming, East Tennessee State University, Cal State University Long Beach, Whitman College, Cal State University Channel Islands, Cerritos College, Colgate University

**260.22 - EDGES: Radial Star Formation Histories in Nearby Galaxies NGC4102 and UGC07608(Isaiah Samuel Cox)**

New deep ugr imaging was obtained on the Wyoming Infrared Observatory 2.3 meter telescope for NGC4102 and UGC07608, two galaxies in the Extended Disk Galaxy Exploration Science survey. These data are coupled with deep GALEX ultraviolet and Spitzer and WISE infrared imaging to study the radial variations in the spectral energy distributions. Results from the CIGALE SED modeling software will be presented, including trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461.

**Author(s):** Carolyn Drake, F. Alexander Slane, Emily L. Jensen, Jessica Sutter, Jacob Pilawa, Nathan Lee, Henry Kobulnicky, Jordan A. Turner, Daniel Dale, Isaiah Samuel Cox, Susana Soto, Kristin Anderson, Louis Bran

**Institution(s):** East Tennessee State University, California State University Channel Islands, California State University Long Beach, University of Wyoming, Whitman College, Cerritos College, Colgate University

### **260.23 - EDGES: Radial Star Formation Histories in 17 Nearby Galaxies(Kristin Rachel Ongsiako Calanoc Anderson)**

New deep UGR was obtained using the Wyoming Infrared Observatory telescope for UGC07699 and NGC4203, two galaxies mapped in the Spitzer Extended Disk Galaxy Exploration Science survey. These data are coupled with ultraviolet images from GALEX and infrared imaging from Spitzer and WISE to study radial variations in their spectral energy distributions. Results will be presented from the CIGALE SED modeling software including radial trends in the galaxy star formation histories. This work is supported by the National Science Foundation under REU grant AST 1560461 and PAARE grant AST 1559559.

**Author(s):** Kristin Rachel Ongsiako Calanoc Anderson, **Institution(s):** Long Beach State, University of Wyoming  
Contributing Team(s): Louis MBran, Isaiah SCox, Carolyn LDrake, Nathan JLee, Jacob DPilawa, FAlexander Slane, Susana Soto, Emily IJensen, Jessica SSutter, Jordan ATurner, Henry AKobulnicky, Daniel ADale

## **261 - Clusters of Galaxies Posters**

### **261.01 - Optical Confirmation of High Signal-to-Noise Galaxy Cluster Candidates**

**from the All-Sky Planck Sunyaev-Zel'dovich Catalog(Peter Doze)**

We report on the results from our galaxy cluster search from the high signal-to-noise end of the second all-sky Planck Sunyaev-Zel'dovich (SZ) catalog (PSZ2). Through deep, optical imaging from the Kitt Peak National Observatory 4m Mayall telescope we identify the richest clusters through visual inspection and other methods. A galaxy cluster is confirmed if it is both rich (based off the number of members within 1 Mpc of the brightest cluster galaxy) and within 5 arcminutes of the PSZ2 position. From the 85 unconfirmed PSZ2 candidates we observed, we find 15 galaxy clusters ( $0.13 < z < 0.74$ ), 12 of which were not previously recognized as the Planck cluster counterpart in the literature. We explore three possibilities for the low confirmation purity: that cluster counterparts are at too low or too high redshift, or are obscured by the Milky Way. We find that these options in total cannot account for the low confirmation fraction, which leads us to suggest that many of the high signal-to-noise unconfirmed PSZ2 candidates are not reliable SZ clusters.

**Author(s):** Leopoldo Infante, Steven Boada, Luis Felipe Barrientos, Peter Doze, John Patrick Hughes, Felipe Menanteau,

**Institution(s):** Rutgers University, Instituto Milenio de Astrofísica, University of Illinois at Urbana-Champaign, National Center for Supercomputing Applications,

### **261.02 - Ultraviolet Background Radiation Around Galaxy Clusters(Brian Welch)**

The diffuse ultraviolet background radiation has been mapped over most of the sky using data from the GALEX survey by Murthy 2014. We take advantage of this map to study the correlation between the UV background and clusters of galaxies discovered via the Sunyaev-Zeldovich effect in the Planck survey (Planck Collaboration 2015). We use only high galactic latitude ( $|b| > 60^\circ$ ) galaxy clusters to avoid contamination by galactic foregrounds, and we only analyze clusters with a measured redshift. This leaves us with a sample of  $\sim 185$  clusters over the redshift range  $0.02 < z < 0.89$ . In analysing our stacked sample, we find a statistically significant excess of UV background radiation over the average measured around random blank fields. We measure the stacked radial profile of these clusters, and find that the excess UV radiation decays to the level of the background at a radius roughly consistent with the maximum radial extent of the clusters. While the coarse  $2'$  resolution of the diffuse background maps used prevents more detailed analysis of the substructure of the cluster contribution to the background radiation, the presence of this excess diffuse UV radiation around galaxy clusters provides an intriguing new contributor to the ultraviolet background. Support for this work was provided by NASA to the Johns Hopkins University through APRA grant NNX17AC26G.

**Author(s):** Dan Coe, Brian Welch, Stephen McCandliss  
**Institution(s):** Johns Hopkins University, Space Telescope Science Institute

### **261.03 - Quantifying the Lensing Power of Cosmic Telescopes(Leonardo A Ruales)**

Massive objects, such as galaxy clusters, distort images through the phenomenon of gravitational lensing: light rays are redirected by the bending of spacetime. "Cosmic telescopes" such as the Hubble Frontier Fields (HFF) harness the power of gravitational lensing by magnifying dim, small sources, making them appear larger and brighter. Current research involves looking for the best fields that can act as cosmic telescopes and produce a high quantity of lensed images. Using well-calibrated mass models, we place distant sources behind various clusters and use ray tracing to simulate their lensed. We compute the number of images and quantify how powerful the clusters are as cosmic telescopes. This project has been supported by funding from National Science Foundation grant PHY-1560077.

**Author(s):** Sean Brennan, Leonardo A Ruales, Catie Raney, Charles Keeton

**Institution(s):** Stony Brook University, Rutgers University, Essex County College  
**Contributing Team(s):** Leonardo Ruales, Catie Raney, Sean Brennan, Charles Keeton, Frontier Fields

#### **261.04 - The PIPER Survey: An Initial Look at the Intracluster Globular Cluster Population in the Perseus Cluster(Patrick R. Durrell)**

We outline the goals and first results of the Program for Imaging of the PERseus cluster of galaxies (PIPER) project. The first phase of the program builds on deep Hubble Space Telescope ACS/WFC and WFC3/UVIS B and I images of fields throughout the Perseus cluster. Our PIPER target HST fields include major early-type galaxies including the active central giant NGC 1275, known ultra-diffuse galaxies, and the intracluster medium. The resulting photometry reaches deep enough to resolve and measure the globular cluster (GC) populations in the Perseus member galaxies. Here we present initial results for three pairs of fields that confirm the presence of intracluster GCs (IGCs) as distant as 740 kpc from the Perseus center, or 40% of the virial radius of the cluster. The majority of the IGCs are identifiably blue (metal-poor) but there is a trace of a red (metal-rich) component as well, even at these very remote distances.

**Author(s):** Aaron J. Romanowsky, Carolin Wittmann, Patrick R. Durrell, Sakurako Okamoto, Jean Brodie, Steven Janssens, John Blakeslee, William E. Harris, Thorsten Lisker

**Institution(s):** Youngstown State University, San Jose State University, McMaster University, UC Santa Cruz, Gemini Observatory, Heidelberg University, University of Toronto, Subaru Telescope, NAOJ

#### **261.05 - Mapping the Chemodynamics in the A85 BCG.(Percy Gomez)**

We will present the results of a recent Keck KCWI observation of the BCG in A85. These IFU observations have allowed us to map OII, OIII and Hydrogen-beta emission within and around the BCG. In this paper, we explore the possible mechanisms responsible for these emission features and for the X-ray cavities found in this BCG.

**Author(s):** Percy Gomez

**Institution(s):** WM Keck Observatory

#### **261.06 - Improving Distance Estimates in the Local Universe: Applications to ALFALFA(Tim Rehm)**

To understand the larger scale structure of the local Universe ( $z < 0.06$ ), we require adequate distance assignments and an understanding of their uncertainties. Local departures from smooth Hubble flow introduce large errors in distances derived from CMB velocities alone. For analysis of data from the blind extragalactic HI survey ALFALFA, the ALFALFA distance estimation routine takes advantage of pre-determined redshift-

independent distances from the literature - including primary distances measurements such as TRGB or secondary Tully-Fisher measurements, a flow model developed by Masters (2005) and assignments of membership in known groups and clusters. Here we report an update of the previous methodology used for ALFALFA. To reduce the impact of orbital scatter and peculiar motions, a halo-based group-finder algorithm is used to assign a group CMB velocity and corresponding distance to galaxies identified as group/cluster members. We make use of six different group catalogs created using SDSS or 2MRS. For the nearest volume  $z < 0.02$ , the multi-attractor flow model is still used to account for local peculiar velocities. The new code, written in Python, is useable on other low-redshift galaxy catalogs, with mutable inputs for which group catalogs are used. We present an analysis of the impact of group catalog choice. This research has been supported by NSF grant NSF/AST-1714828 to M.P.Haynes and by the Brinson Foundation for the Arecibo Pisces-Perseus Supercluster Survey (APPSS).

**Author(s):** Tim Rehm, Martha P Haynes

**Institution(s):** Cornell University

#### **261.07 - Targeted HI Line Observations of Low Mass Galaxies in the Pisces-Perseus Supercluster: Results for the Declination Strip $30^\circ < \text{Dec} < 32^\circ$ .(Samuel Franklin Kumagai)**

The Arecibo Pisces-Perseus Supercluster Survey (APPSS) is an observing project undertaken by the Undergraduate ALFALFA Team that aims to detect HI in galaxies in the Pisces-Perseus neighborhood and analyze the dynamics and the properties of the galaxies. The galaxies targeted in APPSS are suspected from their optical properties (color, morphology, surface brightness) to lie in the Pisces-Perseus Supercluster (PPS) but are below the detection threshold of the ALFALFA blind HI survey. Here we present results for galaxies targeted in a strip across the PPS region in declination from 300 to 320. This region is along the main filament of the supercluster and includes objects such as the Pisces Cluster. The data was recorded by the L-Band Wide receiver of the Arecibo Observatory. Data reduction was done using routines derived for the APPSS in IDL. After baselining the spectra and sifting out radio interference, we fit either a gaussian or two-horned profile to their 21-centimeter line to measure the HI line flux density, velocity, and velocity width. From these parameters we calculate distances, hydrogen gas mass, and rotational velocities. As expected, the galaxies analyzed in this slice of declination have consistently lower mass than the ALFALFA detections thus extending the sampling of galaxies within the PPS. The combined ALFALFA and APPSS HI line detections will be used for future applications of the Baryonic Tully-Fisher Relation in this region. This research has been supported by NSF grant NSF/AST-1714828 to M.P.Haynes and by the Brinson Foundation for the Arecibo Pisces-Perseus Supercluster Survey (APPSS).

**Author(s):** Samuel Franklin Kumagai

**Institution(s):** Cornell University

**261.08 - Detection of a superluminous disk galaxy in the center of a low-mass galaxy cluster(Akos Bogdan)**

Brightest Cluster Galaxies (BCGs) residing in the centers of galaxy clusters are typically quenched giant ellipticals. A recent study hinted that star-forming galaxies with large disks, so-called superluminous disk galaxies, are the BCGs of a subset of galaxy clusters. Based on XMM-Newton X-ray observations of five galaxy clusters, we map the morphology of the intracluster medium (ICM), characterize the galaxy clusters, determine the position of the cluster center, and measure the offset between the cluster center and the superluminous disk galaxies. We demonstrate that one superluminous disk galaxy resides at the center of a low-mass galaxy cluster. This represents the first conclusive evidence that a superluminous disk galaxy is the BCG of a galaxy cluster. We speculate that the progenitor of the BCG was an elliptical galaxy, whose extended disk was re-formed due to the merger of galaxies. We exclude the possibility that the other four spiral galaxies reside at the center of galaxy clusters, as their projected distance from the cluster center is 150-1070 kpc. We conclude that these clusters host quiescent massive elliptical galaxies at their center.

**Author(s):** Akos Bogdan, Christine Jones, Felipe Andrade-Santos, Ralph Kraft, Lorenzo Lovisari, William Forman, Orsolya Kovacs

**Institution(s):** Smithsonian Astrophysical Observatory

**261.09 - Using Chandra X-ray Observations to Determine the Physical Properties of G211.21+38.66, a Planck-Detected, Merging Galaxy Cluster at  $z = 0.505$ (Megan Masterson)**

Mergers of galaxy clusters probe the formation and evolution of large scale structure in the Universe. We present a detailed Chandra X-ray study of G211.21+38.66 (G211), a Planck-detected galaxy cluster at  $z = 0.505$ . As a merging galaxy cluster, G211 provides a snapshot of cluster evolution and cosmic structure growth at an intermediate redshift. G211 contains a main cluster and smaller subcluster, whose X-ray center is approximately 1.2 Mpc northwest of the main cluster center. The region between the two clusters is hotter than the rest of the main cluster outskirts, and the hot gas in the main cluster appears more extended toward the subcluster, both of which are indicative of an interaction between the two systems. We find that both the main cluster and subcluster are non-cool-core clusters. We also derive the gas properties of the main cluster, excluding the region toward the subcluster. The gas fraction for the main cluster is too large under the assumption of hydrostatic equilibrium, exceeding the cosmic baryon fraction and the typical values for other clusters at the same radius. These findings suggest that this merging system has yet to reach equilibrium. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST1659473, and by the Smithsonian Institution.

**Author(s):** Megan Masterson, Felipe Andrade-Santos,

Yuanyuan Su

**Institution(s):** Case Western Reserve University, Harvard-Smithsonian Center for Astrophysics

**261.10 - Instantaneous and Cumulative Star Formation in Moderate Redshift X-ray Clusters(Jacob P Curtis)**

Galaxy clusters provide a laboratory for determining the impact of environment on star formation in galaxies. We use Spitzer IRAC and MIPS photometry to measure stellar masses and star formation rates in a sample of 41 X-ray-selected clusters at moderate redshift. We apply statistical background subtraction to IRAC photometry to construct luminosity functions and estimate the total stellar masses of the clusters. We compare stellar masses to gas masses and total masses from Chandra observations. Using MIPS 24-micron imaging, we identify mid-infrared sources as candidate star-forming galaxies. We use IRAC and optical photometry to identify likely cluster members and determine instantaneous cluster-wide star formation rates. We calculate specific star formation rates (sSFR; star formation rate divided by stellar mass) for the cluster galaxies and compare with field galaxies at similar redshifts. We also calculate the cluster-averaged sSFRs and compare to studies of clusters at other redshifts. This study represents the largest sample of moderate redshift X-ray clusters to date and will provide insights into the evolution and efficiency of star formation in the cluster environment.

**Author(s):** Alexey Vikhlinin, Rose A Finn, Jacob P Curtis, Jess Mollerup, Kenneth Rines

**Institution(s):** Western Washington University, Smithsonian Astrophysical Observatory, Siena College

**261.11 - Measuring stellar masses of the brightest cluster galaxies in X-ray luminous galaxy clusters using Hubble Space Telescope archival data(Yuzo Ishikawa)**

We have analyzed broadband HST photometry available to study the brightest cluster galaxies (BCGs) in X-ray luminous clusters of galaxies. These galaxies span a redshift interval of  $0.152 < z < 0.55$  and were identified by the Canadian Cluster Comparison Project. We used this sample to build a robust analysis pipeline to produce stellar mass estimates of the BCGs from HST images of galaxy clusters. We apply the observed colors to constrain the parameters in the simple stellar population synthesis models to produce the best light-to-mass ratios and stellar mass profiles of the BCGs. By applying variable fit-parameters, we can build metallicity profiles and trace the star-formation histories in the BCG. Since BCGs sit at the potential wells of the host cluster and houses most of the cluster mass, the new stellar mass estimates will allow us to build improved mass profiles of the clusters to characterize the amount of dark matter present.

**Author(s):** Yuzo Ishikawa, Andisheh Mahdavi

**Institution(s):** San Francisco State University

#### **261.12 - Using Machine Learning to Predict the Masses of Galaxy Clusters(Nicel Mohamed-Hinds)**

Galaxy clusters are the most massive gravitationally bound systems in the universe and thus are largely influenced by cosmological parameters, yet the predicted masses of these clusters often have significant scatter. One way that cluster masses have historically been predicted is dynamically, by using a power law relationship that relates mass to velocity dispersion. We predict cluster masses by using more statistical measures from the velocity probability distribution function in conjunction with machine learning. For our study, we use a mock cluster catalog from the Multidark N-body simulation to find correlations between cluster mass and statistical measures beyond velocity dispersion, including biweight scale, median absolute deviation, skewness, and higher order moments. Biweight scale and median absolute deviation correlate with mass by a power law relationship similar to that which relates velocity dispersion to mass, but with reduced scatter. While velocity dispersion presents a scatter of 0.423, biweight scale presents a scatter of 0.374 and median absolute deviation presents a scatter of 0.295, where we quantify scatter as the standard deviation of the log of the predicted mass minus the log of the true mass. We find that negative 4th moment corresponds to overpredicted cluster masses, while positive 4th moment corresponds to underpredicted cluster masses. We also find that high 6th moment corresponds to overpredicted cluster masses. Odd moments and higher order moments beyond 6th moment did not demonstrate significant correlation with mass. We use a data vector of biweight scale, median absolute deviation, 4th moment, and 6th moment as input for a machine learning tool, which learns correlations with mass and how to account for interlopers: galaxies that appear to be a part of the cluster from our line of sight but are not. We predict cluster masses with a scatter of 0.174, which is less than half the scatter from predicting dynamically. Acknowledgement: This work was supported by the Banneker & Aztlan Institute.

**Author(s):** Nicel Mohamed-Hinds, Michelle Ntampaka

**Institution(s):** Stanford University, Harvard University

#### **261.13 - Measuring the Mass at the Cores of Strong Gravitational Lensing Galaxy Clusters(Juan David Remolina)**

New surveys are discovering large numbers of galaxy clusters, including strong lensing clusters. Strong lensing offers a unique opportunity to study both the cluster itself and the background universe that it magnifies. While lens modeling provides measurements of the total projected mass distribution at the core of the cluster independent of assumptions on cluster astrophysics, this process is time consuming and computationally expensive. We would therefore like to use a faster method allowing us to process the large quantity of

strong lensing clusters discovered. To zeroth order, the projected enclosed mass can be determined from the observed Einstein Radius, by assuming spherical symmetry. This method has been routinely used in the literature, but its uncertainty has not yet been properly quantified. To address this, we use the Outer Rim N-body cosmological simulation. We find strong lensing clusters in an SPT-like cluster sample, and use ray tracing to produce lensed images of background sources. We compute the mass estimates from the Einstein Radius and compare them to the true mass of the simulated clusters cores. In addition, we compute a “basic” lens model, which requires minimal human interaction, is automatically generate once the lensed images have been identified and redshifts measured, and takes a fraction of the computing time compared to a detailed lens model. Our analysis will provide for the first time an accurate assessment of the uncertainties in the mass enclosed by the Einstein radius and “basic” lens models mass estimates, enabling their use in large surveys.

**Author(s):** Guillaume Mahler, Juan David Remolina, Michael Gladders, Keren Sharon, Lindsey Bleem, Brendan Reed

**Institution(s):** University of Michigan, Argonne National Laboratory, Indiana University, The University of Chicago

#### **261.14 - The Shapes of Galaxy Groups in SDSS DR7(Yuhan Guo)**

We study the projected two-dimensional shapes of galaxy groups identified in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7). We quantify group shapes by calculating their minor-to-major axis ratio, and we evaluate the statistical significance by constructing null samples that take into account the discreteness effect caused by low multiplicity of the groups. We find that, regardless of multiplicity, the projected shapes of galaxy groups have strong elongation that cannot be solely explained by the discreteness effect. However, the apparent dependence of shape on multiplicity, is mainly due to the discreteness effect. We also investigate whether there are correlations between group shapes and group properties, such as color, magnitude and velocity dispersion, or environment properties, such as number density and alignment angle. We find no such significant correlations. We then compare these SDSS results to a suite of 100 mock galaxy catalogs that were constructed by populating dark matter halos in a cosmological N-body simulation with galaxies in a way that preserves the shapes of halos. We find that the shapes of SDSS groups are consistent with those of mock groups, suggesting that galaxies trace the shapes of LCDM halos.

**Author(s):** Yuhan Guo

**Institution(s):** Vanderbilt University

### **261.15 - Mapping Galaxy Cluster Orientations from Cosmo-OWLS Simulations(PJ Gibson)**

Galaxy clusters, after superclusters, are the largest gravitationally bound structures in the Universe and are comprised mostly of dark matter - about 80%. Dark matter may only be observed via its gravitational interactions with other matter. Studying weak gravitational lensing, an example of one of these gravitational interactions, can be made more accessible and controlled when working with simulated data from cosmological simulations. Simulations allow us to generate and refine procedures that can be applied in the observable Universe. Through analysis of weak lensing maps that we created by examining the passage of light through the “cosmo-OWLS” simulations, we separate out simulated galaxy clusters in specific fields of view. By fitting ellipses to weak lensing signals around the clusters and comparing major axis orientations to the true values stored in the simulation, we aim to create a method of calculating the projected orientations of observable galaxy clusters as accurately as possible. This project was supported in part by the NSF REU grant AST-1757321 and by the Nantucket Maria Mitchell Association.

**Author(s):** Lindsay King, Matthew Fong, PJ Gibson,

**Institution(s):** Willamette University, University of Texas at Dallas, Maria Mitchell Observatory

### **261.16 - A Hydrodynamical Simulation of the Off-Axis Cluster Merger Abell 115(Wonki Lee)**

A merging galaxy cluster is a useful laboratory to study many interesting astrophysical processes such as intracluster medium heating, particle acceleration, and possibly dark matter self-interaction. However, without understanding the merger scenario of the system, the interpretation of the observational data is severely limited. In this work, we focus on the off-axis binary cluster merger Abell 115, which possesses many remarkable features. The cluster has two cool cores in X-ray with disturbed morphologies and a single giant radio relic just north of the northern X-ray peak. In addition, there is a large discrepancy (almost a factor of 10) in mass estimate between weak lensing and dynamical analyses. To constrain the merger scenario, we perform a hydrodynamical simulation with the adaptive mesh refinement code RAMSES. We use the multi-wavelength observational data including X-ray, weak-lensing, radio, and optical spectroscopy to constrain the merger scenario. Our results support a scenario wherein Abell 115 is in the returning phase after the first core passage. The infalling scenario (with no previous collision) is highly disfavored because of the predicted brightness of the radio relic being much lower than the observed value. We will present detailed comparisons between the simulation results and our multi-wavelength observations.

**Author(s):** Taysun Kimm, Myungkook James Jee, Wonki Lee

**Institution(s):** Yonsei University, University of California, Davis

### **261.17 - Constraining the Physics of the Intracluster Medium with the Angular Power Spectra in X-ray(Erwin Tin-Hay Lau)**

Astrophysical uncertainties remain one of the major systematics in constraining cosmological parameters with galaxy clusters. Angular power spectra provide unique constraints on the physics of the intracluster medium (ICM), especially for clusters and groups at high redshifts. By comparing the X-ray angular power spectra from the Chandra COSMOS Legacy Survey and the ROSAT All Sky Survey against theoretical predictions from semi-analytic models, we constrain the impact of ICM physics in cluster cores (e.g., AGN feedback) and cluster outskirts (e.g., clumping) on cosmological parameters. Based on our results, we provide forecasts on the constraints on cluster astrophysics and cosmology for upcoming multi-wavelength galaxy cluster surveys.

**Author(s):** Masato Shirasaki, Erwin Tin-Hay Lau, Daisuke Nagai, Nico Cappelluti

**Institution(s):** University of Miami, NAOJ, Yale University

### **261.18 - Observing ICM ram pressure, galaxy orbits, and large-scale structure using the bending of radio galaxies(Avery Garon)**

We study the impact of cluster environment on the morphology of a sample of 4304 extended radio galaxies from Radio Galaxy Zoo. The bending of radio galaxies is found to be related to the inferred ram pressure from the intracluster medium, varying both with projected distance from the nearest cluster center and with the cluster mass. Beyond  $1.5 r_{500}$  ( $\sim 1$  Mpc), there is no further decrease in the median amount of bending. We use the orientation of bent radio galaxies with respect to the cluster as an indicator of their orbits, and find that within  $10 r_{500}$  ( $\sim 7$  Mpc), they are preferentially in radial orbits. 61% of highly bent radio galaxies in our sample are actually found farther than  $1.5 r_{500}$  from the nearest cluster center; they are commonly found in locally overdense regions at distances up to 10 Mpc.

**Author(s):** Tom W. Jones, Francesco de Gasperin, Jean Tateo, Stanislav S. Shabala, Ray P. Norris, Lawrence Rudnick, O. Ivy Wong, Jin-Ah Kim, Avery Garon, Heinz Andernach, Hongming Tang, Anna Kapinska

**Institution(s):** University of Manchester, University of Oxford, University of Minnesota, Yonsei University, The University of Western Australia, University of Tasmania, Universidad de Guanajuato, CSIRO Astronomy and Space Science, National Radio Astronomy Observatory

### **261.19 - Supernovae explosion models discrimination using the intracluster gas(Rebeca Maria Batalha De Melo)**

Intragroup/cluster medium (IGM/ICM) metal enrichment results from material ejected by supernovae (SNe), mostly through mechanisms which inject material from galaxy members to IGM/ICM. However, neither SNe explosion mechanisms nor enrichment mechanisms are completely understood. Discriminating between different enrichment mechanisms depends on the understanding of the progenitor and explosion mechanisms of SNe, since they determine the SNe metal output (yields). Observing supernova remnant (SNR) to determine yields is not trivial since SNRs are typically multi-phase and have often optically thicker regions requiring complex emission models. They are also embedded in the surrounding interstellar medium. On the other hand, the ICM is optically thin providing a clean view of the original X-ray photons produced, the plasma physics is simple, and one can get robust 3D abundances. Therefore, measuring chemical abundances from IGM/ICM is a promising technique to constrain SN models. In order to select consistent models, we compare observed elemental abundance ratios of the IGM/ICM from 18 clusters and groups of galaxies to predicted ones from 34 theoretical explosions models, using the Suzaku satellite. Our analysis indicates that medium and high metallicity Hypernova (HNe) models are favored in describing the SNe core collapse yields, compared to other Type II SN models. This accentuated distinction suggests that the diffuse medium in clusters and groups is predominantly enriched by heavy elements ejected by HNe explosions, likely during pre-cluster formation. For the Type Ia SN scenarios, models of the double degenerate scenario such as in Papish & Perets (2016) are strongly disfavored. In this context, our analysis favors single degenerate scenarios for the nature of the progenitor system. Furthermore, we propose an empirical (heuristic) model, which minimally describes the observed ratios. We apply these heuristic model to assess the origin of the material in cavities and bubbles found in some clusters.

**Author(s):** Renato A Dupke, Rebeca Maria Batalha De Melo

**Institution(s):** Observatorio Nacional, Univof Alabama, Univof Michigan

### **262 - Education: Astronomy In & Out of the Classroom -- iPosters**

#### **262.01 - Blogging about Astronomy: Insights from Astrobites(Mithi Alexa Caballes de los Reyes)**

Astrobites is a website run by graduate students, aimed at making current astrophysical research accessible to undergraduate physical science majors and astronomy enthusiasts. Since its founding in December 2010, Astrobites has featured more than 100 contributors posting from four continents (including Antarctica!). Over the past eight years, authors have contributed more than 2000 posts. Weekday posts summarize cutting-edge research papers from arXiv; additional "beyond astro-ph" content includes career advice, current event updates and conference liveblogging, and summaries of seminal

astronomy papers. Astrobites has inspired similar science communication efforts in other scientific disciplines and in other languages. Today, Astrobites is further expanding to include new content---about science policy, equity and inclusion efforts, and other topics---and to be used as a pedagogical tool for teaching about current research.

**Author(s):** Mithi Alexa Caballes de los Reyes

**Institution(s):** Caltech Contributing Team(s): Astrobites Collaboration

#### **262.02 - Data and Design: Jupyter Notebook Tutorials for STScI(Josephine Bunnell)**

The Mikulski Archive for Space Telescopes (MAST) is an important tool for professional and student astronomers conducting research. A key part of this archive is its capacity to host publicly accessible data products from all Space Telescope Science Institute missions. In order to help maximize the ease of use of these data products, STScI has started to build a repository of Jupyter Notebook tutorials that demonstrate methods of accessing, reducing, and analyzing data. These first Notebooks define a structure for more tutorials to follow, eventually building a large collection as a readily available, educational resource. These tutorials use Kepler data products and future Notebooks will make use of data from a large range of STScI missions. The goal of all the tutorials is to demonstrate how to download, read, and plot data in different ways so the user may become familiar with methods to analyze data and use it in research or projects beyond the tutorials. The intended audience for these Notebooks are undergraduate students who are studying astronomy or working professionals who may not be familiar with how to use these specific data products. Data to run the tutorials is obtained in each Notebook through Astroquery code walk-throughs, so the user does not need to download data beforehand. Ultimately, the Notebooks will be able to run on an online server, thereby omitting the need for users to obtain software packages and allowing all parts of the tutorial to be operated through an internet browser. These tutorials have the potential to become tools that create a greater accessibility around data usage for students or other users who do not have access to substantial resources already.

**Author(s):** Jennifer Kotler, Josephine Bunnell,

**Institution(s):** Bennington College, Space Telescope Science Institute Contributing Team(s): STScI Kepler Archive Scientists, STScI Data Science Mission Office

#### **262.03 - The Path to Newton: An Interactive Infographic(Alyssa Ann Goodman)**

"The Path to Newton" is a new interactive infographic designed to tell the backstory of how the findings and ideas of observers, natural philosophers and scientists interacted in order to ultimately permit Newton to make his theory of gravity. The graphic includes images (and hyperlinked profiles) of dozens of scientists and their scholarly works, and it shows the linkages



between their ideas. Some ideas are called out as steps "toward" Newton, and others as less helpful. The work was motivated by a new online edX educational resource, PredictionX (see [predictionx.org](http://predictionx.org)) that covers the history of how humans have predicted their futures, from Ancient Babylonian times up to the present. The central piece of PredictionX focuses on the evolution from detailed observations and record keeping (e.g. in Ancient Mesopotamia or Egypt) to empirically-based mathematical explanations (e.g. Ptolemy or Kepler) to truly physical, predictive, theory (Newton). In addition to calling out individuals and their ideas, the piece also highlights evolution in mathematics and instrumentation that allowed for progress along the path. The Path to Newton crosses through many cultures and regions, starting in Ancient Mesopotamia, traversing Ancient Egypt and Greece, then India and the Islamic world, and then finally Europe. While the piece was originally intended to be experienced online, as its elements are linked to rich background material, it makes a fabulous large-format printed poster, which will be displayed at the American Astronomical Meeting.

**Author(s):** Alyssa Ann Goodman, Jais Brohinsky, Katie Peek, Drew Lichtenstein

**Institution(s):** Harvard University, Harvard University, Radcliffe Institute for Advanced Study, Freelance Designer

#### **262.04 - Web Accessible Database to the Astronomical Photographic Data Archive(Thurburn Barker)**

The Astronomical Photographic Plate Archive (APDA) at Pisgah Astronomical Research Institute (PARI) acquired its first plate collection in 2004. Plate collections come from individual researchers with the majority coming from universities, observatories and institutions who no longer have the funds and/or facilities to house their collections. Currently, APDA contains about 350,000 photographic plates and films representing approximately 50 collections. APDA's top five collections, in number of plates, have come from: US Naval Observatory, Yale, Harvard, University of Michigan and Case Western Reserve University. Documentation about the contents of these plate collections, when provided, come in various formats such as spreadsheets, CSV text, typed or handwritten logs. During FY18, with support from the Institute of Museums and Library Services, APDA designed and implemented a PostgreSQL database providing a standardized plate collection catalog. In September 2018, APDA began the process of uploading existing plate data into the database. Digitized images of plates, plate envelopes, and other metadata, where available, will be included in the database. The database is accessible on-line using the <u>A</u>PDA <u>d</u>atabase <u>We</u>b Search <u>Tool</u> (ADWeST).

**Author(s):** Sheldon Kagel, Michael Castelaz, Thurburn Barker, Tim DeLisle

**Institution(s):** Pisgah Astronomical Research Institute, Brevard College

#### **262.05 - On-line Eclipse Resources from the U.S. Naval Observatory: Planning Ahead for October 2023(Jennifer Lynn Bartlett)**

On 14 October 2023, an annular solar eclipse like that described by Thucydides (c. 431 B.C.)- "assumed the form of a crescent and some of the stars had come out, [the Sun] returned to its natural state"-will astound fortunate observers along a narrow band, approximately 130 mi (209 km) wide, crossing 15 states from Oregon to Texas. In response to the avid interest in eclipses generated by the spectacular total solar eclipse on August 21, 2017, the U.S. Naval Observatory developed the 2023 October 14 Annular Solar Eclipse page (<http://aa.usno.navy.mil/data/docs/Eclipse2023.php>), an on-line resource center with direct links to 2023-specific resources. The 2023 resource center organizes materials from across the USNO web site. The Solar Eclipse Computer (<http://aa.usno.navy.mil/data/docs/SolarEclipses.php>) calculates tables of local circumstances for events visible throughout the world. Users may incorporate USNO data into their own projects via its application programming interface (API; <http://aa.usno.navy.mil/data/docs/api.php>). The USNO Eclipse Portal

([http://astro.ukho.gov.uk/eclbin/query\\_usno.cgi](http://astro.ukho.gov.uk/eclbin/query_usno.cgi)) provides diagrams and animations showing the global circumstances for events visible throughout the world and local circumstances for events visible at selected locations. The Portal, which includes both solar and lunar eclipses, is a joint effort with Her Majesty's Nautical Almanac Office. The Eclipses of the Sun and Moon page

(<http://aa.usno.navy.mil/data/docs/UpcomingEclipses.php>) links to electronic copies of the visibility maps from The Astronomical Almanac. The Eclipse Reference List ([http://aa.usno.navy.mil/faq/docs/eclipse\\_ref.php](http://aa.usno.navy.mil/faq/docs/eclipse_ref.php)) is a representative survey of the available literature for those interested in delving into these phenomena, either technically or historically. The following year, another total solar eclipse will cross the continent on April 8, 2024. The USNO resource center for that event is also available

(<http://aa.usno.navy.mil/data/docs/Eclipse2024.php>). If your plans for 2023 and 2024 are not yet made, visit the appropriate solar eclipse page to prepare for the "unexampled beauty, grandeur, and impressiveness" (Newcomb 1890) of darkness.

**Author(s):** Gregory Bliss, Jennifer Lynn Bartlett, Eric Barron, Malynda R Chizek Frouard, Steve Bell, Mark Stollberg

**Institution(s):** U.S. Naval Observatory, HM Nautical Almanac Office, George Mason University

### **262.06 - Astronomy at Orange Coast College: Growth and Future Directions(Jerome Fang)**

Orange Coast College (OCC), located in Costa Mesa, California, is one of the largest community colleges in the state, serving over 21,000 students across 150 academic disciplines and career programs. It ranks among the top five community colleges in California in number of transfers to four-year institutions. The OCC astronomy department is recognized as a standalone area that serves approximately 1500 students per year and has its own Associate's in Science degree. The staff is comprised of two full-time and three part-time instructors. It offers a broad scope of courses, covering areas from general-education surveys to a sophomore-level astrophysics course. Thanks to a \$1 million donation, the department recently completed the "Astronomy House", a forward-looking space that offers students, faculty, and staff a novel environment that fosters creativity, collaboration, and community. The House serves as the focal point for our "Astronomy Village", which will include a state-of-the-art, 129-seat planetarium (opening in 2019) and a "Telescope Farm" for students and the public to have "eye-on" contact with the cosmos. As the department continues to thrive, we seek collaborations with interested faculty and institutions who share our commitment to energize and engage young and college-aged students along with the public in the joys and awe of the night sky.

**Author(s):** Jerome Fang, Nicholas Contopoulos

**Institution(s):** Orange Coast College

### **262.07 - Intro Astro: an open-access moderately mathematical text(Andrea K Dobson)**

Intro Astro is a currently free online textbook designed for students in the introductory part of an astronomy undergraduate degree. While not purely calculus based, it is designed to have an appropriate level of mathematical rigor and depth. The introductory chapter provides background necessary for a wide variety of different course configurations. Subsequent chapters cover topics in planetary science, solar and stellar astronomy, galaxies, and cosmology. Additional chapters provide a review of basic mathematics and an introduction to observational astronomy and all chapters include sample problems. The text had its genesis at Whitman College due to the scarcity of affordable reasonably current books with appropriate levels of mathematics. Specifically, it has been used in the introductory astronomy major courses (Whitman also offers an introductory course for non-science majors and many students, even in the introductory major courses are taking the class as an elective). These students have strong science and math backgrounds in high school and are typically taking first or second year physics and calculus concurrently with astronomy. Intro Astro is available at [http://people.whitman.edu/~dobson/IntroAstro\\_AndreaKDobson/](http://people.whitman.edu/~dobson/IntroAstro_AndreaKDobson/).

**Author(s):** Andrea K Dobson

**Institution(s):** Whitman College

### **262.08 - Exocast: The Exoplanet Podcast(Hannah R Wakeford)**

Podcasts have become increasingly popular with easy distribution through social media and the ability to reach a wide audience in their own time. Here we present Exocast: The exoplanet podcast, a monthly hour-long podcast on exoplanet discoveries, characterization, and astrobiology. The podcast is produced and hosted by Drs Hannah Wakeford (Space Telescope Science Institute), Andrew Rushby (University of California: Irvine), and Hugh Osborn (Laboratoire d'Astrophysique de Marseille), who are each experts in different areas of exoplanet studies. We present the results of two years of The Exocast Exoplanet Cup, 2017 and 2018, a twitter-poll based knock-out competition between exoplanets selected by the community. In association with the ExoCup we present fact cards for each planet which can be used for education at all levels and in outreach events.

**Author(s):** Hugh Osborn, Andrew Rushby, Hannah R Wakeford

**Institution(s):** Space Telescope Science Institute, University of California: Irvine, Laboratoire d'Astrophysique de Marseille

### **262.09 - Using Astrobites to Teach Contemporary Astronomy(Caitlin Doughty)**

Astrobites, billed as "the astro-ph reader's digest", is a graduate-student run astrophysical literature blog ([astrobites.org](http://astrobites.org)) that posts daily summaries of recent, high-impact journal articles published on astro-ph. Written at the undergraduate level, these summaries can provide a pedagogical tool for instructors to introduce cutting-edge modern astronomy to their students in a manner that is comprehensible. We aim to evaluate the effectiveness of existing lesson plans which incorporate Astrobites articles, as well as to establish the best-practice methods for instructors to effectively utilize this vast resource of over 1600 articles in their classrooms. We describe the teaching workshop at the 231st AAS Meeting in January 2018 that introduced the project to the community, the creation of the focus-group for our follow-up research study, and survey questions distributed to focus-group participants. We present here the preliminary results from responses to the questionnaire and an analysis addressing the results pertaining to class size, grade level, and other specifics that may affect the utility of Astrobites in the classroom.

**Author(s):** Nora Shipp, Gourav Khullar, Susanna Kohlero, Caitlin Doughty, Benny Tsz Ho Tsang, Chris Faesi, Lisa Drummond, Michael Zevin, Vatsal Panwar, Elisa Chisari, Nathan Sanders, Ashley Villar

**Institution(s):** University of Oxford, oAmerican Astronomical Society, New Mexico State University, Kavli Institute of Cosmological Physics, University of Chicago, University of Amsterdam, University of Texas, Astrobites Collaboration, University of Melbourne, Nort

### **262.10 - The Pulsar Search Collaboratory: A Decade of STEM Education and Discovery(Maura McLaughlin)**

The Pulsar Search Collaboratory (PSC) is an NSF-funded astronomy education program between the Green Bank Observatory and West Virginia University. Over the past decade, the PSC has engaged over 200 high-school students and teachers in authentic research by searching for pulsars in data collected with the 100-m Green Bank Telescope (GBT). Over the past several years we have expanded the program through the development of online workshops and the involvement of undergraduate mentors at institutions across the country. Through their work with the PSC, students learn about radio astronomy, pulsars, radio frequency interference, pulsar timing, gravitational waves, programming, and big data analysis. The PSC trains both students and teachers in a professional scientific community, promotes STEM interest and careers, and encourages student use of information technologies through online activities and workshops and an online database. Seven pulsars, including a millisecond pulsar and a double neutron star binary, have been discovered by PSC students so far. These and future discoveries may be used for fundamental advances such as for testing of general relativity, constraining neutron star masses, and detecting gravitational waves.

**Author(s):** Harsha Blumer, Joe Swiggum, Duncan Lorimer, Kathryn Williamson, Sue Ann Heatherly, Maura McLaughlin

**Institution(s):** West Virginia University, University of Wisconsin-Milwaukee, Green Bank Observatory

### **262.11 - NRAO's National and International Exchange Non-traditional Exchange (NINE) Program(Lyndelee Von Schill)**

The global radio astronomy landscape is changing rapidly, with an increasing number of developing countries showing an interest in the development of a radio astronomy sector as a tool for development and others building or operating their own radio astronomy facilities. The National Radio Astronomy Observatory (NRAO) enables cutting-edge scientific research by providing state-of-the-art radio telescope facilities, instrumentation, and expertise for use by the international scientific community. One of the pillars of the NRAO's Mission Statement is to train the next generation of scientists and engineers to develop a world-wide pipeline of talent. The National and International Non-Traditional Exchange (NINE) Program was established as an initiative of the NRAO's Office of Diversity and Inclusion to increase the numbers of underrepresented community members in the field of astronomy, both nationally and internationally. NRAO's NINE program addresses this need by providing opportunities for members of underrepresented communities to participate in radio astronomy and related fields. The NINE program develops "Hub" partnerships with Historically Black Colleges and Universities (HBCUs) and Hispanic Serving Institutions (HSIs) in the U.S., and with universities or observatories in countries with a radio astronomy presence. Professionals and students

from the partner organizations visit the NRAO and complete a short, intense training programme in the use of Very Large Array Sky Survey (VLASS) data and Raspberry Pi units to learn about astronomical image analysis. The participants also learn project management principles and develop a fully described plan for establishing NINE Hubs at their home institution where they can transfer their learned skills to students, faculty, and the community. Since 2016, the NRAO NINE Program has led to the establishment of four active NINE Hubs in the USA, South Africa, and Trinidad and Tobago and the exchange of NINE trainers between these Hubs. Here we outline the NINE methodology: outcomes of the skills training programs, activities implemented at the Hubs, best practices in human capacity development, and opportunities for organisations to participate in the NRAO NINE Program.

**Author(s):** Lyndelee Von Schill, Anja Fourie, Brian R. Kent,

**Institution(s):** National Radio Astronomy Observatory, South African Radio Astronomy Observatory, National Radio Astronomy Observatory

### **262.12 - The APUS Supernova Search Program: Getting Undergraduate Students Excited About Astronomy(Edward Albin)**

We report on the American Public University System's (APUS) supernova search program. The university operates a Planewave CDK24 robotic telescope fitted with a SBIG STX-16803 CCD camera, located in Charles Town, WV. The telescope is a fundamental technological component in the Department of Space Studies' new astronomy concentration. The instrument is scripted to image galaxies on clear evenings when the observatory is otherwise not in use. Target galaxies are photographed when within 30 degrees of the celestial meridian. On a typical night, several dozen galaxies are imaged for later analyses by undergraduate students. Reference images for each galaxy are available for comparison purposes using software to "blink compare" imagery for the presence of supernova. Since supernovae occur without notice and then peak in brightness in a very short period of time, it is worthwhile to reimage selected galaxies on a regular basis. The unique aspect of our program is its emphasis on providing research opportunities for undergraduate students. The project is being piloted by students in the Department's "Students for the Exploration and Development of Space" (SEDS) organization. APUS is an online institution with over 900 undergraduate students enrolled globally in the Space Studies program. The thrill of discovery is a great motivator for our Space Studies majors, with the goal to expand student based research into other projects (e.g., exoplanets and variable star photometry).

**Author(s):** Kristen Miller, Katelyn Milliman, Edward Albin

**Institution(s):** American Public University System

## **262.13 - Helping Others See Themselves in Physics(Elon Price)**

As the 2018 APS Careers Program intern, I worked on two major projects to promote physics as a profession with many available options. The statistics (sourced from the AIP Statistical Center) are clear: only 1 in 7 physics majors go on to earn a Ph.D., about half go straight into the workforce and a 95% employment rate. I sought to deliver a creative message dispelling common misconceptions about what and who a physicist should be and encouraged my audience to use their many resources to educate themselves. Most of my time was spent perfecting an informational video to be soon posted to the APS YouTube page. The approximately 5-minute video outlines the cool things you can do with a physics degree, addresses myths, and provides some statistics about diversity within the field. It also directs the viewers to the APS Careers webpage and recently updated Professional Development Guide. In addition to the video, I collaborated with the APS Marketing team to create an accompanying poster with a similar theme. I also learned many important things about project management and communication that I think are worth noting.

**Author(s):** Elon Price,

**Institution(s):** North Carolina State University, SPS  
**Contributing Team(s):** Crystal Bailey (Mentor)

## **263 - The Solar System -- iPosters**

### **263.01 - Observations of Eight Large Main Belt Asteroids with HST(Sergio Lainez)**

We present diameter and albedo measurements for eight large main belt asteroids using data taken with the WFPC-2 Planetary Camera aboard the Hubble Space Telescope. Images taken in five different wavelength filters spanning the visible spectrum, in 1997. The images were subsampled and reconstructed using IRAF's "Maximum Entropy" routine. Our diameter measurements for these asteroids match those reported by IRAS to within 2%. The C type bodies in particular show a systematic shift to lower albedo in the visible spectrum than reported by IRAS. This is expected since the albedo for rocky objects such as these should be higher in the infrared than the visible. Overall our measurements for both albedo and diameter confirm those reported by IRAS. No clear surface variation was observed.

**Author(s):** Sergio Lainez, Alex Storrs

**Institution(s):** Towson Univ

### **263.02 - Impact Probability Evolution of Virtual Impacting Asteroids(Bryce Bolin)**

The Large Synoptic Survey Telescope (LSST) will discover more than 10 times as many Near Earth Asteroids (NEAs) as all other telescopes combined (Ivezic et al., 2008, Jones et al., 2018). Among the more than 100,000 expected newly discovered NEAs, will be hundreds of asteroids with a worrisome chance (more than  $10^{-4}$ ) of hitting Earth. The probability of impact of

any given asteroid is a function of the uncertainty in the orbit determination, and evolves as the knowledge of the orbit of the asteroid is refined by repeated observations. Eventually, the probability drops low enough to know that a collision with Earth can be ruled out, or in rarer cases the probability rises large enough to consider the asteroid a serious threat. The goal of our study is to understand how the impact probabilities evolve with time prior to potential impact. This is critical because the danger posed by an asteroid may not be fully apparent because the uncertainty in the knowledge of the orbit may be large enough that the estimated impact probability is still small. As a result, the warning time for a threatening asteroid may be too short for mitigation efforts which can take years to execute and plan. To understand the warning times that are likely to result for impacting asteroids, we have simulated decades of operation of LSST in observing an ensemble of 100,000 asteroids which are chosen to be representative of Earth impacting asteroids. From these series of observations, we carry out the orbit determination process and examine the evolution of the estimated asteroid orbits and their uncertainties to understand the evolution of impact probability as a function of time before impact. The tools for studying asteroid observations, including the calculation of asteroid impact probabilities, developed as part of this study will eventually become part of the Asteroid Decision and Mapping project (a program of the Asteroid Institute). These tools are intended to be public and open-source for use by the scientific community for orbit determination of NEA discoveries by LSST and other observatories in the coming decade.

**Author(s):** Mike Loucks, John Carrico, Mario Jurić, Bryce Bolin, Ed Lu

**Institution(s):** B6 Asteroid Institute, University of Washington

### **263.03 - Required deflection impulses as a function of time before impact for Earth-impacting asteroids(Sarah Greenstreet)**

The Large Synoptic Survey Telescope (LSST) will increase the number of known near-Earth asteroids (NEAs) by more than an order of magnitude (Ivezic et al., 2008, Jones et al., 2018). These ~100,000 newly discovered NEAs will include those on potentially Earth-impacting orbits. For any asteroid on an impact trajectory, the amount of time prior to impact a deflection can be implemented can drastically change the amount of deflection impulse required. In this study we use the precision cloud-based asteroid orbit propagation and targeting capability of the B612 Asteroid Institute's Asteroid Decision and Analysis Mapping platform (ADAM) to investigate the distribution of deflection  $\Delta v$  required to divert asteroids on Earth impact trajectories as a function of time prior to impact for 10,000 virtual impacting asteroids. We calculate the distribution of deflection  $\Delta v$  required if applied 10, 20, 30, 40, and 50 years prior to impact. In initial studies, we found a fraction of impacting asteroids are significantly easier to deflect than the mean, with >10 times less velocity impulse required; the fraction increases as the time before impact rises. A portion

of these easily-deflected asteroids are found to have intervening close approaches with a planet prior to Earth impact, which substantially reduces the delta-v deflection requirement. While these represent a small fraction of asteroid impact cases, we expect them to be over-represented among the difficult deflection decision cases because they are also the asteroids that are observationally most difficult to rule out as impact threats. The initial study, which used desktop software to calculate the deflection delta-v for all 10,000 asteroids, took several months to complete. ADAM, which operates using Google Compute Engine, allows us to get targeting results for all 10,000 asteroids in <24 hours. This allows us to both perform the calculations much faster and to study the required deflection delta-v as a function of time prior to impact. The tools developed in ADAM will eventually be open to the public for precision studies of asteroid deflection scenarios.

**Author(s):** Sarah Greenstreet, Mike Loucks, John Carrico, Ed Lu, Tatiana Kichkaylo

**Institution(s):** University of Washington, B6 Asteroid Institute

#### **263.04 - Testing the WISE Saturation Correction with Asteroids(Edward L Wright)**

The WISE Allsky [4-band cryo] source catalog and single exposure source table report fluxes for bright sources that saturate the detectors that are based on fitting the wings of the PSF to the image pixels. The Explanatory Supplement uses 2MASS stars to test the accuracy of these flux estimates. For W1 they are quite good, but for W2 there is a definite trend showing that a correction is needed. The NEOWISE asteroid diameter analyses used a correction to W3 for saturated sources that has the same form as the correction needed for W2, but since both 2MASS Ks and WISE W3 saturate at about the same Vega magnitude it is hard to use stars to validate this correction. In this note I use hundreds of asteroids with diameters known from radar, occultation or spacecraft observations to test the W3 saturation correction.

**Author(s):** Edward L Wright

**Institution(s):** UCLA

### **264 - Stars, Cool Dwarfs, Brown Dwarfs -- iPosters**

#### **264.01 - Constraining the low-mass cutoff for star formation with CatWISE(Federico Marocco)**

One of the lingering puzzles in astronomy is determining how star formation can create objects of extremely low mass, and the efficiency with which it does so. Studies of star formation regions and nearby, young moving groups have shown that objects as low as a few Jupiter masses can form in isolation, and this mass range has overlap with traditional planets that form via a protoplanetary disk. Older isolated field objects with masses as low as a few Jupiter masses must exist, and will have had many Gyr to cool, making them cold analogs to planets in exosolar systems. Observing more of these frigid, free-floating

objects will enable us to determine the frequency with which low-mass objects are formed in isolation. The only data set capable of uncovering more of these objects is the set from WISE. Funded by NASA's ADAP program, CatWISE (PI Eisenhardt) is combining data from the original WISE and NEOWISE Reactivation phases, to produce a catalog of ~1 billion sources with greater sensitivity in W1 and W2, and an order of magnitude more precise proper motion measurements compared to AllWISE. Crucially, CatWISE has access to the coldest, least massive members of the local sub-stellar neighborhood, a population completely undetectable by Gaia and any other existing optical and near-infrared survey. We will present initial results from our search for late T and Y dwarfs in the Solar Neighborhood, showcasing the search-and-follow-up strategy adopted, and the expected final yield.

**Author(s):** J. Davy Kirkpatrick, Aaron Michael Meisner, Renata Koontz, Federico Marocco, David J. Schlegel, Christopher Gelino, Jacqueline K Faherty, Michael C. Cushing, Bahram Mobasher, John W. Fowler, Peter R. M. Eisenhardt, Daniel Stern, Anthony H. Gonzalez, Amy

**Institution(s):** University of California Davis, oLBNL, ICEBRG / Gigamon, JPL, University of Toledo, IPAC/Caltech, University of California Los Angeles, NOAO, University of Florida, American Museum of Natural History, University of California Riverside, University

#### **264.02 - Metallicity Dependence of Main-Sequence Knee Feature(Hyun-chul Lee)**

The main-sequence knee feature of the low mass stars at the near-infrared color-magnitude diagram is a promising new way to measure the age of star clusters. The location of this feature is known to be independent of age of star cluster at a given metallicity. In this presentation, we look into the metallicity dependence of the main-sequence knee feature at given ages by employing the MIST and the PARSEC isochrones. Moreover, we compare the HST observations of the main-sequence knee features with wide range of metallicity to the theoretical stellar models. Furthermore, we present how the JWST photometric system can improve the study on the Main-Sequence Knee Feature.

**Author(s):** Hyun-chul Lee, Amanda Champion, Stephan Jabs

**Institution(s):** The University of Texas Rio Grande Valley, Veterans Memorial High School

#### **264.03 - Spectral Library of Hot Stars with Hubble Space Telescope(Guy Worthey)**

Libraries of stellar spectra find a plethora of applications, from photometric calibration to stellar population synthesis. We present low resolution spectra obtained with STIS (Space Telescope Imaging Spectrograph) of 40 stars spanning 0.2 to 1.0 micrometers in spectral coverage. The stars include normal O-type stars, helium-burning stars, and post-asymptotic giant branch (PAGB) stars. Observations through three low

resolution gratings, G230LB, G430L, and G750L enabled coverage of the wide wavelength interval. Cosmic ray hits, fringing in the red, and scattered light corrections were applied. Cross-correlation was used to bring the spectra to a common, final, zero velocity wavelength scale. Finally, synthetic stellar spectra were used to estimate line of sight dust extinction to each star, and a five-parameter dust extinction model was fit, or a one-parameter fit in the case of low extinction. These spectra dovetail with the similar Next Generation Stellar Library (NGSL) spectra, extending the NGSL's coverage of stellar parameters, and extending to helium burning stars and stars that do not fuse. The fitted dust extinction model showed considerable variation from star to star, indicating variations in dust properties for different lines of sight. Interstellar absorption lines are present in most stars, notably Mg II. The spectra are available at MAST (Mikulski Archive for Space Telescopes) and the CDS (Centre de Données astronomiques de Strasbourg). Support for this work was provided by NASA through grant number HST-GO-14141.001-A from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555.

**Author(s):** Guy Worthey, Islam Khan

**Institution(s):** Washington State University

## **265 - Molecular Clouds, HII Regions and the ISM -- iPosters**

### **265.01 - The Infrared Properties of Giant H II Regions W51A and M17(James De Buizer)**

Giant H II regions are the sites of extensive, clustered, high-mass star formation, producing more than 1050 LyC photons/sec. They are so energetic that they are a dominant source of emission contributing to the bolometric luminosity that we see from galaxies. Therefore, studying the global and detailed properties of GH II regions within our own Milky Way can help us to understand star formation in such extreme galactic environments. We will present the initial results from a large-scale project with the goal of creating a 20 and 37 micron maps of all known GH II regions within the Milky Way with the Stratospheric Observatory For Infrared Astronomy (SOFIA) and its mid-infrared instrument FORCAST. Starting our analyses with W51A and M17, we combined the data from the mid-infrared SOFIA images with archival imaging data from the near-infrared, far-infrared, as well as radio CO maps to understand more about the physical properties of the environments within these GH II regions and the YSOs they contain.

**Author(s):** Wanggi Lim, James De Buizer

**Institution(s):** SOFIA-USRA

### **265.02 - Probing the radiation field color towards (and beyond) Per OB3 (Richard Spolzino, Kristin Kulas, B-G Andersson, Archana Soam, Ilija Medan, Andrew Helton)(Richard Joseph Spolzino)**

Polarization of starlight can indirectly tell us many things about the universe around us. From identifying star nurseries to mapping galactic scale magnetic fields, the properties of polarized light allow astronomers to observe phenomena that would otherwise be very hard to observe. The wavelength dependence of visual-light polarization shows a characteristic dependence parametrized by the Serkowski curve, which can be understood in terms of the size distribution of aligned dust grains. In the direction of Per OB3, a loose association of super hot, massive stars, the polarization curves seem systematically shifted to short wavelengths than is typical of the interstellar medium. We have mapped the the origin of the polarization in 3D by observing stars at various positions in and around the Per OB3. These observations allow us to probe the possible causes of this short wavelength excess, which will lead to a better understanding of how light becomes polarized in the interstellar medium.

**Author(s):** Richard Joseph Spolzino, B-G Andersson, Ilija Medan, L. Andrew Helton, Kristin Rose Kulas, Archana Soam

**Institution(s):** Santa Clara University, USRA

## **266 - Groups of Stars - Galactic & Extragalactic -- iPosters**

### **266.01 - Interstellar Extinction in the Direction of the Cyg OB7 Association and the Open Cluster IC 1369 and the New Parameters of the Cluster(Richard P. Boyle)**

The open cluster IC 1369 area in Cygnus is investigated applying two-dimensional photometric classification of stars observed in the Vilnius seven-color photometric system down to  $V = 17$  mag. The cluster members are identified applying their proper motions and parallaxes taken from the Gaia DR2 catalog. New parameters of the cluster (distance, interstellar reddening and age) are obtained. Reddenings of the association Cyg OB7 members are determined from their BV photometry and MK spectral types, taken from the literature; for 16 B-type stars the MK types are redetermined.

**Author(s):** Marius Maskoliunas, Richard P. Boyle, Vytautas Straizys, Mindaugas Macijauskas, Kazimieras Cernis, Algirdas Kazlauskas, Christopher Corbally, Robert Janusz

**Institution(s):** Vatican Observatory, The Jesuit University Ignatianum, University of Arizona, ITPA, Vilnius University

### **266.02 - The Globular Cluster Systems of Virgo Cluster Dwarf Galaxies(Gene Wang)**

Star clusters are collections of thousands to millions of stars formed and bound together by their gravity. The oldest and most massive star clusters are called globular clusters (GCs) for their round appearance. GCs can be seen at much greater distances than individual stars because they shine with the

combined luminosity of many stars while occupying a relatively small volume. We examined GCs within low-luminosity galaxies of the nearest large cluster of galaxies, the Virgo cluster, using images from the Next Generation Virgo Cluster Survey (NGVS). It is challenging to locate GCs in the glare of the host galaxy's light (similar to how fireflies are almost impossible to see when they are flying around a bright lamp). Our work involved developing smooth models of galaxy light and subtracting these models from the NGVS galaxy images in order to detect and characterize previously shrouded globular star clusters. To accomplish this goal, we utilized the software packages IRAF, ISOFIT, and SourceExtractor. We wrote software to automate the modeling and light subtraction process for thousands of distinct galaxy images. Finally, we generated color-color diagrams to identify and characterize the GCs. The chemical composition of GCs can shed light on the evolutionary history of their host galaxies. While many GC studies have been done on massive galaxies, fewer GC studies have been done on lower-mass galaxies; thus, the results of our study will yield a unique new dataset that will make it possible to understand what happens in the different steps of the hierarchical mass assembly, from massive/luminous systems to low mass/ low luminosity galaxies. This research was funded in part by NSF and NASA/STScI. High school students VL, RS, and GW conducted this research under the auspices of the Science Internship Program at UC Santa Cruz.

**Author(s):** Sungsoon Lim, Alessia Longobardi, Gene Wang, Puragra Guhathakurta, Youkyung Ko, Vivian Liu, Eric W. Peng, Rishi Sankar

**Institution(s):** The Harker School, The Menlo School, Henry M Gunn High School, UC Santa Cruz, Peking University

### **266.03 - A Study of Young Stellar Cluster IC 348 with Gaia DR2(Madeline Boyce)**

We investigate the distance and three-dimensional spatial and velocity distributions of the young stellar cluster IC 348 using newly available, highly precise parallax and position data from the Gaia astrometry mission's Data Release 2 (DR2). We found all 478 confirmed IC 348 members listed in Luhman et al. (2016, ApJ, 827, 52) have entries in the DR2 catalog that appear to correspond in position. We limited the sample studied here to 173 targets by excluding those stars whose parallax error was larger than 25 parsecs, and whose coordinates in Luhman et al. (2016) and Gaia DR2 differed by greater than  $1''$ . We find the mean distance to these cluster members to be  $311 \pm 32$  parsecs. An interactive 3D map of IC 348 was created using Plotly in Python. Relations between spectral and class type and location in the cluster were also studied. M and K type stars appear to lie somewhat closer than the mean cluster distance; this is likely a selection effect, as M and K type stars are less luminous and therefore more difficult to detect at greater distances. Class II and class III stars follow a similar distribution for the same reason, with Class II stars at a median distance of  $305 \pm 32$  parsecs and Class III stars at a median distance of  $315 \pm 32$  (the sample did not contain any class I stars). Radial velocities and proper motions were used to

ascertain and analyze the UVW space motions for the cluster members in DR2. Most of the 173 targets are tightly clustered in UVW, as expected. These velocities can be further studied to determine if IC 348 is bound or expanding.

**Author(s):** Joel H Kastner, Madeline Boyce, Dary Ruiz-Rodriguez

**Institution(s):** University of Massachusetts Amherst, Rochester Institute of Technology

### **266.04 - An analysis of bulk cluster rotation signatures present within open clusters using Gaia DR2 data.(Karl Jaehnig)**

Open clusters offer a unique opportunity to study the dynamical evolution of star clusters. As they are not as dense in stellar populations as globular clusters, more observations can be taken to measure dynamical properties. With the advent of the high-volume, high-precision astrometric data from the Gaia satellite and the Gaia DR2 release, we can study the dynamical state of open clusters to an unprecedented degree. We primarily look at quantifying any signatures of bulk cluster rotation that may be still present within open clusters that was imparted from the collapse of their nascent molecular cloud. We form a 6-dimensional picture of the dynamical state of these open clusters using the available data. We analyze the bulk cluster of several open clusters, and discuss the implications as it relates to the resulting evolution of binary stars, as well as exotic stellar phenomena such as blue straggler stars.

**Author(s):** Karl Jaehnig, Kelly Holley-Bockelmann

**Institution(s):** Vanderbilt University

### **267 - The Milky Way & The Galactic Center -- iPosters**

#### **267.01 - Survey of Water and Ammonia in the Galactic center (SWAG): Morphologies of Molecular Tracers(Juergen Ott)**

We present an overview of our comprehensive ~600h survey with the Australia Telescope Compact Array to map the Galactic center Central Molecular Zone through spectral lines in the 21.2 to 25.6GHz range. The "Survey of Water and Ammonia in the Galactic center (SWAG)" targets ~42 spectral lines with a focus on multiple metastable and non-metastable ammonia lines as well as 22GHz water masers across the entire Central Molecular Zone at 1pc resolution. We show the morphologies of the different molecular tracers and their relation to Galactic Center objects such as the supermassive black hole Sgr A\*, star forming regions Sgr B2 and Sgr C, the molecular streamers and the  $l=1.4$  gas reservoir. A focus will be the relation between stellar water masers and their surrounding molecular envelopes.

**Author(s):** Tierra Candelaria, Nico Krieger, Juergen Ott, Adam Ginsburg, David S Meier,

**Institution(s):** National Radio Astronomy Observatory, Max-Planck Institut für Astronomie, New Mexico Institute of

Technology Contributing Team(s): SWAG team

### **267.02 - The Radial Velocity Experiment RAVE - Final Data Release(Matthias Steinmetz)**

The 6th and final data release of the RAVE survey is scheduled to be released in late 2018/early 2019. This concludes a major effort establishing one of the first systematic spectroscopic Galactic Archeology surveys which started with observations taken between 2003 and 2013. RAVE DR6 will publish about 520,000 spectra ( $R \sim 7500$  in the CaT region at  $8410\text{--}8795\text{\AA}$ ...) of some 450,000 unique stars. RAVE DR6 also provides enhanced radial velocities, stellar parameters (effective temperature, surface gravity, and overall metallicity) and individual abundances for Mg, Al, Si, Ti, Fe, and Ni. By matching distances using isochrones to those of Gaia DR2 with a Bayesian scheme, considerably improved stellar parameters, age estimates and abundances can be derived compared to earlier data releases. Asteroseismic calibrations using K2 data allow to derive further information and enhancements on the stellar properties derived from RAVE spectra. Furthermore, comparisons with meanwhile available higher resolution survey such as APOGEE and GALAH allow data driven methods applied to RAVE spectra. Owing to the publication of about 520,000 spectra with resolution and S/N similar to those of the Gaia RVS, RAVE DR6 can serve as a formidable preview of what Gaia is going to deliver in the coming data releases.

**Author(s):** Matthias Steinmetz

**Institution(s):** Leibniz Institute for Astrophysics Postdam (AIP) Contributing Team(s): RAVE collaboration

### **267.03 - Ionized Gas Near Galactic Center: Physical Parameters and Mass Estimates(Dhanesh Krishnarao)**

The environment around Galactic Center is very complex; it is influenced by a supermassive black hole, the Central Molecular Zone (CMZ), the Galactic Bar, and the large scale outflow associated with the Fermi Bubble. In particular, gas within the bar radius is an important interface region between the dense, cooler CMZ and the diffuse, hotter Fermi Bubble and exhibits strongly non-circular kinematics and tilted distributions. An early model of this gas first developed by Burton & Liszt (1978-1992; Papers I-V) predicts the observed kinematics of neutral hydrogen and molecular CO with a tilted elliptical disk of gas. Using the WHAM Sky Survey and follow-up multi-wavelength observations of optical emission lines, we have discovered an ionized gas counterpart to this structure and, for the first time, describe the physical conditions of the gas at  $\sim 1\text{--}2$  kpc from Galactic Center. Small modifications of the Liszt & Burton (1980) model can predict the ionized gas observations toward Baade's window, a known low extinction view towards Galactic Center. Preliminary results suggest the Galactic Center environment has a total ionized hydrogen gas mass comparable, if not greater than, the total neutral hydrogen gas mass.

Extinction corrected line ratio measurements, combined with an HST UV absorption line observation from Savage et al. (2018) provide a measure of the gas pressure, gas temperature, metallicity, and ionization mechanisms. The line ratios of the ionized gas associated with this structure can be compared with extragalactic sources, where they are typically used to differentiate Active Galactic Nuclei and starburst galaxies.

**Author(s):** L. Matthew Haffner, Dhanesh Krishnarao, Robert A Benjamin

**Institution(s):** Embry-Riddle Aeronautical University, University of Wisconsin-Whitewater, University of Wisconsin-Madison

### **267.04 - Spatial distribution of black hole binaries within $\sim 1$ pc of the Galactic Center revealed by NuSTAR and Chandra X-ray observations(Kaya Mori)**

We report NuSTAR observations of two new X-ray transients detected by the Neil Gehrels Swift Observatory in the Galactic Center (GC). Broadband 3-79 keV NuSTAR spectra of both transients exhibit various components including thermal disk blackbody, X-ray reflection with relativistically broadened Fe emission lines, and a power-law like continuum well described by thermal Comptonization models. A milli-Hz QPO feature was detected from one of the transients. These spectral and timing characteristics, as well as the deduced physical parameters, are consistent with those of black hole (BH) transients. In addition, the BH binary scenario is further supported by the lack of detection of prior X-ray outbursts by Swift and other X-ray telescopes that frequently monitored the GC in the last decade, whereas neutron star LMXBs have short ( $< \sim 10$  year) outburst recurrence time. The two new BH transients, combined with the 12 quiescent BH-LMXBs discovered by Chandra (Hailey et al. 2018) and another BH transient detected with radio jet (Muno et al. 2005), allow us to investigate their spatial distribution in the central 1 pc region. Our results have strong implications for binary formations in galactic nuclei and test the predictions from recent theoretical models.

**Author(s):** Charles Hailey, Yvette Schutt, Kaya Mori, Shifra Mandel

**Institution(s):** Columbia University

### **267.05 - HALO7D: Separating Sun-like Stars in the Milky Way Halo from Foreground White Dwarfs and Interesting Background Contaminants(Andrew Lu)**

We present a study of Milky Way stars from the HALO7D survey based on deep spectroscopy with Keck II/DEIMOS and photometry from the Hubble Space Telescope (HST) to gain insight into the dark matter content and accretion history of the galaxy. Our observations focus on four fields from the CANDELS survey: GOODS-N, GOODS-S, EGS, and COSMOS. Because stars are known to generally form a linear sequence in multi-band photometric space (based almost solely on effective



temperature) while the light of galaxies is comprised of a mix of stars, we construct color-color diagrams (2CDs) from different HST filters and create empirical moving medians using stellarity and brightness cuts to determine the stellar locus. By calculating the distance from the stellar loci in the 2CDs, we are able to distinguish stars from galaxies for objects up to  $10^8$ - $10^9$  times fainter than those visible to the naked eye. Using Keck data to classify a small subset of stars, we confirm these spectroscopically-classified objects validate our 2CD analysis. We then identify a subset of unusual Milky Way stars within the HALO7D data set and conclude them to be in one of two groups. The first are white dwarfs (with Balmer absorption lines) whose distances, proper motions, and radial velocities we analyze to classify them as part of the Milky Way thin disk, thick disk, or halo with comparison to the synthetic Besancon model on white dwarfs. The other interesting background contaminants have a weak Paschen absorption line series, relatively bright apparent magnitudes, and small proper motions, indicating that these stars are likely not white dwarfs but rather more intrinsically luminous horizontal branch stars or blue stragglers in the remote Milky Way halo. The data analysis techniques developed in the course of this project could be potentially applicable to larger, more complex data sets that will be available in the future. This research was funded in part by the NSF, NASA, and STSCI. High school students AL, TJ, and JT conducted this research under the auspices of the Science Internship Program at UC Santa Cruz.

**Author(s):** Puragra Guhathakurta, Emily Cunningham, Madison Harris, Tanshi Jain, Andrew Lu, Jin Tuan

**Institution(s):** The Harker School, University of California Santa Cruz, Saint Francis High School

## 268 - Supernovae -- iPosters

### 268.01 - Narrow Transient Absorption Features in Late-Time Optical Spectra of Type Ia Supernovae: Evidence for Large Clumps of Iron-Rich Ejecta?(Robert Fesen)

An examination of late-time, optical spectra of type Ia supernovae revealed surprisingly narrow absorption features which only become visible a few months after maximum light. These features, most clearly seen in the late-time spectra of the bright, recent type Ia supernovae ASASSN-14lp and SN~2017bzc, appear as narrow absorptions at 4840 Å, 5000 Å, and as a sharp inflection at 4760 Å on the red side of the prominent late-time 4700 Å feature. A survey of on-line archival data revealed similar features present in the spectra of ten other normal and 91T-like SNe Ia, including SN 2011fe. Unlike blue spectral features which exhibit progressive redward shifts, these narrow absorptions remain at the same wavelength from epoch to epoch for an individual SN, but can appear at slightly different wavelengths for each object. These features are also transient, appearing and then fading in one to three months. After ruling out instrumental, data reduction, and atmospheric affects, we discuss possible explanations including progenitor mass-loss material, interaction with material from previous novae events, and absorption by large discrete clumps of high-velocity Fe-rich ejecta.

**Author(s):** Jerod T. Parrent, Robert Fesen, Christine S. Black

**Institution(s):** Dartmouth College

### 268.02 - Towards 3D Parameter Space Studies of CCSNe With Grey, Two-Moment Neutrino Transport(Robert Daniel Murphy)

Neutrino transport is among the most computationally intensive components of multi-physics, core-collapse supernovae (CCSNe) simulations. A complete Boltzmann treatment of multi-angle, multi-energy 3D neutrino transport will require sustained exascale computing and beyond. Even multi-energy moments treatments of 3D neutrino transport will only allow a limited set of models to be considered. This project is a work in progress that attempts to combine the computational efficiency of a grey approach with as much of the realism of Boltzmann and moments based neutrino transport as possible in order to enable numerous multi-physics, 3D simulations of CCSNe. Using the General Astrophysics Simulation System (GenASiS) framework, an object-oriented, Fortran code utilizing both OpenMP and MPI, this project will be an investigation of multidimensional CCSNe simulations spanning a large parameter space of progenitor characteristics, e.g. mass, rotation, and perturbation methods. Current progress includes implementation of grey, two-moment neutrino-transport, relativistic multipole gravity, realistic equation of state table interface, and modern neutrino opacities into GenASiS. Various tests have verified the accuracy of each implementation individually and in conjunction together, culminating in a simulation of a realistic progenitor with limited neutrino interactions.

**Author(s):** Anthony Mezzacappa, David Pochik, Reuben D. Budiardja, Eirik Endeve, Robert Daniel Murphy, Christian Y. Cardall,

**Institution(s):** Department of Physics and Astronomy, University of Tennessee, Computer Science and Mathematics Division, Oak Ridge National Laboratory, Joint Institute for Computational Sciences, Oak Ridge National Laboratory, National Center for Computational Science

### 268.03 - Coupling a DG-IMEX method for two-moment neutrino transport with FLASH(Ran Chu)

To simulate neutrino transport in core-collapse supernova (CCSN) explosions, we develop numerical methods for a spectral two-moment model. In the two-moment model, the evolved variables are the neutrino number density and flux - angular moments of the neutrino distribution function. Our numerical scheme is based on the high-order discontinuous Galerkin (DG) method for phase space discretization, implicit-explicit (IMEX) time stepping, and the two-moment model is closed with the maximum entropy procedure of Cernohorsky & Bludman (1994). Importantly, the scheme is designed to remain consistent with Fermi-Dirac statistics. The IMEX method treats streaming terms explicitly and the collision terms, which model

the interaction between neutrinos and matter, implicitly. It is second-order accurate in the streaming limit and works well in the diffusion limit, characterized by frequent collisions and long timescales. Neutrino-matter interactions and a nuclear equation of state are tabulated and provided by the WeakLib library, which currently includes emission, absorption and scattering on nucleons and nuclei. The DG-IMEX scheme has been implemented in the Toolkit for High-Order Neutrino-Radiation Hydrodynamics (thornado), and an interface to the adaptive mesh refinement code FLASH has been created. As an initial step, we run one-dimensional stellar core collapse simulations, including electron-type neutrinos and antineutrinos. Preliminary numerical results are presented and future plans are discussed.

**Author(s):** Ran Chu, Eirik Endeve, Anthony Mezzacappa, O. E. Bronson Messer, Cory Hauck,

**Institution(s):** Univ of Tennessee, Knoxville, Oak Ridge National Laboratory

## **269 - AGN, QSO, Blazars -- iPosters**

### **269.01 - SOFIA reveals [CII] emission from jet and ghostly arms in NGC 4258(Dario Fadda)**

We report the first resolved detection of [CII] $_{157.7\frac{1}{4}\mu\text{m}}$  emission from a jet in an active galaxy. Our SOFIA/FIFI-LS observations of the inner 5 kpc of the active galaxy NGC 4258 revealed emission associated with warm molecular hydrogen distributed along and beyond the end of the southern jet in a region known to contain shock-excited optical filaments. Emission is also associated with soft X-ray hot-spots which are the counterparts of the "ghostly" radio arms of NGC 4258. The rest of the emission is associated with star formation, namely the northern arm of the galaxy and a 1 kpc long region on the minor axis of the galaxy with H-alpha filaments and young star clusters. The [CII] emission along the jet and in the hot-spots exhibit anomalous [CII]/FIR and [CII]/PAH ratios as well as large intrinsic [CII] line widths, suggesting that shocks and turbulence in the warm gas are causing the [CII] emission. We estimate that 40% of the total [CII] luminosity from the inner 5 kpc of NGC 4258 arises in shocks and turbulence (approximately 1% of the bolometric luminosity of the active nucleus). The rest is consistent with [CII] excitation associated with star formation. Such a large fraction of shock related [CII] emission has implications for interpreting [C II] luminosity of high-z galaxies, where turbulence and feedback effects from star formation and AGN probably play an important role in galaxy evolution.

**Author(s):** Dario Fadda, Tanio Diaz-Santos, Patrick Ogle, Aditya Togi, Lauranne Lanz, Philipp N Appleton

**Institution(s):** SOFIA Science Center - USRA, Universidad Diego Portales, Caltech, University of Texas at San Antonio, STSCI, Dartmouth College

### **269.02 - The response of optical Fe II emission to changes in the ionizing continuum, II: evidence from variability data(Anjana Saravanan)**

It has been suggested that unlike other broad emission lines, optical Fe II emission might not be produced by photoionization. We have compared observed Fe II and H $\beta$  line flux responses to the responses predicted by convolving the observed optical continuum with expected transfer functions for nine AGNs. Despite considerable scatter, the general agreement between predicted and observed Fe II line fluxes demonstrates clearly that the Fe II emission is produced by photoionization and that early failures of Fe II reverberation mapping were primarily due to the larger observational uncertainties in measuring Fe II fluxes. We find the response of the Fe II emission to continuum changes in different objects. We discuss how the combination of fundamentally different transfer functions of Balmer lines and Fe II with different spectral sensitivities cause differences in the responses of Fe II and H $\beta$  in the same object.

**Author(s):** Neha Thakur, Betsy Tian, Anjana Saravanan, C. Martin Gaskell

**Institution(s):** SIP, UC Santa Cruz

### **269.04 - Light Curves from the Catalina Real-Time Transient Survey of G-hat Galaxies: Is 6dFGS gJ065559.0-404912 a Kardashev Type-III Galaxy?(Fred A. Ringwald)**

We show long-term light curves from the Catalina Real-Time Transient Survey of 90 galaxies from the G-hat survey of R. L. Griffith, J. T. Wright, et al. and analyzed by M. A. Garrett. We measured photometry for these galaxies in approximately the visual, or V band with the SExtractor tool of the CRTS. Many of these galaxies show light curves constant to within 0.1 magnitudes over the 5-10 years the survey monitored them. Several galaxies, such as NGC 4355 and ESO 400-28, show variability. IRAS F21384-4556 shows continuous variability over 0.4 magnitudes over 3000 days, reminiscent of a quasar. MCG+03-38-076 varies erratically over 2.5 magnitudes and faster than the average 11.5 days between observations. IC 630 shows flaring, although the photometry may be unreliable since it is near the survey's bright limit, although fainter galaxies such as ESO 434-13, 2MASX J00082041+4037560, 2MASX J11185912-4000135, and 6dFGS gJ232610.6-303106 show similar variability. One anonymous galaxy, 6dFGS gJ065559.0-404912 (= 2MASX J06555900-4049122 = Gaia DR2 5563745165460932608) has a light curve that was sampled on average once per 8.2 days for 5.0 years. It shows irregular, aperiodic fadings from V ~ 16.2 by as much as 1.4 magnitudes. These fadings are reminiscent of those of Boyajian's star (KIC 8462852). One possible explanation may be this is a Kardashev Type-III galaxy-but of course the fadings may be natural, for example from stars moving in front of the central engine of this apparently edge-on galaxy, or by variability of the central engine, or by dust, as was the case for Boyajian's star. Another possibility may be that CSDR2

photometry needs to be better understood. Any of these cases would merit continued monitoring and detailed follow-up. The Catalina Sky Survey (CSS) is funded by the National Aeronautics and Space Administration under Grant No. NNG05GF22G issued through the Science Mission Directorate Near-Earth Objects Observations Program. The Catalina Real-Time Transient Survey (CRTS) is supported by the U.S. National Science Foundation under grants AST-0909182.  
**Author(s):** Christopher M. Parry, Fred A. Ringwald  
**Institution(s):** California State University, Fresno

### **269.05 - New UV and X-ray Spectra of NGC 5548 during its Long-Lived Obscuration Event (Gerard Kriss)**

We obtained coordinated UV and X-ray spectra of the Seyfert 1 galaxy NGC 5548 in January 2016, two and a half years after it was discovered to be in an unusual obscured state by Kaastra et al. High column density ( $> 10^{22} \text{ cm}^{-2}$ ), low-ionization gas strongly suppressed the soft X-ray continuum and produced broad ( $1800 \text{ km s}^{-1}$ ), blue-shifted ( $v_{\text{out}} = -500 \text{ km s}^{-1}$ ) UV absorption troughs associated with all UV permitted transitions including C II, C III, Si II, Si III, Si IV, C IV, N V, and Ly $\alpha$ . The strength of the obscuration varied on timescales from a day to weeks, and it persisted from 2013 throughout the 2014 reverberation mapping campaign on NGC 5548 using HST. In 2016, our new observations show that NGC 5548 was still obscured. Our new spectra with HST/COS use 9 orbits with grating settings G130M/1096, G130M/1327, and G160M/1600 to cover 950  $\text{\AA}$  to 1800  $\text{\AA}$ . We obtained 70 ks simultaneously with the XMM-Newton RGS. The spectra show continued soft X-ray absorption along with broad, fast, UV absorption associated with O VI and Ly $\beta$  and all other ions previously seen.  
**Author(s):** Tyler Desjardins, Jelle Kaastra, Gerard Kriss, Bradley M Peterson, Nahum Arav  
**Institution(s):** Space Telescope Science Institute, SRON, Virginia Tech, Ohio State University, Leiden University  
 Contributing Team(s): NGC 5548 Team

### **269.06 - Gauging the Power of AGN Feedback: Multi-kiloparsec Outflows in Seyfert 2 Galaxy 2MASX J04234080+0408017 (Travis Fischer)**

We present optical SNIFS integral field spectroscopy, VLA radio interferometry, HST optical imaging, and Chandra X-ray imaging of the merging galaxy 2MASX J04234080+0408017, which hosts a Seyfert 2 active galactic nucleus (AGN) at  $z = 0.45$ . Feedback from Active Galactic Nuclei (AGN), in the form of massive outflows of ionized and molecular gas, is thought to play a pivotal role in the self-regulation of supermassive black holes and galactic bulge growth. However, recent analysis on the effects of ionized-gas AGN feedback in nearby non-merging Seyferts and QSOs has shown the extent of outflowing gas to remain on the scales of approximately a kiloparsec, a fraction of

the distance required to evacuate typical host bulges. We present optical IFU observations that exhibit continuous, outflowing kinematics out to distances of  $\sim 5 \text{ kpc}$  from the nucleus, and examine the relationship between the extended outflows observed in the optical with cospatial structures observed in the radio and X-ray.

**Author(s):** Krista Lynne Smith, Michael Koss, Travis Fischer,  
**Institution(s):** NASA's Goddard Space Flight Center, Stanford University, Catholic University of America, Eureka Scientific

### **300 - Plenary Lecture: The Energetic Universe in Focus: Twenty Years of Science with the Chandra X-ray Observatory. Ryan Hickox (Dartmouth College)**

#### **300.01 - The Energetic Universe in Focus: Twenty years of Science with the Chandra X-ray Observatory (Ryan C. Hickox)**

Over the past two decades, NASA's Chandra X-ray Observatory has revolutionized our understanding of the high-energy sky. With its extremely sharp X-ray vision enabled by large-area, sub-arcsecond mirrors, Chandra has brought many important astrophysical processes into focus for the first time and has comprised a key component of our multiwavelength view of the Universe. In this talk I will give an overview of the vast array of groundbreaking science enabled with Chandra. I will focus on a handful of the most exciting results, including breakthrough discoveries on the births and deaths of stars, the cosmic growth of black holes, and the formation and evolution of galaxies and clusters. I will conclude with a look toward the exciting future of high-resolution X-ray observatories.

**Author(s):** Ryan C. Hickox  
**Institution(s):** Dartmouth College

### **301 - Extrasolar Planets: Characterization & Theory Track 1: X. Atmosphere Models and Orbital Architectures**

#### **301.01 - A Jovian World in a Highly Eccentric 65-year Orbit Discovered with Radial Velocities (Sarah Blunt)**

We present the discovery of HD 120066 b, a giant planet with eccentricity  $0.84 \pm 0.04$ , minimum mass  $3.14 \pm 0.14 \text{ MJ}$ , and orbital period  $66+31-17$  years. This is the longest-period exoplanet discovered with radial velocity (RV) measurements. At periastron, HD 120066 b is closer to its star than our solar system's asteroid belt is to the Sun, and at apastron, it is farther than Neptune. We combined RV data from Keck/HIRES, McDonald Observatory/Tull, and the Automated Planet Finder (APF) to detect the  $80 \text{ m/s}$  signal from pericenter passage induced by HD 120066 b over the last 20 years. We explored the parameter space of orbits consistent with these data, and from these fits inferred that the planet passed through periastron in January 2018. HD 120066 is an excellent target for coronagraphic imaging with the WFIRST coronagraph, and an ideal testbed for theories of eccentric giant planet formation.

**Author(s):** John Wisniewski, Glenn Schneider, Kellen Lawson, Molly Kosiarek, Benjamin J Fulton, Michael Endl, Lauren Weiss, Andrew Howard, William Cochran, Sarah Blunt,  
**Institution(s):** Harvard-Smithsonian Center for Astrophysics, UT Austin, Caltech, University of Arizona, University of Hawaii at Manoa, UC Santa Cruz, University of Oklahoma  
**Contributing Team(s):** California Planet Search Team

### **301.02 - Revised Orbital Parameters for Kepler-4b with Secondary Eclipse(Holly Sheets)**

Radial velocity data combined with transit photometry for Kepler-4b suggested an eccentric orbit, like those of fellow hot Neptunes HAT-P-11b and GJ 436b, but the eccentric model was not highly favored over the circular model. The eccentricity of these planets is surprising, as they are expected to have tidally circularized. I will present a revised, eccentric model for Kepler-4b based on fits to the radial velocity data and Kepler photometry, most importantly including the recently-discovered secondary eclipse near phase 0.7, and I will discuss the implications of the eccentric orbit.

**Author(s):** Holly Sheets

**Institution(s):** Albion College

### **301.03 - Gaia search for close stellar fly-bys within the Sco-Cen star forming region(Robert De Rosa)**

Close stellar flybys have the potential to significantly alter the architecture of planetary systems and produce interstellar objects such as the recently discovered 11/2017 U1 (“Oumuamua). Stars passing very close to our own solar system have been invoked to explain the formation of the Oort cloud of comets, comet showers, the disruption of the Kuiper Belt, and the distant detached orbits of dwarf planets such as 90377 Sedna, as well as the hypothetical Planet Nine. Here we search for close stellar encounters within the Sco-Cen OB2 association that may explain planetary systems observed to have asymmetric architectures. Using the exquisite astrometric precision of the Gaia catalogue, we traced the space motion of the ~450 known members of Sco-Cen back 10 Myr to identify potential dynamically-significant encounters. We present initial results from this analysis where we discovered a relatively close stellar flyby that is near co-planar with an extended circumstellar disk. Work to extend this analysis to other highly-disrupted systems outside Sco-Cen is ongoing. This work benefited from grants NSF AST-1518332, NASA NNX15AC89G, NNX15AD95G/NEXSS, and HST-GO-14670.

**Author(s):** Robert De Rosa, Paul Kalas

**Institution(s):** Stanford University, University of California, Berkeley

### **301.04 - Forward modelling and retrievals with PLATON, a fast open source tool(Michael Zhang)**

We introduce PLANETARY Atmospheric Tool for Observer Noobs (PLATON), a Python package that calculates transmission and emission spectra for exoplanets and retrieves atmospheric characteristics based on observed spectra. PLATON is easy to install and use, with common use cases taking no more than a few lines of code. It is also fast, with the forward model taking much less than one second and a typical retrieval finishing in minutes on an ordinary desktop. PLATON supports the most common atmospheric parameters, such as temperature, metallicity, C/O ratio, cloud-top pressure, and scattering slope. It also has less commonly included features, such as a Mie scattering cloud model and unocculted starspot corrections. The code is available online at <https://github.com/ideasrule/platon> under the open source GPL-3.0 license.

**Author(s):** Michael Zhang, Eliza Kempton, Heather Knutson, Yayyati Chachan

**Institution(s):** Caltech, Grinnell College, University of Maryland

### **301.05 - Characterizing Exoplanets with SKYWALKER: An Open Source, Multi-Model, Spitzer Self-Calibration Pipeline(Carlos Eduardo Munoz Romero)**

We introduce SKYWALKER, an open-source pipeline designed to detrend Spitzer/IRAC exoplanet light curves to measure exoplanetary and brown dwarf atmospheric properties. The code implements several modeling techniques for noise self-calibration to remove the sub-pixel sensitivity variations; i.e. telescope jitter, pixelation, and other systematics. Our routine fits for the transit, eclipse, and phase curve values from lightcurves, and works in conjunction with the BATMAN and SPIDERMAN packages. The parameterized posterior distributions are extracted with an Affine-Invariant Ensemble Markov Chain Monte Carlo algorithm (emcee). The user only needs to input a photometry file and select a self-calibration method for the pipeline to extract transit/eclipse/phase curve parameters; example Jupyter notebooks are included. For illustration, we present here an analysis of 13 transits of the super-Earth GJ 1214b at 4.5 microns and report the transit parameters with improved uncertainties compared to Fraine et al 2013. The SKYWALKER pipeline is written entirely in Python and is available publicly on GitHub at [github.com/munozcar/SKYWALKER](https://github.com/munozcar/SKYWALKER).

**Author(s):** Eliza Kempton, Carlos Eduardo Munoz Romero, Kevin Stevenson, Jonathan D Fraine

**Institution(s):** Grinnell College, University of Maryland, Space Telescope Science Institute

## **302 - The Solar System**

### **302.01 - Constraining Jupiter's Orbit with VLBA Astrometry of Juno(Dayton Jones)**

We have used the Very Long Baseline Array (VLBA) to determine the positions of Juno with respect to nearby reference radio sources during four epochs in 2016 and 2017. The reference sources all have accurate positions in the International Celestial Reference Frame (ICRF). These measurements were combined with a fit for Juno's orbit about Jupiter from Deep Space Network (DSN) tracking to produce ICRF positions for the Jupiter system barycenter at each epoch. All observations were made during Juno's perijove passes, when there is a continuous downlink signal to Earth and the best DSN orbit determinations are possible. Combined with range measurements by the DSN, our VLBA observations have already improved the accuracy of the Jupiter ephemeris by about a factor of four. Spacecraft range measurements constrain the semi-major axis and ellipticity of Jupiter's orbit, while VLBA astrometric measurements constrain the orbital inclination and ascending node longitude. The updated Jupiter ephemeris is accurate to better than 10 km in both right ascension and declination. Continuing VLBA observations during the rest of Juno's mission will provide further improvements to the Jupiter ephemeris. In particular, Jupiter's orbit inclination will be better constrained as the time span of VLBA observations approaches one quarter of Jupiter's orbital period. In this respect the extended duration of the Juno mission is a distinct benefit. Partial support for this work was provided by a grant from the NASA Planetary Astronomy Program to the Space Science Institute. Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contact with NASA. The VLBA is a facility of the National Science Foundation operated under a cooperative agreement by Associated Universities, Inc.

**Author(s):** Dayton Jones, Ryan Park, Jonathan romney, Christopher Jacobs, William Folkner, Vivek Dhawan

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology, National Radio Astronomy Observatory, Long Baseline Observatory, Space Science Institute

### **302.02 - An occultation network as a detector of distant solar system objects(Malena Rice)**

We discuss the feasibility, initial designs, and cost estimates for a large ( $N \sim 2000$ ) network of small photometric telescopes that is purpose-built to monitor  $G < 15$  Gaia DR2 stars for occultations by solar system minor planets, including near-Earth objects, main-belt asteroids, Jovian and Neptunian Trojan asteroids, Kuiper belt objects, and "Oumuamua-like interstellar asteroids. There are several scientific use cases for such a network. Ephemerides for all small solar system bodies could be radically improved, benefiting planetary protection from near-Earth objects and improving spacecraft navigation. Occultation monitoring would generate a definitive size distribution for asteroids down to objects with  $D \sim 10$  m, and, under reasonable assumptions regarding spatial density, the

sizes and shapes of interstellar objects such as "Oumuamua could be measured directly. Finally, operation of a large-scale occultation network would permit measurement of the solar system's tidal gravity field to high precision, thereby potentially revealing the existence of distant trans-Neptunian objects such as the proposed "Planet Nine".

**Author(s):** Gregory Laughlin, Malena Rice

**Institution(s):** Yale University

### **302.03 - Calculation of kinetic rate constants using high-level ab initio quantum chemical methods for astrochemistry and planetary sciences(Shiblee Ratan Barua)**

Existing photochemical models for the atmospheres of planetary bodies suffer from large errors when predicting the mole fraction profiles of various compounds. Global sensitivity analyses show that a major source of these model errors can be attributed to inaccurate rate coefficients for "key" radical-radical and radical-neutral reactions in low-temperature conditions. Accurate rate coefficients for key reactions thus improve the accuracy of photochemical models. Unfortunately, accurate experimental rate constants for such low-T reactions are difficult, if not impossible, to measure, and the lab data are affected by uncertainties in determining the absolute concentrations of radical species. Currently, the most common theoretical approach involves uncertainty extrapolation technique in which uncertainties in room-temperature rate constants are extrapolated to low-temperature conditions, resulting in large errors in the theoretical low-T rate constant data. To solve this existing problem, we are employing the two-transition-state (2TS) model developed by Klippenstein and coworkers to calculate high-level ab initio rate-constants for key low-T (i.e. 10-200K) reactions relevant to planetary atmospheres like that of Titan. In particular, we are investigating key reactions that have not yet been studied in the lab, and for which accurate rate coefficients are still unknown. Our calculated ab initio rate coefficients will be made available to the astrochemistry community via well-established free online kinetic databases (e.g. KIDA). These rate coefficients will be used by scientists in photochemical models to make accurate predictions of mole fraction profiles for planetary atmospheres and improve our understanding of the diverse chemistry of these bodies.

**Author(s):** Shiblee Ratan Barua, Paul Romani

**Institution(s):** NASA Goddard Space Flight Center, Universities Space Research Association (USRA)

### **302.04 - A Bayesian Method for Inferring Asteroid Properties from Sparse Light Curves(Christina Willecke Lindberg)**

Light curve data from asteroids can provide constraints on their rotation periods, shape, and spin states, and when fitting with multi-band data, can also constrain colors and phase curves.

The distribution of these parameters provides information on the structural properties of asteroids and constrains models of the collisional history of the asteroid belt. With ZTF and LSST set to make first light in the next decade, there is a precedent for developing new asteroid modeling methods that overcome these sparse sampling limitations. We present the use of Gaussian Process regression to develop a flexible modeling framework for parameter inference and data extrapolation of asteroid time series. We show on both simulated and real asteroid light curves that the new method is capable of reliably deriving periods and physical parameters from sparsely sampled asteroid light curves with better precision relative to previous methods, as well as providing rigorous estimates of the parameter uncertainties.

**Author(s):** Zeljko Ivezić\*, Andrew Connolly, Lynne Jones, Mario Juric, Daniela Huppenkothen, Bryce Bolin, Christina Willecke Lindberg,

**Institution(s):** University of Washington, DIRAC Institute, B6 Asteroid Institute, eScience Institute, University of Washington

### **302.05 - Exploring a Cluster Birth Origin for 2015 BP519's High Inclination Orbit(Megan E. Schwamb)**

2015 BP519 is a distant outer Solar System object on an orbit with a semimajor axis of 450 au, an eccentricity of 0.92, and an inclination of 54 degrees. 2015 BP519's high inclination makes it unique compared to the known sample of icy small bodies residing within the Kuiper belt and beyond with  $250 \leq a \leq 2000$  au. Within the known architecture of the Solar System, Neptune's gravitational influence cannot significantly modify 2015 BP519's orbital inclination over the age of the Solar System. Some other mechanism is likely needed to emplace 2015 BP519 on its orbit and excite its inclination. We explore whether a scenario where the Solar System is birthed in an embedded stellar cluster, with multiple close stellar passages sculpting distant small body orbits, is capable of producing the high inclination of 2015 BP519. We argue that 2015 BP519's orbit can be the natural result of this early Solar System phase, without the need to invoke a planetary mass beyond Neptune.

**Author(s):** Megan E. Schwamb, Ramon Brasser

**Institution(s):** Gemini Observatory, Earth-Life Science Institute, Tokyo Institute of Technology

### **302.06 - Probing Oort clouds around Milky Way stars with CMB surveys(Cullen Blake)**

Long-period comets observed in our solar system are believed to originate from the Oort cloud, which is estimated to extend from roughly a few thousand to one hundred thousand AU from the Sun. Despite many theoretical arguments for the existence of the Oort cloud, no direct observations of outer Oort cloud objects have been reported. We explore the possibility of measuring Oort clouds around other stars through their thermal emission at submillimeter wavelengths. Observations

with the 545 and 857 GHz bands of the Planck satellite are well matched to the expected temperatures of Oort cloud bodies (on the order of 10 K). By correlating the Planck maps with catalogs of stars observed by the Gaia mission, we are able to constrain interesting regions of the exo-Oort cloud parameter space, placing limits on the total mass and the minimum size of grains in the cloud. We compare our measurements with known debris disk systems - in the case of Vega and Fomalhaut we find a significant excess that is in agreement with measurements from Herschel. We explore an observed excess around the brightest and nearest stars in our sample as arising from possible exo-Oort clouds or other extended sources of thermal emission. We argue that future CMB surveys and targeted observations with far-infrared and millimeter wavelength telescopes have the potential to detect exo-Oort clouds or other extended sources of thermal emission beyond 1000 AU from the parent stars.

**Author(s):** Bhuvnesh Jain, Eric Baxter, Cullen Blake

**Institution(s):** University of Pennsylvania

### **302.07 - Using the T-Matrix Method to Quantify Solar Radiation Forces on Interplanetary Dust Grains(Elizabeth Metzler-Winslow)**

Interplanetary dust is important to both understanding ongoing near-Earth phenomena, as approximately 50~100 tons of interplanetary dust grains from different hypothesized sources fall into the Earth's atmosphere per day, as well as studying conditions of the early solar system. This dust population consists primarily of remnants from asteroid collisions and particles released during sublimation of a comet's outer ice layers as the body passes close to the Sun. The orbits of interplanetary dust particles vary widely due to differences in origin point, size and shape, orbit of the origin body, and so on. We study how solar forces like Poynting-Robertson Drag and non-radial radiation pressure force upon dust particles interacting with sunlight at ~1 AU vary between grains of different chemical compositions and spatial arrangements. We implement Waterman's T-Matrix for randomly-oriented independent scatterers to model each particle's interaction with sunlight, due to the advantages of the T-matrix method over Mie theory in modeling aggregate grains of mixed chemical composition. Understanding how solar radiation affects the motion of a particle with given shape and composition offers the capability to model its orbital path, resulting in dust population models pertinent to future experimental measurements as well as further theoretical study. We present preliminary results for scattering properties of aggregates grains using the T-matrix method.

**Author(s):** Elizabeth Metzler-Winslow, Geoffrey Bryden, Neal Turner

**Institution(s):** California State University, Los Angeles, Jet Propulsion Laboratory

### **302.08 - Building an Artificial Martian Atmosphere(Ilias Fernini)**

Simulations of a build-up of an artificial Martian atmosphere have been examined by an injection of gases and looking into sustainability over time, despite the low surface gravity of Mars and lack of a magnetosphere. The simulations are based on the impulsive and continuous injection of gases in a neutral and in an ionized atmosphere. A variety of initial physical conditions, i.e, temperature range, and different molecular gases were used to check the sustainability of the artificial atmosphere over a longer period of time. Initial results show that the build-up atmosphere will decay after just four months using moderate gas injection rates similar to a rocket gas exhaust or a permanent Martian base. The results of these simulations and its implication on terraforming Mars will be discussed in the present talk.

**Author(s):** Ilias Fernini,

**Institution(s):** University of Sharjah, Sharjah Center for Astronomy and Space Sciences  
**Contributing Team(s):** Maitha Ahmed Abdulla Saif Alshamsi; Ridwan Fernini; Arzoo Sohail Noorani; Maryam Muntasir Khaled Saqr Alqasemi; Arzoo Sohail Noorani

### **302.09 - Non-thermal Processes in the Formation of Mercury's Tenuous Exosphere(Micah J Schaible)**

Observations from the MESSENGER spacecraft orbiting Mercury revealed a population of ions and electrons with 1-10 keV energy, including abundant Ca<sup>+</sup>, Mg<sup>+</sup> and S<sup>+</sup> ions, at a distance of about 1.5 RM (RM is Mercury's radius). Though the sources of these ions are not known, it was previously suggested that electron-stimulated desorption (ESD) could play a significant role. ESD can directly desorb ions that are subsequently transported to the plasma cusp regions observed by FIPS. Additionally, neutrals desorbed from the surface by ESD, photon-stimulated desorption (PSD) and meteorite impact may also be photoionized and transported/injected into the cusp region. Our work has focused on the PSD of sulfur bearing minerals such as calcium sulfide (CaS) and magnesium sulfide (MgS) since these are thought to be major constituents of the hollows on Mercury's surface. Here, measurements of the 193 nm PSD and (50-1000 eV) ESD neutral and direct-ion yields from CaS and MgS (with FeS<sub>2</sub> used as a calibration material) are reported and these processes are evaluated as a potential sources of ions and neutrals present in the exosphere of Mercury. The ESD and PSD ion yields and velocity measurements were obtained directly by sampling with a time-of-flight (TOF) mass spectrometer. The measured ESD and PSD direct-ion yields from adsorbate covered Mercury surface analogs under realistic solar irradiation conditions were low. Under higher photon flux conditions that simulate micrometeorites, the ion yields were considerably higher. Overall, the results indicate that PSD and impact ejection predominantly eject neutral S, Ca, and Mg into the exosphere. These atomic desorbates were detected using resonance enhanced multi photon ionization (REMPI) TOF mass spectrometry. The resulting velocity distribution of the desorbed neutrals was fit with two Maxwell-Boltzmann distributions at 300 K and 1200 K indicating both a thermal

and non-thermal process are present. The information obtained from these experiments was then incorporated into model simulations to determine abundances, particularly in the lower altitude regions.

**Author(s):** Thomas Orlando, Brant Jones, Micah J Schaible

**Institution(s):** Georgia Institute of Technology

## **303 - Extrasolar Planets: Detection - Radial Velocity Techniques**

### **303.01 - Reproducing Measured Solar RV Variations Using Full-Disk Solar Images(Timothy Milbourne)**

On timescales of the stellar rotation period, stellar radial-velocity (RV) variations are dominated by the effects of magnetic features, such as spots and faculae. These features have velocity signatures exceeding 1 m/s, an order of magnitude larger than the 10 cm/s shift induced by an Earth-mass planet orbiting a Sun-like star. In this work, we use the Sun as a model system to study the effects of magnetic processes on measured RVs. We perform high-precision Sun-as-a-star measurements of the solar RV using a purpose-built solar telescope at HARPS-N/TNG on La Palma. RV measurements are taken near-continuously, and span three years. We compare the measured RVs with contemporaneous full-disk solar images from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO) and photometry from Solar Radiation and Climate Experiment (SORCE). From this comparison, we infer the impact of magnetic features on solar convection and the solar rotation profile. We then estimate the relative contributions of these effects to the solar RVs, and investigate how these contributions vary on timescales of several rotation period.

**Author(s):** Timothy Milbourne,

**Institution(s):** Harvard University, Harvard-Smithsonian Center for Astrophysics  
**Contributing Team(s):** The HARPS-N Solar Telescope Collaboration

### **303.02 - Improving the radial velocity precision of CHIRON with telluric line masking(Allen B Davis)**

Ground-based precision radial velocity (RV) measurements of stars are contaminated by the presence of and variation in telluric lines - molecular absorption lines produced in the Earth's upper atmosphere that raster back and forth across a stellar spectrum because of the Earth's barycentric velocity. In Doppler spectrographs that use the iodine technique, telluric contamination can lead to a poor determination of the spectral line spread function, which adds scatter to the measured RVs. In this work, we apply a new telluric code called CRYSTAL ("CRYSTAL Removes Your Spectrum's Terrestrial Atmospheric Lines"; Leet, Fischer & Valenti, in review) to build an empirical model of water and non-water telluric lines, trained on a collection of B-star spectra from the CHIRON spectrograph. This model is used to mask out pixels corresponding to telluric lines in the spectra of CHIRON planet-search stars before running the iodine RV code. We reanalyze a sample of CHIRON

spectra to compare the RVs obtained before and after applying CRYSTAL.

**Author(s):** Debra Fischer, Allen B Davis, Christopher Leet

**Institution(s):** Yale University

### **303.04 - Spectroscopic Extraction of Suppression of Convective Blueshift Near Solar Minimum(Maya Miklos)**

Efforts to detect low-mass long-period exoplanets using stellar radial velocities (RVs) are currently limited by magnetic photospheric activity. Suppression of convective blueshift (RVconv) is known to provide the dominant magnetic contribution to RV variability in low-activity Sun-like stars. Due to plasma motion driven by convective processes, the magnitude of RVconv is related to the relative depth of spectral lines used to compute the RV timeseries. Meunier et al. 2017 use this relation to demonstrate a method for spectroscopic extraction of RVconv timeseries in order to isolate common-mode RV contributions (RVsppl). We extract disk-integrated solar RVs from the solar telescope installed at the HARPS-N spectrograph on La Palma and apply the methods described in this paper, but we are not able to isolate physically meaningful RVconv contributions from this solar dataset. RVconv and RVsppl timeseries derived from Solar Dynamics Observatory/Helioseismic and Magnetic Imager (SDO/HMI) data suggest that other thermal or magnetic contributions should be considered. These contributions play a particularly important role near solar minimum, when the variability of RVconv is reduced. Future research must construct models for these contributions in order to achieve sub-meter per second sensitivity to planetary RVs in low-activity Sun-like stars.

**Author(s):** Maya Miklos

**Institution(s):** Harvard University Contributing Team(s): HARPS-N Solar Telescope Collaboration

### **303.05 - Finding small circumbinary planets - HARPS radial velocities and advanced transit algorithms(David Martin)**

One of the most remarkable new discoveries by the Kepler mission has been of planets orbiting around two stars - circumbinary planets. They present unique challenges to our understanding of planet formation and evolution. However, our knowledge to date is limited by poor statistics and observational biases. In particular, the by-eye searches for transiting circumbinary planets to date are insensitive to super-Earths, owing to large transit timing variations which inhibit traditional search algorithms. I will demonstrate two solutions to this problem. First, for transiting planets I have developed a new algorithm which incorporates TTVs directly into the search, permitting the signal binning of the shallow transits of small circumbinary planets. Second, I am running the BEBOP radial velocity survey. With a large 80 night program on the HARPS spectrograph, we obtain a precision down to 2 m/s, allowing the

detection of circumbinary super-Earths.

**Author(s):** David Martin,

**Institution(s):** University of Chicago, Swiss National Science Foundation

### **303.03D - Finding Activity-Sensitive Spectral Lines: Combined Visual Identification and an Automated Pipeline Find a Set of 40 Activity Indicators(Alexander Wise)**

Starspots, plagues, and activity cycles cause radial velocity variations that can either mimic planets or hide their existence. To verify the authenticity of newly discovered planets, observers may search for periodicity in spectroscopic activity indices such as Ca H & K and H  $\pm$ , then mask out any Doppler signals that match the activity period or its harmonics. However, not every spectrograph includes Ca H & K, and redder activity indicators are needed for planet searches around low-mass stars. Here we show how new activity indicators can be identified by correlating spectral line depths with a well-known activity index. We apply our correlation methods to archival HARPS spectra of  $\mu$  Eri and  $\pm$  Cen B and use the results from both stars to generate a master list of activity-sensitive lines whose core fluxes are periodic at the star's rotation period. Our newly discovered activity indicators can in turn be used as benchmarks to extend the list of known activity-sensitive lines toward the infrared or UV. With recent improvements in spectrograph illumination stabilization, wavelength calibration, and telluric correction, stellar activity is now the biggest noise source in planet searches. Our suite of > 40 activity-sensitive lines is a first step toward allowing planet hunters to access all the information about spots, plagues, and activity cycles contained in each spectrum.

**Author(s):** Kelsey Bevenour, Sarah Dodson-Robinson, Alexander Wise, Anthony Provini

**Institution(s):** University of Delaware, Bartol Research Institute

### **304 - Extrasolar Planets: Characterization & Theory Track 2: IX. Instruments, New Techniques, and Disks**

#### **304.01 - The Oxyometer: A Novel Instrument Concept for Characterizing Exoplanet Atmospheres(Ashley Baker)**

With TESS and ground-based surveys searching for rocky exoplanets around cooler, nearby stars, the number of terrestrial exoplanets that are well-suited for atmospheric follow-up studies will increase significantly. For atmospheric characterization, JWST will only be able to target a small fraction of the most interesting systems, and the usefulness of ground-based observatories will remain limited by a range of effects related to Earth's atmosphere. Here, we explore a new method for ground-based exoplanet atmospheric characterization that relies on simultaneous, differential, ultra-narrow-band photometry. The instrument uses a narrow-band



interference filter and an optical design that enables simultaneous observing over two 0.3 nm wide bands spaced 1 nm apart. We consider the capabilities of this instrument in the case where one band is centered on an oxygen-free continuum region while the other one band overlaps the 760 nm oxygen band head in the transmission spectrum of the exoplanet, which can be accessible from Earth in systems with large negative line-of-sight velocities. Given the expected planet yield from TESS, we estimate that multiple systems discovered by the next generation of exoplanet surveys will be amenable to ground-based characterization by an instrument of this type, which we call an oxyometer. We show that observations of an Earth-like planet orbiting a star similar to Barnard's star using an oxyometer on a 15-m telescope can achieve a signal-to-noise ratio of three by combining data from 20 transits and also present estimates of the observing time required for an oxyometer on an ELT-sized telescope to detect oxygen for M dwarfs at a range of distances. We describe the design of our oxyometer and present a detection of a 50 ppm simulated transit signal in the lab, in addition to on-sky photometry tests that demonstrate the ease of use of the compact instrument design. This technique is simple, versatile, and could be adapted to enable the study of a wide range of atmospheric species.

**Author(s):** Ashley Baker, Sam Halverson, Cullen Blake

**Institution(s):** University of Pennsylvania, MIT

### **304.03 - Recent upgrades to the pyLIMA software for microlensing modeling and analysis of two binary events.(Etienne Bachelet)**

pyLIMA is an open-source software package designed to make microlensing modeling and event simulation widely available to the community, first released in 2017. Here I will discuss recent upgrades to the capabilities of the software, starting with improvements to the core binary package, including the optimization of the magnification estimation for high cadence lightcurves. This is an essential adaptation to support the expected WFIRST Mission data. I will also discuss the revised modeling functionality include in the package and present new analysis of two events: OGLE-2011-BLG-0417 and OGLE-2015-BLG-0232. I will conclude by discussing the challenges that remain to be tackled in preparation for the upcoming WFIRST mission.

**Author(s):** Etienne Bachelet, Valerio Bozza, Rachel Street

**Institution(s):** Las Cumbres Observatory, Salerno University

### **304.04 - Cool results for cold exoplanets: OGLE-2015-BLG-0966 as pathfinding for WFIRST(Calen Henderson)**

The mass and distance of a microlens are degenerate, thus requiring at least two relations to yield a unique solution. Measuring the finite-source effect from the light curve helps provide one mass-distance relation for the lens system.

Currently, the primary avenue for establishing a second relation and thus uniquely solving for the mass and distance of the lens is by measuring the microlens parallax. One specific implementation is the satellite parallax technique, which involves taking observations simultaneously from two locations separated by a significant fraction of an au, and which has been employed by Spitzer and K2's Campaign 9. However, a significant fraction of microlensing exoplanets to be discovered in the coming decades, up to and including the detections predicted for WFIRST, will not have a measurement of the satellite parallax, requiring another avenue for converting microlensing observables into physical parameters. Enter the lens flux characterization technique, through which a microlensing target is observed with a high-resolution facility, facilitating a constraint on the flux from the lens system. This yields a third mass-distance relation for the lens and can be combined with that from finite-source effects to determine the mass of the lens system as well as its distance from Earth. I will highlight results from a Key Strategic Mission Support Program using NIRC2 on Keck designed to make such lens flux measurements for a myriad of exoplanetary lens systems. In particular, the specific test case of the event OGLE-2015-BLG-0966 emphasizes how a multi-modal solution space can be clarified with the aid of lens flux measurements.

**Author(s):** Calen Henderson, Aparna Bhattacharya, David Bennett

**Institution(s):** Caltech/IPAC-NExSci, NASA Goddard Space Flight Center

### **304.05 - An Ultra-Stable Mid-Infrared Detector for the Detection of Bio-Signatures by Means of Exo-Planet Transit Spectroscopy(Johannes G Stagnu)**

Future space missions such as Origins Space Telescope (OST) will be the instrument of choice to detect these bio-signatures in exoplanets around M-dwarfs by means of Mid-IR Transit Spectroscopy. However, current mid-IR detectors have significant problems with stability. As a result, those detectors are not expected to provide the required stability of ~5 ppm needed for a reliable detection of the spectral lines from the most important atmospheric tracers for biological activity on the planet. Here we describe the science enabled, as well as the development of an ultra-stable Mid-IR Array Spectrometer demonstration for Exoplanet Transits, which includes a calibration system that, as we show, is needed to achieve the required sensitivity for the detection of atmospheric bio-signatures in habitable-zone planets around M-dwarfs. The spectrometer will be demonstrated with arrays of Transition Edge Sensor detectors (TES). These devices are known to be intrinsically very stable and the required detector parameters (sensitivity, dynamic range) for space based mid-IR transit spectroscopy can be easily met with existing devices. No new detector developments are required. This project will include the development of a high-accuracy calibration system with a stable reference source. This scheme will allow for real time monitoring of the detector gain, which we anticipate will result in a background limited performance with the required stability

of better than 5 ppm for the detection of bio-signatures in a designated spectrometer flying e.g. on the OST space telescope, and as such will help to answer one of NASA's main questions: "are we alone?"

**Author(s):** Stephen Maher, John Sadleir, Dale Fixsen, Ari Brown, Tiffany Kataria, Jonathan Fortney, S. Harvey Moseley, Edward Wollack, Kevin Stevenson, Johannes G Staguhn,  
**Institution(s):** Johns Hopkins University, Space telescope Science Institute, NASA/Goddard Space Flight Center, University of California, University of Maryland, SSAI, JPL/Caltech  
**Contributing Team(s):** Origins Space Telescope Study Team

### **304.07 - A Planetary Mass Companion in an Edge-on Circumstellar Disk System(Karl Stapelfeldt)**

Using Hubble Space Telescope imaging we have discovered a new edge-on circumstellar disk in the Ophiuchus star-forming region. A faint companion object is associated with this disk. The companion is projected 130 AU from the central star, near the disk outer radius and aligned with the disk plane. Optical and near-IR photometry and spectroscopy obtained with HST and Keck reveal that the companion has a late M or early L spectral type, H $\alpha$  emission, and an overall spectral energy distribution very similar to the young brown dwarf GQ Lupi B, but with 10x less luminosity, consistent with a planetary mass object. The companion is also detected in the 1.3 mm continuum with ALMA, with a flux density suggesting  $\sim 0.01$  Mjupiter of circumplanetary material. The properties of the companion are consistent with a protoplanet accreting from a circumplanetary disk, making it the first such object to be observed.

**Author(s):** Virginie Faramaz, François Ménard, Karl Stapelfeldt, William J. Fischer, Deborah Padgett, Gaspard Duchene

**Institution(s):** JPL / Caltech, University of California, Berkeley, Space Telescope Science Institute, NASA Exoplanet Exploration Program Office, Grenoble University

### **304.06D - Steady-State Pileups Around Planets in Accreting Disks(Adam Dempsey)**

Young planets are known to interact gravitationally with their natal protoplanetary disks, acting as facilitators of angular momentum transport and disk accretion. When a planet's tidal torque becomes comparable to the viscous torque in the disk, it carves a low-density "gap" in the vicinity of its orbit. These gaps are visible in the near-IR by telescopes such as ALMA, and so understanding how the gap properties connect to the planet's properties is crucial to testing our theories of planet formation. In this talk I will describe the results of new 2D hydrodynamical simulations of planet-disk interaction which have been evolved to steady-state and which utilize new, torque-free boundary conditions. These boundary conditions allow the disk to relax to a configuration which is independent of where the

computational boundaries are located, and where the mass flux is independent of radius. In particular, in order for viscous torques to overcome the tidal torques of the planet gas must pile-up exterior to the planet. This density enhancement increases as the planet's mass increases or viscosity decreases and is directly connected to the overall planetary torque asymmetry. This asymmetry stems both from the intrinsic asymmetry of Lindblad resonances as well as asymmetries in the wave deposition properties of the inner and outer planet-induced spiral waves. Moreover, we find that planetary gaps are deeper and wider than previous studies have found. This implies that previous studies focused on inferring planetary properties from continuum observations of dust emission rings may have overestimated the masses of any unseen planets. We find that although the gaps are deep for high mass planets, they are not completely empty, and gas can freely cross from the outer to the inner disk. This necessarily implies that the classical picture of Type II migration is incorrect for these gap opening planets. Instead, they migrate through a series of quasi-steady-state profiles at a rate that is similar to the secondary-dominated Type II regime, but modified to take into account the enhanced torque from the exterior pile-up.

**Author(s):** Adam Dempsey, Wing-Kit Lee, Yoram Lithwick  
**Institution(s):** Northwestern University

### **305 - Exploring our Cosmic Origins: New Results from the Atacama Large Millimeter/submillimeter Array**

#### **305.01 - ALMA - science highlights and a look to the future.(Sean Dougherty)**

The Atacama Large Millimeter Array (ALMA) is the world's premier millimeter/submillimeter observatory. The total collecting area and highly sensitive receiver systems, combined with the long baselines and a high-altitude site confer unprecedented performance capabilities for exploration of the Universe. This talk will present some of the game-changing science results produced in the first six years of ALMA's operation, and discuss the current operational status of the observatory. I will also introduce the ALMA Development Roadmap, which presents challenging scientific goals that will be addressed through new technology developments over the next decade, and provide outstanding capabilities for advancing scientific exploration of the Universe.

**Author(s):** Sean Dougherty  
**Institution(s):** ALMA

#### **305.02 - Probing the particle nature of dark matter with ALMA observations of strong gravitational lenses(Yashar Hezaveh)**

The nature of dark matter is one of the most important outstanding questions in modern cosmology and astrophysics. Uncovering the properties of the dark matter particle could result in significant leaps in our understanding of fundamental physics and impact numerous astrophysical models. It is well

understood that the microphysics of the dark matter particle impacts its clustering properties on different scales. The most widely accepted dark matter model, cold dark matter, has had tremendous success explaining the large-scale structure of the universe. However, it has faced many challenges for its predictions of the distribution of matter on small, sub-galactic scales, with some observations seemingly favoring a warm dark matter alternative. A definitive answer to this question can only be achieved by mapping the distribution of dark matter on small scales with a purely gravitational probe. Strong gravitational lensing is the only probe capable of doing this at cosmological distances. In this talk, I will discuss how the discovery of a new population of strong gravitational lenses, a new observatory, ALMA, and new advances in analysis methods are allowing us to map the distribution of dark matter on small scales with high precision. In the coming years, thousands of new lenses from large surveys will transform this field, allowing us to understand the small-scale behavior of dark matter with unprecedented accuracy and precision, opening a new window for testing dark matter models in a previously inaccessible regime.

**Author(s):** Yashar Hezaveh,

**Institution(s):** Flatiron Institute, University of Montreal  
Contributing Team(s): SPT-DMS

### **305.03 - Probing Planet Formation and Habitability with ALMA(Meredith Ann MacGregor)**

The Atacama Large Millimeter/submillimeter Array (ALMA) is revolutionizing our understanding of how planetary systems form and evolve. I will present ongoing work with ALMA that explores two related aspects of this field by (1) connecting debris disk structure to sculpting planets and (2) understanding the impact of stellar flares on planetary habitability. More than 20% of nearby main sequence stars are surrounded by debris disks, where planetesimals, larger bodies similar to asteroids and comets in our own Solar System, are ground down through collisions. The resulting dusty material is directly linked to any planets in the system, providing an important probe of the processes of planet formation and subsequent dynamical evolution. Detailed modeling of ALMA continuum observations can place constraints on possible planets responsible for sculpting nearby debris disk systems (including Fomalhaut and HD 15115). Through resolved imaging of debris disks, we also detect the host stars in many cases, yielding additional insights into the radiation environment of these planetary systems. Recently, ALMA detected a large millimeter flare from Proxima Centauri, opening a new window on the mechanisms responsible for stellar flares since the flaring properties of M dwarfs have not been well-studied at these wavelengths. M dwarfs are the most abundant stars in the galaxy and have a high frequency of Earth-sized planets, making them the favored targets of upcoming missions to detect and characterize exoplanets. Through future multi-wavelength monitoring campaigns, ALMA has the potential to better constrain the properties of M dwarf flares and their impact on planetary habitability.

**Author(s):** Meredith Ann MacGregor

**Institution(s):** Carnegie

### **305.04 - The Chemistry and Dynamics of Star-forming Regions Revealed with ALMA at Band 10: Water (HDO) Outflows and Complex Organic Line Forests with 300 au Resolution(Brett McGuire)**

We present the first results of a pilot program to conduct an Atacama Large Millimeter Array (ALMA) band 10 spectral line survey of the high-mass star-forming region NGC 6334I. The observations were taken in exceptional weather conditions (0.19 mm precipitable water), and reveal a bright, bipolar water outflow driven by the embedded massive protostar. We compare the morphology of the outflow to the locations of water masers observed with complementary VLA observations, showing maser flaring at the impact walls of the outflow with the surrounding gas. We also compare our new observations to those taken with the Herschel HIFI instrument in the same frequency range. More than an order of magnitude more lines are seen, a consequence of the substantial beam dilution suffered by Herschel in observations toward the hot core. We demonstrate the detection and characterization of glycolaldehyde across ALMA bands through to band 10.

**Author(s):** Eric Willis, Ewine van Dishoeck, Robin Garrod, Geoffrey Blake, Andrew Michael Burkhardt, Brett McGuire, P. Brandon Carroll, Todd Russell Hunter, Anthony Remijan, Christopher Shingledecker, Crystal Brogan, Harold Linnartz

**Institution(s):** National Radio Astronomy Observatory, Harvard-Smithsonian Center for Astrophysics, California Institute of Technology, University of Virginia, Leiden Observatory, Max Planck Institute for Extraterrestrial Physics, Sackler Laboratory for Astrophysics

### **305.05 - A close look at an evolved debris disk - ALMA observations of Kuiper Belt Objects(Arielle Moullet)**

With more than 2000 identified bodies, the Solar System's Kuiper Belt is the most accessible example of an evolved debris disk. It is also believed to contain some of the most pristine material in the Outer Solar System, which can provide clues on its formation and evolution. The sensitivity offered by ALMA in the thermal range is key to access information on the largest objects, in particular size, density, reflectance (albedo), atmospheric composition and thermal / radiative surface properties. These measurements specifically inform on the size distribution in each sub-population and the distribution of surface and interior properties as a function of body size. With a sufficient number of sampled objects, such information can strongly constrain the primordial composition of the early Solar nebula, as well as historical and ongoing processes such as collisional grinding, accretion, dynamic capture, space weathering, cryovolcanism and surface-air interactions. Some of the measurements achievable by ALMA can also be essential for planetary mission planning support. I will present an

overview of the most recent results obtained in this field, including topics such as thermal mapping of binary systems, surface emissivity and density trends studies, as well as observations of Pluto's atmosphere.

**Author(s):** Arielle Moullet

**Institution(s):** SOFIA/USRA

### **305.06 - PHANGS-ALMA: Physics at High Angular resolution in Nearby Galaxies using the Atacama Large Millimeter/Submillimeter Array(Erik Rosolowsky)**

In this talk, I will present the PHANGS-ALMA survey, a Large Project conducted in ALMA Cycle 5 to survey nearby galaxies at arcsecond resolution in CO (2-1). Combined with precursor data, the PHANGS-ALMA sample provides fully-sampled data for 74 galaxies, combining ALMA's 12-m, 7-m, and total power arrays. These targets are selected from the star-forming main sequence of nearby (<17 Mpc) galaxies, chosen to uniformly sample the stellar-mass and specific star formation rate space. At these distances, the projected resolution reaches scales <100 pc and we can resolve structures on scales comparable to the molecular scale height of galaxies. I will present the status of the ALMA survey, the data release plans, and highlight the preliminary results from the CO data. Notably, we find that the dynamical state of the molecular interstellar medium is remarkably close to self-gravitating over a wide range of galactic environments. Despite this, we find that the mass distribution of molecular clouds in these targets varies substantially, depending on the covering fraction of molecular material within the galaxy disk. This work makes use of the following ALMA data: ADS/JAO.ALMA#2017.1.00886.L. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

**Author(s):** Erik Rosolowsky

**Institution(s):** University of Alberta Contributing Team(s): The Physics at High Angular resolution in Nearby Galaxies (PHANGS) Team

## **306 - AGN Feedback I**

### **306.01 - Convolutional Neural Network Classification of Broad Absorption Line Quasars(Zhiyuan Guo)**

Broad absorption line (BAL) quasars are spectacular probes of black hole feedback on galaxy evolution, and are important to identify in high redshift samples intended for cosmological studies with the Lyman-alpha forest. Yet the large quasar sample from the Sloan Digital Sky Survey (SDSS), and the even larger sample expected from the Dark Energy Spectroscopic Instrument (DESI) survey, are rapidly outpacing human classification. We present a new, automatic BAL classification method based on a Convolutional Neural Network (CNN). We trained our CNN classifier on the CIV region of a sample of

quasars with reliable human classifications, and have applied it to the SDSS Data Release 14 (DR14) quasar catalog. The CNN classifier correctly classifies over 98% of the BAL quasars with visual classifications from the earlier DR12 quasar catalog, which demonstrates comparable reliability. We describe how we prepare the spectra for our classifier, the structure of the CNN, and various tests and comparisons with other datasets. Our new catalog includes a BAL probability, along with the balnicity index, velocity data, and other information about all significant absorption systems in each spectrum. This catalog should enable future cosmological analyses to more selectively mask potential BAL features in the Lyman-alpha forest and thereby improve their measurements. It will also be valuable for myriad other astrophysical investigations.

**Author(s):** Zhiyuan Guo, Paul Martini

**Institution(s):** The Ohio State University

### **306.04 - Determining the Kinematics of Ionized and Molecular Gas in Nearby Active Galaxies with the Gemini Near Infrared Field Spectrometer (NIFS)(D. Michael Crenshaw)**

We are building a sample of integral field unit (IFU) observations of nearby AGN using Gemini NIFS to resolve the physical mechanisms of feeding and feedback in their narrow-line regions (NLRs). Our goal is to obtain Z-band observations of ~34 Seyfert galaxies and LINERS with existing NIFS K-band data in the Gemini archives. We are using the Z-band observations of [S III] to map the distribution and kinematics of ionized gas on a scale of ~1 kpc for comparison with K-band observations of warm molecular hydrogen and the stellar CO bandheads to map the gravitational potential. We are also using long-slit spectra from the Apache Point Observatory's Dual Imaging Spectrograph (DIS) to trace the ionized gas kinematics into the host galaxy. We will present preliminary results from the sample including different feeding mechanisms (e.g., minor merger, fueling by a companion, secular feeding along a bar) and the extent to which the ionizing radiation can drive out the ionized and molecular gas.

**Author(s):** D. Michael Crenshaw, Henrique R. Schmitt, Beena Meena, Steven Kraemer, Crystal L. Gnillka, Francisco Martinez, Mitchell Revalski, Travis Fischer

**Institution(s):** Georgia State University, Naval Research Laboratory, The Catholic University of America

### **306.06 - The X-ray properties of extremely red quasars observed during the epoch of peak galaxy formation(Andy Goulding)**

Rapidly accreting obscured black holes have long since been predicted to drive powerful winds that clear the host galaxy of gas and shut off star formation in a process now commonly referred to as quasar feedback. Identifying the obscured quasar population, particularly at early epochs where they may have made the strongest impact on galaxy formation, has always

been a critical goal of extragalactic surveys. However, studies of high redshift obscured and reddened quasars have yet to produce a self-consistent picture of black hole growth and AGN feedback. I will present our recent results on the X-ray and rest-frame optical properties of  $z \sim 3$  extremely red quasars that are driving powerful galactic scale outflows at velocities of up to 500 km/s, giving rise to the idea that these objects are signposts for the pivotal "blow-out" phase of quasar feedback. This intriguing class of high- $z$  quasars appear to be heavily obscured at X-ray energies, they are enshrouded in copious levels of dust, and exhibit extremely unusual optical/UV emission lines. Having already grown to  $M_{\text{bh}} \sim 10^9 M_{\odot}$  by  $z \sim 3$ , this quasar population likely represents the predecessors to the now dormant black holes residing in massive early-type galaxies at the centers of present-day clusters.

**Author(s):** Andy Goulding

**Institution(s):** Princeton University

### **306.02D - The Environments of Accreting Supermassive Black Holes (Meredith Powell)**

The details of black hole-galaxy co-evolution can be revealed by studying the multi-scale environments of accreting SMBHs. Using state-of-the-art multiwavelength surveys of complementary depth, size, and resolution, I present recent results on the galaxies and cosmic environments that host Active Galactic Nuclei (AGN) to test current models of AGN feeding and feedback. On galactic scales, we do not find evidence of AGN outflows in the form of extended x-ray emission in nearby quasars, ruling out models of the hot-wind feedback mode. However at moderate redshifts, I show that the morphologies and galaxy properties of galaxies and AGN are consistent with major mergers being associated with black hole accretion and subsequent quenching, although the direct role of the black hole remains elusive. An independent constraint comes from the halo-scale environments of AGN, which are determined via clustering analyses. By measuring the spatial correlation function of hard x-ray selected AGN from the Swift/BAT Spectroscopic Survey (BASS) and modeling it via populating dark matter halos from the Bolshoi-Planck simulation with subhalo- and HOD-based models, the halo occupation statistics of local AGN are constrained. I show that on average, the AGN occupy halos consistently with inactive galaxies of the same stellar mass distribution; however, when disaggregating by column density, we find that obscured AGN reside in denser environments than unobscured AGN, despite no significant differences in their luminosity, redshift, stellar mass, or Eddington ratio distributions. We show that, while high- and low-obscuration AGN may reside in halos of different mass with distinct halo occupation distributions, an alternative explanation is that their halos have systematically different concentrations/assembly histories. Lastly, I present the first measurement of the characteristic host halo masses of luminous X-ray selected AGN at the peak of SMBH growth at  $z \sim 2$ , where triggering and feedback may be different from the moderate-luminosity AGN in the local universe.

**Author(s):** Meredith Powell

**Institution(s):** Yale University

### **306.03D - Feedback in Nearby Active Galaxies: Quantifying the Impact of Narrow Line Region Outflows (Mitchell Revalski)**

We present the results of our study to quantify the impact of narrow line region (NLR) outflows in a sample of nearby active galactic nuclei (AGN). Using spatially-resolved spectroscopy and imaging, in combination with Cloudy photoionization models, we map the kinematics of the ionized gas and determine its radial mass distribution as a function of distance from the supermassive black hole (SMBH). Using these quantities, we determine spatially-resolved mass outflow rates and energetics, and compare the results to commonly used global techniques that average over the spatial extent of the NLR. We find that mass estimates based on emission line luminosities provide more consistent results than geometric techniques employing filling factors. The calculated energetics are also strongly affected by the adopted methods for determining gas density, velocity, and outflow radius. Finally, we examine correlations between properties of the AGN and the outflows. In general, we find that the outflow energetics and radii scale with AGN luminosity, while spatially-resolved mass outflow rates do not. The outflows can contain up to several million solar masses of ionized gas, and the energetics reach model benchmarks for effective feedback, indicating that NLR outflows in nearby AGN can have sufficient power to impact their host galaxies. These results will help us to better interpret observations of AGN outflows at higher redshifts observed by JWST, where feedback is thought to strongly influence star formation and galactic structure.

**Author(s):** Mitchell Revalski

**Institution(s):** Georgia State University

### **306.05D - Probing Quasar Winds Using Intrinsic Narrow Absorption Lines (Christopher Culliton)**

Quasar outflows are important for understanding the accretion and growth processes of the central black hole. Furthermore, outflows potentially have a role in providing feedback to the galaxy, and halting star formation and infall of gas. The geometry and density of these outflows remain unknown, especially as a function of ionization and velocity. Having searched ultraviolet spectra at both high redshift (VLT/UVES;  $1.4 < z < 5$ ) and low redshift (HST/COS;  $z < 0.45$ ), we have located narrow absorption lines (NALs) that are intrinsic to (physically associated with) the quasar. We identify intrinsic NALs with a wide range of properties, including ejection velocity, coverage fraction, and ionization level. We also consider the incidence of intrinsic absorbers as a function of quasar properties (optical, radio and X-ray fluxes), and find that radio properties and quasar orientation are influential in determining if a quasar is likely to host an intrinsic system. We find that there is a continuum of properties within the intrinsic NAL sample,

rather than discrete families, ranging from partially covered C IV systems with black Ly $\lambda$  and with a separate low ionization gas phase to partially covered N V systems with partially covered Ly $\lambda$  and without detected low ionization gas. Additionally, we construct a model describing the spatial distributions, geometries, and varied ionization structures of intrinsic NALs. Finally, we determine that the probability of finding one or more intrinsic N V systems in radio-loud quasars is dependent upon the radio core fraction, and hence the orientation angle. Our observations suggest that a clumpy, sporadic outflow is the most likely explanation.

**Author(s):** Christopher Culliton

**Institution(s):** Penn State

### **307 - Selections from the PRPER Focused Collection on Astronomy Education Research**

#### **307.01 - Finding the Time: Efforts to Improve Temporal Frameworks in Astronomy(Laci Shea Brock)**

One goal for a scientifically literate citizenry would be for learners to appreciate when the Earth came to be and where it resides in the Universe. Understanding the Earth's formation in time in both a sociohistorical and scientific sense allows us to place humanity within the larger context of our existence in the Universe. In this talk I discuss prior research from cognitive science, psychology, history, and Earth and space science education to inform a new research agenda in astronomy education. Although prior research related to learners' ideas of time and Earth's location exists, research on how to help students develop a coherent model of Earth's place in space and time in the Universe is still lacking. I will highlight a set of preliminary findings from our pilot study that is part of this new agenda and focus on new efforts to connect students' ideas of Earth's formation with prior events in the Universe.

**Author(s):** Laci Shea Brock, Edward Prather, Chris David Impey

**Institution(s):** University of Arizona

#### **307.02 - Design and Development of a Learning Progression about Stellar Structure and Evolution(Italo Testa)**

Several Learning Progressions (LPs) have been recently developed around big ideas in astronomy. Examples include celestial motion and Solar system formation. In this presentation, we will discuss the iterative design and development of a LP about Stellar Structure and Evolution (SSE). We chose SSE as big idea since it provides a meaningful explanatory framework for a broad range of phenomena in the field of astronomy as, e.g., the presence and production of heavy elements, or the conditions under which life may develop in the universe; moreover, SSE is useful to improve and validate models of the composition and expansion of the universe. Building on previous research studies and on curriculum teaching, we initially chose three knowledge dimensions to

describe students' reasoning about SSE: hydrostatic equilibrium; composition and aggregation state; functioning and evolution. Then, we empirically constructed the levels of the hypothetical LP using interview data from 77 high school students of different ages, who had been taught about the LP topics. Interview questions included seven questions built from previously validated instruments. Data were analyzed using "facets" approach. Facets were iteratively extracted using a constant comparative method and coded as naïve, partial or scientific views. Reliability was assessed through evaluation of inter-rater reliability. Subsequent revisions of the LP were validated with two further samples of 50 high school students participating to an extra-curricular program organized at our physics department. Teaching activities, which include paper-and-pencil tasks, video analysis with Tracker software and measurements using a low-cost spectrometer, were designed and revised starting from LP levels to ensure a close link between the hypothesized LP and instruction. Data show that the teaching activities helped most students progress along the LP levels in all the three chosen dimensions. However, upper levels of the LP were reached by few students even after instruction. This study provides an example of connection between LPs and instructional design. Implications for research in astronomy education and development of LPs for other big ideas in astronomy will be discussed.

**Author(s):** Italo Testa, Silvio Leccia, Emanuella Puddu, Arturo Colantonio, Silvia Galano,

**Institution(s):** Università degli Studi di Napoli Federico II, I.N.A.F.- Osservatorio Astronomico di Capodimonte , University of Camerino

#### **307.03 - Assessing Astronomy Students' Views about the Nature of Scientific Inquiry(Jennifer Blue)**

Students taking a second astronomy course for non-scientists were asked to reflect on the nature of scientific inquiry three times during the first half of the semester. First they were assigned a short paper in which they were asked to argue for or against the thesis that observers of the night sky in ancient civilizations were scientists, and nearly all of the students argued that yes, they were. Second, they were asked to write a second paper in which they argued the opposite of their first thesis. Lastly, they were asked, on a midterm exam, to write an essay about whether the Ancient Greek astronomers were good scientists. In writing these papers and essays, many students included definitions of science or scientists, and these definitions progressed from paper to paper. In addition, the evidence students used to argue that ancient observers were scientists changed, with students becoming more expert-like.

**Author(s):** Jennifer Blue

**Institution(s):** Miami University

### **307.04 - Characteristics of Effective Astronomer-Educator Partnerships in Formal Urban Middle School Science Classrooms(Rommel J. Miranda)**

This qualitative study investigates astronomers' and urban public middle school teachers' beliefs about the characteristics of effective outreach partnerships in formal science classroom settings. Twelve astronomers and twelve science teachers participating in Baltimore Project ASTRO, a NSF grant-funded astronomer-educator partnership outreach program, were interviewed after participation using semi-structured, in-depth interview techniques. Constant comparative analysis was used to analyze the interview transcripts. The findings suggest that astronomers and urban public middle school teachers believe that the characteristics of effective outreach partnerships center on the following three themes: partnership collaboration, astronomer and teacher characteristics, and astronomer and teacher dispositions. Regarding partnership collaboration, astronomers and teachers believed that establishing a relationship; maintaining communication; planning, preparing, and facilitating lessons collaboratively; and following-up on lessons taught and modifying lessons for future implementation were vital characteristics for effective astronomer-educator partnerships. Concerning astronomer and teacher characteristics, effective astronomer partners were described as being willing to volunteer their time; willing to provide resources; and willing to purchase supplies. Effective educator partners were characterized as being responsible for managing the classroom and students; differentiating lessons and activities; and administering pre/post astronomy assessments to students before and after their astronomer partner visits. In reference to astronomer and teacher dispositions, effective astronomers were prompt, able to relate to kids, excited, passionate about what they do, knowledgeable, tolerant, and easy going. Effective teachers were committed; motivated to have a volunteer astronomer in their classroom; passionate about teaching and about their students; and knowledgeable about the astronomy curriculum. The findings of this study help to provide essential guidance to all who are interested in designing and facilitating science educational outreach programming.

**Author(s):** Rommel J. Miranda

**Institution(s):** Towson University

### **308 - Alert Followup**

#### **308.01 - Multi-wavelength alert followup: opportunities and challenges(Raffaella Margutti)**

Follow-up of astronomical transients outside the optical window (including gamma-rays, X-rays and radio) often provides key information that can uniquely constrain the intrinsic nature of transient events and their physics. Here I will provide a brief overview of the opportunities and challenges of multi-wavelength follow up in the era of thousands of alerts per night.

**Author(s):** Raffaella Margutti

**Institution(s):** Northwestern University

#### **308.02 - Time-domain Spectroscopic Observatory (TSO): A Probe-Class Mission Proposed for Astro2020(Jonathan E Grindlay)**

A "Probe-class" NASA mission concept for the Time-domain Spectroscopic Observatory (TSO), is being proposed for the upcoming Astro2020 Decadal Survey. TSO would be a ~1.5m optical-IR (0.3um - 5um) imaging and spectroscopic telescope, radiatively cooled (110K) and in Geosynch orbit over LSST. This talk will present the TSO concept and discuss how the highest priority LSST and multi-wavelength variables and transients can be studied with a synergistic space telescope devoted to rapid-response imaging and spectroscopy extending to the mid-IR. The rapid-slew (<5min) capability to targets over 80% (!) of the sky (>300 from Earth, Sun and Moon) and cold mirror enable broad-band imaging and spectroscopy sensitivities not possible from the ground or other space telescopes: 300 sec exposures for 4-band simultaneous imaging and R = 200 spectroscopy over the full 0.3um - 5um band reach 10sigma significance magnitudes of AB = 25 and 22, respectively. Key science objectives include high-z Gamma-Ray Bursts, which will trace massive star formation and the Epoch of Reionization out to (and beyond?) redshifts  $z \sim 8 - 12$ , and Reverberation Mapping of AGN using Hbeta emission line spectroscopy combined with LSST continuum flaring to measure SMBH masses out to  $z = 8$ . TSO would conduct a broad range of Time Domain Astrophysics (TDA) rapid-response followup studies and TDA surveys not possible with JWST or WFIRST. This is achieved by a Probe-class (<\$1B) mission with low-cost operations and continuous telemetry and commanding enabled by its unique Geosynch orbit.

**Author(s):** Jonathan E Grindlay

**Institution(s):** Harvard University - CfA

#### **308.03 - The ZTF and LSST Alert Streams(Eric Bellm)**

New optical time-domain surveys are monitoring ever-larger swaths of the night sky for dynamic phenomena to increasing depths. The resulting haul of explosive transients, variable stars, moving objects, and other time-variable phenomena can enable great science, but only if these events can be rapidly identified and appropriate follow-up observations secured. I will describe the motivation for astrophysical alert streams and their implementation in two surveys, the Zwicky Transient Facility (ZTF) and the Large Synoptic Survey Telescope (LSST). These surveys package all significant difference image detections together with contextual information in rich alert packets and send them out in near real-time to downstream brokers for filtering, crossmatching, and classification. I will present lessons learned from early ZTF operations and implications for time-domain science in the LSST era.

**Author(s):** Eric Bellm

**Institution(s):** University of Washington Contributing Team(s): Zwicky Transient Facility Collaboration, Large Synoptic Survey Telescope Project

### **308.04 - Alert Management Systems(Andrew Connolly)**

Surveys such as the Zwicky Transient Facility (ZTF) or the Large Synoptic Survey Telescope (LSST) will generate millions of alerts per night from observations of variable, transient, and moving sources. Given the scale of the resulting alert or event streams we face the challenge of how to process, analyze, annotate, and classify these data in order to separate the unusual from the mundane. Analyses must be undertaken in real time to enable rapid followup and in batch mode to study the populations of variable sources. This need has led to the development of Alert Management Systems or "Brokers" within the astronomical community. In this talk I will provide an overview of the status and functionality of current broker systems and what we might expect to accomplish with these systems in the era of ZTF and the LSST.

**Author(s):** Andrew Connolly,

**Institution(s):** University of Washington, Seattle, DiRAC Institute

### **310 - Galaxy Formation and Evolution VI**

#### **310.01 - Decoupling the Production and Escape of Lyman-alpha Photons(Ryan Trainor)**

Lyman-alpha emission plays a crucial role in selecting galaxies, and it is an important tracer of their ionizing emission and the neutrality of the intergalactic medium. While Lyman-alpha photons are produced primarily in star-forming regions, their observed galaxy-scale emission depends sensitively on both the production rate of these photons and their subsequent scattering and absorption on much larger scales. I will present new results from several spectroscopic surveys of more than 1000 galaxies at  $z=2-3$  (including the KBSS, KBSS-Lya, and KLCS) that are allowing us to empirically study the relationships between observed Lyman-alpha emission and many different physical properties of galaxies. I will discuss how these observations allow us to separate the physics of Lyman photon production from that of photon escape and what these relationships tell us about the overall ionizing photon production of galaxies.

**Author(s):** Ryan Trainor

**Institution(s):** Franklin & Marshall College Contributing Team(s): Keck Baryonic Structure Survey Team

#### **310.03 - The populations of star-forming and quenched galaxies(Tjitske Starkenburg)**

Galaxies having little to no active star formation are termed "quiescent" or "quenched", but many different observational and theoretical indicators are used to define this classification. Moreover, the galaxy star formation sequence itself, whether predicted from simulations or observed, varies depending on the dataset and the tracers used to measure star formation rates. We explore star formation and quenching of galaxies in a

large observational dataset plus numerous independent sets of simulated galaxies from large-scale and zoom cosmological simulations. We describe the populations in the star formation rate - stellar mass plane and discuss the differences between the datasets. Additionally, we build mock galaxy spectra for all simulated galaxies and compare the observational star formation and quenching indicators for the mock galaxy spectra to the galaxy properties in the simulations and to the star formation and quenching indicators for observed galaxies. We describe the galaxy star forming sequence and population of quenched isolated galaxies in theoretical predictions, mock observations, and observational data, how to define "quenched" in a consistent way, and the implications of this comparison on the star formation and feedback processes in galaxies.

**Author(s):** Chang Hoon Hahn, Tjitske Starkenburg

**Institution(s):** Flatiron Institute, University of California Berkeley, Lawrence Berkeley National Laboratory Contributing Team(s): The IQ (Isolated and Quiescent galaxies) - Collaboratory

#### **310.04 - Genetically Modified Halos with Cosmic Ray Feedback(Iryna Sotolongo Butsky)**

The majority of galactic baryons reside outside of the galactic disk in the diffuse gas known as the circumgalactic medium (CGM). The gas reservoirs in the CGM govern galaxy evolution and may explain why some galaxies quench. While state-of-the-art simulations excel at reproducing galactic disk properties, many struggle to drive strong galactic winds or to match the observed multiphase structure of the CGM with thermal supernova feedback. Non-thermal cosmic ray (CR) supernova feedback is likely to reconcile this discrepancy and has been recently shown to drive strong outflows and better match the observed low-ion column densities. Using a suite of simulated genetically-modified Milky Way-type galaxies (in which the initial conditions are strategically altered to control its merger history), I will demonstrate the role of CR feedback in quenching galaxies and shaping the ionization structure of the CGM.

**Author(s):** Andrew Pontzen, Iryna Sotolongo Butsky, Natalie Nicole Sanchez, Thomas Quinn

**Institution(s):** University of Washington, University College London

#### **310.06 - Ages and Metallicities of Quiescent Galaxies at $1.0 < z < 1.8$ Derived from Deep Hubble Space Telescope Grism Data(Vicente Estrada-Carpenter)**

The ages and metallicities of massive quiescent galaxies contain important formation and quenching history information. When observed close to their quenching time we can better constrain these properties. This requires observations in the near-IR, which are sensitive to the (rest-frame) optical age and metallicity spectroscopic features (where ground-based observations suffer from strong sky backgrounds). Here, we use



deep Hubble Space Telescope spectroscopy to constrain the metallicities and (light-weighted) ages of massive ( $\log M^*/M_\odot > 10$ ) galaxies selected to have quiescent stellar populations at  $1.0 < z < 1.8$ . The data include 12--orbit depth coverage with the WFC3/G102 grism covering  $\sim 8,000 < \lambda < 11,500 \text{ \AA}$ , at a spectral resolution of  $R \sim 210$  taken as part of the CANDELS Lyman- $\alpha$  Emission at Reionization (CLEAR) survey. At  $1.0 < z < 1.8$ , the spectra cover important stellar population features in the rest-frame optical, such as Ca HK, the 4000  $\text{\AA}$  break, Balmer lines ( $H\delta$ ,  $H\gamma$ ,  $H\beta$ ), and MgB absorption features. We forward model a suite of stellar population models at the grism resolution, fit these to the data for each galaxy, and derive posterior likelihood distributions for metallicity, age, star-formation history, redshift, and dust. Using an iterative stacking procedure we combine the posteriors for subgroups of galaxies in different redshift ranges that include different combinations of stellar absorption features. Our results give light-weighted ages of  $t_{z \sim 1.1} = 3.2 \pm 0.7 \text{ Gyr}$ ,  $t_{z \sim 1.2} = 2.2 \pm 0.6 \text{ Gyr}$ ,  $t_{z \sim 1.3} = 3.1 \pm 0.6 \text{ Gyr}$ , and  $t_{z \sim 1.6} = 2.0 \pm 0.6 \text{ Gyr}$ , for galaxies at  $z \sim 1.1, 1.2, 1.3$ , and  $1.6$ . This implies that most of the massive quiescent galaxies at  $1 < z < 1.8$  had formed  $> 68\%$  of their stellar mass by a redshift of  $z > 2$ , supported by the comoving number densities of massive galaxies. The posteriors give metallicities of  $Z_{z \sim 1.1} = 1.16 \pm 0.29 Z_\odot$ ,  $Z_{z \sim 1.2} = 1.05 \pm 0.34 Z_\odot$ ,  $Z_{z \sim 1.3} = 1.00 \pm 0.31 Z_\odot$ , and  $Z_{z \sim 1.6} = 0.95 \pm 0.39 Z_\odot$ . This is evidence that massive galaxies had enriched rapidly to approximately Solar metallicities as early as  $z \sim 3$ .

**Author(s):** Gabe Brammer, Ryan Quadri, James Long, Steven Finkelstein, Catherine Gosmeyer, Benjamin Weinero, Mauro Giavalisco, Henry Ferguson, Vicente Estrada-Carpenter, Rosalind Skelton, Mark Dickinson, Jonathan R. Trump, Joanna Bridge, Brett Salmon, Casey Papovich,

**Institution(s):** University of Arizona, Texas A&M University, University of Louisville, Space Telescope Science Institute, University of Texas, National Optical Astronomy Observatory, NASA Goddard Space Flight Center, University of Massachusetts, University of Conn

### **310.07 - Active Galactic Nuclei Heat Dust and Molecular Gas in Star Forming Hosts (Allison Kirkpatrick)**

Active Galactic Nuclei (AGN) can have a strong heating effect on the dust in galaxies, contributing non-negligibly to the far-IR energy budget. We explore whether the energy output from active galactic nuclei has a measurable effect on the cold molecular gas in host galaxies. We compile galaxies from the literature spanning the range  $z=0.1-4$  which have molecular CO transitions, and we diagnose IR AGN strength by comparing the amount of hot dust with the total infrared luminosity. We create new CO spectral line energy distributions for AGN and star forming galaxies. We find that the AGN have more dense gas, evidenced by enhanced emission in the CO(6-5) and CO(7-6) transitions, than star forming galaxies. Surprisingly, AGN even have enhanced emission in the lower transitions (CO(2-1)) compared to the ground state, which has implications for using

CO as a gas mass tracer in AGN. AGN do not have preferentially higher star formation efficiencies than star forming galaxies, nor do they have shorter gas depletion timescales, indicating that IR AGN are no closer to quenching than massive star forming galaxies.

**Author(s):** Chelsea Sharon, Alexandra Pope, Erica Keller, Allison Kirkpatrick

**Institution(s):** University of Kansas, NRAO, Yale NUS, UMass

### **310.02D - The impact of environment on the HI gas of galaxies in the large-scale structures around the Virgo Cluster (Hyein Yoon)**

Pre-processing may play a critical role in altering gas and stellar properties of galaxies in low-to-moderate density environments outside clusters. A major goal of this dissertation is to present observational evidence that describes how galaxies are influenced by the intergalactic medium and/or neighbors while falling into clusters. We perform a neutral atomic hydrogen (HI) imaging study of the galaxies selected from two large-scale filaments and one infalling group around the Virgo cluster. HI gas can be a great tracer for probing the impact of various environmental processes attributable to the ambient medium. Based on the detailed HI morphology and kinematics obtained with the WSRT, GMRT and JVLA, we identify the signatures of gas accretion, ram pressure stripping, and tidal interaction which the sample galaxies are potentially experiencing in the selected environments. In addition, we investigate the star formation properties of our targets and the galaxies embedded in the same environments as our sample as well as the large-scale structures around Virgo using three different multi-wavelength colors such as  $W3-W1$ ,  $NUV-r$ , and  $g-r$ . As a result, we find a significant fraction of red galaxies in several filaments and groups. Over a broad range of stellar masses, a gradual increase in the fraction of red galaxies is observed from field to groups/filaments, and to higher density regions. These suggest that star formation quenching is already beginning in the intermediate density environment in the outskirts of the cluster.

**Author(s):** Aeree Chung, Hyein Yoon

**Institution(s):** Yonsei University

### **310.05D - Evolution of the Stellar Mass - Stellar Metallicity Relation (Nicha Leethochawalit)**

The correlation between stellar mass and metal abundance (or MZR, the mass-metallicity relation) reflects the balance between galactic feedback and gravitational potential. Feedback ejects metals out of galaxies, while gravitational potential retains the produced metals, which enrich later generations of stars. Because stellar metallicity indicates the amount of metals incorporated into stars at their formations, it reflects the "star-formation history average" metal abundance. We present stellar MZR based on the stellar metallicities of individual quiescent

galaxies in the Cl0024 and MS0451 galaxy cluster at redshifts 0.4 and 0.54 respectively. The measurements were made via full-spectrum stellar population synthesis modeling. The lower limit of our stellar mass range is  $109.7 M_{\odot}^{\text{TM}}$ . To our knowledge, this is the lowest galaxy mass at which individual stellar metallicity has been measured beyond the local universe. We detect an evolution of the stellar MZR with observed redshift when the metal is iron (Fe). We do not detect any significant evolution with observed redshift when the metal is Magnesium (Mg). However, when the relevant redshift is the redshift of the galaxy's formation (not observation), the evolutions of both Fe and Mg are more easily detectable. We trace these quiescent galaxies back to their star-formation epochs by taking their ages into account. We find that Fe abundance strongly depends on galaxy formation epoch; Mg abundance has a weaker, but significant, dependence. The stronger evolution of Fe than Mg can be explained by the difference in their recycling times. Fe, mainly produced in Type Ia supernovae (SN), has a longer recycling time than Mg, which is mainly produced in core-collapse SN. Fe elements that return to the interstellar medium after quenching would not have been incorporated into stars. The evolution of Mg with formation time supports the idea that galaxies have different dominating quenching mechanisms at different redshifts, i.e. the mass-loading factor is redshift dependent. Lastly, the gentle slope in the MZRs suggest that the mass-loading factor might be minimally dependent on mass over the observed range of masses.

**Author(s):** Nicha Leethochawalit

**Institution(s):** California Institute of Technology

## 311 - ISM & Related Topics II

### 311.01 - The PDR in M17-SW analyzed with FIFI-LS onboard SOFIA (Randolf Klein)

Photo-dissociation regions (PDRs) are the places where molecular clouds are destroyed by UV radiation of forming massive stars. The molecular gas is photo-dissociated and then ionized by UV radiation. The UV radiation below 13.6 eV heats the gas via the photo-electric effect on dust grains. Cooling happens through the dust continuum and a handful of far infrared (FIR) fine-structure lines. FIFI-LS, the FIR spectrometer onboard the US-German airborne observatory, SOFIA, can map these main cooling lines efficiently. We observed the well-studied edge-on PDR, M17-SW, with high spatial resolution in all major FIR cooling lines of the ionized and neutral medium. By comparing the observed line intensities to model predictions we mapped the physical conditions of the ionized and neutral layer of the PDR by the [OIII] line ratio readily provides the electron density maps in the ionized layer just above the PDR. The median electron density in that area is about  $10^3 \text{ cm}^{-3}$ . The analysis of the [OI], [CII], CO and continuum emission with the PDR Tool box allowed us to map the gas density and UV radiation field strength over the region. The gas density in the PDR varies between  $10^5$  and  $10^6 \text{ cm}^{-3}$ . The UV field is about  $10^{4.4}$  in

Habing units. We also estimated the optical depth effects to the [OIII]  $63\mu\text{m}$  line and the contribution of the PDR to the ubiquitous [CII] emission for each map position. While the applied model is comparatively simple, a consistent picture of the spatial variation of the physical parameters over the mapped region could be derived. Based on these findings the processes and energetics in the PDR can be studied further possibly by applying more detailed models together with more data from other wavelengths.

**Author(s):** Sebastian Colditz, Randolf Klein, Dario Fadda, Alfred Krabbe, William Vacca, Chrisitan Fischer, Leslie Looney, Alexander Reedy

**Institution(s):** USRA, University of Illinois, DSI, JSTF  
Contributing Team(s): FIFI-LS Team

### 311.03 - STO2 Observations of [CII] and the Structure of the Tr14 Region (Paul Goldsmith)

The Stratospheric Terahertz Observatory 2 (STO2) balloon mission flew from McMurdo station in the Antarctic in Dec. 2017 - Jan. 2018 allowing 20 days of observation of the [CII] 158 micron fine structure line emission from the inner galaxy. One of the areas mapped was the Trumpler 14 (Tr14) region in Carina. [CII] spectra with 0.17 km/s velocity resolution and 48 arcsecond angular resolution were obtained over a region  $0.25^\circ \times 0.29^\circ$  in size, with antenna temperature greater than 5 K over 80% of the area surveyed. The [CII] emission has a good correlation with dust continuum emission at  $160\mu\text{m}$ , which is produced by 20 K dust grains. The strongest [CII] emission is at the Carina I-E cloud which is located four arcminutes southwest of Tr14 and one arcminute east of the CO peak intensity of the Carina I-E cloud, suggesting that the photodissociation region of Carina I-E produces the strongest [CII] emission in the Carina I region. The kinematics show that [CII] structures are spatially and spectrally correlated with the surfaces of CO clouds, resolving the photodissociation region of each CO cloud. Our results show multiple photodissociation regions along the line-of-sight in the Trumpler 14 / Carina I region. Comparisons among multiple gas tracers including HI 21cm, [CII], CO, and radio recombination lines suggest that the HII region of the Carina Complex may have a champagne flow with its axis being aligned along the line of sight and having the foreground bubble burst toward us.

**Author(s):** STO Team, Chris Walker, Paul Goldsmith, Russ Shipman, Volker Tolls, Youngmin Seo, Mark Wolfire, Craig Kulesa, Dave Hollenbach

**Institution(s):** JPL, CfA, University of Arizona, University of Maryland, SRON, various, SETI Institute

### **311.05 - Quantifying the effects of spatial resolution and noise on galaxy metallicity gradients(Ayan Acharyya)**

Metallicity gradients are important diagnostics of galaxy evolution, because they record the history of events such as mergers, gas inflow and star-formation. However, the accuracy with which gradients can be measured is limited by spatial resolution and noise, and hence measurements need to be corrected for such effects. We use high resolution ( $\sim 20$  pc) isolated galaxy simulations, coupled with photoionisation models, to produce a suite of synthetic high resolution integral field spectroscopy (IFS) datacubes. We then degrade the datacubes, with a range of realistic models for telescope spatial resolution and noise, to investigate and quantify how well the input metallicity gradient can be recovered as a function of resolution and signal-to-noise ratio (SNR). Given appropriate propagation of uncertainties and pruning of low SNR pixels, we show that a resolution of 3-4 telescope beams per galaxy scale length is sufficient to recover the gradient to  $\sim 10$ -20% uncertainty. The uncertainty escalates to  $\sim 60\%$  for lower resolution. Inclusion of the low SNR pixels causes the uncertainty in the inferred gradient to deteriorate, likely due to increased error in the underlying continuum fit. Our results can potentially inform future IFS surveys regarding the resolution and SNR required to achieve a desired accuracy in metallicity gradient measurements.

**Author(s):** Rob Sharp, Christoph Federrath, Mark Krumholz, Nathan Goldbaum, Ayan Acharyya, Lisa Kewley,

**Institution(s):** Australian National University, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D)

### **311.06 - Measuring 3D structure, dust extinction, and star formation histories from deep Hubble Space Telescope multi-color photometry in the Small Magellanic Cloud(Petia Yanchulova Merica-Jones)**

Dust properties in the Small Magellanic Cloud (SMC) provide insight into the interstellar environment of one of the closest analogs to early-Universe and low-metallicity galaxies. We examine the spatial variations in dust extinction curve properties and the three-dimensional structure in the Southwest Bar of the SMC using resolved stellar populations observed with the Hubble Space Telescope (HST) as a part of the Small Magellanic Cloud Investigation of Dust and Gas Evolution (SMIDGE) program. Our eight-band HST photometry enables us to use color-magnitude diagrams (CMDs) of reddened red clump and red giant branch stars to simultaneously constrain SMC's 3D structure allowing us to accurately measure dust extinction from the CMD. Our CMD models are based on a detailed analysis of the SMC star formation history using red clump and red giant branch statistics to constrain the star formation rate and metallicity evolution of the SMIDGE region. We use the Bayesian Extinction And Stellar Tool (BEAST, Gordon et al. (2016)) to model the photometric effects of extinction on the spectral

energy distribution of individual stars in SMIDGE taking into account a log-normal distribution of  $A_V$  and an input extinction curve. We additionally model the relative positions of the stellar and dust distributions and the galactic depth along the line of sight. We then use CMD matching techniques similar to Dolphin (2002) based on Poisson statistics to extract the best-fit dust extinction and 3D structure parameters. We find a large line-of-sight depth ( $\sim 10$  kpc) and a slight offset of the dust on the near side of the stars resulting in a 0.65 - 0.70 reddened fraction. We find an extinction curve shape which varies only modestly even towards regions with high molecular gas content. These results yield the first detailed dust extinction curve properties in a key region in the SMC and have potential implications for how dust coagulates in molecular clouds in low-metallicity galaxies.

**Author(s):** Petia Yanchulova Merica-Jones, L. Clifton Johnson, Karin Sandstrom

**Institution(s):** University of California, San Diego, Northwestern University Contributing Team(s): SMIDGE Team

### **311.07 - Overview and First Results of the SOFIA Mid-Infrared Imaging Survey toward Giant H II Regions(Wanggi Lim)**

We present an overview of the on-going large-scale infrared imaging survey at 20 and 37 micrometers of Milky Way Giant H II (GH II) regions with the FORCAST instrument on SOFIA. We discuss the first results from this survey with our detailed analysis of W51A, which is one of the largest GH II regions in our Galaxy and host to prolific high-mass star formation activity. In addition to the SOFIA-FORCAST observations, we utilized multi-wavelength archival data from several facilities in order to investigate the detailed physical properties of individual sources within W51A, and of the larger-scale star-forming sub-structures. From this multi-band photometry we created spectral energy distributions (SEDs), and using young stellar object (YSO) models, we found several dozen compact sources in the region that are likely to be massive YSOs, many of which are revealed as such for the first time. We also found about half of these sources do not have a radio continuum counterpart which likely indicate the sources are at their very early stages of star formation. We determined the relative ages of the sub-regions of W51A analytically, and find that W51A possesses star-forming regions in various evolutionary stages, though none show strong evidence of being internally triggered.

**Author(s):** Wanggi Lim, James De Buizer

**Institution(s):** SOFIA-USRA Contributing Team(s): SOFIA-USRA

### **311.02D - The Southern HII Region Discovery Survey(Trey V Wenger)**

The morphological and chemical structure of the Galaxy is an important constraint on models of Galactic formation and evolution. HII regions, the zones of ionized gas surrounding recently formed high-mass stars, are the classic tracers of Galactic structure. The census of Galactic HII regions in the Southern sky is vastly incomplete due to a lack of sensitive radio recombination line (RRL) surveys. The Southern HII Region Discovery Survey (SHRDS) is a 900-hour Australia Telescope Compact Array cm-wavelength RRL and continuum emission survey of hundreds of third and fourth quadrant Galactic HII region candidates. The first SHRDS data release, the Bright Catalog, increases the number of known Galactic HII regions in the surveyed zone by 82%, to 568 nebulae. In the fourth quadrant we discover 50 RRLs with positive velocities, placing those sources outside the Solar circle. Nearly all of these lie along the Galactic longitude-velocity locus of the Sagittarius-Carina spiral arm, suggesting that this feature is a major spiral arm. I will discuss the SHRDS observing strategy, preliminary results from the first data release, and the scientific goals we will accomplish with the complete SHRDS catalog.

**Author(s):** Christopher Jordan, Joanne Dawson, Thomas Bania, Loren Anderson, John Dickey, Jeanine Sheao, Naomi McClure-Griffiths, William Armentrout, Dana Balser, Trey V Wenger,

**Institution(s):** oBucknell University, University of Virginia, University of Tasmania, NRAO, Green Bank Observatory, Curtin University, Boston University, West Virginia University, Australian National University, Macquarie University

### **311.04D - Kinetic Tomography: Measuring ISM motions to understand the nature of spiral structure in the Milky Way(Kirill Olegovich Tchernyshyov)**

It is generally agreed upon that the Milky Way has spiral arms but their number and nature are still under debate. The spiral arms are thought to be either quasi-stationary density waves or transient arms that quickly form, wind up, and dissipate. These two models of spiral structure make qualitatively different predictions for the velocity fields of interstellar matter in and around spiral arms. To determine which model applies to the Milky Way, we have used two different techniques to map the velocity field of interstellar gas and dust as a function of location in the Galactic plane. These are the first maps of the spatially resolved velocity field of diffuse interstellar matter in the Milky Way. The maps are inconsistent with simulations of quasi-stationary density wave spiral structure and consistent with simulations of transient spiral structure.

**Author(s):** Kirill Olegovich Tchernyshyov

**Institution(s):** Johns Hopkins University

### **312 - Supernovae III**

#### **312.01 - Planetary Nebulae and How to Find Them: Color Identification in Big Broadband Survey(George Vejar)**

Planetary nebulae (PNe) provide tests of stellar evolution, can serve as tracers of chemical evolution in the Milky Way and other galaxies, and are also used as a calibrator of the cosmological distance ladder. To better understand this short-lived phase of stellar evolution a complete census of PNe in our galaxy and beyond is essential. Current and upcoming large scale photometric surveys have the potential to discover many new PNe, but it is a challenge to disambiguate partially or fully unresolved PNe from the myriad other sources observed in these surveys. Here we carry out synthetic observations of simulated nebular models to assess the most promising ugrizy color-color spaces that can successfully identify potential PNe out of billions of other sources. Using our results, a grid of synthetic absolute magnitudes for PNe at various stages of their evolution, we make comparisons with real PNe observations from the Sloan Digital Sky Survey. We present our synthetic models and their ability to identify PNe. Specifically, we find that the r-i versus g-r, and the r-i versus u-g, color-color diagrams show the greatest promise for cleanly separating PNe from stars, background galaxies, and quasars. Finally, we consider the potential harvest of PNe from upcoming large surveys. For example, for progenitor host star masses  $\sim 3 M_{\odot}$ , we find that the Large Synoptic Survey Telescope (LSST) should be sensitive to virtually all PNe in the Magellanic Clouds with extinction up to  $A_v \sim 5$  mags; for a stellar system at the distance of Andromeda, LSST would be sensitive to the youngest PNe (age less than  $\sim 6800$  yr) and with  $A_v$  up to 1 mag.

**Author(s):** Rodolfo Montez, George Vejar, Keivan G Stassun, Margaret Morris

**Institution(s):** Vanderbilt University, Fisk University, Smithsonian Astrophysical Observatory, Scripps

#### **312.04 - Finding Needles in the Haystack: Outlier Detection for Astronomical Light Curves Using Machine Learning(Rafael Martnez-Galarza)**

Upcoming large observational surveys such as the Large Synoptic Survey Telescope (LSST) will produce millions of irregularly-sampled astronomical light curves. The enhanced sensitivity and time-sampling strategies of LSST will open a new window for several fields of astronomy, including precision cosmology, variable stars, as well as the discovery and characterization of new solar system objects. However, the large volume of the data that LSST will produce will require sophisticated algorithms for processing and interpreting these light curves. One important related question is how to find the most anomalous light curves, those that are perhaps not explained by current models, and that are fertile ground for new discoveries. In this talk I will discuss state-of-the-art anomaly detection methods that use machine learning to find needles in the upcoming haystack of data, such as persistent homology and

unsupervised random forest. I will discuss several approaches to feature extraction for irregular light curves, including the use of auto-encoding recurrent neural networks, and the performance of several anomaly detection algorithms with respect to the features used. I will show the results of applying these methods to several time domain surveys, including Kepler, SDSS's Stripe 82 and the All Sky Automated Survey (ASAS) catalog of variable stars, and present the weirdest light curves found in each dataset. The methods presented show should be easily adapted to upcoming time domain catalogs such as LSST and the Transiting Exoplanet Survey Satellite.

**Author(s):** Dennis Crake, Matthew Graham, Rafael MartÃ-nez-Galarza, Federica Bianco, Ashish Mahabal

**Institution(s):** Smithsonian Astrophysical Observatory, California Institute of Technology, New York University, University of Southampton

### **312.05 - Data-driven modeling of Stripped Envelope Supernovae lightcurves with Gaussian Processes for photometric classification and physical insight.(Federica Bianco)**

Stripped envelope supernovae (SESNe) are the explosive death of massive stars that have lost some or all of their outer layers of H and He. They are intriguing objects, as the mechanism for mass loss prior to explosion has not been identified clearly and they are at times seen in conjunction with GRBs. Four subtypes are identified from spectroscopic differences in the strength or overall presence of H and He features, and in the width of the spectral lines: SESN type IIb, Ib, Ic, and Ic-BL (broad lined Ic). Despite these spectroscopic differences, distinguishing these subtypes photometrically has proven difficult, and photometric classification is necessary to leverage the sample size of the forthcoming LSST data, which will detect thousands of SESNe, but most of them will be too faint for spectroscopy. Leveraging Gaussian Processes we generate templates for each subtype that convey the mean sample behavior and the diversity in the sample in a way that is robust to observational uncertainty and small sample size. We then can compare the subtype templates and systematically investigate photometric differences to understand physical differences and work toward photometric classification.

**Author(s):** Federica Bianco, Maryam Modjaz

**Institution(s):** University of Delaware, New York University

### **312.02D - The Influence of Environment Age and Host Mass on Type Ia Supernova Light Curves(Benjamin Rose)**

Type Ia supernovae are good standardizable candles, but their reliability as distance indicators may be limited by the imprint of their galactic origins on supernova progenitors. To investigate the connection between supernovae and their host characteristics, we have developed an improved method to estimate the stellar population age and apply it to the integrated

light of the host as well as the local environment around the site of the supernova. We use a Bayesian method to estimate the star-formation history of a supernova's environment by matching observed global and local spectral energy distributions (SEDs) to a synthesized stellar population. We apply an MCMC technique to estimate the most probable star-formation history for a given SED, its mass weighted age, and the corresponding uncertainties. Applying this age estimator to a large sample of supernovae from the Sloan Digital Sky Survey II, we find a  $0.108 \pm 0.035$  mag 'step' in the average Hubble residual at a stellar age of  $\sim 7$  Gyr; it is nearly twice the size of the currently popular mass step correction. This age step is seen in both the local environment age and the average age of the host galaxy at a significance of  $3\sigma$ . We then apply a principal component analysis on the SALT2 parameters, host stellar mass, and local environment age. We find that a new parameter, PC1, consisting of a linear combination of stretch, host stellar mass, and local age, shows a very significant ( $>6\sigma$ ) correlation with Hubble residuals. This strong correlation between Hubble residuals and environment may affect the accuracy of precision cosmological measurements such as current H<sub>0</sub> measurements and future measurements of dark energy with WFIRST.

**Author(s):** Benjamin Rose, Peter Garnavich

**Institution(s):** University of Notre Dame, STScI

### **312.03D - Investigation of Stellar Populations in the Early-type Host Galaxies of Type Ia Supernovae(Yijung Kang)**

The origin of the well-known correlation between the luminosity of type Ia supernova (SN Ia) and mass of their host galaxies is yet to be understood. In order to investigate this more directly, 7 years ago, we have initiated the YOnsei Nearby Supernova Evolution Investigation (YONSEI) project. The main purpose of this project is to determine the stellar population properties of the nearby early-type host galaxies from long-slit spectroscopy with LCO 2.5m and MMT 6.5m telescopes in order to compare them directly with the Hubble residual (HR). We found a significant ( $\sim 3.9$  sigma) correlation between the host galaxy mass and population age among our sample. This implies that population age is mostly responsible for the host mass and HR correlation. More interestingly, our results further suggest that there is a significant difference ( $\sim 2$  sigma) in HR between the younger and older host groups. We conclude that the luminosity evolution plays a major role in the systematic uncertainties of SN Ia cosmology.

**Author(s):** Young-Wook Lee, Yijung Kang,

**Institution(s):** Yonsei University, Center for Galaxy Evolution Research

### **312.06D - Modeling Dust in the CSM and Ejecta of SN 2010jl(Kelsie Krafon)**

Our original motivation for studying dust formation in core collapse supernovae (CCSNe) was the exciting discovery that some high redshift ( $z > 6$ ) galaxies were dust rich. These galaxies are less than 1 Gyr old, and so a significant fraction of the observed dust must be coming from massive stars, which evolve quickly and return their material back to the interstellar medium through supernovae (SNe). Even still, the amount of dust required per star or SN is high, with theoretical models predicting that 0.1 - 1 solar masses of dust would be needed per CCSN, and many studies by our group and others found that only a small amount of new dust was forming in the SN ejecta. Typically, only about 0.0001 - 0.01 solar masses of dust have formed two or three years after the explosion. How is it that CCSNe have formed only a small amount of dust after three years, but SN 1987A has a dust mass that is several orders of magnitude larger after 25 years? To investigate the suggestion of continuous dust formation, I am using two Monte Carlo Radiative transfer codes to model dust in the circumstellar medium (CSM) and ejecta of SN 2010jl. MOCASSIN fits visible and IR SEDs, while DAMOCLES fits individual emission lines, in particular, the Balmer lines. When dust is present in the ejecta, the dust will preferentially extinguish emission from the far-side, red-shifted gas and result in a shift of the emission line profiles to the blue and a flattening of the profiles. The presence of dust also increases the infrared excess. Both models estimate the mass of dust produced by SN 2010jl. I present estimates of both new and preexisting dust masses at each epoch for SN 2010jl. The preexisting dust, generated in the wind of the evolved star before it goes supernova, is located in the CSM and is on the order of 0.0001 solar masses for SN 2010jl. The newly formed dust in the cooling ejecta of SN 2010jl is again only on the order of 0.01 solar masses in the first 4 years. This mass of new dust is increasing and may reach levels similar to that of SN 1987A if given enough time. Longer term study of this object is required.

**Author(s):** Kelsie Krafon, Geoffrey C Clayton

**Institution(s):** Louisiana State University

### **313 - Surveys & Large Programs**

#### **313.03 - Kaiju: A Highly Efficient Collision Avoidance Algorithm for SDSS-V Robotic Fiber Positioners(Conor Sayres)**

In the current landscape of wide field multi-object spectroscopic surveys and instrumentation, robotic fiber positioner (RFP) focal plane arrays are becoming a standard technology for maximizing telescope efficiency and achieving the ambitious scientific aims of robotic spectroscopy programs. SDSS-V includes a dual-hemisphere robotic fiber positioning system to feed optical and infrared spectrographs to map stars and black holes spatiotemporally. A critical concern common to all RFP systems including SDSS-V becomes: how does one compute trajectories for all robots transitioning between configurations while ensuring that no collisions between robots occur? SDSS-V has chosen an RFP design exhibiting heavily

overlapping patrol zones in which not only nearest, but even next nearest neighbors may interfere with any single positioner. Building efficient non-colliding paths between robot configurations in this case becomes very difficult. I will be presenting Kaiju: an anti-collision RFP trajectory planning code under active development for SDSS-V that currently achieves >99% target acquisition efficiency even in the regime of heavily overlapping RFP systems. I will demonstrate the behavior of our relatively simple algorithm which employs a "reverse path" solving strategy. Kaiju is being developed in Python and Python-wrapped C++. Currently, the routine will solve simultaneous paths for a grid of ~500 positioners in ~1 second on a standard laptop using a single core. The speed and efficiency of Kaiju will both maximize scientific output over the course of a multi-year survey and allow for "real time" path planning equipping SDSS-V with a very nimble RFP system. The code is being developed to be generic enough to accept any RFP system geometries, and it is open source.

**Author(s):** Conor Sayres, Juna Kollmeier, Sarah Tuttle, Michael Blanton, Curtis Bartosz, José SÁinchez-Gallego

**Institution(s):** University of Washington, New York University, Carnegie Observatories Contributing Team(s): SDSS-V Collaboration

#### **313.04 - Extending the HelioLinC algorithm to sparse single detections(Matthew Jon Holman)**

Most minor planet surveys identify moving objects in 'tracklets', groups of observations taken over short enough time spans that it is clear that the individual detections in each tracklet represent the same object. The greater computational challenge has been to determine which tracklets, which may be separated by weeks or months, go together. Our recently developed HelioLinC algorithm allows for the efficient linking of tracklets that represent the same minor planet. This algorithm scales as  $O(N \log N)$ , with the number of tracklets  $N$ , a significant advance over conventional algorithms, which scale as  $O(N^3)$ . However, as originally developed, HelioLinC requires tracklets to have already been identified. We present an extension of the HelioLinC algorithm to the case of sparse individual detections (i.e. that does not require tracklets). We demonstrate this algorithm using synthetic observations inserted into DECam exposures.

**Author(s):** David Gerdes, Hsing-Wen Lin, Matthew John Payne, Kyle Steckler, Matthew Jon Holman

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Michigan

#### **313.06 - Swift and INTEGRAL: A Deep Look at the Hard X-ray Sky(Eugenio Bottacini)**

Swift/BAT and INTEGRAL/IBIS are surveying the non-thermal sky with their coded mask telescopes. Such telescopes suffer from an inevitable low sensitivity due to the optics. In this talk I will show how the sensitivity of their ongoing surveys can be

improved by combining the independent observations of their telescopes. Especially the INTEGRAL mission has performed deep observations to allow this technique reaching unmatched survey sensitivity. I will review this observing technique and show how the combined observations of BAT and IBIS tie in well with deep NuSTAR surveys.

**Author(s):** Eugenio Bottacini

**Institution(s):** University of Padova (Italy)

### **313.02D - The DECam Minute Cadence Survey: A Search For Habitable Planets Around White Dwarfs(Kyra Dame)**

Stellar variability on short timescales has been largely unexplored until recently, but is relevant in the era of transient surveys like the Zwicky Transient Facility (ZTF), the Large Synoptic Survey Telescope (LSST), and in searches for optical counterparts to gravitational wave events detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO). The DECam Minute Cadence Survey is the first high cadence survey of its kind, observing a total of 9 square degrees of the sky at a cadence of ~90 sec over 8 consecutive half-nights per 3 square degree field. We present minute cadence photometry of ~100,000 point sources. We use these data to search for eclipse-like events consistent with a planet in the habitable zone of a white dwarf and other sources of variability. We do not find any significant evidence for minute-long transits around our targets, hence we rule out planetary transits around the ~1000 white dwarfs that should be present in this field. Our results allow us to place stringent constraints on the frequency of planets orbiting white dwarfs in the habitable zone.

Additionally, we identify ~150 variable sources, the majority of which are previously unknown systems. These include 77 detached or contact stellar binaries, two eclipsing white dwarf + M dwarf binaries, 27 Delta Scuti, 13 RR Lyrae, six ZZ Ceti, and one subdwarf A or low-mass white dwarf pulsator candidate. Upcoming surveys like SuperWASP, the Next-Generation Transit Survey, the Transiting Exoplanet Survey Satellite, and ZTF will obtain high-cadence observations for millions of stars, allowing us to probe the variability of the night sky on timescales that remain largely unstudied.

**Author(s):** Warren Brown, Sara Barber, Alex Gianninas, Claudia Belardi, Armin Rest, Kyra Dame, Mukremin Kilic

**Institution(s):** University of Oklahoma, The Johns Hopkins University, University of Leicester, Smithsonian Astrophysical Observatory, House Committee on Science, Space, and Technology

### **313.05D - Probabilistic data analysis methods for large photometric surveys(Alex Malz)**

Upcoming photometric telescope missions will produce massive catalogs of detected objects down to unprecedented floors in signal-to-noise ratio, opening the door to a new space of potential discoveries. The trade-off for the vast number of

measurements is their nontrivial error properties, which demand statistical rigor the likes of which were unnecessary prior to the era of noise-dominated big data. Posterior probability distribution functions (PDFs) that quantify complex uncertainties are appropriate replacements for conventional point estimates of physical parameters that suffice for higher quality data. In contrast with traditional data analysis pipelines for point estimates that have evolved over decades, infrastructure compatible with the relatively recent introduction of PDFs is underdeveloped. I present new techniques for storing, validating, and using such probabilities in physical inference, as well as approaches to vetting these methods, in the context of cosmology with the Large Synoptic Survey Telescope (LSST).

**Author(s):** Alex Malz

**Institution(s):** New York University

### **314 - Binaries and Their Properties**

#### **314.01 - Radio Fluctuations from a Quiescent Black Hole Jet(Richard M Plotkin)**

Most black hole X-ray binaries (BHXBs) spend the majority of their time in a weakly accreting 'quiescent' state, which we define as Eddington ratios  $L_x/L_{\text{edd}} < 10^{-5}$  (where  $L_x$  is the X-ray luminosity). In quiescence, a larger fraction of the radiative power from the accretion flow/jet system tends to be released as jetted synchrotron radio emission, as compared to hard state BHXBs (i.e.,  $10^{-5} < L_x/L_{\text{edd}} < 10^{-2}$ ). In turn, quiescent BHXB radio jets provide promising signposts for discovering new populations of stellar mass black holes in our Galaxy. Surveys that combine radio and X-ray observations have already made headway in discovering new populations of candidate BHXBs in the Milky Way. However, one current limitation in planning such surveys (and interpreting the resulting BHXB candidates) is a lack of empirical constraints on the degree to which radio jet emission varies with time. Here, present an analysis of the quiescent BHXB jet from V404 Cygni, using over two decades of archival radio observations from the Very Large Array and the Very Long Baseline Array. Our analysis represents the most comprehensive time-domain study to date on a quiescent BHXB jet in the radio waveband, where we quantify flux density and spectral variations on timescales from minute through decades. We conclude by using our results to provide recommendations on how to coordinate future multiwavelength observations, and on how to help control for variability-induced systematics when planning radio/X-ray surveys.

**Author(s):** Jay Strader, J. C. A. Miller-Jones, Laura Chomiuk, Richard M Plotkin

**Institution(s):** International Centre for Radio Astronomy Research - Curtin University, Michigan State University

### **314.03 - Observations of Spin-down in Post-Mass-Transfer Binaries and the Resulting Possibility of Blue Straggler Gyrochronology(Emily Leiner)**

Theory predicts that blue stragglers and other mass-transfer products are born with rapid rotation rates, but little work has been done to understand the angular momentum evolution of these stars as they age. Here we present an observational study of post-mass-transfer angular momentum evolution in these systems. For a sample of known post-mass-transfer binaries, we present rotation periods from  $v \sin i$  measurements or photometric spot modulation, and ages from white dwarf cooling models. This sample includes F-type blue stragglers in the cluster NGC 188 and post-mass-transfer FGK main-sequence stars in the field, all wide binaries ( $88 < P_{\text{orb}} < 3030$  days) with white dwarf companions. Within several Myr of formation these systems are rotating at a significant fraction of break-up velocity. They then spin down as they age. Strikingly, the spin-down rate agrees with spin-down models developed for standard solar-type main-sequence stars. We suggest that spin-down in post-mass-transfer stars is physically similar to the typical spin-down behavior observed in single main-sequence stars and can be described by the same magnetic braking prescriptions. Critically, this opens up the possibility of using gyrochronology to determine the time since formation of blue straggler stars and other post-mass-transfer binaries, and to detect hidden populations of post-mass-transfer binaries in clusters based on their anomalously fast rotation rates. The authors acknowledge funding support from NSF AST-1714506, NSF AST-1801937 and NASA-NNX15AW69G

**Author(s):** Alison Sills, Robert Mathieu, Natalie M. Gosnell, Emily Leiner

**Institution(s):** University of Wisconsin-- Madison, Colorado College, CIERA/Northwestern University, McMaster University

### **314.05 - Newly Discovered Spectroscopic Binaries Among the Nearest Mid-to-late M Dwarfs(Jennifer Winters)**

M dwarfs in short-period, spectroscopic binaries provide a unique opportunity to probe star formation and evolution scenarios for objects at the low-mass end of the main sequence. The short periods of these systems facilitate the measurement of their orbits, and the resulting orbital parameters offer hints of their individual histories. However, statistical studies of these objects are challenging, as only a dozen of the currently known nearest, mid-to-late M dwarf multiple systems have orbital solutions. We are conducting a multi-epoch, high-resolution spectroscopic survey of the mid-to-late M dwarfs that lie within 15 parsecs via accurate trigonometric parallaxes. Observations with the Tillinghast Reflector Echelle Spectrograph (TRES,  $R = 44,000$ ) on the 1.5m telescope at the Fred Lawrence Whipple Observatory (FLWO) on Mt. Hopkins, AZ, are nearing completion. We are beginning year two of the southern part of this survey with CHIRON ( $R = 80,000$ ) at the Cerro Tololo Inter-American Observatory / Small and Moderate

Aperture Research Telescope System (CTIO/SMARTS) 1.5m. We have discovered eight newspectroscopic binaries during the TRES portion of our survey whose orbital parameters we present. Their values cover a range of periods, separations, mass ratios, and eccentricities. The addition of these new systems with orbital parameters to the known population of multiple M dwarf systems improves our understanding of the true mass ratio and separation distributions of these fully convective stars. Furthermore, the combination of these systems' gamma velocities with their proper motions permits the exploration of how these systems form and evolve over time. This work was made possible through the support of grants from the National Science Foundation and the John Templeton Foundation. A.M. is supported by an NSF Graduate Research Fellowship.

**Author(s):** Jennifer Winters, Michael Calkins, David W Latham, Perry Berlind, Amber Medina, Jessica Mink, Gilbert Esquerdo, Jonathan Irwin, David Charbonneau

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

### **314.06 - Visual Orbit and Physical Parameters of the Spectroscopic Binary HD 224355 (F5 IV/V + F5 IV/V)(Kathryn Lester)**

We present the visual orbit of the double-lined spectroscopic binary, HD 224355. We resolved the position of the secondary star relative to the primary on milliarcsecond scales using fringe visibility variations in interferometric observations with the CHARA Array. We also obtained echelle spectra using ARCES on the APO 3.5m telescope to measure the radial velocities of each component. By combining the visual and spectroscopic observations, we solved for the best-fit orbital parameters for this system and derived the stellar masses and distance to be  $M_1 = 1.628 \pm 0.004 M_{\odot}$ ,  $M_2 = 1.610 \pm 0.004 M_{\odot}$ , and  $d = 64.1 \pm 0.8$  pc. We then estimated the stellar radii to be  $R_1 = 2.65 \pm 0.15 R_{\odot}$  and  $R_2 = 2.48 \pm 0.20 R_{\odot}$  from the distance and the angular diameter, set by fitting spectrophotometry from the literature to binary SED models.

**Author(s):** Christopher Farrington, Douglas Gies, Kathryn Lester, Gail Schaefer

**Institution(s):** Georgia State University, The CHARA Array

### **314.07 - Pre-explosion Spiral Mass Loss of a Binary Star Merger(Ondrej Pejcha)**

There is mounting evidence of circumstellar material distributed in disks and rings around many massive stars, supernovae, classical novae, and other interesting stellar objects. The origin of this circumstellar material is often attributed to interactions within a binary star system, including poorly-understood processes such as the common envelope and stellar mergers. Recently, a connection was established between these astrophysically critical, catastrophic binary star interactions and a group of astronomical transients characterized by their red color and the luminosity in the gap



between novae and supernovae. I will present an exploration of the dynamics of outflows from mass-losing binary stars and the associated menagerie of transients. I will show how is the binary enshrouded in a "death spiral" outflow, which affects the amplitude and phase modulation of its light curve, and contributes to driving the system together. This circumstellar material explains many puzzling observed phenomena.

**Author(s):** Ondrej Pejcha

**Institution(s):** Charles University

### **314.02D - Detection and physical properties of massive binary stars with hot subdwarf companions(Luqian Wang)**

Growing evidence suggests that massive stars are formed through close binary interaction, in which the more massive donor star will be the first to inflate and transfer its mass and angular momentum to the gainer star. Mass transfer continues until the donor is stripped of its outer envelope and left as a helium core-burning, subdwarf star. We conducted four investigations to detect and characterize these subdwarf stars. We first investigated the binary system, HR 2142. It is observed as a rapidly rotating Be star, in which its optical spectra display a broad H-alpha emission feature associated with a circumstellar decretion disk. We detected the subdwarf (sdO) of this system using the FUV spectra from International Ultraviolet Explorer (IUE) by computing cross correlation functions (CCF) with a model spectrum. We extended our search for other subdwarfs in a sample of six Be binary systems with known orbits using the same CCF algorithm. We computed the Doppler shifts of each system and shifted the CCFs to frame of the subdwarf. We found a striking detection of the subdwarf in the binary system 60 Cygni. Based on calculations from spectral model fitting, we argue that the subdwarf of 60 Cygni is massive enough to lead to a future supernova explosion. Thus, it may become a neutron star plus Be star binary, forming a Be X-ray binary system. We further conducted an IUE survey of 264 stars to search for additional Be+sdO systems using the CCF algorithm, and we detected another 12 candidate systems with a hot subdwarf companion. Our studies have increased the population of known Be+sdO systems from three to 17. The final investigation is a study of the eclipsing binary system EL CVn. This is the prototype of EL CVn-type binaries consisting a lower mass A-type star and a helium companion. We used the Hubble Space Telescope to detect the UV spectrum of helium companion star of EL CVn for the first time, and we also determined its physical properties. The detected companions only represent a small number of the overall population, and a large fraction of massive stars may experience such binary interactions.

**Author(s):** Luqian Wang, Douglas Gies, Geraldine Peters, Kathryn Lester

**Institution(s):** Georgia State University, University of Southern California

### **314.04D - Quasi-periodic oscillations and the global modes of hydromagnetic accretion disks(Janosz Dewberry)**

The high-frequency, quasi-periodic oscillations (HFQPOs) observed in the emission from galactic black hole binaries present an important but unresolved problem in astrophysics. An attractive explanation offered by hydrodynamic theory involves the excitation of 'diskoseismic' oscillations in the inner regions of a black hole accretion disk, where they are confined by relativistic effects. However, magnetic fields can significantly alter the dynamics of such pulsations, which additionally require a driving mechanism to reach observable amplitudes. I present a magnetohydrodynamic analysis of the effects of magnetic fields with different geometries on so-called trapped inertial waves, and numerical simulations exhibiting the modes' excitation to large amplitudes through non-linear coupling with eccentric disk deformations.

**Author(s):** Janosz Dewberry

**Institution(s):** Cambridge University

### **315 - Cosmology: SNe and CMB**

#### **315.01 - Confirmation of Inflaton-Like Oscillations in the Scale Factor from the Pantheon Compilation of 1048 SNe(Harry I Ringermacher)**

We have confirmed the presence of low frequency temporal oscillations at  $\sim 7$  cycles/Hubble-time in the Pantheon Compilation of 1048 SNe. These precisely match - in amplitude and phase - our initial observation.(Ringermacher and Mead, 2015, AJ 149, 137 ) from SNLS3 supernovae (Conley et al., 2011, ApJS, 192,1 ). The pantheon Compilation comprises an independent set of SNe in different portions of the sky compared to SNLS3. We have also merged these two data sets creating a set of approximately 1500 SNe. The merger improved the SNR sufficiently to permit the observation of an additional half-cycle of oscillation at earlier times. It has been suggested (by Shtanov, Traschen and Brandenberger and separately by Kofman, Linde and Starobinsky) that "the inflaton field will eventually decouple from the rest of the matter and the residual inflaton oscillations may provide the cold dark matter of the universe". Our model, presented in the AJ paper above, is the Chaotic Inflation Model of Linde carried into the present epoch. The inflaton energy density substitutes for the dark matter energy density in LCDM cosmology providing precisely this criterion for dark matter creation. The observed oscillations match the model in phase and show damping with characteristic time also nearly matching that of the model. Our scalar model is short in overall amplitude by a factor of 2.5 compared to the observation.

**Author(s):** Lawrence R mead, Harry I Ringermacher

**Institution(s):** U.of Southern Mississippi

### **315.02 - A Search for Miras in the SN Ia Host Galaxy NGC 1559(Caroline Huang)**

The improved precision in local Hubble constant measurement has revealed a 3.8% discrepancy with the value inferred from observations of the cosmic microwave background under the assumption of a  $\Lambda$ CDM cosmology. Oxygen-rich Mira variables, as alternative distance indicators to Cepheids, provide an crosscheck of the extragalactic distance scale, and the potentially increase the number of SN Ia calibrators and thus the precision of local Hubble constant measurements. I present the preliminary results of year-long, near-infrared Hubble Space Telescope observations of Mira variables in the SN 2005df host galaxy NGC 1559.

**Author(s):** Caroline Huang, Adam Riess, Wenlong Yuan

**Institution(s):** The Johns Hopkins University

### **315.03 - Results from RAISIN: SNIa in the IR(Robert Kirshner)**

The RAISIN project has used the Hubble Space Telescope to obtain red-frame infrared observations of 47 Type Ia supernovae in the redshift range  $0.22 < z < 0.62$ . These objects are intended for use as accurate and precise tracers of cosmic expansion to constrain dark energy properties. They have the advantage that in the near-IR SN Ia are more nearly standard candles and suffer less extinction in their hosts than at the optical rest wavelengths of all previous high- $z$  samples. Suitable targets were provided through Pan-STARRS and the Dark Energy Survey. Every one was spectroscopically confirmed as a young SN Ia in the desired redshift range for cosmological analysis. They were then placed into the HST observing plan and imaged at three epochs with WFC/IR using F125W or F160W. A template image obtained later was used to subtract galaxy light at the position of each supernova. We have now extracted photometry for each supernova and have a preliminary Hubble diagram that can be combined with the low- $z$  sample in Y-band to provide constraints on  $(1+w)$ , the dark energy equation of state. This report will describe the present state of the analysis, the principal systematic uncertainties, and the prospects for using restframe infrared observations with WFIRST for even more powerful cosmological constraints.

**Author(s):** Peter Challis, Robert Kirshner, David Jones, Kaisey Mandel, Andrew Friedman, Arturo Avelino

**Institution(s):** Harvard University, University of Cambridge, Gordon and Betty Moore Foundation, University of California San Diego, University of California Santa Cruz  
**Contributing Team(s):** The RAISIN Team

### **315.04 - Foreground-immune CMB lensing with shear-only reconstruction(Emmanuel Schaan)**

CMB lensing from current and upcoming CMB experiments such as AdvACT and Simons Observatory relies heavily on temperature, rather than polarization. In this regime,

foreground contamination to the temperature map produces significant lensing biases, which cannot be fully controlled by multi-frequency component separation, masking or bias hardening. In this work, we split the standard CMB lensing quadratic estimator into a new set of optimal “multipole” estimators. On large scales, these multipole estimators reduce to the known magnification and shear estimators, and to a new shear B-mode estimator. We leverage the different symmetries of the lensed CMB and extragalactic foregrounds to argue that the shear estimator should be immune to extragalactic foregrounds. Using realistic simulations, we demonstrate that the shear estimator is indeed insensitive to extragalactic foregrounds, even when applied to a single-frequency temperature map contaminated with CIB, tSZ, kSZ and radio point sources. This dramatic reduction in foreground biases allows us to include higher temperature multipoles than with the standard quadratic estimator, thus increasing the total lensing signal-to-noise, equivalent to doubling the effective area observed by Simons Observatory. In addition, the magnification-only and shear B-mode estimators provide useful diagnostics for potential residuals.

**Author(s):** Simone Ferraro, Emmanuel Schaan

**Institution(s):** Lawrence Berkeley National Laboratory, University of California at Berkeley

### **315.05 - DeepCMB: Lensing Reconstruction of the Cosmic Microwave Background with Deep Neural Networks(W. L. Kimmy Wu)**

Next-generation cosmic microwave background (CMB) experiments will have lower noise and therefore increased sensitivity, enabling improved constraints on fundamental physics parameters such as the sum of neutrino masses and the tensor-to-scalar ratio  $r$ . Achieving competitive constraints on these parameters requires high signal-to-noise extraction of the projected gravitational potential from the CMB maps. Standard methods for reconstructing the lensing potential employ the quadratic estimator (QE). However, the QE performs suboptimally at the low noise levels expected in upcoming experiments. Other methods, like maximum likelihood estimators (MLE), are under active development. In this work, we demonstrate reconstruction of the CMB lensing potential with deep convolutional neural networks (CNN) - ie, a ResUNet. The network is trained and tested on simulated data, and otherwise has no physical parametrization related to the physical processes of the CMB and gravitational lensing. We show that, over a wide range of angular scales, ResUNets recover the input gravitational potential with a higher signal-to-noise ratio than the QE method, reaching levels comparable to analytic approximations of MLE methods. We demonstrate that the network outputs quantifiably different lensing maps when given input CMB maps generated with different cosmologies. We also show we can use the reconstructed lensing map for cosmological parameter estimation. This application of CNN provides a few innovations at the intersection of cosmology and machine learning. First, while training and regressing on images, we predict a continuous-variable field rather than

discrete classes. Second, we are able to establish uncertainty measures for the network output that are analogous to standard methods. We expect this approach to excel in capturing hard-to-model non-Gaussian astrophysical foreground and noise contributions.

**Author(s):** W. L. Kimmy Wu, Shubhendu Trivedi, Joao Caldeira, Camille Avestruz, Kyle Story, Brian Nord,

**Institution(s):** University of Chicago, Brown University, Fermilab, Descartes Lab

### **315.07 - Easily Interpretable Bulk Flows: Continuing Tension with the Standard Cosmological Model(Richard Watkins)**

We present an improved Minimal Variance (MV) method for using a radial peculiar velocity sample to estimate the average of the three-dimensional velocity field over a spherical volume, which leads to an easily interpretable bulk flow measurement. The only assumption required is that the velocity field is irrotational. The resulting bulk flow estimate is particularly insensitive to smaller scale flows. We also introduce a new constraint into the MV method that ensures that bulk flow estimates are independent of the value of the Hubble constant  $H_0$ ; this is important given the tension between the locally measured  $H_0$  and that obtained from the cosmic background radiation observations. We apply our method to the CosmicFlows3 catalogue and find that, while the bulk flows for shallower spheres are consistent with the standard cosmological model, there is some tension between the bulk flow in a spherical volume with radius 150h-1Mpc and its expectations; we find only a 2% chance of obtaining a bulk flow as large or larger in the standard cosmological model with Planck parameters.

**Author(s):** Hume Feldman, Sarah Peery, Richard Watkins

**Institution(s):** Willamette University, University of Kansas

### **315.08 - The Simons Observatory: Science goals and forecasts(Renée Hlozek)**

The Simons Observatory (SO) is a new cosmic microwave background (CMB) experiment being built on Cerro Toco in Chile, due to begin observations in the early 2020s. SO will measure the temperature and polarization anisotropy of the cosmic microwave background in six frequency bands: 27, 39, 93, 145, 225 and 280 GHz. The initial configuration of SO will have three small-aperture 0.5-m telescopes (SATs) and one large-aperture 6-m telescope (LAT), with a total of 60,000 cryogenic bolometers. Our key science goals are to characterize the primordial perturbations, measure the number of relativistic species and the mass of neutrinos, test for deviations from a cosmological constant, improve our understanding of galaxy evolution, and constrain the duration of reionization. SO will achieve an order of magnitude lower polarization noise than maps from the Planck satellite. The high-resolution SO sky maps will constrain cosmological parameters derived from the

damping tail, gravitational lensing of the microwave background, the primordial bispectrum, and the thermal and kinematic Sunyaev-Zel'dovich effects, and will aid in delensing the large-angle polarization signal to measure the tensor-to-scalar ratio at a target level of  $\tilde{r}(r)=0.003$ . We describe the scientific goals of the experiment and forecast its performance.

**Author(s):** Renée Hlozek

**Institution(s):** University of Toronto Contributing Team(s): The Simons Observatory Collaboration

### **315.06D - Non-Gaussian information from weak lensing data via deep learning(Jose Manuel Zorrilla Matilla)**

Weak lensing maps contain information beyond two-point statistics on small scales. Much recent work has tried to extract this information through a range of different observables or via nonlinear transformations of the lensing field. Here we train and apply a 2D convolutional neural network to simulated noiseless lensing maps covering 96 different cosmological models over a range of  $\{\Omega_m, \Omega_b\}$ . Using the area of the confidence contour in the  $\{\Omega_m, \Omega_b\}$  plane as a figure-of-merit, derived from simulated convergence maps smoothed on a scale of 1.0 arcmin, we show that the neural network yields  $\sim 5\%$ —tighter constraints than the power spectrum, and  $\sim 4\%$ —tighter than the lensing peaks. Such gains illustrate the extent to which weak lensing data encode cosmological information not accessible to the power spectrum or even other, non-Gaussian statistics such as lensing peaks.

**Author(s):** Arushi Gupta, Zoltan Haiman, Daniel Hsu, Jose Manuel Zorrilla Matilla

**Institution(s):** Columbia University

### **316 - Dwarf & Irregular Galaxies I: Using Spectra of Individual Stars to Reveal Dwarf Galaxy Evolution**

#### **316.01 - APOGEE Chemical Abundances of the Large Magellanic Cloud(Sten Hasselquist)**

To date, the SDSS-IV APOGEE survey has obtained  $S/N > 70$  spectra for over 2,500 red giant stars distributed across much of the Large Magellanic Cloud (LMC), allowing for the characterization of the detailed abundance patterns for 10+ chemical elements. In this project, we interpret the chemical abundance patterns of the LMC by comparing them to the chemical abundance patterns of the Sagittarius Dwarf Galaxy (Sgr) and the Milky Way (MW), as well as by invoking chemical evolution models (such as flexCE and chempy) that include the LMC's star formation history. Preliminary results show that the LMC shares [Ni/Fe] and [Al/Fe] deficiencies with Sgr, but exhibits alpha-element abundances ([O/Fe], [Mg/Fe], and [Si/Fe]) that are near-solar. There is also a correlation with [O/Fe] and [Mg/Fe] with [Fe/H] at [Fe/H]  $> -1.0$ . These results suggest that the LMC exhibited low star formation efficiency (as compared to Sgr and the MW) at early times, but has since experienced several starbursts which spawned the stars with

[Fe/H] > -1.0. Using these APOGEE chemical abundance patterns as constraints, we use chemical evolution models to better characterize the nature (strength, time, duration, IMF, etc.) of these starbursts.

**Author(s):** John T. Mackeretho, Carme Gallart, Hans-Walter Rix, Katia Cunha, Christian R Hayes, Andres Almeida, Yumi Choi, Verne Smith, Richard R. Lane, Jennifer Sobeck, David Weinberg, Ricardo Carrerao, Jose G. Fernandez-Trincado, Jianhui Lian, Borja Anguiano, Timot

**Institution(s):** Instituto de Astrofísica de Canarias, oLiverpool John Moores University, Pontificia Universidad Católica de Chile, The Ohio State University, Max Planck Institute for Astronomy, Universidad de Antofagasta, Observatório Nacional, University of Pitt

### **316.02 - Unraveling the Chemical Evolution of the Magellanic Clouds(David Nidever)**

How galaxies form and evolve remains one of the cornerstone questions in our understanding of the universe on grand scales. While much progress has been made in understanding the formation and chemical evolution of larger galaxies by studying the Milky Way and other L\* galaxies in the Local Volume, our knowledge of the evolution of dwarf galaxies, especially their chemical enrichment histories, is far more limited because these systems are intrinsically faint, and offer access to significantly fewer resolved stars. The SDSS-IV/APOGEE survey is dramatically improving this situation through its large spectroscopic census of 5,000 giant stars in the nearby Magellanic Clouds (MCs) spanning a large range of radii and position angles. To date, high-S/N spectra of over 3,000 giant stars have been obtained. Using these data, we identify a significant fraction of metal-poor stars in the Large MC (LMC) and make the first clear detection of the  $[\alpha/\text{Fe}]-[\text{Fe}/\text{H}]$  "knee" - a drop in the abundance of  $\alpha$ -elements relative to iron due to the increased iron production in SNIa - at  $[\text{Fe}/\text{H}] = -2.2$ . The LMC knee is more metal-poor (indicating a low star formation efficiency) than those of less massive MW dwarf galaxies (e.g., Fornax, Sagittarius), a counter-intuitive result that suggests the LMC likely formed in a lower-density environment - but one that is, however, consistent with the recently developed paradigm that the LMC only recently fell into the MW potential. We also make the first large-scale elemental abundance maps of the MCs, which enable us to compare directly to APOGEE-derived abundance gradients of the Milky Way. Interestingly, the LMC spatial abundance gradients are significantly smaller than those in the MW suggesting that the LMC's star forming gas was better mixed over the last few gigayears.

**Author(s):** Verne Smith, Borja Anguiano, Sten Hasselquist, Christian R Hayes, Guy Stringfellow, David Nidever, Steve Majewski

**Institution(s):** Montana State University, University of Utah, NOAO, CU Boulder, University of Virginia Contributing Team(s): SDSS-IV/APOGEE

### **316.03 - Binary Fraction in the Large and Small Magellanic Clouds(Cody Brown)**

The Large and Small Magellanic Clouds are two of the closest dwarf galaxies to our Milky Way and offer an excellent laboratory to study the evolution of galaxies. The close proximity of these galaxies allow for individual stars to be studied in detail, giving us insights into stellar properties and galactic formation of the Clouds. The Apache Point Observatory Galactic Evolution Experiment (APOGEE), part of the SDSS-IV, has gathered high quality, multi-epoch, spectroscopic data for a multitude of stars in the Magellanic Clouds. The new multi-epoch, high resolution data are being used to detect and characterize binary stars and make the first spectroscopic measurements of the field binary fraction of the Clouds. This information will be used to constrain star formation processes and binary evolution in the Magellanic Clouds.

**Author(s):** Adrian Price-Whelan, Guy Stringfellow, David Nidever, Cody Brown, Hannah Lewis, Nathan Michael De Lee

**Institution(s):** Montana State University, Northern Kentucky University, Princeton University, University of Virginia, CU Boulder

### **316.05 - The Chemical Evolution of Andromeda's Satellites: Individual Stars(Evan Kirby)**

We present results from the largest systematic study to date of chemical abundances in the halo and dwarf spheroidal (dSph) satellite system of Andromeda (M31), using Keck/DEIMOS medium resolution ( $R \sim 6000$ ) spectra obtained via the SPLASH (Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo) survey. We measured  $[\text{Fe}/\text{H}]$  and  $[\alpha/\text{Fe}]$  for hundreds of red giants confirmed to be members of the satellites Andromeda I, III, V, VII, and X. The uncertainties on both quantities are less than 0.3 dex for 135 of these stars. We find broad similarities in the metallicity distributions and the detailed chemical evolution between the Milky Way and Andromeda satellite galaxies at similar stellar mass.

**Author(s):** Jennifer Wojno, Ivanna Escala, Karoline M Gilbert, Evan Kirby

**Institution(s):** California Institute of Technology, Johns Hopkins University, Space Telescope Science Institute

### **316.06 - The Chemical Evolution of Andromeda's Satellites: Coadded Spectra(Jennifer Wojno)**

We present first results from the largest systematic study to date of chemical abundances in the halo and dwarf spheroidal (dSph) satellite system of Andromeda (M31), using medium resolution ( $R \sim 6000$ ) spectra obtained via the SPLASH (Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo) survey. Where abundance measurements are not possible for individual red giant branch (RGB) stars, we group them according to their similarity in color-magnitude space, and coadd these groups of spectra to obtain a signal-to-noise

ratio (S/N) high enough to measure average [Fe/H] and  $[\pm/\text{Fe}]$  abundances. We present [Fe/H] and  $[\pm/\text{Fe}]$  measurements based on coadded measurements for M31 dSphs, and then compare these results with the observed chemistry of the Milky Way halo and its dSphs. These abundance measurements from low-S/N spectra greatly increase the number of measurements of the chemical composition of M31 and its satellites, which are crucial to understanding its formation history and evolution, and placing M31 in context with complementary studies of the Milky Way.

**Author(s):** Jennifer Wojno, Ivanna Escala, Karoline M Gilbert, Evan Kirby

**Institution(s):** Johns Hopkins University, California Institute of Technology, Space Telescope Science Institute

### **316.07 - A Keck DEIMOS Spectroscopic Survey of M33(Puragra Guhathakurta)**

M33, a relatively low mass galaxy in the Local Group, serves as an important testbed for the study of the formation and evolution of thin disks. This galaxy has recently been the target of an extensive spectroscopic campaign with the Deep Extragalactic Imaging Multi-Object Spectrograph (DEIMOS) on the Keck II 10-meter telescope. Our team has used the 600 lines/mm grating on DEIMOS to obtain medium resolution spectra ( $R \sim 2000$ ) of several hundred stars in M33. These spectra cover the wavelength range 4500-9500 Angstrom and enable us to measure radial velocities and spectral characteristics of the target stars. The Keck/DEIMOS spectroscopic targets were selected from a variety of sources: (1) Panchromatic Hubble Andromeda and Triangulum (PHAT), specifically the M33 component of a six-filter (ultraviolet, visible light, near infrared) HST ACS and WFC3 mosaic imaging survey, (2) archival HST ACS visible light images, and (3) archival ground-based Canada-France-Hawaii Telescope (CFHT) MegaCam images originally obtained as part of the Pan-Andromeda Archeological Survey (PAndAS). This talk will present the first results from this Keck/DEIMOS spectroscopic survey of M33. Stellar kinematics can be used to identify and characterize M33's distinct structural subcomponents. This large spectroscopic sample of stars at a common distance is ideal for the identification and characterization of rare evolved stars such as carbon stars and a mysterious set of "weak CN" stars. This research was supported in part by the National Science Foundation and the National Aeronautics and Space Administration/Space Telescope Science Institute.

**Author(s):** Jennifer Wojno, Amanda C. N. Quirk, Evan Kirby, Karoline M Gilbert, Puragra Guhathakurta

**Institution(s):** University of California Santa Cruz, Space Telescope Science Institute, Johns Hopkins University, California Institute of Technology Contributing Team(s): SPLASH, PHAT

### **316.04D - Feedback and Chemical Enrichment in Low Mass Dwarf Galaxies: Insights from Simulations Tracking Individual Stars(Andrew Emerick)**

Galactic chemical evolution is driven by the complicated interplay of gas accretion, galaxy mergers, star formation, stellar feedback, mixing and turbulence in the ISM, and galactic outflows. Stellar feedback is fundamental in this evolution. How metals -- ejected in stellar winds and supernovae -- mix with a multi-phase ISM and couple to galactic winds depends sensitively on feedback physics that is poorly understood. Improving our theoretical understanding of both stellar feedback and galactic chemical evolution is becoming increasingly important as number and quality of observations of stellar and gas phase abundances in nearby galaxies continues to grow. Using these observations to understand the complex history of galactic chemical evolution requires detailed simulations capable of self-consistently resolving the processes that drive stellar abundances. We use high resolution, hydrodynamics simulations of isolated, low mass dwarf galaxies to better understand the complex relationship between feedback and galactic chemical evolution. By following stars as individual star particles, we can model both stellar feedback and stellar yields in unprecedented detail. Our star-by-star feedback model includes stellar winds from massive stars and AGB stars, photoelectric heating, stellar ionizing radiation followed through a ray-tracing radiative transfer method, core collapse supernovae, and Type Ia supernovae. We have used these simulations to explore differences in how metals with different nucleosynthetic origins mix within the ISM and couple to galactic winds. I will summarize these results to-date and present ongoing work in understanding the role each component of our multi-channel stellar feedback model plays in driving the chemical evolution of galaxies.

**Author(s):** Andrew Emerick, Mordecai-Mark Mac Low, Kathryn V. Johnston, Benoit Cote, Greg Bryan, Brian W. O'Shea,

**Institution(s):** Department of Astronomy, Columbia University, Center for Computational Astrophysics, Flatiron Institute, Department of Astrophysics, American Museum of Natural History, Konkoly Observatory, Department of Physics and Astronomy, Michigan State University

### **317 - Circumstellar Disks I**

#### **317.01 - Mass loss rates and MHD-driven disk winds traced by optical forbidden lines(Illaria Pascucci)**

MHD-driven disk winds are often invoked to enable accretion in planet-forming disks. However, their efficiency and relation to stellar accretion has not been constrained observationally. Here, we report results from two high-resolution ( $Dv \sim 7\text{km/s}$ ) surveys of optical forbidden lines targeting young stars with disks. We track the kinematics of different forbidden line components including a high-velocity component (HVC) associated to jets and two lower velocity components emitting from different disk radii (LVC-NC and LVC-BC) that trace disk winds. We find that LVC and HVC are kinematically linked, that the LVC-NC and LVC-BC kinematics correlate, and that their

velocity is maximum at an angle of 35 degrees. These properties can be explained by radially-extended MHD-driven winds that feed jets. Using the [OI] and [SII] line ratios we also constrain, for the first time, the excitation of different kinematic components. We find that most HVC ratios are reproduced by shock models with a pre-shock number density of H nuclei of  $\sim 10^{(6-7)} \text{ cm}^{-3}$ . In contrast, LVC-BC and NC ratios are better explained by thermally excited gas with temperatures between 5,000–10,000 K and electron densities  $\sim 10^{(7-8)} \text{ cm}^{-3}$ . Using these physical properties, we estimate mass loss rates relative to stellar accretion rates. In agreement with previous studies, we conclude that the mass carried out in jets is modest compared to stellar accretion rates. We also find that the LVC-BC mass loss rates are larger than the NCs, suggesting that most of the mass loss occurs close to the central star, within a few au. Depending on the scale height of the wind in the BC component, the BC mass loss rate could be as high as the stellar accretion rate, meaning that MHD winds might play a major role in the evolution of the disk mass.

**Author(s):** Andrea Banzatti, Uma Gorti, Ilaria Pascucci, Suzan Edwards, Min Fang

**Institution(s):** LPL, Smith College, Steward Observatory, NASA/Ames

### **317.03 - Gaps and Rings in ALMA Observations of Protoplanetary Disks: Implications for the Young Planet Population(Shangjia Zhang)**

Discoveries over the past few decades show that planets are common. However, most discovered exoplanets are mature, so their orbital properties have gone through dynamics alteration. To test planet formation theory, it is crucial to constrain the young planet population right after they are born in protoplanetary disks. Recent high resolution imaging in millimeter interferometry reveal a variety of disk features, some of which may be imprinted by young protoplanets. Our recent ALMA Large Program, “The Disk Substructures at High Angular Resolution Project” (DSHARP), provides the first homogeneous overview of disk substructures. In this work, we explore the possibility that these gaps/rings are induced by young planets, by carrying out a grid of hydrodynamics simulations with different values for viscosity, scale height and planet mass. I will first introduce our simulations including dust particles with drift and explain how they are scaled to the dust emission at DSHARP observation wavelength. Then I will highlight our simulation demonstrating that the intricate series of gaps in the AS 209 disk can be explained by a single planet. I will also demonstrate that the angular resolution and sensitivity of DSHARP observations are able to reveal disk structures induced by giant planets in the young solar system and HR 8799 analogs. Finally, I will explore the potential young planet population on the planet mass-semimajor axis diagram. We find the occurrence rate of giant planet  $> 5 \text{ MJ}$  is consistent with direct imaging constraints. We also probe a new parameter space of Neptune to Jupiter mass planets beyond 10 au, which are not accessible to other planet searching techniques.

**Author(s):** Luca Ricci, Cornelis P. Dullemond, Clément

Baruteau, Jane Huang, Shangjia Zhang, Xue-Ning Bai, Sean M. Andrews, Andrea Isella, Zhaohuan Zhu, Viviana V. Guzmán, Laura M. Pérez, Tilman Birnstiel, Myriam Benisty, John M. Carpenter

**Institution(s):** Tsinghua University, OCNRS / Institut de Recherche en Astrophysique et Planétologie, UnivGrenoble Alpes, California State University, Northridge, University of Nevada, Las Vegas, Joint ALMA Observatory, Harvard-Smithsonian Center for Astrophysics, U

### **317.05 - A Multicolor Study of Polarization Variability in Isolated B[e] Stars HD 45677 and HD 50138(Chien-De Chandler Lee)**

HD 45677 and HD 50138 are two B[e] stars isolated from any known star-forming regions. We investigated the polarization characterization of their surrounding gas and in situ dust in the inner edge of the circumstellar disk. Our measurements of the intrinsic polarization of each star between 2010 and 2011, after correcting for foreground polarization through field star observation, reveal a decreasing level of polarization with wavelength, with the polarization angle independent of wavelength. However, reanalysis of literature data by applying our foreground correction method clarified the relative roles of electron scattering versus dust scattering in the circumstellar disk. Combining the multicolor data from the available epochs led us to conclude that a general electron scattering-dominated disk exists in both B[e] stars, with evidence of micron-sized grains seen at some epochs, likely condensed in the inner disk.

**Author(s):** Anil Pandey, Chakali Eswaraiah, Wen-Ping Chen, Chien-De Chandler Lee

**Institution(s):** Institute of Astronomy, National Central University, Aryabhata Research Institute of Observational Sciences

### **317.06 - On the edge: Assessing the structure of protoplanetary disks from a unique perspective(Gaspard Duchene)**

The physical structure of protoplanetary disks both sets the stage for, and is strongly affected by, planet formation. A full understanding of that process therefore requires a detailed characterization of the radial and vertical structure of the gas-rich disks associated with young pre-main sequence stars. Of particular interest are disks observed edge-on, as they provide the ideal configuration to unambiguously disentangle the radial and vertical dimensions. Here we present HST and ALMA high resolution imaging (up to a few AU scales) of three edge-on disks in the nearby Taurus and Ophiuchus star-forming regions. The combination of scattered light images, millimeter continuum images and CO emission maps enable a robust comparison of the spatial distribution of the micron-sized dust grains, millimeter-size grains and gas in each of these disks. We find that the large dust grains are constrained to a remarkably flat subdisk as a consequence of dust settling. We place

stringent constraint on the thickness of this subdisk in each system. Furthermore, this subdisk is markedly more compact radially than both the small dust and gas components, confirming the prediction of dust radial migration. We also present compelling evidence that the millimeter continuum emission is strongly optically thick in at least one system. Finally, we find the gas component to extend even further out (by up to a factor of 2) than the small dust component, suggesting either a dust-poor outer region or that the outer reaches of disks are shielded from the central starlight.

**Author(s):** Schuyler Wolff, Christian Flores, Christophe Pinte, Gaspard Duchene, François Ménard, Karl Stapelfeldt, Deborah Padgett, Marion Villenave

**Institution(s):** University of California Berkeley, NASA Exoplanet Exploration Program, Université Grenoble Alpes, Leiden Observatory, University of Hawaii, Jet Propulsion Laboratory

### **317.07 - The "dipper" stars: challenging our view of protoplanetary disk structure (Megan Ansdell)**

Protoplanetary disks are traditionally thought to be flared disks with relatively smooth profiles. However, recent observations that are able to probe the very inner regions of protoplanetary disks suggest that misalignments between the inner and outer disk components are not only possible but also somewhat frequent. Namely, the young “dipper” stars are a common class of variable object (~25% in ~Myr old star-forming regions) whose optical light curves exhibit large ( $\geq 10\%$ ) episodic day-long drops in flux. Because the dippers all host protoplanetary disks, they were thought to be explained by transiting dusty structures orbiting in the inner disk and thus likely seen nearly edge-on. However, we have conducted a survey of dippers with high-resolution sub-mm ALMA observations to show that dipper disks span the full range of viewing geometries and are not biased towards nearly edge-on inclinations. This suggests that their inner disks are indeed misaligned, a conclusion that is supported by direct imaging with extreme adaptive optics systems, in particular SPHERE, which have revealed variable shadows in the outer disk that likely reflect dynamic, inclined inner disks. These results inform our understanding of disk structure and dynamics as well as the environment in which close-in terrestrial planet form. This work benefited from NASA NNX15AD95G/NEXSS.

**Author(s):** Megan Ansdell, Eric Gaidos

**Institution(s):** University of California, Berkeley, University of Hawaii

### **317.02D - Detection and Characterization of Circumstellar Disks in Scattered Light with Space- and Ground-based Telescopes (Bin Ren)**

Circumstellar disks interact with the exoplanets and their surrounding interstellar medium, thus offering a unique vantage point of the status of these systems. To study

circumstellar disks in scattered light, I will present my efforts in (1) constructing the largest Hubble/STIS coronagraphic archive for circumstellar system imaging, and characterizing its BAR5 position for dithering and high-contrast imaging; (2) developing a machine learning method (sequential non-negative matrix factorization, sNMF) to extract disk structures, robustly recovering the disks with minimal alteration than previous methods. These studies are then combined for (3) quantifying the spiral arm rotation for the MWC 758 protoplanetary disk with a 10-yr timeline using Hubble/NICMOS, VLT/SPHERE and Keck/NIRC2, showing that the rotation is consistent with being driven by a planet at ~90 au; (4) characterizing the HD 191089 debris disk system with joint Hubble (NICMOS, STIS) and Gemini/GPI efforts, extracting two components—a young Kuiper Belt, and a secondary halo extending to ~640 au—with distinct status in their grain population.

**Author(s):** Bin Ren

**Institution(s):** Johns Hopkins University Contributing Team(s): STScI EPSIG Group, GPI Exoplanet Survey Team

### **317.04D - Discovery and Classification of New Circumstellar Disks in the AllWISE Catalog from Disk Detective (Steven Silverberg)**

In its four years since launch, DiskDetective.org has led to many new discoveries in the field of circumstellar disks. This presentation gives a brief overview of the project, and highlights our new results. We show that at most 7.9% of all WISE-detected infrared excesses are circumstellar disks, and find that some published excess searches have false positive rates greater than 70%. We also highlight new data on WISEA J080822.18-644357.3, a 45-Myr primordial disk around an M5 star in the Carina association first identified by Disk Detective in 2016. We find accretion rates of  $10^{(-12)}-10^{(-10)}$  solar masses per year, variable on 24-hour timescales, based on near-IR spectroscopy. We also note flare activity and potential accretion bursts in nine nights of ground-based high-cadence optical photometry. We use J0808 as the prototypical example of “Peter Pan” disks, long-lived primordial disks around mid-M or later stars. Using these characteristics, we explore possible origin scenarios for Peter Pan disks, including longer lives for primordial disks around mid-M stars than previously thought, and discuss methods of testing their validity. If Peter Pan disks are shown to be a typical phenomenon around mid-M stars, the timescale for planet formation around these stars would also be greatly increased, affecting our expectations for planet yields and UV input onto the newly formed planets. Such disks would also potentially explain the near-circular resonant orbits of the TRAPPIST-1 system. This work was supported by grant 14-ADAP14-0161 from the NASA Astrophysics Data Analysis Program and grant 16-XRP16\_2-0127 from the NASA Exoplanets Research Program.

**Author(s):** John Wisniewski, Steven Silverberg, Marc J Kuchner

**Institution(s):** University of Oklahoma, NASA Goddard Space Flight Center Contributing Team(s): Disk Detective

Collaboration

## **318 - Stars, Stellar Evolution and Stellar Populations I**

### **318.01 - Eta Carinae scheduled for release from hospital(Kris Davidson)**

Three reasons together make Eta Carinae essential for massive-star physics: (1) It's the most luminous star that has been studied in detail. (2) More important, it is the <u>only</u> giant-eruption survivor that can be observed well. (3) About 20 years ago it entered an unexpected phase of rapid changes, covered well with HST spectroscopy. Evidently, recovery from a supernova impostor event can be dramatically fitful for a surprisingly long time. HST data obtained in 2015-2018 now suggests that the changes have begun to abate; the star is approaching the state that Halley saw in 1677 -- apart from the lost mass.

**Author(s):** John Martin, Roberta Humphreys, Kris Davidson, Kazunori Ishibashi

**Institution(s):** University of Minnesota, University of Nagoya, University Illinois Springfield

### **318.02 - Recent High Mass Loss Events in the Extreme Red Supergiant VY CMa(Roberta Humphreys)**

VY CMa is famous for its extended complex ejecta revealing a history of discrete high mass loss episodes over the past few hundred years. Its ejecta is also full of small knots and filaments suggest that these mass loss episodes have been on-going. Recent high resolution spectra with HST/STIS of the innermost knots reveal mass loss events in the past 100 years. The spectra also surprisingly revealed strong molecular emission arising in the knots, not from the star's wind or circumstellar gas. The identification of the molecular emission, their excitation mechanism and its implication for the mass loss mechanism for VY CMa and for other highly evolved red supergiants will be discussed.

**Author(s):** Wouter Vlemmings, Lucy Ziurys, K. Ishibashi, Roberta Humphreys, L. Andrew Helton, Terry J Jones, Michael S Gordon, Jacob Jacob Bernal, Anita Richards

**Institution(s):** University of Minnesota, USRA/SOFIA, University of Arizona, Nagoya University, Chalmers University, University of Manchester

### **318.03 - Separating out carbon-rich AGBs, oxygen-rich AGBs, and YSO BAaDE objects based on IR color and 43GHz spectra(Megan Lewis)**

The BAaDE (Bulge Asymmetries and Dynamical Evolution) project is the largest ever SiO maser survey of the Galactic Plane. About 19,000 sources have been observed at 43GHz with the VLA, and the production of spectra for these sources is well underway. The name-sake goal of the project is to collect line-

of-sight velocities for all the detected masers in the sample to probe Galactic dynamics, and with an expected detection rate of over 60% we should collect over 11,000 velocities. However, the survey is also a large sample of infrared sources, with which to explore the different evolved stellar populations within the Milky Way. So far we can discern three distinct groups in the BAaDE sample: the main group containing oxygen-rich, evolved stars with a high SiO maser detection rate, a much smaller population of carbon-rich evolved stars, and finally a group of what likely consists of young stellar objects with no maser emission. These populations can be separated out using 2MASS and MSX (Mid-course Space eXperiment) color-color diagrams, and we find a particularly useful cut between the young and evolved objects using the MSX  $[14\frac{1}{4}\mu\text{m}] - [21\frac{1}{4}\mu\text{m}]$  color. Identification of these populations will help isolate BAaDE's evolved star sample, and will more tightly define the region in the IR color-magnitude diagram where the SiO masers occur. We can further characterize these groups utilizing infrared data, allowing for a more fine-tuned understanding of how the stellar properties change as a function of position and/or kinematical population in the Galaxy. This information will be used to inform calculations of metallicity gradients and mass-return to the interstellar medium from evolved stars.

**Author(s):** Lorant Sjouwerman, Ylva Pihlstr m, Michael Stroh, Megan Lewis

**Institution(s):** University of New Mexico, NRAO  
Contributing Team(s): the BAaDE team

### **318.04 - New Stellar Mass-Loss Rates for Massive Stars in Bowshock Nebulae(Henry Kobulnicky)**

Second only to the initial stellar mass (or interaction with a close companion), the rate of wind-driven mass loss determines the final mass of a massive star and the nature of its remnant. Measurements of mass-loss rates over the last several decades have proven controversial, with orders-of-magnitude discrepancies between different observational approaches. Motivated by the need to reconcile observational values and theoretical expectations, we use a recently vetted measurement technique to analyze a sample of OB stars that generate stellar bowshock nebulae. We measure the peculiar velocities and spectral types for the stars using new Gaia parallax and proper motion data along with new optical and infrared spectroscopy. For our sample of 70 central stars in morphologically selected candidate bowshock nebulae, 66 turn out to be early type (OB) stars. The median peculiar velocity is 15 km/s, significantly smaller than classical "runaway star" velocities. Mass-loss rates for these O and early-B stars agree well with recent theoretical predictions, ranging from  $10^{-6}$  solar masses for mid-O dwarfs to several times  $10^{-8}$  for late-O dwarfs, with an order of magnitude dispersion at any given spectral type and luminosity class, suggesting real variations exist. Evolved stars show elevated mass-loss rates compared to dwarfs, consistent with model expectations. Our results provide the first observational mass-loss rates for B0--B2 dwarfs ---  $10^{-9}$  to  $10^{-7}$  solar masses per year --- significantly higher than theoretical expectations. Early type dwarfs exhibit a correlation



between mass-loss rate and stellar luminosity with a power law index of 2.0, nearly identical to theoretically predicted value of 2.1.

**Author(s):** Henry Kobulnicky, William T Chick

**Institution(s):** University of Wyoming

### **318.05 - Probing the Mass Loss and Evolutionary State of Magellanic Cloud B[e] Supergiants with HST/COS(Raghvendra Sahai)**

Massive stars end their lives as supernovae (SNe), which drive their host galaxy's chemical evolution by returning gas and dust to it. A significant fraction of the dust detected with SNe remnants is likely to have been created by the SN progenitor, making it important to understand dusty mass loss from massive progenitors of these SNe. One particularly poorly understood class of post-main sequence massive star, and therefore SN progenitor, is the B[e] supergiant (hereafter sgB[e]). SgB[e]s are mass-losing luminous B stars with a fast polar wind and a slower equatorial wind. Although these stars usually have large thermal IR excesses due to large amounts of circumstellar dust, a few recently-identified sgB[e]s in the low-metallicity Small Magellanic Cloud have been found to be largely without circumstellar dust. Here, we report on HST-COS ultraviolet (UV) spectroscopy of a sample of Large and Small Magellanic Cloud sgB[e]s, some previously studied and others more recently identified. We are using these COS spectra to determine basic stellar atmospheric parameters and characterize stellar mass loss, with the overall goal of understanding how mass loss is related to sgB[e] evolutionary state.

**Author(s):** Benjamin Sargent, Raghvendra Sahai, Joel Kastner, Claus Leitherer

**Institution(s):** Jet Propulsion Laboratory, Caltech, Rochester Institute of Technology, Space Telescope Science Institute

### **318.06 - Asymptotic Giant Branch Stars in the Low-Metallicity Galaxy NGC 6822(Alec Seth Hirschauer)**

The high-redshift systems in which the earliest generations of stars were formed, produced heavy elements and dust, and subsequently ended their life cycles were vastly different from the Milky Way. Nearby galaxies with low metal abundances provide important laboratories for observationally accessing the physical conditions equivalent to what had been ubiquitous throughout the early Universe. In order to more fully understand the role of dust in metal-poor environments, it is critically important to robustly identify their evolved, dust-producing asymptotic giant branch (AGB) stars. The local ( $\sim 500$  kpc) metal-poor ( $[\text{Fe}/\text{H}] \approx -1.2$ ;  $Z \approx 30\% Z_{\odot}^{\text{TM}}$ ) star-forming galaxy NGC 6822 is thought to be analogous to higher-redshift systems at the epoch of peak star formation. We present color-magnitude diagrams (CMDs) utilizing archival photometry from the Spitzer Space Telescope (Khan et al. 2015; IRAC 3.6, 4.5, 5.8, and 8.0  $\mu\text{m}$  and MIPS 24  $\mu\text{m}$ ) and the

United Kingdom Infrared Telescope (Sibbons et al. 2012; UKIRT J-, H-, and K-band) of NGC 6822. Isolating red-excess objects and carefully employing color cuts, we identify oxygen- and carbon-rich AGB star candidates. Subsequent work will entail spectral energy distribution (SED) fitting of these sources to quantify the dust mass and dust mass loss rate of this galaxy. This project was completed in anticipation of a James Webb Space Telescope (JWST) guaranteed time observation (GTO) program for this galaxy, which will probe NGC 6822 to a depth comparable to the Spitzer SAGE (Surveying the Agents of a Galaxy's Evolution; Meixner et al. 2006) surveys of the Large and Small Magellanic Clouds.

**Author(s):** Laurin Gray, William Paranzino, Benjamin Sargent, Margaret Meixner, Olivia Jones, Alec Seth Hirschauer, Martha Boyer

**Institution(s):** Space Telescope Science Institute, Johns Hopkins University, University of Arizona, United Kingdom Astronomy Technology Centre, University of Notre Dame

### **318.08 - Properties of former second-generation globular cluster stars in the Inner Halo / Bulge field(David Moise Nataf)**

I discuss the properties of nitrogen-enriched stars in the Galactic Bulge, which are identified from SDSS DR14 / APOGEE spectra. These stars have enhanced values of nitrogen, and correspondingly deficient of oxygen and carbon, relative to the bulge field population. They are plausibly former members of globular clusters. Relative abundances with the other elements reliably measured by APOGEE, specifically with the PAYNE pipeline, are discussed. The sample of  $\sim 100$  stars can be used to constrain the origin of this population, such as whether or not they come from disproportionately low-mass or high-mass globular clusters.

**Author(s):** Rosemary Wyse, David Moise Nataf, Ricardo Schiavon

**Institution(s):** Johns Hopkins University, Liverpool John Moores University Contributing Team(s): APOGEE

### **318.07D - The Galactic Chemical Evolution of Chlorine and Phosphorus(Zachary Maas)**

The odd, light elements chlorine (Cl) and phosphorus (P) are thought to be produced in interesting nucleosynthesis events. Current nucleosynthesis models predict that both isotopes of Cl are produced primarily during core collapse supernovae (CCSNe) with the energy and progenitor mass impacting the isotopic ratio of the ejected material.  $^{35}\text{Cl}$  may be produced from neutrino spallation and  $^{37}\text{Cl}$  may be created in AGB stars. Phosphorus is thought to be made via neutron capture during hydrostatic neon and carbon shell burning in massive stars. However few measurements of Cl exist to compare to chemical evolution models, and current P abundances do not match predictions. We report the first Galactic chemical evolution study of Cl by deriving stellar abundances for a sample of 55

cool giants ranging from  $-0.6 < [\text{Fe}/\text{H}] < 0.2$ , finding no significant offsets between  $[^{35}\text{Cl}/\text{Fe}]$  ratios and chemical evolution models. Our results suggest additional proposed nucleosynthesis processes are not significant in the production of Cl. We also measured the Cl isotope ratio for six cool M giants and found an average isotope ratio of  $2.66 \pm 0.58$  and with a range of  $1.76 < ^{35}\text{Cl}/^{37}\text{Cl} < 3.42$ . The spread in observed Cl isotope ratios is similar to measurements in the ISM and is more consistent with isotope ratios from CCSNe yields of rotating progenitor stars. For P, we confirmed chemical evolution models of P are under-abundant compared to measurements and our results suggest yields need to increase and/or include additional process like O-C shell mergers or proton capture reactions. We also found an average  $[\text{P}/\text{Fe}] = 0.00 \pm 0.06$  dex for stars in the Hyades cluster and the abundances are consistent between dwarfs and giants. For both studies, our conclusions are derived from infrared spectroscopic observations. We combined IR and optical echelle spectroscopy to determine atmospheric parameters and Cl abundances for the target stars. We derived Cl abundances from HCl features at 3.7 microns in stars with temperatures below  $\sim 4000$  K. For phosphorus, we measured  $[\text{P}/\text{Fe}]$  in  $\sim 40$  FGK stars ranging between  $-1 < [\text{Fe}/\text{H}] < 0.2$  using P I features at 1.06 microns.

**Author(s):** Zachary Maas, Catherine Pilachowski  
**Institution(s):** Indiana University-Bloomington

### 319 - Star Clusters Near and Far I

#### 319.01 - New chemical evolution models for the Na-O anti-correlation in globular clusters (Jenny Jaeyeon Kim)

In order to investigate the origin of multiple stellar populations found in globular clusters (GCs) in the halo and bulge of the Milky Way, we have constructed chemical evolution models for their putative low-mass progenitors. In light of recent theoretical developments, we assume that supernova blast waves undergo blowout without expelling the pre-enriched ambient gas, while relatively slow winds of massive stars, together with the winds and ejecta from low to high mass asymptotic-giant-branch stars, are all locally retained in these less massive systems. Interestingly, we find that the observed Na-O anti-correlations in GCs can be reproduced when multiple episodes of star formation and enrichment are allowed to continue in these subsystems. A specific form of star formation history with decreasing time intervals between the successive stellar generations, however, is required to obtain this result. We also find that the parameters suggested from our chemical evolution models can simultaneously reproduce the observed Hertzsprung-Russell diagram morphology of GCs. The “mass budget problem” is mostly resolved by our models without ad-hoc assumptions on star formation efficiency, initial mass function, and the preferential loss of first-generation stars. Our results further underscore that gas expulsion or retention is a key factor in understanding the multiple populations in GCs.

**Author(s):** Sohee Jang, Jenny Jaeyeon Kim, Young-Wook Lee  
**Institution(s):** Yonsei University

#### 319.03 - Close companions to young stars (Marina Kounkel)

Multiplicity is a fundamental stellar property set early in the star formation process. Since the nearby field population is composed of stars that were once young, we expect that stars leaving their birth sites should have multiplicity properties similar to what have been measured in the field. However, it is still unclear whether it is possible to reproduce the field multiplicity distribution from the dissolution of the nearby star forming regions. We present an analysis of multi-epoch spectra obtained with APOGEE-2 towards Orion, Taurus, Perseus, NGC 2264, alpha Per, and the Pleiades. In these regions we identify close companions (up to 10 AU) through a systematic search of both single and double lined spectroscopic binaries. We also measure the close companion fraction, and examine its consistency as a function of stellar density and age.

**Author(s):** Kaitlin M Kratter, Maxwell Moe, Marina Kounkel, Kevin Covey

**Institution(s):** Western Washington University, University of Arizona  
**Contributing Team(s):** SDSS-IV APOGEE-

#### 319.04 - Two Thresholds for Globular Cluster Formation and their Dominance of Star Formation in the Early-Universe (Bruce G. Elmegreen)

Young massive clusters (YMCs) are usually accompanied by lower-mass clusters and unbound stars with a total mass equal to several tens times the mass of the YMC. If this was also true when globular clusters (GCs) formed, then their current cosmic density implies that most star formation before redshift  $\sim 2$  made a GC that lasted until today. Star-forming regions had to change significantly after this time for the modern universe to be making very few bound clusters with such large masses. Here we consider the most basic conditions for the formation of a  $\sim 10^6 M_{\odot}$  cluster. These include a star formation rate inside each independent region that exceeds  $\sim 1 M_{\odot}/\text{yr}$  to sample the cluster mass function up to such a high mass, and a star formation rate per unit area of  $\dot{\Sigma}_{\text{SFR}} \sim 1 M_{\odot}/\text{kpc}^2/\text{yr}$  to get the required high gas surface density from the Kennicutt-Schmidt relation, and therefore the required high pressure from the weight of the gas. The ratio of these two quantities gives the typical area of a GC-forming region,  $\sim 1 \text{ kpc}^2$ , and the young stellar mass converted to a cloud mass gives the typical gas surface density of  $500\text{--}1000 M_{\odot}/\text{pc}^2$ . Observations of star-forming clumps in young stellar disks are consistent with these numbers, suggesting they formed today's GCs. Observations of the cluster cut-off mass in local galaxies agree with the maximum mass calculated from  $\dot{\Sigma}_{\text{SFR}}$ . Metal-poor stellar populations in local dwarf irregular galaxies confirm the dominant role of GC formation in building their young disks.

**Author(s):** Bruce G. Elmegreen

**Institution(s):** IBM T.J. Watson Research Center

### **319.06 - Further constraints on the age and helium abundance of NGC 6791 from modeling of the asteroseismic oscillations(Jean McKeever)**

NGC 6791 is an old ( $\sim 8$  Gyr), metal rich ( $[\text{Fe}/\text{H}] \sim 0.35$ ) open cluster in which previous studies have indicated also has a high initial helium abundance. The cluster happened to lie within the Kepler field of view and had unprecedented light curves for many of the red giant branch (RGB) stars in the cluster. Asteroseismic studies have constrained the age through grid based modeling of the global asteroseismic parameters ( $\Pi^{\text{r}}_{1/2}$  and  $\Pi^{\text{r}}_{1/2\text{max}}$ ). However, with Kepler data it is possible to do detailed asteroseismology of individual mode frequencies to better constrain the stellar parameters, something that has not been done for these cluster stars as yet. In this work, we use the radial ( $l=0$ ) and quadrupole ( $l=2$ ) modes in  $\sim 25$  hydrogen shell burning RGBs to better constrain the age and initial helium abundance ( $Y_0$ ). We have created a grid of stellar evolution models using MESA that span the expected ranges of mass, initial  $[\text{Fe}/\text{H}]$ ,  $Y_0$ , and mixing length in the cluster RGBs. We compute model oscillation frequencies at each timestep along the RGB in the expected  $\log g$  range of our stars with the pulsation code GYRE. The distribution of parameters for all the giants are then combined to create a probability distribution for age and helium of the entire cluster that is consistent with previous results based on main sequence stars.

**Author(s):** Sarbani Basu, Jean McKeever

**Institution(s):** Yale University

### **319.02D - The Initial Final Mass Relation From 1 to 7 Solar Masses: A Monte Carlo Approach with the Addition of the new M67 White Dwarf Sample(Paul Anthony Canton)**

The initial-final mass relation (IFMR) maps a star's initial, or ZAMS mass, to its final mass as a white dwarf (WD). The difference between these two parameters measures the total integrated mass loss of stars as a function of ZAMS mass. Through this, the IFMR is a tool for the broader community which has already found application in studies of galactic evolution and in examining the history of post main sequence exoplanet systems. With studies such as the one presented here it also possible to constrain the ages of the galactic components from the coolest field WDs and to constrain the cut off mass at which a star will undergo a core collapse supernova rather than forming a WD. With our recent analysis of WDs in the aged solar-metallicity open star cluster M67 we revisit the IFMR with new constraints in the initial-final mass parameter space. We reanalyze data from a total of four additional open clusters for internal consistency. We show, with a Monte Carlo simulation, that the historically illustrated perpendicular error bars along the initial and final mass axes fail to illustrate the complicated correlation between the initial and final mass from using the standard procedure for deriving initial masses for WDs in open clusters. We include additional objects from elsewhere in the literature which have been analyzed in a consistent manner to

our sample, and rederive the IFMR using the results of our Monte Carlo simulation from a sample size of 64 objects. Our relation spans from 1 to 7 solar masses in ZAMS mass and 0.50 to 1.18 solar masses in WD mass.

**Author(s):** Alex Gianninas, Kurtis Williams, Mukremin Kilic, Paul Anthony Canton

**Institution(s):** University of Oklahoma, Texas A&M University Commerce

### **319.05D - Model establishment of nearby young moving groups and identification of members(Jinhee Lee)**

Nearby young moving groups (NYMGs hereafter) are loose stellar associations, younger than  $\sim 100$  Myr and located within  $\sim 100$  pc of the Sun. NYMGs are useful in stellar age-dating and exoplanet imaging as well as studies of star formation and evolution in the solar neighborhood and the initial mass function. Since members of a NYMG share a common position, motion, and age, new members can be identified based on mean values of these parameters of previously known NYMG members. Initially a NYMG was distinct from other NYMGs. As additional members were identified, average group properties such as centers and extensions in XYZ and UVW were changed. Nowadays, extensions of NYMGs in XYZ and UVW overlap each other which now raised an ambiguity in membership assessments. A model for a certain NYMG (i.e., average group properties in XYZ, UVW, and age space) critically depends on how one build up a NYMG with a combination of initial members (i.e., members in the discovery paper) and additional members identified later on. We investigate the effect of NYMG build-up methods starting with the initial members. Initially, NYMG models were constructed utilizing these initial members and then updated by incorporating acceptable additional members based on two approaches: the nearest neighbor and membership probability. These two approaches result in similar but different updated models, which enable us to establish more reliable, finalized NYMG models by combining results from two approaches. In the entire set of NYMG candidate members,  $\sim 50$  per cent of members are identified as bona fide members,  $\sim 20$  per cent of members identified as non-members, and  $\sim 30$  per cent of members are inconclusive in their memberships. The mass function from the bona fide NYMG members implies that  $>300$  more M-type NYMG members should be identified. Utilizing the Gaia DR2 catalog, we identified hundreds of new candidate members and an observational confirmation (e.g., RV) program has already been started.

**Author(s):** Inseok Song, Jinhee Lee

**Institution(s):** The University of Georgia

## **320 - YSOs & Friends**

### **320.01 - Modeling Shock Chemistry in Isolated Molecular Outflows(Andrew Michael Burkhardt)**

Shocks are a crucial probe for understanding the ongoing chemistry within ices on interstellar dust grains where many complex organic molecules (COMs) are believed to be formed. However, previous work has been limited to the initial liberation into the gas phase through non-thermal desorption processes such as sputtering. Here, we present results from the adapted three-phase gas-grain chemical network code NAUTILUS, with the inclusion of additional high-temperature reactions, non-thermal desorption, collisional dust heating, and shock-physics parameters. This enhanced model is capable of reproducing many of the molecular distributions and abundance ratios seen in prior observations of the prototypical shocked-outflow L1157. In addition, we find that, among others,  $\text{NH}_2\text{CHO}$ ,  $\text{HCOOCH}_3$ , and  $\text{CH}_3\text{CHO}$  have significant post-shock chemistry formation routes that differ from those of many other COMs observed in shocks. Finally, a number of selected species and phenomena are studied here with respect to their usefulness as shock tracers in various astrophysical sources.

**Author(s):** Romane Le Gal, Eric Herbst, Andrew Michael Burkhardt, Brett McGuire, Anthony Remijan, Christopher Shingledecker,

**Institution(s):** University of Virginia, Max-Planck-Institut für extraterrestrische Physik, Harvard-Smithsonian Center for Astrophysics, National Radio Astronomy Observatory, University of Stuttgart

### **320.03 - Probing the Dissipation of Planet-forming Disks with Warm Molecular Hydrogen Signatures(Keri Hoadley)**

The evolution of protoplanetary disks from primordial gas- and dust-rich stages to their dispersal has become one of the leading topics in planet formation studies (Alexander et al. 2014). In particular, disks that are found to have gaps or holes in their radial structures provide an intermediate evolutionary stage (disks “in transition” or “transitional disks”, e.g. Calvet et al. 2005; Espaillat et al. 2014) and offer an exciting opportunity to study the initial conditions and development of planetary systems (e.g. Zhu et al. 2011). Observations show that disks disperse from the inside out: the first material to be depleted is the hot/warm dust between sublimation temperatures ( $\sim 1500$  K) to a few hundreds K at disk region between  $\sim 0.05$  au out to several AU in radius. Understanding how disks evolve and disperse is therefore intimately connected to our ability to model planet formation and the initial conditions of exoplanet populations. Currently underway is a multi-wavelength investigation into the mechanisms which drive the dispersal of protoplanetary disks, tying together the behavior of molecular signatures ( $\text{H}_2$  in the UV, and CO in the IR) probing warm disk material. The investigation looks to make a connection between the physical conditions of a variety of planet-forming disks found at different phases of their evolution, creating a copacetic

picture of gas evolution in disks and defining the path towards planet formation. We present recently results from a modeling effort of UV- $\text{H}_2$  signatures in 7 new data sets obtained with HST-COS, which increases our sample space of protoplanetary disks with both high-resolution IR-CO spectra and UV- $\text{H}_2$  emission. We present our results, along with the effort started in Hoadley et al. 2015, and examine the driving mechanisms of gas dissipation in these planet-forming disks.

**Author(s):** Keri Hoadley, Kevin France, Andrea Banzatti

**Institution(s):** Caltech, University of Colorado, University of Arizona

### **320.04 - Candidate Protostars within 10,000 years of Hydrostatic Core Formation(Nicole Karnath)**

We present a study five of the most deeply embedded protostars known in the Orion Molecular Clouds down to 40 AU scales. These data reveal structures at an early ( $< 10$  kyr) phase of star formation that have previously been limited to theoretical work. These protostars were selected by their weak or lack of emission at  $24\frac{1}{4}\mu\text{m}$  from Spitzer but are bright at  $70\frac{1}{4}\mu\text{m}$  and were first identified by the HOPS (Herschel Orion Protostar Survey) program. Due to their rarity ( $< \sim 5\%$  of known protostars) these deeply embedded protostars have estimated ages  $< 25$  kyr. Using the Atacama Large Millimeter Array (ALMA) and Very Large Array (VLA) radio interferometers, we map the thermal dust emission at wavelengths of 0.87 mm and 8 mm, respectively. Our data show dense and complex structures in the inner regions of the collapsing gas clouds. The inferred optical depth at 0.87 mm exceeds unity within 160 AU of the center, demonstrating that the regions are extremely dense and thus trapping radiative energy produced by the central protostar. Adopting dust temperatures inferred from the 0.87 mm data, we estimate dust masses of up to  $\sim 1.5$  solar masses concentrated in regions 160 AU in extent from the 8 mm data, excluding a prostatic disk origin for this structure. We present the detection of outflows from three of the five protostars and constrain their outflow properties. Our analysis provides the first direct observational constraints into the adiabatic contraction phases of the gas clouds during the formation of hydrostatically supported protostars. Support for this work was provided by the NSF through award SOSP1519126 from the NRAO

**Author(s):** Nicole Karnath, Amelia Stutz, S. Thomas Megeath, John Tobin

**Institution(s):** University of Toledo, Universidad de Concepción, National Radio Astronomy Observatory

### **320.05 - Tracing UV Emission from Warm Gas in Shocked Stellar Outflows(Jon Morse)**

The near-UV lines of Mg II at 2796 & 2803 Å... have been observed from space for decades in solar system objects, stars, the interstellar medium and galaxies. Most Mg II observations have been spectroscopic, but the Hubble Space Telescope (HST)

has a narrowband imaging filter that allows Mg II emission distributions in stellar outflows within star forming regions and other environments to be compared with common visible wavelength lines such as H-alpha, [N II]6584, [S II]6724, [O III]5007, [O II]3727, etc. Some recent examples of HST Mg II imaging will be shown that indicate the potential for exploiting this diagnostic feature to trace warm (~3000-5000 K), dense gas that may bridge the gap between tracers of hotter atomic and cooler molecular structures and flows. Such examples can be used to build the case for a dedicated imaging survey in Mg II and other UV lines (e.g., C II], O II], C IV) of large regions of the Milky Way and nearby galaxies, possibly carried out with a smallsat class telescope from the lunar surface or by other means to achieve sub-arcsecond spatial resolution.

**Author(s):** John Bally, Nathan Smith, Jon Morse

**Institution(s):** BoldlyGo Institute, University of Arizona, University of Colorado

### **320.06 - Accretion, Infall and a Mysterious One Sided Molecular Jet: SOFIA Observations of Intermediate Mass Protostars in Orion(S. Thomas Thomas Megeath)**

Observations of intermediate luminosity protostars promise new insights into mass accretion, the role of episodic accretion in low mass star formation, and the impact of feedback from protostars on the surrounding cloud. The Herschel Orion Protostar Survey found that ~10% of Orion protostars have intermediate luminosities between 20-1000 solar luminosities. We present SOFIA imaging and spectroscopy with FORCAST of five intermediate luminosity protostars in the Orion molecular clouds and GREAT spectroscopy of an outflow driven by one of the five. FORCAST 9-14 micron spectra and 19.7 and 22.7 micron images are combined with data from HOPS to constrain the luminosities and envelope properties of the protostars; in this contribution we concentrate on the properties of the protostar OMC2-FIR3 (or HOPS 370). This protostars is driving a powerful outflow previously mapped by Herschel/PACS in the 63 micron [OI] line. GREAT [OI] and CO 16-15 spectra combined with an APEX CO 6-5 map resolve the kinematics of this outflow. They show, contrary to prior expectation, that the far-IR lines from the southern lobe are dominated by emission from the swept up gas and that there is no detected far-IR, high velocity jet. In contrast, for the northern lobe of the outflow, a high velocity jet is detected in the CO and [OI] lines. We propose that UV radiation from the terminal shock of the southern lobe, which is propagating into a high density structure, is heating the gas entrained by the outflow and dissociating/ionizing the southern jet. In contrast, the northern jet, which is propagating into lower density gas, and where the terminal shock is much further from the driving protostar, is not exposed to a strong UV field. We also assess the potential UV contribution from a nearby luminous companion to OMC2-FIR3. These observations suggest that differences in the ambient cloud density can alter the properties of outflows and the atomic and molecular lines used to trace them. Financial support for this work was provided by NASA through awards SOF3-0097 and SOF4-0090 and issued by USRA.

**Author(s):** S. Thomas Thomas Megeath, Mayra Osorio, Nicole Karnath, Beatriz Gonzales, Helmut Wiesemeyer, Manoj Puravankara, Ana Karla DÃ-az RodrÃ-guez, John Tobin, Elise Furlano, Friedrich Wyrowski, William J. Fischer, Dan Watson, Amelia Stutz

**Institution(s):** oIPAC, University of Toledo, TIFR, MPIfR, University of Rochester, NRAO, STScI, IAA, ESAC, Univesidad de ConcepciÃ³n

### **320.07 - Using ALMA to Push the Limits of Mapping Magnetic Fields in Protostars(Erin Guilfoil Cox)**

Magnetic fields can control star formation on all size scales. Theoretically, the local magnetic field should hinder disk growth in the youngest protostars, however, observations have revealed disks these young sources. Questions remain regarding what sizes these fields matter, as well as what their typical strength is. Recent interferometric, polarization observations of young protostars have sought to probe the morphology of the local magnetic field is on small (~80 au) scales. Complicating these observations is that scattering can be a significant source of polarized emission in these high density regions. We present an ALMA 870Åm polarization survey of 10 protostars in the Perseus Molecular Cloud. This diverse sample includes multiple disk candidates, and sources that do not have an observable disk down to telescope limits (~10 au). Our survey hints that multiple mechanisms might be dominating the polarized emission, and brings into question whether we can faithfully determine the magnetic field morphology in such high density regions.

**Author(s):** Ian William Stephens, Haifeng Yang, Erin Guilfoil Cox, Robert Harris, Leslie Looney, John Tobin, Zhi-Yun Li

**Institution(s):** University of Illinois, University of Virginia, Northwestern University, Harvard-Smithsonian Center for Astrophysics, NRAO

### **320.08 - Kepler/K2 and IGRINS constrain starspot filling factors and temperatures.(Michael Gully-Santiago)**

Kepler/K2 affirmed the unsurprising existence of stellar surface inhomogeneities on  $\sim 10^5$  stars. Increasing evidence shows that starspots can grow to over 100x their diminutive solar counterparts, sunspots. The non-negligible emission from starspots upends seemingly common-sense assumptions throughout astrophysics. In this contribution I highlight three domains in which large starspot coverage fractions alter the interpretation of existing data: age biases and spreads in young clusters, the Transit Light Source Effect (TLSE), and spectral-type mismatches in the optical and infrared. I showcase results of probabilistic spectral decomposition using custom extensions to the Starfish inference framework. High spectral resolution, high bandwidth near-infrared spectra from IGRINS are shown to detect the collective emission from large starspots and/or spot groups. I demonstrate these precision measurements on

the most conspicuously spotted benchmarks, Weak Line T-Tauri Stars in nearby young star forming clusters. I report their starspot coverage fractions and photospheric temperatures. These measurements indicate large biases in isochrone-derived ages of young stars, and inform strategies for mitigating TLSE for exoplanet characterization in the JWST era.

**Author(s):** Michael Gully-Santiago,

**Institution(s):** NASA Ames Research Center, Baeri.org

### **320.02D - The Time Variable Scattered Light Morphology of the HD 163296 Protoplanetary Disk(Evan A Rich)**

We present multi-epoch observations of the protoplanetary disk around HD 163296 with Subaru/HiCIAO and Subaru/SCEXAO along with contemporaneous infrared spectroscopic observations. We modeled our contemporaneous data with a Monte Carlo Radiative Transfer code and show that the Subaru/HiCIAO image and SED of HD 163296 are consistent with a thin disk and an optically thin envelope around the star. Our observations join a host of other images of HD 163296 taken from 2011 to 2018, which collectively exhibit clear evidence of variability in the spatially resolved scattered light disk surrounding the star. We suggest that the observed asymmetrical change in flux is caused by shadowing either from dust ejected above the plane of the disk or local warping of the disk. Finally, our SCEXAO data do not confirm the purported detection of a candidate planetary mass object located at 67 au from the central star that was reported by Guidi+ (2018) based on analysis of Keck L' observations. This research was supported by grant NNX17AF88G from NASA's Exoplanet Research Program and from HST GO-15437.

**Author(s):** Michael Sitko, John Wisniewski, Thayne Currie, Evan A Rich, Misato Fukagawa, C. A. Grady,

**Institution(s):** University of Oklahoma, University of Cincinnati, Ames Research Center, Eureka Scientific, Goddard Space Flight Center, Osaka University Contributing Team(s): SEEDS Team

### **321 - Plenary Lecture: The Climates of Other Worlds: Exoplanet Climatology as a Pathway to Accurate Assessments of Planetary Habitability, Aomawa Shields, (UC Irvine)**

#### **321.01 - The Climates of Other Worlds: Exoplanet Climatology as a Pathway to Accurate Assessments of Planetary Habitability(Aomawa Shields)**

The discovery of numerous relatively close planets orbiting low-mass stars signals a major planetary population that may be the primary environment explored in the search for life beyond the Solar System. However, many factors and processes can affect planetary climate and habitability, and their effects must be understood to accurately determine a planet's habitability potential. While three-dimensional global climate models have long been used to predict climate and weather patterns on the Earth, a growing community of researchers has begun to apply

these models to extrasolar planets. This work has provided a better understanding of how orbital, surface, and atmospheric properties affect planetary climate and habitability, and how these climatic effects might change for different stellar and planetary environments. Professor Shields will describe the methods used by her research group to quantify the effects on planetary climate of a range of factors currently unconstrained by observations. She will share recent results from this work using a hierarchy of computer models, and discuss the implications of these results for planetary habitability and the identification of those planets most capable of supporting life.

**Author(s):** Aomawa Shields

**Institution(s):** University of California, Irvine Contributing Team(s): Shields Center for Exoplanet Climate and Interdisciplinary Education (SCECIE)

### **325 - Joint AGU-AAS session on Frontiers in Exoplanets**

#### **325.01 - Planetary Atmospheres: Where do they come from? Where do they go?(Ray T. Pierrehumbert)**

Planetary atmospheres are dynamic entities. Their story begins with the inventory of volatiles delivered in the course of planet formation. Over the subsequent history of the planet, the atmosphere evolves through outgassing of volatiles from the interior of the planet, through chemical reactions between the atmosphere and the crust (sometimes with liquid oceans as an intermediary), and through escape to space. The elements making up the volatiles are rearranged into different molecules by interior geochemistry and by both abiotic and biotic chemistry within the atmosphere and near the surface. Understanding the climate and climate evolution of exoplanets requires a deeper and more general understanding of these processes. At the same time, once it becomes possible to characterize the atmospheres of a large number of rocky exoplanets, radically new opportunities for testing theories of atmospheric evolution will come into view. This talk will introduce some key problems in planetary climate in which engagement with the Earth Science disciplines on the matter of volatile exchange between planetary interiors and atmospheres is crucial. The first is the deep carbon cycle, which is one of the key constraints that determines how much carbon dioxide is in a planet's atmosphere. The relevant geophysics and geochemistry involve mantle convection, mantle chemistry, plate tectonics, volcanism and weathering processes both on continental surfaces and the seafloor. These enter in a crucial way into the determination of the outer edge of the conventional liquid-water habitable zone, and into the lifespan of a planet's habitability. It is argued, for example, that the proportion of long-lived radionuclides delivered to a planet is the key determinant of the lifespan of habitability for planets around low-mass stars. A key open question is whether planets without plate tectonics can maintain habitability. The second topic concerns the nitrogen cycle, and the third concerns magma oceans and their influence on the subsequent evolution of a planet.

**Author(s):** Ray T. Pierrehumbert

**Institution(s):** University of Oxford

### **325.02 - The Search for Other Earths(Giada Arney)**

The search for habitable and inhabited exoplanets is underway. These efforts will increase in coming years and decades as more powerful observatories capable of characterizing potentially habitable rocky planets become available. Observatory designs and search strategies aimed at discovering life on exoplanets must be informed by comprehensive analyses of the remotely observable properties produced by diverse habitable environments and biospheres. Would we recognize a habitable exoplanet if its spectrum was dramatically different compared to Earth's? Would we recognize biosignatures on worlds dominated by unfamiliar metabolisms? Earth's history reminds us that our own planet has not always looked the way it does today: the dominant metabolisms and environmental conditions on our planet have changed over its geological history. Early Earth is the only "alien" globally habitable and inhabited planet for which we have data, so exploring Earth's evolution over time can widen our perspective on the types of life-sustaining environments and biosignatures known to be possible. For example, Archean Earth (4-2.5 billion years ago) may have occasionally hosted a global organic haze in its atmosphere formed from methane photochemistry. This haze would have dramatically impacted Earth's spectral appearance and habitability; organic haze can even be a biosignature in some circumstances. In addition, Earth's atmosphere was anoxic for about half of our planet's history, but oxygen is generally considered the canonical biosignature of modern Earth. The challenges and opportunities of detecting life on planets with no or low oxygen levels is vitally important to consider when seeking inhabited exoplanets. We are separated from exoplanets by vast interstellar distances, and we are separated from early Earth by a vast gulf of time; yet just as spectra provide evidence of alien environments on exoplanets, the rock record provides a direct window into Earth's "alien" past.

**Author(s):** Giada Arney

**Institution(s):** NASA Goddard Space Flight Center

### **325.03 - Planetary Interiors and Evolution(Anat Shahar)**

Observations of exoplanets and planet hosting stars indicate that the composition of exoplanets should vary widely, in terms of volatile content, heat producing elements, and bulk mantle mineralogy. However, the implications of planet composition for internal dynamic processes that are essential to habitability are almost entirely unexplored. Composition is central to how a planet forms and evolves, and is the starting point for understanding what makes a planet habitable. The bulk composition can be broken down into three components: 1) major elements, 2) volatile elements, and 3) heat-producing radioactive elements. Each of these compositional components

plays a first order role in controlling the surface atmosphere and ocean state, internal structure, tectonic state, recycling efficiency, and magnetic field generation. Each of these components, in turn, have a direct impact on the habitability of the surface - providing a favorable environment for life to emerge and thrive over billions of years. While we are far away, experimentally, from understanding how composition plays a role in planetary formation and evolution, experiments are now able to reach the pressures and temperatures needed to probe exoplanetary interiors. Experiments such as these are needed in order to fully interpret the observations of exoplanets (mass, radius, and possibly atmosphere). Research is underway to conduct high pressure and temperature experiments both in the laboratory and at national facilities through static and dynamic compression studies. These experiments will lead to a new understanding of material properties at extreme conditions and be essential inputs into models probing planetary interiors. There are many questions regarding the formation and evolution of exoplanets and many exciting opportunities for scientists to work together. In order to truly understand how composition and internal evolution lead to a habitable surface, a multi-disciplinary approach is key, whereby astronomers, geophysicists, and geochemists work together towards a common scientific goal. Through the combination of observations, experiments, and theoretical calculations, a new understanding of planetary evolution will begin to emerge.

**Author(s):** Anat Shahar

**Institution(s):** Geophysical Laboratory, Carnegie

## **326 - Extrasolar Planets: Characterization & Theory Track 1: XII. Toward Terrestrial Exoplanet Characterization**

### **326.01 - Constraining M Dwarf Planetary System Lifetimes with the TESS Yield(Sarah Ballard)**

There exist conflicting hypotheses about the longevity of M dwarf planetary systems over Gyr timescales. This question bears upon the potential for M dwarf systems to evolve and sustain life. While some dynamical studies conclude that TRAPPIST-like systems of many planets in circular orbits are long-term stable (~20% of M dwarfs host such a system), other hypothesize that such systems self-disrupt (resulting in the remaining 80% of systems). If indeed an average system of M dwarf planets eventually self-excites, it stands to reason that dynamically cooler systems ought to be younger on average. We propose an observational mechanism to test the hypothetical disruption timescale of M dwarf planetary systems. Using the TESS yields of planets orbiting M dwarfs, we will be able to test whether self-disruption is a likely mechanism for these planetary systems, or whether they are long-term stable over evolutionary timescales after formation.

**Author(s):** Sarah Ballard

**Institution(s):** MIT

### **326.02 - Synchronously Rotating Ocean Earths Around Cool Stars: What to ExPECTRA(Gabrielle Engelmann-Suissa)**

The hunt for ocean-covered, Earth-sized exoplanets is rapidly gaining attention because of these planets' exciting potential and implications for habitability. Understanding the atmospheres of these planets and determining the optimal strategy for characterizing them through transmission spectroscopy with our upcoming instrumentation is essential if we are ever to constrain the environments of these ocean worlds. For this study, we present simulated transmission spectra of tidally locked Earth-like planets around M and K stars, utilizing GCM modeling results for ocean planets previously published by Kopparapu et al. (2017) as inputs for our radiative transfer calculations performed using NASA's Planetary Spectrum Generator ([psg.gsfc.nasa.gov](https://psg.gsfc.nasa.gov); Villanueva et al. 2018). We identify trends in the expected transmission spectral signal of H<sub>2</sub>O features. In particular, we find that planets undergoing runaway water loss lack observable spectral features, while non-runaway planets share a consistent amplitude of their H<sub>2</sub>O features across a range of incident stellar fluxes. These trends allow us to calculate the exposure times necessary to detect water vapor in the atmospheres of ocean-worlds with the upcoming James Webb Space Telescope (JWST) as well as several future flagship space telescope concepts under consideration (LUVOIR, HabEx and OST) for the brightest M- and K-type stars from the TESS Input Catalog (TIC). Our calculations reveal that only a small subset of potentially detectable ocean planets in the habitable zones of cool stars may have realistic exposure times. We thus present a careful prioritization of targets that are most amenable to follow-up characterizations with next-generation instrumentation, in order to assist the community in efficiently utilizing precious telescope time.

**Author(s):** Eric T Wolf, Gabrielle Engelmann-Suissa, Ravi Kopparapu, Avi M Mandell, Geronimo L Villanueva

**Institution(s):** Columbia University, University of Colorado Boulder, NASA Goddard Space Flight Center

### **326.03 - Modeling Super-Earth Atmospheres in Preparation for Upcoming Extremely Large Telescopes(Maggie Thompson)**

We present the current state of our flexible exoplanet atmosphere modeling tool that can solve for radiative-convective equilibrium for arbitrary exoplanet atmospheres, with a focus on characterizing super-Earth-sized (1-4 Earth Radius) planets around M, K and G stars. Simulating the pressure-temperature structure and visible and thermal spectra of a planet's atmosphere, we use the code to determine, of the currently confirmed exoplanets, which ones will be prime targets for observations on the upcoming Extremely Large Telescopes, especially the Planetary Systems Imager (PSI) planned for the Thirty Meter Telescope (TMT), in particular with J-band (1.25 microns) reflected light and thermal infrared. Currently in the design phase, PSI's 2-5 micron instrument

(PSI-Red) is a planned science instrument for TMT and will have the ability to collect low-, medium- and high-resolution spectroscopy via integral field spectrographs. Using our modeling tool to create a suite of model super-Earth-like planets composed of various elemental abundances at varying distances from a variety of host star spectral types, we also analyze which of these model planets will be detectable and at which wavebands with TMT's PSI.

**Author(s):** Steph Sallum, Tyler Robinson, Andrew J Skemer, Maggie Thompson, Jonathan Fortney, Theodora Karalidi

**Institution(s):** University of California, Santa Cruz, Northern Arizona University

### **326.04 - Comparisons of polarised light signatures from terrestrial planets(Kimberly Bott)**

The detection of oceans and the characterisation of terrestrial worlds is central to understanding whether other planets are likely habitable, and thus to estimating the probability of life existing on those worlds. The method of polarimetry shows promise for exoplanet characterisation with advancements in instrumentation in the last decade—even in the face of limited funding—providing scientists with a means to detect polarized light from the atmospheres of gas giants. While previous models of terrestrial planets in polarised light exist, these are often simplified with Lambertian (non-polarising) surfaces, or idyllic atmospheres. We aim to model a comprehensive signal that includes complete treatment of ground covers and liquid surfaces, clouds, and self-consistent, realistic atmospheres in combination. The purpose of this is to determine if these signatures are readily distinguishable and measurable with near-future instruments. Using the VSTAR radiative transfer solver's updated polarimetric capabilities and the suite of planet outcomes predicted for terrestrial and super Earth worlds (see Meadows 2017 for a review) we produce predictive signatures for habitable and non-habitable small worlds around sun-like stars and M-dwarfs. We find that in some of these cases, detections of the atmosphere and possibly ocean glint are likely only 1-2 orders of magnitude beyond current polarimetric capabilities, suggesting advances in instrumentation over the next decade—if akin to the rate of advancement in the last—might make this a viable means of characterisation if noise sources can be well characterised.

**Author(s):** Victoria Meadows, Andrew Lincowski, Kimberly Bott, Ilyana Guez, Lucyna Kedziora-Chudczar, Jeremy Bailey

**Institution(s):** University of Washington, UNSW Australia, Virtual Planetary Laboratory

### **326.05 - Retrieving Biosignatures in the Mid-Infrared(Luke Tremblay)**

With the forecasted increase of temperate terrestrial exoplanets soon to be discovered by TESS, it is pertinent to begin questioning the nature and diversity of their atmospheres, as well as the plausibility of detecting signs of life. While previous



studies have attempted to produce predictive models of plausible atmospheric compositions, very little work has been done to quantify the observational requirements necessary to probe the indicators of habitability on these planets. Through well-established atmospheric retrieval techniques, we establish constraints on temperature structure and molecular composition using transmission spectra of an Earth-like atmosphere orbiting an M-dwarf. Specifically, we explore the parameter spaces over spectral resolution, wavelength range, and aperture size on our ability to constrain apparent surface temperature and the abundances of six key molecules (H<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub>, O<sub>3</sub>, N<sub>2</sub>O, and CO) thought to impact habitability. In the context of JWST, we determine the optimal observational configuration for making definitive detections of biosignatures in an Earth-like atmosphere and ascertaining the atmospheric conditions conducive to life.

**Author(s):** Caroline Morley, Michael R. Line, Robert Thomas Zelle, Tiffany Kataria, Luke Tremblay, Jonathan Fortney, Kevin Stevenson

**Institution(s):** Arizona State University, Space Telescope Science Institute, Jet Propulsion Laboratory, University of Texas - Austin, UC - Santa Cruz

### **326.06 - Cassini Phase Curves of the Galilean Satellites and Implications for Direct-Imaging of Icy Exoplanets(Laura Mayorga)**

Direct observation of the disk-integrated brightness of bodies in the Solar System, and the variation with illumination and wavelength, is essential for both planning imaging observations of exoplanets and interpreting the eventual datasets. In my previous work, I used the Imaging Science Subsystem cameras aboard Cassini to determine the disk-integrated and wavelength-dependent variations of Jupiter, which will serve to inform observations of gas-giant exoplanets. Here, I present the derived phase variations of the four Galilean satellites, which may be useful proxies for icy exoplanets with little or no atmosphere and will help constrain surface contamination in patchy cloud scenarios. The data span a range of wavelengths from 400 - 950 nm and predominantly phase angles from 0 - 140 degrees. Despite the similarity in size and density between the moons, surface inhomogeneities result in significant changes in the disk-integrated reflectivity with planetocentric longitude and phase angle. This implies that future exoplanet observations could exploit this effect to deduce surface variations, determine rotation periods, and infer surface composition. This work was supported by the Harvard Future Faculty Leaders Postdoctoral fellowship.

**Author(s):** Laura Mayorga

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

### **326.07 - Segmented-Aperture Coronagraphy for Exo-Earth Direct Imaging: Design and Demonstration(Brendan Crill)**

The search for life in the Universe is a priority for NASA Astrophysics, embodied in the question "Are we alone?" The 2018 National Academies' Exoplanet Science Strategy final report recommends a future NASA mission to perform reflected light spectroscopy on terrestrial planets in the habitable zone of Sun-like stars. This mission would require starlight suppression technology, such as a coronagraph. The entrance pupils of large space telescopes of the future are likely to be segmented like JWST and/or obscured by secondary mirror support structures, presenting additional challenges for a coronagraph to achieve the necessary contrast, throughput, and stability performance. We report on the current status and future plans for two of the efforts by NASA's Exoplanet Exploration Program to enable the design and demonstration of segmented-aperture coronagraph technology: 1. the Segmented Coronagraph Design and Analysis (SCDA) study and 2. the Decadal Survey Testbed (DST) in JPL's High Contrast Imaging Testbed facility. The SCDA aims to develop designs for coronagraphs capable of discovering and characterizing terrestrial exoplanets, and analyze their robustness to finite stellar diameter, telescope wavefront errors and stability, and polarization. The DST, currently being commissioned, will provide a facility stable enough for laboratory demonstrations of coronagraphs at an unprecedented 10<sup>-10</sup> contrast over a 10% bandwidth, first with a clear aperture and later with a segmented pupil. Both efforts will support the technology development efforts of on-going mission concept studies such as HabEx and LUVOIR as well as inform the upcoming 2020 Decadal Survey of the technology readiness of exo-Earth direct-imaging.

**Author(s):** Keith Patterson, Brendan Crill, Stuart Shaklan, Nicholas Siegler, Camilo Mejia Prada

**Institution(s):** Jet Propulsion Laboratory, California Institute of Technology

### **326.08 - Building the Future: The NASA in-Space Assembled Telescope Study(Nicholas Siegler)**

The recent top recommendation of the National Academies' Exoplanets Science Strategy Report for NASA to commission a telescope capable of directly imaging exoplanets and conducting reflection spectroscopy opens up the possibility that a large aperture telescope may also be recommended by the 2020 Decadal Survey. While large apertures offer the possibility of greater exoplanets yield the current paradigm of folding large telescope into smaller fairings and deploying them from single launch vehicles also pose the risk of great cost and risk. An alternative to the current paradigm is assembly in space where the telescope and its instruments are architected as a collection of individual modules capable of being robotically assembled. Multiple medium-lift commercial launch vehicles would then be used to transport the modules to a space platform and orbit where the assembly and checkout would occur. This talk will present the current status of a NASA Astrophysics Division

chartered study whose objective is to assess the cost and risk benefits, if any, of this new paradigm. The key deliverable of this Study is a white paper submitted to the Decadal Survey Committee.

**Author(s):** Harley Thronson, Rudranarayan Mukherjee, Nicholas Siegler

**Institution(s):** Jet Propulsion Laboratory, NASA

### **326.09 - Observing Exoplanets with a Ground-Based Telescope and Orbiting Starshade(John C. Mather)**

An orbiting starshade could work with adaptive optics on a ground-based telescope to enable imaging and spectroscopic observation of Earth-like planets and planetary systems around Sun-like stars. With 30 m class telescopes in both hemispheres, the entire sky is observable with exposure time spans from minutes for imaging to hours for spectroscopy per Earth-like target system at 10 pc distance. With ~ 70 sun-like stars (F, G, and K classes) within 10 pc, we could observe hundreds of planets with imaging and spectroscopy, to determine chemical composition and learn how many resemble Earth. The higher angular resolution of the starshade - ground telescope combination can enable science that is not accessible with smaller space telescopes, and could potentially be implemented much sooner.

**Author(s):** Eliad Peretz, John C. Mather

**Institution(s):** NASA Goddard Space Flight Center

### **327 - Extrasolar Planets: Characterization & Theory Track 2: XI. Deep Searches in Kepler and K2 Light Curves**

#### **327.01 - A Search for Transiting Planets in NGC 6791(Benjamin Montet)**

Planets in clusters with known ages and metallicities provide essential information about how environment effects the formation and evolution of planetary systems. NGC 6791, an 8 billion year old cluster with iron abundance twice that of the Sun, is one such cluster; understanding differences in planet occurrence between this cluster and the field can inform us both about the role metallicity plays in planet formation and the long-term dynamical evolution of planetary systems. This cluster was in the Kepler field of view, but due to the relatively high stellar density and low resolution of Kepler, light curves were never produced for the vast majority of stars in NGC 6791. Rather than using a standard aperture photometry approach, here we employ a model of the Kepler pixel response function to recover the brightness of thousands of stars in NGC 6791 observed by Kepler throughout the mission, which we search for planets. We identify several planet candidates in this dataset as well as previously unknown eclipsing binaries in the cluster, including the highest eccentricity eclipsing binary ever discovered. We discuss the implications of these results in the context of the long-term evolution of planetary systems.

**Author(s):** Benjamin Montet

**Institution(s):** University of Chicago

#### **327.03 - Identifying Exoplanets with Deep Learning: Towards Improved Planet Occurrence Rates with Kepler, K2, and TESS(Andrew Vanderburg)**

Robustly measuring the occurrence rates of different classes of planets, and in particular, potential Earth analogs, is a major goal of astronomers. A crucial ingredient for calculating occurrence rates is the automatic detection, identification, and vetting of planet candidates so that biases due to a given survey's incompleteness and false positive rate can be measured and corrected. We present new work to automatically identify exoplanet candidates using deep learning, a cutting edge machine learning technique. I will present results using Kepler data, including the discovery of the first system with eight exoplanets, and will discuss the prospects for using similar techniques on data from K2 and TESS. This work could yield improvements on the occurrence rates measured from Kepler data, and will enable occurrence rate calculations for planets orbiting different types of stars and in different galactic environments with K2 and TESS data.

**Author(s):** Christopher Shallue, Liang Yu, Andrew Vanderburg, Anne Dattilo, Alex Tamkin

**Institution(s):** University of Texas at Austin, Massachusetts Institute of Technology, Google, Stanford University

#### **327.06 - EPIC 247418783 b: A rocky super-Earth in a 2.2 day orbit.(Molly Kosiarek)**

From K2 C13 data, we found one super-Earth planet transiting a solar type star, EPIC 247418783, on a short period orbit. We followed this system up with adaptive-optic imaging and spectroscopy to derive stellar parameters, search for stellar companions, and determine a planet mass. From our 75 radial velocity measurements using HIRES on Keck I and HARPS-N on Telescopio Nazionale Galileo, we constrained the mass of EPIC 247418783 b to five sigma. We found it necessary to model correlated stellar activity radial velocity signals with a Gaussian process in order to more accurately model the effect of stellar noise on our data; the addition of the Gaussian process also improved the precision of this mass measurement. This planet is consistent with an Earth-like rock/iron composition and no substantial gaseous envelope. Such an envelope, if it existed in the past, was likely eroded away by photo-evaporation during the first billion years of the star's lifetime.

**Author(s):** Emilio Molinari, David W Latham, Adrien Coffinet, Damien Segransan, Chris Watson, Annelies Mortier, Christophe Lovis, Francois Bouchy, Stephane Udry, Lars A. Buchhave, Mercedes Lopez-Morales, Mario Damasso, Luca Malavolta, Ian Crossfield, Ennio Por

**Institution(s):** Queen's University Belfast, o University of Copenhagen, INAF - Osservatorio Astronomico di Palermo, INAF - Osservatorio Astronomico di Cagliari, University of Edinburgh, University of California, Santa Cruz, California

Institute of Technology, Unive

### **327.07 - A Pursuit of Optical Phase Curves with K2(Prajwal Niraula)**

We have systematically searched for the planetary phase curves among the planets discovered by K2. Using the planetary parameters, we filter out the best candidates, and examine their light curves in detail for the potential presence of the phase curve. For our work, we consider light curves from two different detrending pipelines - EVEREST and K2SFF. In order to remove any stellar and systematics, we use different flattening techniques and perform a detailed injection-retrieval test in order to understand the reliability and completeness of our pipeline to extract the phase curve. In this talk, we report potential phase curves for five planets observed with K2, two of which appear to be robust. However, we find the phase curve fit parameters are not consistent with the known RV masses, and therefore dive deeper into the reasons why such discrepancies could arise and potential ways for mitigating them.

**Author(s):** Julien deWit, Fei Dai, Prajwal Niraula, Ismael Mireles, Seth Redfield, Dilovan Serindag

**Institution(s):** MIT, Princeton, Wesleyan University, Leiden University

### **327.02D - Planetary Archaeology: A Search for Transiting Planets Orbiting Evolved Stars with K2(Samuel Grunblatt)**

While the Kepler mission discovered thousands of planets around main sequence stars, red giant stars were largely unexplored. A sample of transiting planets around these more evolved stars can test theories of giant planet inflation and migration, problems that have gone unsolved for more than 20 years. For my thesis, I searched for transits around red giant stars with the K2 Mission to reveal the effects of stellar evolution on planet inflation, migration, and occurrence. My survey increased the number of confirmed transiting planets around red giant stars by more than 50%. Comparing these and similar planets orbiting main sequence stars to planet evolution models revealed that planets orbiting red giants can be re-inflated by the rapid evolution of their host stars. Additional followup measurements of this population showed that these planets preferentially reside on moderately eccentric orbits, suggesting that stellar evolution can also result in inward planet migration and orbit circularization. This is supported by my most recent finding that red giant stars host significantly more super-Jupiter-sized planets than main sequence stars at orbital periods of 10 days or less. Together, these results provide a clearer view of how star-planet interaction drives planet evolution. Soon, the TESS Mission will shed new light on unexplored dimensions of this interaction with its predicted discovery of an order of magnitude more transiting planets orbiting evolved stars over the next two years.

**Author(s):** Samuel Grunblatt, Eric Gaidos, Daniel Huber, Eric

D. Lopez

**Institution(s):** University of Hawaii, Goddard Space Flight Center

### **327.04D - Planets in Binary Star Systems(Lea Hirsch)**

Nearly half of all solar-type stars have at least one stellar or brown dwarf companion, and planets around G- and K-type stars appear to be quite common. Yet the impact of stellar multiplicity on planet formation and evolution is not well understood. In this talk I will describe a simultaneous radial velocity (RV) and imaging survey for both stellar and planetary companions to a volume-limited sample of sun-like stars within 25 pc. By comparing the planet occurrence rates in binary systems to those in single star systems, the effects of stellar companions on planet formation can be assessed. The results of this survey demonstrate that the occurrence rate of planets with masses between 0.1 and 10 Jupiter masses, and with semi-major axes between 0.1 and 10 AU, is statistically equivalent in single star and binary star systems. However, all of the planet-hosting binary systems in the 25 pc sun-like star sample have binary separations wider than 100 AU. We conclude that binary companions with separations of hundreds of AU do not seem to strongly impact the planet formation process. Follow-up work with larger sample sizes and detailed attention to our observational sensitivity to planets in close binary systems is needed to confirm the hypothesis that binaries with separations 10 - 100 AU more strongly impact the planet formation process.

**Author(s):** Lea Hirsch, David Ciardi, Andrew Howard

**Institution(s):** Stanford University, Caltech, University of California Berkeley, Caltech/IPAC-NExSci

## **329 - Theoretical Advances Guided by Radio-Millimeter-Submillimeter Arrays**

### **329.01 - The Scientific Impact of Radio-Millimeter-Submillimeter Facilities.(Anthony Beasley)**

Over the last decade, theoretical frontiers have opened on numerous scientific fronts, based on high quality radio and millimeter data delivered by the National Science Foundation's Karl G. Jansky Very Large Array (VLA) and the Atacama Large Millimeter/submillimeter Array (ALMA), and mm/submillimeter interferometers and single-dish telescopes around the world. In this brief introductory talk, a survey of recent science outcomes and current/upcoming instrumental capabilities will be presented, reviewing the observational constraints and inspirations driving theoretical research lines in the field, and motivating the great observatories that will be commissioned in the next decade.

**Author(s):** Eric Joseph Murphy, Anthony Beasley, Mark McKinnon

**Institution(s):** NRAO

### **329.02 - Astrophysical Jets: Formation, Evolution, and Environmental Impact(Roger Blandford)**

The first astrophysical jet was discovered over a century ago. Since then, we have learned much from observation, theory and simulation. We know that jets are many types of source and emit throughout the electromagnetic spectrum and are quite possibly sources of neutrinos and Very High Energy Cosmic Rays. In this talk I shall concentrate on magnetized, relativistic jets formed by massive, spinning black holes in Active Galactic Nuclei. I will argue that while the black hole spin is necessary for jet formation, it is insufficient and that it is the nature of the inflow at the black hole radius of influence that determines if magnetic flux is trapped and magnetic field is concentrated by the orbiting accretion disk that determines if the AGN is radio loud or quiet. The case that these jets are primarily collimated by strong hydromagnetic winds that carry away energy, angular momentum and mass from the disk and that the observed radio and millimeter emission close to the hole comes from a boundary layer between the jet and the wind. I will also review the evidence that it is the nature of the flow in the vicinity of this radius that dictates if the morphology is of FR I or II type and that, in the latter case, the supersonic jet that emerges is likely to be inertial rather than electromagnetic. It will further be argued that the gamma rays observed from blazars and some other sources are synchrotron and not Compton radiation, following the acceleration of protons to EeV energies and photo-pair production. The blazar sequence and radio core-shifts can be interpreted in these terms. Observable implications of this set of ideas will be sketched and the implications for other classes of jet from those associated with protostars, gamma ray bursts, pulsar wind nebulae and binary X-ray sources will be mentioned. I will conclude with an exploration of the role of AGN jets in promoting and inhibiting star formation as well in limiting the inflow of gas.

**Author(s):** Roger Blandford

**Institution(s):** KIPAC, Stanford University

### **329.03 - Galaxies: Mechanisms of Galaxy Formation and Evolution(Claudia del P Lagos)**

The advances in the technology and availability of radio, millimeter and submillimeter arrays in the last decades have enabled important observational results to be established in the area of galaxy formation and evolution. These observations have triggered a massive effort in the theory and simulations community to improve several aspects of the modelling of galaxy formation, most notably in the areas of active galactic nuclei feedback, star formation and interstellar medium in galaxies. During this talk I will present highlights of those improvements and describe how observations have enabled these developments. I will particularly focus on the area of star formation quenching in massive galaxies, and the gas content of galaxies and the Universe across time. I will end by discussing which future radio observations are key to test our understanding of galaxy formation and the interaction with the formation of structures in the Universe.

**Author(s):** Claudia del P Lagos

**Institution(s):** University of Western Australia

### **329.04 - Planet Formation: Peering into the Dust & Gas that Forms Rocky Worlds(Luca Ricci)**

The discovery of thousands of exoplanets over the last couple of decades has shown that the birth of planets is a very efficient process in nature. Theories invoke a multitude of mechanisms to describe the assembly of planets in the disks around pre-main-sequence stars, but observational constraints have been sparse on account of insufficient sensitivity and resolution. Understanding how planets form and interact with their parental disk is crucial also to illuminate the main characteristics of a large portion of the full population of planets that is inaccessible to current and near-future observations. In this talk I will describe the critical contribution expected in this field by the Next Generation Very Large Array.

**Author(s):** Luca Ricci

**Institution(s):** California State University, Northridge

### **329.05 - Astrochemistry: Building Potentially Habitable Worlds(L. Ilse-dore Cleeves)**

Protoplanetary disks are the birthplaces of planetary systems. In recent years the unprecedented sensitivity of ALMA has revealed a wide variety of observed structure in both the continuum and spectral lines. From source-to-source there is also a great deal of variation in both the strength and emission morphology of various molecular lines coming from the disk, hinting at an active disk chemistry during planet formation even for simple molecules. However, ALMA has also uncovered large continuum (and line) optical depths and correspondingly weak line emission in the inner disk ( $<10\text{--}20$  AU). To characterize the solid budget and volatile composition where terrestrial, and potentially even habitable, planets are forming, longer wavelength observations at high sensitivity -- such as anticipated by the ngVLA -- are complementary and necessary.

**Author(s):** L. Ilse-dore Cleeves

**Institution(s):** University of Virginia

### **329.06 - Multi-Messenger Astrophysics: Modeling Explosive Transients(Davide Lazzati)**

The detection of GW170817 in gravitational waves and multiwavelength electromagnetic radiation has opened a new era in multimessenger astrophysics. In this talk, I will review the importance of radio observations in modeling the high-velocity outflow from merger events. The propagation of a relativistic jet through a static ambient medium drives a bow shock that feeds a cocoon around the jet itself. As the jet breaks out, the cocoon is released, adding a mildly relativistic, wide angle component to the outflow. I will discuss the dynamics and radiative properties of the ensuing structured jet, considering

both radiation from the outflow itself (the so-called prompt emission) and radiation produced by the interaction of the outflow with the interstellar medium (the so-called afterglow). The resulting electromagnetic transients will be discussed as possible interpretations for the observations of GW170817 as well as possible counterparts of future binary merger detections.

**Author(s):** Davide Lazzati

**Institution(s):** Oregon State University

## **330 - AGN Feedback II**

### **330.01 - AGN and galaxy properties in post merging galaxies(Preethi Nair)**

Understanding the mechanisms which trigger AGN and the role of these AGN in galaxy evolution, specifically feedback and quenching is a highly debated area of study. The variation in the observed frequency of AGN in different merger phases (wide/close pairs, merger remnants) are due to a number of factors including obscuration, time delays between triggering and the AGN turning on, AGN lifetimes, AGN detection and luminosities. This overall interdependence of AGN luminosities and lifetimes impacts any correlation that should be seen between merger signatures and AGN frequency. Here we investigate a volume limited sample of post merger galaxies, spanning the blue cloud to red sequence whose merger lifetimes are theoretically expected to be similar to the AGN lifetimes. We will present results on the AGN fraction in this phase and the relationships between AGN luminosity and host galaxy properties.

**Author(s):** Jimmy Irwin, Preethi Nair, Sara L Ellison, Shobita Satyapal

**Institution(s):** The University of Alabama, George Mason University, University of Victoria

### **330.04 - AGN variability using optical and WISE photometry(Abhishek Prakash)**

The growth of super-massive black holes (SMBH) and their connection to galaxy evolution is one of the pressing topics in modern astrophysics. Active galactic nuclei (AGN) are powered by the accretion of matter onto the SMBH, hence are a crucial tool to understand the formation and growth of SMBHs over cosmic time. AGN can exhibit flux variation on timescales ranging from minutes to years over the entire electromagnetic spectrum. The underlying physics of the variability is not clearly understood. It is suggested that on short timescales, disk instabilities play a significant role, while on longer timescales, the fueling of gas into the nuclear regions and regulation through feedback processes dominates. AGN feedback is expected to have a significant impact on the star formation of the host galaxy. A major contribution to the ultraviolet (UV) - near-infrared (NIR) part of the Spectral Energy Distribution (SED) of an AGN is produced is by the innermost regions of the accretion disk. The dusty region at larger distances from the accretion disk, often referred as the 'dusty torus' absorbs the

light of the accretion disk and re-emits it in the mid-infrared (MIR), dominating the SED at wavelengths longer than  $\sim 1.0$  micron. The variability of AGN not only places size limits on the accretion disk but also inform about gas inflows that power the AGN. To be explored further, a combination of observations in the time-domain and across multiple wavelengths is necessary. In this talk, I will present a statistical analysis of AGN variability using optical and MIR (WISE) light curves and focus on a MIR variable AGN J030654.88+010833.6 discovered in WISE data in Stripe 82 field. The extreme MIR variability shown in WISE W1 and W2 filters is not seen in the optical light curve taken over overlapping time. It has a bright optical, IR, radio, and a faint ultraviolet source associated with it. SED fitting using photometric observations identifies this source as a ULIRG undergoing intense star formation at  $z = 0.32$ . This object provides a rare opportunity to put important constraints on the growth of SMBHs and their connection to galaxy evolution at late cosmic times.

**Author(s):** Abhishek Prakash, George Helou, Ranga-Ram Chary

**Institution(s):** California Institute of Technology

### **330.05 - X-ray Emission from the NLR of NGC 4151: the Chandra/HETG view(Steven Kraemer)**

We present an analysis of the X-ray emission line spectrum of NGC 4151, based on a 240 ksec Chandra/HETG observation from Feb and March of 2014. The source was in a low-flux state, which simplified the isolation of the individual emission features. We detected H- and He-like lines and radiative recombination continuum from O, Ne, Si, Mg, and S. Inner shell lines were detected from Fe, S, and Si. The data were fit with Cloudy models, using three components with ionization parameters and column densities ( $\log U/\log NH$ ) of 0.99/22.5, 0.20/22.5, and -0.30/23.0. Using the Delta R/R constraint, the three components lie within 10 pc of the central Black Hole. However, based on the zeroth-order images, we find that the He-like emission is extended to at least 200pc, in agreement with previous Chandra/ACIS results. Assuming density laws similar to that determined for the optical NLR, we obtain a total mass of emission-line gas of several  $\times 10^5 M_{\odot}$ . We measure outflow velocities  $\sim 200$  km/sec, in agreement with the XMM/RGS results. Hence, the X-ray emission line gas is a major component of mass outflow in NGC 4151.

**Author(s):** Steven Kraemer, T. Jane Turner, D. Michael Crenshaw

**Institution(s):** Catholic University of America, Georgia State University, UMBC

### **330.02D - The Supermassive Black Hole Mass of NGC 4151 from Stellar Dynamical Modeling(Caroline A. Roberts)**

We use archival Gemini NIFS data of the weakly barred galaxy NGC 4151 to constrain the nuclear stellar and gas kinematics for

determination of the supermassive black hole mass (MBH) and exploration of ionized gas feedback from the active galactic nucleus (AGN). Studies of black holes at the centers of galaxies and their feedback when active are key to explaining scaling relationships (which compare two properties of the objects, often MBH and details of another galaxy component such as the bulge) and integral to understanding cosmological models and galaxy evolution. We implement stellar dynamical modeling for determining MBH using spatially-resolved spectral observations of the nucleus of the galaxy to constrain the line-of-sight velocity distribution of stars at each location. The kinematic data are then modeled to determine the most likely gravitational potential, from which MBH is obtained. The gas kinematics are constrained from the emission lines in the same data as the stellar kinematics. NGC 4151 has been studied in the past with both stellar dynamical modeling and reverberation mapping, which is the most commonly used method for determining MBH in active galaxies. Application of more than one MBH determination method to individual objects is a means to confirm the validity of the individual procedures; NGC 4151 is one of only about a dozen objects that can be studied with multiple methods. Furthermore, at this time, all objects whose MBH are found through stellar dynamical modeling are treated with modeling codes that are unable to deal with the strong flattening and frame rotation of barred disk galaxies. Our work prepares the data for its future use with a bar orbit superposition stellar dynamical modeling code that is currently being developed. When applied, this will be the best comparison of MBH determination techniques to date. Improved understanding of MBH measurements and AGN outflows in the local universe will inform our understanding of black hole and galaxy co-evolution.

**Author(s):** Merida Batiste, Christopher A. Onken, Misty Bentz, Eugene Vasiliev, Caroline A. Roberts, Monica Valluri

**Institution(s):** Georgia State University, University of Cambridge, University of Michigan, Emory University, Australian National University

### **330.03D - Feeding vs Feedback in the Narrow Line Region: the Morphology and Kinematics of Mrk 3(Crystal L. Gnilk)**

We present an analysis of the morphology and kinematics of the narrow-line region (NLR) and surrounding host galaxy of the nearby ( $z=0.013509$ ) Seyfert 2: Mrk 3. The NLR of Mrk 3 is composed of several overlapping and spatially-defined emission-line knots that together form a characteristic backwards “S” shape. Using observations from Gemini North’s Near-infrared Integral Field Spectrograph (NIFS), we map the kinematics of both ionized and molecular gas within these knots, tracing active galactic nuclei (AGN) outflows as well as fueling flows. We compare these kinematics to those from the host disk with observations from Apache Point Observatory’s (APO) 3.5m Dual-Imaging Spectrograph (DIS). These observations, combined with an additional data treatment procedure and a Bayesian multi-component gaussian fitting routine, reveal a misaligned gas disk. This misalignment is

likely due to a tidal stream flowing from a nearby gas-rich spiral, UGC 3422. We explore the impact of this encounter on the NLR of Mrk 3 and compare our results to other spatially resolved observations of AGN NLRs. We find vast differences in the sizes and strengths of the AGN outflows and in the structure and sources of the NLR fueling flows.

**Author(s):** Crystal L. Gnilk

**Institution(s):** Georgia State University

### **330.06D - Quasar hosts unveiled by high angular resolution techniques(Andrey Vayner)**

We present a multi-wavelength survey of distant ( $1.3 < z < 2.6$ ) luminous quasars to study their host galaxies using the integral field spectrograph (IFS) OSIRIS and the Keck laser guide star adaptive optics (LGS-AO) system, ALMA, HST and VLA. Studying distant quasar host galaxies is essential for understanding the role of active galactic nuclei (AGN) feedback on the interstellar medium (ISM), and its capability of regulating the growth of both the galaxy and the supermassive black hole (SMBH). The combination of LGS-AO and OSIRIS affords the necessary spatial resolution and contrast to disentangle the bright quasar emission from that of its faint galaxy. We can resolve the nebular emission lines  $H\beta$ , [OIII], [NII],  $H\alpha$  and [SII] at a sub-kiloparsec resolution to study the distribution, kinematics, and dynamics of the warm-ionized ISM in the host galaxy. One of the primary survey goals is to discover and study ionized outflows and relate their spatial extent and energetics to the star-forming properties of the host galaxy. Combining ALMA and OSIRIS, we can directly test whether outflows detected with OSIRIS are affecting the molecular ISM. In approximately 70% of our sample, we detect extended ionized outflows on 1-12 kpc scale. In half of these targets, a significant fraction of the galaxy’s gas mass is within the ionized outflows. For the systems where we can measure the mass of the host galaxies, we find that they reside off the local scaling relationship between SMBH mass and galaxy mass, and are 0.5-1 dex less massive than predicted. We find that their gas phase metallicities are lower compared to local AGN. Combining these results indicates that a substantial stellar build-up is still necessary from  $z=2$  to  $z=0$  if these quasar host galaxies are to grow into the most massive galaxies in the local Universe.

**Author(s):** Shelley A. Wright, Etsuko Mieda, Andrey Vayner, Anna Boehle, James E. Larkin, Norman Murray, Maren Cosens, Lee Armus

**Institution(s):** UC San Diego, Spitzer Science Center, California Institute of Technology, Canadian Institute for Theoretical Astrophysics, Department of Physics and Astronomy, University of California, Los Angeles, Institute for Particle Physics and Astrophysics, Na

### **331 - Gravitational Lenses, Waves, Relativistic Astrophysics & GRBs III**

#### **331.01 - The electromagnetic chirp of a supermassive black hole binary (Zoltan Haiman)**

Supermassive black hole (SMBH) binaries are inevitably produced during galaxy formation, and the expectation is that many of these binaries will be surrounded by plenty of gas. I will discuss the coupled dynamics of a SMBH binary with a circumbinary gas disk, and the expected characteristics of electromagnetic (EM) emission from such a system. In particular, I will argue, based on analytic arguments and two-dimensional hydrodynamical simulations, that in the final stages of the merger of a SMBH, inside LISA's frequency band, it will remain bright, and that its emission will be highly time-variable. In particular, relativistic Doppler modulations, lensing effects, and hydrodynamical modulations of the accretion will inevitably imprint periodic variability in the EM light-curve, tracking the phase of the orbital motion, and serving as a template for the GW inspiral waveform. Advanced localization of the source by LISA weeks to months prior to merger will enable a measurement of this EM chirp by wide-field instruments in X-rays and possibly other wavelengths. A comparison of the phases of the GW and EM chirp signals will help break degeneracies between system parameters, and probe a fractional difference in the propagation speed of photons and gravitons as low as  $10^{-17}$ .

**Author(s):** Zoltan Haiman

**Institution(s):** Columbia University

#### **331.03 - New HST Imaging and Strong Gravitational Lensing Models of Galaxy-overdense Fields Selected by Color Using Planck and Herschel (Massimo Pascale)**

We present strong lensing analysis of six galaxy clusters selected by their far-infrared colors using Planck/Herschel (and not by the Sunyaev-Zeldovich effect). Each cluster has a Dusty Star Forming Galaxy (DSFG) in its background which is ultra-bright as a result of gravitational lensing by the foreground cluster. These are some of the brightest DSFGs on the sky, owing to high magnification factors of  $\sim 10$ . HST WFC3-NIR imaging in the F110W and F160W filters allows for detailed studies of the lensed DSFGs and other giant arcs in the field. In particular, we find in five of six cases that the image of the DSFG appears in more than one location in the image plane. These "arcllet families" provide powerful constraints on the distribution of the dark matter. Our search for image families is complemented also by our adaptive optics-corrected K-band imaging (seeing of 0.3 arcsec) using LBT LUCI-ARGOS to confirm the red arc colors. By using the positions and brightnesses of the cluster members as luminous indicators of the underlying dark matter, in conjunction with the lensing constraints from the positions and parities of the arcllet family members, we constructed a light-traces-mass model for each of the clusters. One cluster in particular, PLCK G165.7+67.0 (G165), is especially rich in arcs, with 11 identified image families confirmed by our mass model. Our analysis yields a

mass of  $2.6 \pm 0.11 \times 10^{14}$  solar masses for this cluster, which is a factor of five lower than our value measured for the dynamical mass based off of our spectroscopy. We interpret this to mean that the dynamical mass may be inflated owing to a possible line-of-sight (non-spherical) cluster configuration. In sum, given the rich systems of arcs combined with the unusually-low X-ray flux and weak SZ decrement, we conclude that this cluster is an example of pre-merger of two smaller galaxy clusters.

**Author(s):** Brenda Frye, Dan Coe, Seth Cohen, Massimo Pascale, José Diego, Rolf A Jansen, Rogier Windhorst, Adi Zitrin

**Institution(s):** University of Arizona, Instituto de Física de Cantabria, Ben-Gurion University of the Negev, Arizona State University, STScI

#### **331.04 - Memory Detection Prospects for Low-Frequency Gravitational Wave Detectors (Kristina Islo)**

General Relativity predicts the gravitational wave signature from coalescing compact binaries to be accompanied by a non-periodic signal born of the non-linearities in Einstein's field equations. This effect is deemed "memory" as it accumulates from the entire past emission of the system. During the most dynamic stages of binary merger, the memory exponentially increases until the masses are tidally disrupted, at which point the signal saturates to a constant value. This effect propagates out into the ambient space, permanently deforming all it encounters. Supermassive system coalescences emit memory signals with amplitudes detectable by low-frequency gravitational wave detectors, including pulsar timing arrays (PTAs) and the Laser Interferometer Space Antenna (LISA). A detection would further corroborate General Relativity and provide an alternate method for observing binary coalescence and place constraints on their formation. In this talk I present current PTA sensitivity to this effect from a simulated population of coalescing supermassive black hole binaries, and estimate LISA's ability to witness memory from these same systems.

**Author(s):** Kristina Islo

**Institution(s):** University of Wisconsin Milwaukee

#### **331.05 - Chandra Observations of Recently Discovered Lensed Quasars (David Pooley)**

Our and others' previous work has shown the unique power of Chandra observations of quadruply gravitationally lensed quasars to address several fundamental astrophysical issues. We have used these observations to (1) determine the cause of flux ratio anomalies, (2) measure the sizes of quasar accretion disks, (3) determine the dark matter content of the lensing galaxies, and (4) measure the stellar mass-to-light ratio (in fact, this is the only way to measure the stellar mass-to-light ratio beyond the solar neighborhood). In all cases, the main source of uncertainty in the results is the small size of the sample of

known quadruply lensed quasars; until recently, only about 15 systems were available for study with Chandra. We have been granted Chandra observations of seven recently discovered quadruply lensed quasars and one quintuply lensed quasar, and we report preliminary results from these observations.

**Author(s):** David Pooley,

**Institution(s):** Trinity University, Eureka Scientific

### **331.06 - A Constant LGRB Metallicity Distribution Across Redshifts $z < 2.5$ (John Graham)**

Recent improvements in the population of Long-duration Gamma Ray Burst (LGRB) host galaxies with measured metallicities and host masses allows us to investigate how the distributions of both these properties change with redshift. First we exclude, out to  $z < 2.5$ , strong redshift dependent populations biases in mass and metallicity measurements. We then find a curious consistency in the metallicity distribution across different redshifts. This is at odds with the general evolution in the mass metallicity relation of typical galaxies, which become progressively more metal poor with increasing redshift at constant mass. By converting the measured LGRB host masses and redshifts to expected metallicities for a typical galaxy of each such mass and redshift, we further find that the increase in LGRB host galaxy mass distribution with redshift seen in the Perley et al. 2016 SHOALS sample is consistent with that needed to preserve the observed, non-evolving LGRB metallicity distribution. However the estimated LGRB host metallicity distribution is approximately a quarter dex higher than the measured metallicity distribution at all redshifts. This corresponds to about a factor of two in raw metallicity and resolves much of the difference between the LGRB formation metallicity cutoff of about a third solar in Graham & Fruchter 2017 with the cutoff value of solar claimed in Perley et al. 2016 in favor of the former. As LGRB hosts do not follow the general mass metallicity relation, there is no substitute for actually measuring their metallicities!

**Author(s):** John Graham

**Institution(s):** Kavli Institute for Astronomy and Astrophysics

### **331.07 - High-Energy Gamma-Ray Bursts detected by Fermi-LAT: The Second Fermi/LAT GRB Catalog (Nicola Omodei)**

The high-energy emission from Gamma-Ray Bursts (GRBs) is a formidable probe for extreme physics, calling for highly relativistic sources with very large Lorentz factors. Despite the advancements prompted by observations from the Fermi Large Area Telescope (LAT) and Gamma-Ray Burst Monitor, as well as other observatories, many questions remain open, especially on radiative processes and mechanisms. We present here the most extensive search for GRBs at high energies performed so far, featuring a detection efficiency more than 50% better than previous works, and returning 180 detections during 10 years of

LAT observations. The large sample size, a great improvement from the 35 detections presented in the first Fermi/LAT GRB catalog, enables us to assess the characteristics of the GRB population at high energy with unprecedented sensitivity. We will review the results of the 10 years Fermi/LAT GRB catalog, as well as their interpretation.

**Author(s):** Magnus Axelsson, Nicola Omodei, Elisabetta Bissaldi, Giacomo Vianello

**Institution(s):** Stanford University/KIPAC, KTH Royal Institute of Technology, INFN, Tokyo Metropolitan University  
**Contributing Team(s):** on behalf of the Fermi Large Area Telescope Collaboration

### **331.08 - Jet Dynamics in Compact Object Mergers (Paul Duffell)**

We use relativistic hydrodynamic numerical calculations to study the interaction between a jet and a homologous outflow produced dynamically during binary neutron star mergers. We quantify how the thermal energy supplied by the jet to the ejecta and the ability of a jet to escape the homologous ejecta depend on the parameters of the jet engine and the ejecta. For collimated jets initiated at early times compared to the engine duration, we show that successful breakout of the forward cocoon shock necessitates a jet that successfully escapes the ejecta. This is because the ejecta is expanding and absorbing thermal energy, so that the forward shock from a failed jet stalls before it reaches the edge of the ejecta. This conclusion can be circumvented only for very energetic wide angle jets, with parameters that are uncomfortable given short-duration GRB observations. For successful jets, we find two regimes of jet breakout from the ejecta, early breakout on timescales shorter than the engine duration, and late breakout well after the engine shuts off. A late breakout can explain the observed delay between gravitational waves and gamma rays in GW 170817. We show that for the entire parameter space of jet parameters surveyed here (covering energies  $\sim 10^{48}$ - $10^{51}$  ergs and opening angles  $\sim 0.07$ - $0.4$  the thermal energy deposited into the ejecta by the jet propagation is less than that produced by r-process heating on second timescales by a factor of  $> \sim 10$ . Shock heating is thus energetically subdominant in setting the luminosity of thermally powered transients coincident with neutron star mergers (kilonovae). For typical short GRB jet parameters, our conclusion is stronger: there is little thermal energy in the cocoon, much less than what is needed to explain the early blue component of the kilonova in GW 170817.

**Author(s):** Paul Duffell, Eliot Quataert, Dan Kasen, Hannah Klion

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of California, Berkeley



### **331.02D - Constraining Neutron-Star Merger and Kilonova Properties Using Radiative Transfer and Numerical Relativity Simulations(Zoheyr Doctor)**

The optical/infrared observation of the neutron-star merger associated with gravitational wave GW170817 provided significant constraints on a wide range of astrophysical phenomena, from the origin of r-process elements to the equation of state of neutron stars. In this talk, I will describe state-of-the-art methods for estimating physical parameters of neutron star mergers and kilonovae using optical/infrared spectra and light curves in concert with radiative transfer simulations and 3D numerical relativity simulations. I will also present the latest use of these methods to constrain the mass ratio and tidal deformability of the GW170817 neutron star merger.

**Author(s):** Zoheyr Doctor, Tim Dietrich, Michael Coughlin  
**Institution(s):** University of Chicago, AEI-Potsdam, Caltech

### **332 - Modern Morphologies - Galaxy Zoo and Beyond**

#### **332.01 - Galaxy Morphology from Galaxy Zoo(Karen Masters)**

The Galaxy Zoo project ([www.galaxyzoo.org](http://www.galaxyzoo.org)) has provided quantitative visual morphologies for over a million galaxies (including the entire Sloan Digital Sky Surveys, or SDSS Main Galaxy Sample, all public HST surveys, UKIDSS, GAMA and most recently images generated by the Illustris Simulation), and has been part of a reinvigoration of interest in the morphologies of galaxies and what they reveal about the evolution of galaxies. The morphological information collected by Galaxy Zoo has shown itself to be a powerful database for studying galaxy evolution, and Galaxy Zoo continues to collect classifications - currently serving imaging from DECaLS. I will review how to make best use of the morphologies from Galaxy Zoo, and highlight some of the results from the last 11 years of the project. I will also look forward to future and ongoing projects in the Galaxy Zoo family.

**Author(s):** Karen Masters

**Institution(s):** Haverford College  
**Contributing Team(s):** Galaxy Zoo Team

#### **332.02 - Galactic Conformity in Both Starformation and Morphology(Justin Atsushi Otter)**

Galactic conformity describes the tendency for satellite galaxies in a group to share properties with the central galaxy. Galactic conformity has been previously detected in star-formation properties of the satellite and central galaxies: groups with star-forming centrals tend have more star-forming satellites than those with passive centrals. Using Galaxy Zoo 2 data on morphology, we investigate conformity in both star-formation properties and morphological properties separately. We find that the conformity signal for morphology behaves differently than that of star-formation properties. These results have

implications for the impact of the environment on galaxy evolution and inform the idea that star-formation properties change faster than morphology, so that while star formation properties may give a reliable short-term snapshot of a galaxy's properties, its morphology traces its longer term cosmic history.

**Author(s):** Justin Atsushi Otter, Karen Masters, Brooke Simmons

**Institution(s):** Haverford College, Lancaster University

#### **332.03 - Modeling with the Crowd: Optimizing the Human-Machine Partnership with Zooniverse(Claudia Scarlata)**

Future all-sky surveys must address the daunting challenge of analyzing the unprecedented volumes of imaging and spectroscopic data that these next-generation instruments will generate. A promising approach to overcoming this challenge involves rapid, automatic image processing using appropriately trained deep learning (DL) algorithms. However, reliable application of DL requires large, accurately labeled samples of training data. Galaxy Zoo Express (GZX) is a recent experiment that simulated using Bayesian inference to dynamically aggregate binary responses provided by citizen scientists via the Zooniverse crowd-sourcing platform in real time. The GZX approach provides rapidly generated, reliably labeled datasets, thereby enabling online training of accurate machine classifiers. We present the results of GZX and show how the Bayesian aggregation engine it uses can be extended to efficiently provide object-localization and bounding-box annotations of two-dimensional data with quantified reliability. DL algorithms that are trained using these annotations will facilitate numerous panchromatic data modeling tasks including morphological classification and substructure detection in direct imaging, as well as decontamination and emission line identification for slitless spectroscopy. Effectively combining the speed of modern computational analyses with the human capacity to extrapolate from few examples will be critical if the potential of forthcoming large-scale surveys is to be realized.

**Author(s):** Hugh Dickinson, Lucy Fortson, Nico Adams, Claudia Scarlata, Vihang Mehta

**Institution(s):** University of Minnesota

#### **332.04 - Galaxy morphology with deep learning(Marc Huertas-Company)**

I will review recent progress in the development of deep learning based algorithms to estimate galaxy morphologies. I will particularly discuss how human labeling can be reduced by transferring knowledge between networks trained over different datasets. I will also show preliminary results on unsupervised learning with generative models to 1- compare the morphological properties of simulated galaxies from numerical simulations with observed ones and 2 - to find anomalous objects on big-data sets.

**Author(s):** Marc Huertas-Company

**Institution(s):** Observatoire de Paris

### **332.05 - Robots and Citizens: A Galaxy Zoo view of Machine Learning(Chris Lintott)**

The Galaxy Zoo catalogues have been used to train many different automatic classifiers, inspired by the need to classify the large datasets provided by missions such as Euclid and facilities such as LSST. The most successful have made use of modern deep learning methods, in particular convolutional neural nets. However, such methods only provide a single scalar classification for each galaxy, which fails to account for the varying difficulty of each image. I will present the result of a novel application of a Bayesian convolutional neural network to provide predictions with uncertainty. Measuring uncertainty facilitates understanding the performance of the network and how it might be improved, but more importantly allows us to select the most informative images for citizen scientist classification. This in turn allows the development and deployment of a hybrid system which classifies new surveys more accurately than either humans or machines alone. We will present the performance of such a system with images from DeCALS, and explore how it allows us to scale citizen science classification while still retaining the potential for serendipitous discoveries of unexpected objects such as the Galaxy Zoo 'Peas'.

**Author(s):** Mike Walmsley, Chris Lintott

**Institution(s):** University of Oxford Contributing Team(s): Galaxy Zoo, Zooniverse

## **333 - Galaxy Formation and Evolution VII**

### **333.01 - Launching the LADUMA deep HI survey(Andrew J. Baker)**

Understanding the detailed properties of galaxies' neutral atomic gas reservoirs is a key requirement for understanding galaxies' overall cosmic evolution. Thanks to the approved 3424-hour Looking At the Distant Universe with the MeerKAT Array (LADUMA) survey, which is on the verge of taking its first data, we are now poised to extend the study of HI emission in galaxies to an unprecedented  $z = 1.4$ , when the universe was only a third of its present age. This talk will present an update on LADUMA's scientific objectives and technical challenges, with a focus on the L-band observations (probing the  $z < 0.58$  universe) that represent the survey's first tier, as well as the multiwavelength observations of its target field that will support spectral line stacking and identification of OH megamaser interlopers. This work has been supported by the National Science Foundation through grant AST-1814421.

**Author(s):** Andrew J. Baker, Benne Holwerda, Sarah Blyth

**Institution(s):** Rutgers, The State University of NJ, University of Louisville, University of Cape Town Contributing Team(s): LADUMA Team

### **333.03 - Rest-frame UV and optical emission line diagnostics of ionised gas properties: a test case in a lensed galaxy at $z \sim 1.7$ (Ayan Acharyya)**

We examine the diagnostic power of rest-frame ultraviolet (UV) nebular emission lines, and compare them to more commonly used rest-frame optical emission lines, using the test case of the bright lensed galaxy RCSGA 032727-132609 at redshift  $z \sim 1.7$ . This galaxy has complete coverage of all the major rest-frame UV and optical emission lines from Magellan/MagE and Keck/NIRSPEC. Using the full suite of diagnostic lines, we infer the physical properties: nebular electron temperature ( $T_e$ ), electron density ( $n_e$ ), oxygen abundance ( $\log(O/H)$ ), ionisation parameter ( $\log(q)$ ) and interstellar medium (ISM) pressure ( $\log(P/k)$ ). We examine the effectiveness of the different UV, optical and joint UV optical spectra in constraining the physical conditions. Using UV lines alone we can reliably estimate  $\log(q)$ , but the same is difficult for  $\log(O/H)$ . UV lines yield a higher (1.5 dex)  $\log(P/k)$  than the optical lines, as the former probes a further inner nebular region than the latter. For this comparison, we extend the existing Bayesian inference code IZI, adding to it the capability to infer ISM pressure simultaneously with metallicity and ionisation parameter. This work anticipates future rest-frame UV spectral datasets from the James Webb Space Telescope (JWST) at high redshift and from the Extremely Large Telescope (ELT) at moderate redshift.

**Author(s):** Melanie Kaasinen, Guillermo Blanc, Matthew Bayliss, Jane Rigby, David Nicholls, Christoph Federrath, Fuyan Bian, Ayan Acharyya, Michael Florian, Lisa Kewley,

**Institution(s):** Australian National University, Astrophysics Science Division, Goddard Space Flight Center, ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), European Southern Observatory, MIT Kavli Institute for Astrophysics and Space Res

### **333.04 - New Infrared SEDs for Local Luminous Infrared Galaxies(Jason Kai Chu)**

We present infrared ( $3 - 500 \mu m$ ) spectral energy distributions (SEDs) for the complete sample of 201 local Luminous Infrared Galaxies (LIRGs:  $LIR \geq 10^{11} L_{\odot}$ ,  $z \leq 0.088$ ) in the Great Observatories All-Sky LIRG Survey (GOALS). These new SEDs have been constructed using the latest photometry from IRAS, Spitzer-IRAC/MIPS, WISE, and Herschel-PACS/SPIRE, and spectroscopy from Spitzer-IRS. The SEDs have been used to compute more accurate total infrared luminosities, far-infrared dust emissivities, dust temperatures, dust masses and infrared colors for individual objects. Mean SEDs and derived galaxy parameters have also been computed for the GOALS sample in 0.25 dex bins of  $\log(LIR/L_{\odot}) = 11.0 - 12.5$ , for use in constructing more realistic models of LIRGs in cosmological simulations. All of these data will be made available through the GOALS website (<http://www.goals.ipac.caltech.edu>).

**Author(s):** David B Sanders, Jason Kai Chu,

**Institution(s):** Gemini Observatory, Institute for Astronomy,

University of Hawai'i Contributing Team(s): GOALS Team

### **333.05 - Megasaura: The definitive UV spectral atlas of star-forming galaxies at cosmic noon(Jane Rigby)**

The rest-frame ultraviolet diagnostics that JWST will use to study galaxies at cosmic dawn sorely need to be tested and calibrated. We are measuring these diagnostics now with Project Megasaura: The Magellan Evolution of Galaxies Spectroscopic and Ultraviolet Reference Atlas. Megasaura is an atlas of high signal-to-noise, medium spectral resolution ( $R \sim 3000$ ) spectra of 15 extremely bright gravitationally lensed galaxies at redshifts of  $1.7 < z < 3.6$  (Rigby et al. 2018a). The sample, selected from the SDSS Giant Arcs Survey, comprises 15 of the brightest known lensed galaxies; the brightest have apparent magnitudes of  $g_{AB} = 20-21$ , which means they appear 30 to 70 times brighter than the typical Lyman Break Galaxy. The Megasaura spectra reveal a wealth of spectral diagnostics: absorption from the outflowing wind; faint nebular emission lines that will be key diagnostics for JWST and the ELTs; and photospheric absorption lines and P Cygni profiles from the massive stars that power the outflow. The stacked Megasaura spectrum (Rigby et al. 2018b) reveals still weaker spectral diagnostics -- with considerably better wavelength coverage and spectral resolution than previous composites, the Megasaura stack is the highest-quality spectrum yet obtained of star-forming galaxies at cosmic noon. We have released the spectra to the community.

**Author(s):** Guillaume Mahler, John Chisholm, Matthew Bayliss, Jane Rigby, Rongmon Bordoloi, Michael Gladders, Keren Sharon

**Institution(s):** NASA Goddard Space Flight Center, UC Santa Cruz, MIT, UMichigan, University of Chicago

### **333.07 - MaStar --- A Large and Comprehensive Empirical Stellar Spectral Library(Renbin Yan)**

As part of the fourth generation of Sloan Digital Sky Survey (SDSS-IV), the MaNGA Stellar Library (MaStar) project is constructing a large, well-calibrated, high quality empirical stellar library with more than 10,000 stars covering the wavelength range from 3622 to 10,354 Å at a resolution of  $R \sim 2000$ . The spectra are taken using the same instrument as the integral field galaxy survey, Mapping Nearby Galaxies at Apache Point Observatory (MaNGA), by piggybacking on the Apache Point Observatory Galaxy Evolution Experiment-2N (APOGEE-2N) observations. The relative flux calibration of the library is accurate to 4.4% in g-r and 3% in r-i and i-z. The great majority of the stars are observed more than once, producing multiple "visit-spectra". The first version of the library contains 8646 high quality visit-spectra for 3321 unique stars. Compared to previous empirical libraries such as MILES, the MaStar Library has a more comprehensive and contiguous stellar parameter coverage, especially in the red giant branch, cool dwarfs, low metallicity stars, and stars with different  $[1\pm/\text{Fe}]$ .

This is achieved by a target selection method based on large spectroscopic catalogs from APOGEE, LAMOST, and SEGUE, combined with photometry-based selection and sources from the literature. This empirical library will provide a new basis for stellar population synthesis and is particularly well suited for stellar population analysis for MaNGA galaxies. The data are released in SDSS Data Release 15.

**Author(s):** Renbin Yan

**Institution(s):** University of Kentucky Contributing Team(s): MaStar Collaboration

### **333.02D - Spatially-resolved studies of nearby star-forming galaxies(Nimisha Kumari)**

Spatially-resolved studies of nearby star-forming galaxies are essential to understanding various physical and chemical phenomena at play in the interstellar medium in the galaxies, and consequently to obtain a comprehensive picture of galaxy formation and evolution. I present spatially-resolved analyses of chemical abundances and star-formation in nearby star-forming galaxies - spiral galaxies and blue compact dwarf galaxies (BCDs). I study spiral galaxies to address long-standing issues related to the reliability of metallicity calibrators and the Schmidt Law of star-formation. Using IFS data of twenty-four spiral galaxies taken with the Multi-Unit Spectroscopic Explorer, I devise new recipes for estimating the metal-content of the diffuse ionised gas. For another set of nine spiral galaxies, I use multi-wavelength data to show that the spatially-resolved Schmidt relation is very sensitive to the consideration of diffuse background, which is a component unrelated to current star-formation. Removal of this component from the SFR tracers and the atomic gas results in similar local and global Schmidt relation. I use IFS observations from the Gemini Multi-Object Spectrograph-North to study the distribution of physical and chemical properties of H II regions in a sample of BCDs, the local analogues of high redshift galaxies. While answering questions related to chemical homogeneity, ionisation mechanisms and stellar populations within BCDs, I address more profound issues, which go beyond the characterisation of studied BCDs and aim to explain global phenomena with broader implications. Such studies are imperative to enhance our understanding of the chemical abundance patterns and star-formation in galaxies in the high-redshift Universe, and hence be better prepared for a whole new era of high-redshift astronomy initialised by JWST, and complemented by facilities like MUSE and MOONS.

**Author(s):** Nimisha Kumari

**Institution(s):** University of Cambridge

### **333.06D - Using Metals to Constrain the History of Gas Flows in Galaxies(Olivia Grace Telford)**

Gaseous inflows and outflows are essential to fueling star formation and shaping galaxies, but precisely how these processes operate and scale with galaxy properties remains

poorly understood. Direct measurements of the diffuse material entrained in these flows for statistical samples of galaxies is challenging, given current technology. We use metals, which must have formed inside galaxies, as tracers to constrain properties of recent and lifetime-averaged gas flows. We analyze the scaling relation between stellar mass, gas-phase metallicity, and star formation rate (SFR) using a sample of 130,000 galaxies from the Sloan Digital Sky Survey. This relation is set by an interplay between recent gas flows and the feedback and metal enrichment from star formation, so how strongly these three parameters are correlated encodes the magnitude and duration of metallicity dilution events due to gas-poor inflows or gas-rich outflows. We demonstrate that the anti-correlation between metallicity and SFR is driven entirely by galaxies with SFRs elevated above their past average, just 15% of our sample, and identify several systematic uncertainties that affect the observed strength of the relation, impacting the inferred gas flow properties. Next, we zoom in on a single, nearby,  $\sim L^*$  galaxy, M31, to measure the metal mass lost over its lifetime and the implied average metal ejection efficiency of outflows. We use star formation histories derived from Panchromatic Hubble Andromeda Treasury survey data to calculate the metal production history, and compare the total metal production to a census of metals present in M31 today. We find that 62% of the metals formed in the disk are missing, broadly consistent with previous estimates for a galaxy of M31's mass. We then use the metal production histories to place constraints on the timing of this metal loss and on the required redistribution of recently produced metals within the disk in the last  $\sim 2$  Gyr. These two complementary approaches to constraining past gas flows provide observational tests for models of gas accretion and feedback-driven outflow in galaxy formation models.

**Author(s):** Julianne Dalcanton, Olivia Grace Telford, Jessica Werk, Benjamin F Williams

**Institution(s):** University of Washington

### 334 - ISM & Related Topics III

#### 334.01 - Blue Asymmetries in MALT90 HCO<sup>+</sup> Line Profiles of Molecular Clumps: Evidence for Global Gravitational Collapse (James M. Jackson)

The Millimetre Astronomy Legacy Team 90 GHz Survey (MALT90) detected dense molecular gas tracers toward thousands of high-mass molecular clumps. We have examined the optically thick HCO<sup>+</sup> 1-0 line in 1,093 clumps for the "blue asymmetry" spectroscopic signature of infall. To quantify the degree of the line asymmetry, we measure the asymmetry parameter  $A = (I_{\text{blue}} - I_{\text{red}}) / (I_{\text{blue}} + I_{\text{red}})$ , the fraction of the total integrated intensity that lies to the blueshifted side of the systemic velocity, as determined from the optically thin tracer N<sub>2</sub>H<sup>+</sup>. For a sample of 1,093 clumps, the mean of  $A$  ( $0.083 \pm 0.010$ ) indicates a preponderance of infall motions over expansion motions at the 8 sigma level. Two other infall indicators, the slope of the optically thick line at the systemic velocity and the "delta v" parameter, also indicate infall motions, but with smaller statistical significance (3 and 4 sigma, respectively). This blue asymmetry indicates that these

high-mass clumps are predominantly undergoing gravitational collapse. The blue asymmetry is larger ( $A \sim 0.12$ ) for the earliest evolutionary stages (quiescent, protostellar and compact H II region) than for the later H II region ( $A \sim 0.06$ ) and PDR ( $A \sim 0$ ) classifications, indicating that global collapse is already underway in the very earliest stages of high-mass star formation, and that either the collapse halts, or else the collapse signal is erased by expansion motions, after the H II regions form. Global gravitational collapse is required by "competitive accretion" models of high-mass star formation. We also present data from a new infall indicator, the 63  $\mu\text{m}$  [O I] line, measured with SOFIA, that clearly indicates gravitational collapse toward an active star-forming region in the "Nessie Nebula."

**Author(s):** Ian William Stephens, David Allingham, James M. Jackson, Jonathan Foster, Yanett Contreras, Patricio Sanhueza, Steven Longmore, J. Scott Whitaker, Jill Rathborne

**Institution(s):** SOFIA Science Center, CSIRO, Boston University, Leiden University, Yale University, CfA, NAOJ, University of Newcastle, Liverpool John Moores University

#### 334.03 - The Stability of the Three-phase Interstellar Medium (Alex S Hill)

Star-forming galaxies are nearly always observed to have a three-phase interstellar medium (ISM), with gas found in the three thermally-stable temperature regimes ( $\sim 10^2$  K,  $\sim 10^4$  K,  $\sim 10^6$  K). Using magnetohydrodynamic simulations of supernova-driven turbulence, we explore the effect of varying the diffuse heating rate on the three-phase character of the medium. We find that, independent of any changes in the star formation rate, the gas physics keeps the ISM in the thermal pressure range in which all three phases coexist. Therefore, the three-phase ISM is very stable to changes in the heating rate.

**Author(s):** Mordecai-Mark Mac Low, Alex S Hill, Andrea Gatto, Juan C Ibáñez-Mejía

**Institution(s):** University of British Columbia, Space Dynamics Services, Space Science Institute, American Museum of Natural History, Universität zu Köln

#### 334.05 - Spectral Index of the Diffuse Radio Sky as Measured by EDGES using the Lowband (50-100 MHz) Antenna (Thomas J. Mozdzen)

We report new measurements of the all-sky Galactic noise spectral index between 50-100 MHz using two implementations of the Experiment to Detect the Global EoR Signature (EDGES) lowband instruments that functioned in a zenith drift-scan mode. Data was collected for 244 nights over the span of nearly one year at the Murchison Radio-astronomy Observatory (MRO) in Western Australia. North-south and east-west antenna orientations were observed. Beam chromaticity correction was applied to all data using a beam model derived from FEKO simulations employing a lossy dielectric soil ground model. For two parameter fitting, the antenna temperature at 75 MHz ( $T_{75}$ ) and the spectral index ( $\beta^2$ ) were extracted, and

for three parameter fitting, the spectral index curvature ( $\hat{I}^3$ ) was also extracted. The daily variations were very low and data scatter in  $\hat{I}^2$  was  $< 0.006$ . Total systematic error in  $\hat{I}^2$  was  $< 0.012$  for two parameter fitting. Fitting was repeated after correcting for expected ionospheric absorption. We find that the correction for the ionosphere leads to a steepening of the best-fit spectral index by an amount between 0.009 and 0.016 across LST. Results were compared to measurements with the EDGES highband instrument (90-190 MHz) and to simulated spectral index values created using several sky models. We find the spectral index measured by the lowband instruments is shallower than the highband results by 0.02 to 0.04 across LST. We also find that the recently improved GSM sky model yields significantly better agreement than the original GSM sky model, and that the Guzman-Haslam sky map combination still yields good agreement with measurements, especially with three parameter fitting, where the maximum difference is  $\pm 0.02$  across all LST values.

**Author(s):** Thomas J. Mozdzen, Nivedita Mahesh, Judd Bowman, Raul A Monsalve, Alan E. E. Rogers

**Institution(s):** Arizona State University, Haystack MIT, McGill University

### **334.06 - Not so Heavy Metals: Black Hole Feedback Enriches the Circumgalactic Medium(Natalie Nicole Sanchez)**

By tracing the redistribution of metals in the circumgalactic medium (CGM) via outflows, we show that OVI is a sensitive indicator of supermassive black hole (SMBH) feedback. We examine the effects of SMBH feedback on the CGM using a cosmological hydrodynamic simulation (Romulus25, Tremmel et al. 2017) and a set of zoom-in “genetically modified” Milky Way-mass galaxies sampling different evolutionary paths. We compare the column densities of OVI in Milky Way-mass galaxies and compare them with observations from the COS-Halos Survey; contrary to previous simulations which underpredicted the CGM column densities of OVI, these simulations are consistent with COS-Halos observations of star forming galaxies and slightly overpredict OVI in quenched galaxies. We determine that a galaxy’s star formation history and overall accretion rate have little effect on the appearance of OVI in its CGM while column densities of OVI are more closely tied to galaxy halo mass and BH growth history. The set of zoom-in, genetically modified Milky Way-mass galaxies confirm that the SMBH acts as the physical mechanism for transporting metals out into its host halo thereby significantly impacting the column densities of OVI found in the CGM.

**Author(s):** Jessica Werk, Charlotte Christensen, Natalie Nicole Sanchez, Andrew Pontzen, Akaxia Cruz, Thomas Quinn, Michael Josef Tremmel

**Institution(s):** University of Washington, Yale Center for Astronomy & Astrophysics, University College London, Grinnell College

### **334.07 - Turbulence and Magnetic Reconnection for Large Magnetic Prandtl Numbers(Ethan Tecumseh Vishniac)**

We have studied the small scale turbulent cascade in the limit of high magnetic Prandtl numbers. When viscosity is much larger than resistivity, as expected in hot low density environments, the usual turbulent cascade will terminate at the viscous damping scale. Below this the magnetic fields will respond to stresses created by larger scale eddies, but motions are strongly suppressed. We present numerical studies of the relative ratio of viscous to resistive damping and show that they are consistent with strong intermittency in the perturbed magnetic field. The magnetic field creates domains approximately the size of the viscously damped eddies, with relatively uniform fields inside each domain. The domain boundaries have a finite thickness which scales with the square root of the resistivity. Within each domain trajectories along magnetic field lines will diverge exponentially. However, in the domain boundaries adjacent trajectories will spread much more rapidly. Consequently, reconnection between adjacent domains occurs in a viscous eddy turnover time, and is insensitive to the value of the resistivity. The slope of the magnetic power spectrum below the viscous damping scale has an extra degree of freedom, depending on the anisotropy of the magnetic field in the domain walls. We illustrate this by comparing results for different large scale conditions.

**Author(s):** Amir Jafari, Ethan Tecumseh Vishniac, Andrey Beresnyak, Alexandre Lazarian

**Institution(s):** American Astronomical Society, Naval Research Laboratories, Johns Hopkins University, University of Wisconsin

### **334.02D - The Velocity Gradient Technique: a new way to map magnetic fields(Diego F Gonzalez-Casanova)**

Turbulence and magnetic fields are ubiquitous in the interstellar medium, shaping star formation and molecular cloud dynamics. As such, it is crucial to understand their effects. Traditional techniques like dust polarization, however, are limited in their ability to probe high density or high opacity environments. To address this, we present the Velocity Gradient Technique (VGT), a new way to measure the direction and strength of magnetic fields perpendicular to the line of sight. The technique uses only spectroscopic observations and an understanding of current magnetohydrodynamic theory in the presence of turbulence. We demonstrate two applications of the VGT in the form of a map of the plane of sky galactic magnetic field and a 3D map (in velocity) of the magnetic field in the region around a forming protostellar disk.

**Author(s):** Diego F Gonzalez-Casanova, Alexandre Lazarian

**Institution(s):** University of Wisconsin - Madison

**334.04D - Links between magnetic fields and molecular cloud fragmentation: Bimodal mass distribution and density structures.(Chi Yan Law)**

The advance in both instrumentation and numerical simulation techniques in the past decade have unfolded the importance of magnetic fields in regulating filamentary clouds formation, evolution, and physical properties of star-forming processes in molecular clouds. In particular, there are emerging interests on the effects of cloud-field orientations on both morphological and kinematics conditions in molecular clouds. Here we present the analysis of the spatial mass distribution and mass distributions in 12 nearby molecular clouds ( $D < 500\text{pc}$ ) column density maps. We show that molecular clouds with long axis orientations align with the magnetic field direction have more even mass distribution, a lower fraction of mass resides in higher column density and a higher column density probability density function(N-PDF) transition density. These findings are consistent with the recently proposed model that magnetic fields perpendicular to clouds will possess a higher magnetic flux, and thus can hinder the cloud fragmentation more efficiently from mass accumulations, and a higher density barrier for the cloud to fragment.

**Author(s):** Chi Yan Law, Hua Bai Li, Po Kin Leung

**Institution(s):** The Chinese University of Hong Kong

**335 - Supernovae IV**

**335.01 - Radio Observations of Nearby Intermediate-Aged Supernovae(Yvette Cendes)**

After the initial flash and bang of a supernova, radio emission can continue for decades as the shockwave interacts with the circumstellar material (CSM) shed by the progenitor star before the explosion. These observations can, in turn, provide key insights into both the explosion mechanism and pre-supernova evolution of the progenitor system, as well as probe the transition from supernova to supernova remnant. In this talk, I will cover recent radio observations of several nearby intermediate-aged supernovae ( $\sim 10\text{-}100$  years post-explosion). First, I will discuss recent results from Supernova 1987A, where radio observations show the shockwave has re-accelerated after emerging from a dense equatorial ring of material. Next, I will cover recent work for two nearby Type Ia supernovae, SN 1895B and SN 1972E, which uses several decades of VLA observations to search for CSM. I will also cover what these observations can tell us about Type Ia progenitor systems via models of CSM density and structure.

**Author(s):** Maria Drout, Yvette Cendes, Bryan Gaensler

**Institution(s):** Dunlap Institute for Astronomy & Astrophysics, Leiden Observatory

**335.02 - NEAR-INFRARED SPECTROSCOPY OF SN 2017EAW: CARBON MONOXIDE AND DUST FORMATION IN A TYPE II-P SUPERNOVA (Jeonghee Rho)**

The origin of dust in the early universe has been the subject of considerable debate. Core-collapse supernovae (ccSNe), which occur several million years after their massive progenitors are born, could be a major source of that dust, as in the local universe, several ccSNe have been observed to be copious dust producers. Here we report nine near-infrared (0.8-2.5 micron) spectra, obtained with GNIRS on Gemini North, of the Type II-P supernova (SN) 2017eaw in NGC 6946, spanning the time interval 22-205 days after discovery. The spectra show the onset of CO formation and continuum emission at wavelengths greater than 2.1 micron from newly formed hot dust, in addition to numerous lines of hydrogen and metals, which reveal the change in ionization as the density of much of the ejecta decreases. The observed CO masses estimated from local thermodynamic equilibrium (LTE) model are typically  $10\text{-}4M_{\text{sun}}$  during days 124-205, but could be an order of magnitude larger if non-LTE conditions are present in the emitting region. The timing of the appearance of CO is remarkably consistent with the chemically controlled dust models of Sarangi & Cherchneff. We will also present additional observations taken in 2018 and discuss the implication of CO and dust formation in the SN ejecta and compare with the measurements of SN1987A.

**Author(s):** Dipankar Banerjee, Jeonghee Rho, Nye Evans, Vjoshi Joshi, Luc Dessart, Thomas Geball

**Institution(s):** SETI Institute, Physical Research Laboratory, Navrangpura, Ahmedabad, Gemini Observatory, Departamento de Astronomia, Universidad de Chile,, Keele University

**335.03 - A High-Resolution X-Ray Kinematics Study of Kepler's Supernova Remnant(Matthew James Millard)**

We report measurements of the bulk radial velocity from a sample of small, metal-rich ejecta knots in Kepler's supernova remnant (SNR). We measure the Doppler shift of the Si K line center energy in the spectra of these knots from our Chandra High-Energy Transmission Grating Spectrometer (HETGS) observation to estimate their radial velocities. We estimate high radial velocities of up to  $\sim 9,000\text{km s}^{-1}$  for some metal-rich ejecta knots in Kepler's SNR. We also measure proper motions for these ejecta knots based on the archival Advanced CCD Imaging Spectrometer (ACIS) data taken from 2000 to 2014. The fastest moving knots showed proper motions of up to  $\sim 0.2$  arcseconds per year. A few knots with the highest radial velocities also exhibit proper motions which imply an expansion parameter approaching  $\dot{r}/v \sim 1$ , indicating that they are nearly freely expanding. By assuming that these high velocity ejecta knots are freely expanding, and are located near and beyond the main shell of the SNR, we estimate a distance to Kepler of  $d \sim 5$  to  $8.5$  kpc. We find that the ejecta knots in our sample have an average space velocity of  $|v| \sim$

5,000 km s<sup>-1</sup> (at a distance of 6 kpc). Nearly all the ejecta knots with high radial velocities of  $|v_r| \sim 1,500$  km s<sup>-1</sup> in our sample show a redshifted spectrum, suggesting a significant asymmetry in the ejecta distribution in Kepler's SNR along the line of sight. This work has been supported in part by NASA Chandra Grants GO6-17060X and AR7-18006X.

**Author(s):** Patrick Slane, David Burrows, Daniel Patnaude, Sangwook Park, Toshiki Sato, Matthew James Millard, Jayant Bhalerao, Carlos Badenes, O, John Patrick Hughes,

**Institution(s):** Universitat de Barcelona, University of Texas at Arlington, RIKEN, NASA's Goddard Space Flight Center, Flatiron Institute, Rutgers University, Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics, University of Pittsburgh

### **335.04 - Pulsar wind nebula DA495 examined in TeV gamma-rays and with broadband spectral modeling(Patrick Wilcox)**

We present observations from the Very Energetic Radiation Imaging Telescope Array System (VERITAS) gamma-ray observatory and the Nuclear Spectroscopic Telescope Array (NuSTAR) hard X-ray observatory of pulsar wind nebula (PWN) DA 495, which was recently found to be a gamma-ray source by the High Altitude Water Cherenkov observatory (HAWC). DA 495 is an aged PWN, previously identified in radio and X-ray, with unusually strong magnetic fields. Broadband spectral modeling, which now includes spectral information in hard X-rays and TeV gamma-rays, can place constraints on the properties of the particle population in this PWN and allows for both leptonic and hadronic emission scenarios to be evaluated. In this dissertation talk, I will discuss the results from the recent observations and present the subsequent multiwavelength modeling study.

**Author(s):** Patrick Wilcox

**Institution(s):** University of Iowa

### **335.05 - Multiwavelength Observations of the Extreme Transient AT2018cow(Daniel Perley)**

The bright, luminous, and fast multiwavelength transient AT2018cow displayed unprecedented behavior at almost every waveband: a fast-evolving UV/optical counterpart that maintains an extremely hot photospheric temperature over its entire evolution, an erratically-fluctuating luminous X-ray counterpart, and a heavily self-absorbed radio/submillimeter counterpart. We present a comprehensive set of photometric and spectroscopic observations of this transient from ground-based observatories spanning four continents and from space, including multiwavelength observations from Swift, NuSTAR, Astrosat, SMA, and ALMA. We consider both supernova and intermediate-mass black hole tidal disruption event interpretations for its origin, although no simple theoretical model can explain the full set of observations. Transients similar to AT2018cow are probably not rare in the universe and

will be detected in large numbers by LSST in the coming decade.

**Author(s):** Daniel Perley, Anna Ho

**Institution(s):** Liverpool John Moores University, Caltech  
Contributing Team(s): GROWTH

### **335.06 - Multimessenger signatures from populations of core-collapse supernovae(MacKenzie Warren)**

We have developed a new method for artificially driving core-collapse supernova explosions in 1D simulations. Turbulence is important for understanding the CCSN explosion mechanism, since turbulence may add a >20% correction to the total pressure behind the shock and thus aid in the explosion. Including turbulence results in successful explosions in spherical symmetry without altering the neutrino luminosities or interactions, as is commonly done to produce explosions in spherical symmetry. This better replicates the physical explosion mechanism and more reliably produces the thermodynamics and composition, which is vital for accurately predicting the nucleosynthesis that occurs in the supernova environment. We have applied this model to explore the multimessenger observable signals - light curves, neutrino emission, and GW emission - for the landscape of supernova progenitors from 9 - 120 M $\odot$ . We have explored correlations between the underlying stellar structure and physics of the CCSNe mechanism with observable quantities.

**Author(s):** MacKenzie Warren, Sean Couch

**Institution(s):** Michigan State University

### **335.07 - Gaia: mapping the dynamics and morphologies of Galactic Planetary Nebulae: First Results from Gaia Data Release 2(Nicholas Walton)**

Planetary Nebulae (PN) are a brief evolutionary stage through which low and intermediate mass stars pass towards the end of their evolution, between red giant and white dwarf. They can probe the kinematical structure of the Milky Way, and provide an indication of the chemical evolution history of the Galaxy. Understanding the nature of the PN itself provides vital insights into the evolutionary pathways of the stars forming the PN. The ESA Gaia satellite is optimised for the detection of point sources, and in general is not sensitive to extended objects (with sizes >0.5 arcsec). However, Gaia is able to resolve local point like maxima within extended objects. This is demonstrated by early observations of the large PN NGC 6543, where the complex nebula is decomposed by Gaia into thousands of individual mapping points. With nominal lifetime Gaia astrometry, it will be possible to accurately map the evolution of the plane of sky expansion of NGC 6543 and from line of sight velocities, the complex dynamical structure of the expanding nebula. We discuss the first results from the Gaia Data Release 2 in mapping the complex dynamics of a number of extended Galactic PN in the plane of the Milky Way. This allows precise limits to be set on the expansion rates (and thus lifetimes) of a

representative sample of PN. Extending the analysis to larger samples of PN enables statistical inferences concerning PN type, shape, environment, likelihood of multiple central star systems to be found. These first results demonstrate how Gaia (with its parallax and proper motion uncertainties below 50 micro-arcsec for G=15 objects) can map extended structure. We describe the combination of Gaia data with optical narrow and broad band imaging data, essential in allowing positive nebular Gaia detection cross matches and rejection of stars in the field. We discuss the use of novel image segmentation techniques, developed for the analysis of histopathology data, applied to the optical image data to create the catalogues of nebula features required when matching with the Gaia sources.

**Author(s):** Nicholas Walton

**Institution(s):** University of Cambridge Contributing Team(s): Gaia DPAC

### **336 - Evolved Stars, Cataclysmic Variables & Friends**

#### **336.01 - The Magnetic Fields of Donor Stars in Magnetic Cataclysmic Variables(Paul Barrett)**

During the last five years, we have obtained 195 hours of VLA radio observations to observe 165 magnetic cataclysmic variables (MCVs). We have detected radio emission from 29 MCVs, increasing the number of known sources by a factor of five (from 6 to 33). This larger sample of MCVs enables a statistical analysis of the number of MCVs versus orbital period, and demonstrates that rapidly-rotating ( $< 10$  d) fully-convective dwarf stars emit strongly at radio frequencies (Barrett et al. 2018). This result is in conflict with the standard model of cataclysmic variable evolution where magnetic braking ceases below an orbital period of about 3 hours. Over two-thirds of the stars in our sample have orbital periods of less than three hours. This result implies that the donor stars in MCVs are magnetically more active below the period gap than above. We also note that ~75% of our radio detections show highly polarized emission that we attribute to electron cyclotron maser emission in a 2 - 8 kG magnetic field. The large percentage of highly polarized emission is in contrast to the early observations of MCVs by Chanmugam et al. (1983) and others that showed mostly unpolarized radio emission.

**Author(s):** Paul Mason, Anthony Beasley, Kulinder Pal Singh, Christopher Dieck, Paul Barrett,

**Institution(s):** US Naval Observatory, National Radio Astronomy Observatory, George Washington University, IISER Mohali, New Mexico State University

#### **336.05 - More Than Just Spots: Detailed Imaging of Evolved Stars Using Optical Interferometry(Ryan Norris)**

Because of their large radii, red supergiant (RSG) and asymptotic giant branch (AGB) stars are compelling topics for imaging using optical interferometry. Both RSGs and AGBs have large convection cells which have been detected as spots

on the surface of these stars. Upgrades to facilities such as CHARA and new facilities, such as the Magdalena Ridge Observatory Interferometer, will offer an unprecedented look into the lives of evolved stars. Understanding the properties of surface features on these objects-their size, lifetime, and contrast-will provide important input into stellar models. Here we will discuss how to use interferometric imaging to study convection in evolved stars, with a look toward the capabilities of interferometers in the coming decade. We will use simulated observations to show the best strategies for image reconstruction, including state of the art techniques for imaging time variable objects, discuss comparison to 3D radiative hydrodynamics (RHD) models, and present methods for distinguishing features from artifacts resulting from noise and observational coverage.

**Author(s):** John S Young, Fabien R Baron, Ryan Norris, Miguel Montarg s, Andrea Chiavassa, Claudia Paladini,

**Institution(s):** Georgia State University, Institute of Astronomy, KU Leuven, Universit  C te d'Azur, Observatoire de la C te d'Azur, Institut d'Astronomie et d'Astrophysique, Universit  libre de Bruxelles, European Southern Observatory, Cavendish Laborat

#### **336.06 - Optical photometry of eclipsing polars for determination of stellar masses and radii(Natalie Wells)**

Polars are cataclysmic binary stars containing a highly magnetic (10 - 250 MG) white dwarf accreting from a Roche-lobe filling low-mass companion. High speed (1 - 5 sec) optical photometry obtained using the McDonald Observatory 2.1 meter telescope was collected during both active accretion high states, where eclipses of one or more accretion spots are observed, as well as low states where accretion is minimal and a relatively clean eclipse of the white dwarf is seen. By example we show that constraints, provided by the combination of the white dwarf and bright spot eclipse timings, allow the determination of stellar radii and masses without assuming theoretical mass-radius relations.

**Author(s):** Natalie Wells, Paul Mason,

**Institution(s):** New Mexico State University, Picture Rocks Observatory

#### **336.07 - Spinning Up Evolved Stars With Stellar Companions?(Don Dixon)**

As stars evolve off the main sequence they should experience significant spin down as a consequence of conserving angular momentum. However, a significant number of evolved stars have rotation rates higher than what should be possible. One hypothesis for explaining these rapidly rotating stars is that they have gained angular momentum from interacting with a close binary companion. These interactions would be in the form of tidal forces or the ingestion of one star by its companion. We compiled a set of giant stars from the Tycho-



Gaia Astrometric Solution (TGAS) and a catalog of radial velocity variable stars (RV). This set was separated into two samples. One sample was for giants that exhibit rapid rotation and the remaining that did not were taken as the control sample. The type of giants picked for both sample were those that were in one of two specific regions of the HR diagram. One region is the lower giant branch where we expect the binary stars to still be interacting and the second is the red clump where we expect interactions to have ceased. Using the 2.2m telescope attached with an adaptive optics system (Robo-AO) atop Kitt Peak we searched each of the giant stars in our set for a wide tertiary star that could have led to the inspiral and ingestion of a former tight binary companion. Currently we have observational data available for 145 of our targets. This dataset consists of  $\sim 30\%$  of the rapidly rotating sample and  $\sim 49\%$  of the control sample. Examining this data we find that the binary fraction in the control sample (14%) is consistent with the fraction observed in the field ( $15 \pm 3\%$ ). However, the fraction of wide companions in our rapidly rotating sample is significantly lower (9%) than the control sample, which is counter to what might be expected from the binary interaction/ingestion hypothesis.

**Author(s):** Alyson Hughes, Don Dixon, Keivan G Stassun, Jamie Tayar

**Institution(s):** Vanderbilt University, Fisk University, University of Hawaii

### **336.02D - The BAaDE survey, possible biases, and SiO masers as tracers of circumstellar shell conditions(Michael Stroh)**

The Bulge Asymmetries and Dynamical Evolution (BAaDE) project aims to explore the complex structure of the inner Galaxy and Galactic Bulge, by using the 43 GHz receivers at the Karl G. Jansky Very Large Array (VLA) and the 86 GHz receivers at the Atacama Large Millimeter/submillimeter Array (ALMA) to observe SiO maser lines in red giant stars. The goal is to construct a sample of stellar point-mass probes that can be used to test models of the gravitational potential, and the final sample is expected to provide at least 20,000 line-of-sight velocities and positions. The SiO maser transitions occur at radio frequencies, where extinction is negligible, thus allowing a dense sampling of line-of-sight velocities in the most crowded regions of the Milky Way. In the ALMA sample, a 71% detection rate of SiO masers is obtained, which increases to 80% when considering only the likely oxygen-rich stars in our sample. In addition to SiO, emission from carbon-bearing molecular transitions is detected in a small subset of the sample. Based on Galactic locations and kinematical associations, the extent of the emission, and infrared colors, we are able to classify a significant fraction of our carbon-molecule detections as likely young stellar objects. Further, since the primary aim of the BAaDE survey is to use stars as point-mass velocity probes, I will discuss possible biases in our derived line-of-sight velocities, as well as a possible distance-sensitive bias between 43 GHz and 86 GHz detected samples. Finally, I will compare the relative SiO line strengths and their agreement with current

pumping models, which suggest the SiO line strengths can trace the changing conditions within the circumstellar envelopes.

**Author(s):** Michael Rich, Lorant Sjouwerma, Mark R Morris, Mark Claussen, Michael Stroh, Ylva Pihlstr m

**Institution(s):** University of New Mexico, University of California at Los Angeles, NRAO

### **336.04D - Simultaneous modelling of X-rays emission and optical polarization of intermediate polars using the CYCLOPS code: the case of V405 Aurigae(Isabel Lima)**

Intermediate polars (IPs) are asynchronous magnetic cataclysmic variables, binary systems in which mass transfer occurs from a low-mass star onto a magnetic white dwarf (WD). Magnetic accretion forms a shock near the WD, and the compressed material-the post-shock region-is responsible by the system emission in high energies. Some IPs present optical polarization that comes from cyclotron emission also by the post-shock region. Our main goal is to model simultaneously optical and X-ray data using the CYCLOPS code in order to study the magnetic accretion structure and geometry of IPs. CYCLOPS was developed by our group to perform multi-wavelength fitting of the accretion column flux. It considers cyclotron and free-free emission from a 3D post-shock region, which is non-homogeneous in terms of density and temperature. V405 Aurigae is considered the highest magnetic field IP. Previous studies of this system were not successful in proposing a geometry that explains both the optical and X-ray data. In this study, we present a model that reproduces the V405 Aurigae observations: broadband (UBVRI) circular polarization and photometry, as well as the X-ray spectrum and light curve. We compare scenarios using one or two post-shock regions. In particular, we propose an one-region model that is able to explain the observed data. Our results also suggest high magnetic field ( $B = 3.6 \times 10^7 \pm 0.5$  MG) makes V405 Aurigae a possible progenitor of a polar.

**Author(s):** Jaziel G. Coelho, Joaquim E. R. Costa, Manuel Castro, Isabel Lima, Karleyne M. G. Silva, G. Juan M. Luna, Fl vio D'Amico, Cl udia Vilega Rodrigues

**Institution(s):** University of Washington, European Southern Observatory, Instituto Nacional de Pesquisas Espaciais, Universidade Tecnol gica Federal do Paran , Instituto de Astronomia y F sica del Espacio

### **337 - Engaging Learners in Research and with Content: Education Practices Across the Human Continuum**

#### **337.01 - Innovators Developing Accessible Tools for Astronomy (IDATA)(Timothy Spuck)**

IDATA is a National Science Foundation STEM+C funded project that works to advance knowledge and understanding of best practices in teaching and learning related to computation and computational thinking in astronomy and how participation influences students' attitudes and beliefs about

who can engage in science, technology, engineering, and mathematics (STEM) and computing. Further, the project brings together blind and visually impaired (BVI) and sighted high school and middle school students and their teachers to create a fully accessible astronomy data retrieval and analysis software tool. Students and teachers will collaborate with astronomy and computing science professionals, and educators and education researchers in the design and development of the software as well as learning modules that help students explore the role of computation in astronomy, and use of the software tool itself. The IDATA team utilizes user-centered design (UCD) processes and the iterative method for the development and testing of software and the modules: improving access to our amazing universe for those with BVI related disabilities. The accessible software and instructional modules produced by the project may be adopted by a range of BVI and sighted individuals, but may also be transferrable to other similarly visually-intensive domains such as satellite, geophysical, and medical imaging.

**Author(s):** Timothy Spuck

**Institution(s):** Associated Universities Inc

### **337.02 - Empowering Research by the Undergraduate ALFALFA Team: An NSF-Sponsored Model for Involving Undergraduates in Major Legacy Astronomy Research(Gregory Hallenbeck)**

The NSF-sponsored Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT) is a collaborative, multifaceted program of faculty and undergraduate research at a consortium of 23 diverse U.S. institutions, founded to promote undergraduate research and faculty development within the extragalactic ALFALFA HI blind survey project and follow-up programs. The objective of the UAT is to provide opportunities for faculty and students from a wide range of public and private colleges and especially those with small astronomy programs to learn how science is accomplished in a large collaboration while contributing to the scientific goals of a legacy radio astronomy survey. Partnering with Arecibo and Green Bank Observatories, the UAT has worked with 334 undergraduates (40% women) and 32 (48% women) faculty in the past 10 years, offering annual workshops, observing runs, and research projects (academic year and summer), and presentation of results at national meetings such as the AAS (at AAS233: Burhenne et al., Cane et al., Gault et al., Hetrick et al., Jong et al., Kumagai et al., Luna et al., Olivieri Villalvazo et al., Page et al., Poulin et al., Rea et al., Rehm et al., Reiter et al., ). In this presentation, we summarize the UAT program and outcomes, highlight several current Team research efforts, including multiwavelength followup observations of ALFALFA sources, the UAT Collaborative Groups Project, and the Arecibo Pisces-Perseus Supercluster Survey (APPSS), and suggest how our model could be applied to other legacy projects. This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, AST-1211005, AST-1211683, and AST-1637339.

**Author(s):** Rebecca Koopmann, Martha P Haynes, Gregory

Hallenbeck, Michael Jones

**Institution(s):** Washington & Jefferson College, Cornell University, Union College, Instituto Astrofísica Andaluza  
Contributing Team(s): Undergraduate ALFALFA Team (UAT)

### **337.03 - The University of the Virgin Island's (UVI) National Radio Astronomy Observatory National and International Non-traditional Exchange Hub: Radio Instrumentation & STEM Education in UVI Physics(Alexander Fortenberry)**

The US Virgin Islands (USVI) currently faces a shortage of transferable technical skills as well as high-level critical-thinking and problem-solving skills. These skills are required in order for the USVI to attract technical business to - and/or develop technical enterprises within the region. To combat this, the University of the Virgin Islands and the National Radio Astronomy Observatory's (NRAO) National and International Non-traditional Exchange (NINE) Program has established the Radio Instrumentation STEM Education in UVI Physics (RISE-UP), an NRAO NINE Hub at UVI that will create partnerships to provide opportunities for USVI K-12 and university students to engage with physics. The program will: provide advanced technical training in physics and engineering for UVI students; provide summer research and training experiences for UVI physics and engineering students; and provide assistance to students in finding employment opportunities for UVI physics and engineering students after graduation.

**Author(s):** Alexander Fortenberry

**Institution(s):** University of the Virgin Islands

### **337.04 - Introductory Astronomy on the Cheap(Alex Storrs)**

We have revised our introductory astronomy course to minimize student expense. Our goal is to keep the cost per student (after tuition) to less than \$40. We were able to make use of the free online textbook at Openstax, as well as free Google Forms for in class polling, a custom printing of Prather et al.'s "Lecture Tutorials for Introductory Astronomy" that only contains the ones we use, and Towson University's Blackboard site to meet this goal. We will discuss some details as well as present some results on gains in understanding by our students.

**Author(s):** Jennifer Scott, Alex Storrs

**Institution(s):** Towson Univ

**337.05 - Creating Science Communication Opportunities in Higher Education(Regina Barber DeGraaff)**

Scientific knowledge must be clearly disseminated to help ensure its very existence through funding and public support. As astronomers, we have the advantage of having large public interest in our subject yet as trained scientists we are also good translators between our and other Science, Technology, Engineering and Math (STEM) fields. We (an Astrophysicist & a Planetary Scientist) developed two courses to address the lack of communication training in the STEM curricula at Western Washington University (WWU). One course is an upper division survey course targeted to STEM majors and covers several ways of communicating technical material to a broader audience: press releases, podcasts, blogs, correspondence with elected officials, responding to “controversy” and popular science articles. The other course focuses on a capstone project where each student develops, scripts and produces a three minutes video featuring a science narrative. STEM majors and Non-STEM majors are paired to utilize complementary skills and to facilitate communication outside disciplines. Each course highlights resources available at WWU and although these resources exist at many university campuses (press officer, media studio, writing center, recording equipment, etc.) they are not well known by people in the STEM community. Coupled with public science communication networks and WWU’s student-edited podcast/blog Spark Science, these courses help students play an active role in creating our media, rather than just passively consuming it. The goal of each course is to introduce students to inclusive science communication through guided discussion, targeted reading, hands-on projects, and peer editing. We plan to share the model as a best practice so faculty members feel empowered to create a similar course. Graduate students and postdocs can share this model with departments. Course materials are available upon request.  
**Author(s):** Regina Barber DeGraaff, Melissa Rice,  
**Institution(s):** Western Washington University, Western Washington University

**337.06 - Astronomers’ Role in Global Warming Education(Jeffrey Bennett)**

As scientists, we may think of climate science as quite distinct from astronomy, but the differences are not so important to the public. After all, both disciplines use the same basic physics, and many aspects of global warming science come directly from astronomy (e.g., Venus). In this brief presentation, which continues discussions I’ve led at prior meetings, I’ll focus on why the high public profile of astronomy gives us a unique platform for educating the public about the underlying science of global warming, and discuss how we can use that platform effectively to increase understanding of this crucial topic. It will be based on ideas covered in my book A Global Warming Primer, which is posted freely online at [globalwarmingprimer.com](http://globalwarmingprimer.com).  
**Author(s):** Jeffrey Bennett

**Institution(s):** Big Kid Science

**337.07 - The Aquarius Project: The First Teen-Driven Underwater Meteorite Hunt(Laura Trouille)**

In 2017 a bright green fireball streaked across the sky and ~150 kg of meteorites fell into Lake Michigan. Adler Planetarium Astronomer Dr. Hammergren was able to derive an orbit, making it one of the rare few for which the original orbit of the parent body is known. The strewn field is in deep water (~100m) and, at the time, we had no detailed maps of the lake bed in that region. Also, no previous systematic attempts at underwater recovery of meteorites provided a roadmap for how to proceed. It was this combination of knowns and unknowns that inspired high school students, scientists, and educators to mount “The Aquarius Project.” This multidisciplinary endeavor is the first teen-driven attempt at underwater meteorite retrieval. In an unprecedented collaboration, NASA researchers, cosmochemists and meteoritics experts from The Field Museum, marine biologists from the Shedd Aquarium and NOAA, and engineers and astronomers from the Adler Planetarium joined forces to support this expedition. The project has engaged over 600 Chicago Public School students in the hunt for submerged meteorites. The Aquarius Project inspires teens with the excitement of a real scientific adventure and provides them a chance to work with scientists across the disciplines and like-minded peers in real-world research and engineering challenges. Over the past year, teens have designed and built a magnetic bilge pump retrieval sled mount that dredges and sorts lake sediment, outfitted an underwater ROV with a magnetic meteorite retrieval arm, mapped the lake bed with sonar and magnetometers, deployed their equipment in Lake Michigan, and successfully retrieved ferromagnetic content from the strewn field. Currently the teens and scientists are analyzing the recovered content to identify possible meteorites. The team also discovered that invasive mussels have unfortunately taken over at these depths (>200ft) as well; unexpected given the low oxygen levels. In this talk, I will provide a brief overview of The Aquarius Project and discuss the lessons learned and open questions in coordinating a multi-institution effort across the disciplines, engaging teens in real research, and promoting a supportive and inclusive teen+scientist community.

**Author(s):** Mark Hammergren, Laura Trouille, Ken Walczak, Chris Bresky, Marc Fries, Jesus Garcia, Phil Willink  
**Institution(s):** The Adler Planetarium, Zooniverse, & Northwestern University, NASA, The Adler Planetarium, The Adler Planetarium, Shedd Aquarium  
**Contributing Team(s):** The Adler Planetarium Teen Programs Project Aquarius Team, The Field Museum, The Shedd Aquarium

### **337.08 - Ten Years of a Community Planet Walk Event(James C. Lochner)**

We report on a planet walk event which we have held annually since the 2009 International Year of Astronomy. The event takes place on a 4.7 mile permanent Planet Walk which is part of the Baltimore & Annapolis (B&A) Trail, a “rails-to-trails” walking and biking trail in Maryland. The B&A Trail Planet Walk is anchored by large sculptures of the Sun and Pluto, with smaller stainless steel markers for the planets at the proper scale distances. This community event, which takes place on a Saturday in the spring, is a collaboration between the Friends of Anne Arundel County Trails, NASA/Goddard Space Flight Center, and Anne Arundel Community College (AACC). The purpose of the event is to provide visitors to the Planet Walk not only information about the planets and NASA missions to the planets, but also the size and scale of the solar system. During the day, volunteer scientists, engineers, graduate and undergraduate students, and amateur astronomers are docents stationed at each of the planet markers. The docents are provided with hand-out materials and demonstrations, and often bring their own additional materials. In the evening, the AACC Astronomy Club hosts a public talk by a local scientist on a recent planetary mission and discoveries, followed by a star party. Hosting the evening event additionally provides a learning opportunity for the students in the club. Through the years, the daytime event has had a steady attendance of 125 people, with 45% of attendees under 16 years old, and a number of repeat attendees. The daytime and evening events appeal to a broad range of participants, including families with young children, high school students, community college students, couples, and scouting groups. Through the years, the event has been continuously improved based on extensive feedback provided by the docents on an annual post-event questionnaire. In the most recent improvement, students from a local high school STEM program volunteer as assistants to the docents, handing out materials and keeping the attendance tally, while also increasing their science knowledge and presentation skills.

**Author(s):** Beth Hufnagel, Jack Keene, Deborah Levine, Lora Bleacher, James C. Lochner

**Institution(s):** Universities Space Research Association, NASA/Goddard Space Flight Center, Friends of Anne Arundel County Trails, Anne Arundel Community College - retired, Anne Arundel Community College

### **337.09 - Muggles & Magic - Haunting your observatory for Halloween(Angela Speck)**

It has become very fashionable to use STEAM, i.e. STEM plus Arts as a way to engage audiences, whether K-12, college or the general public. Since 2013 the Laws Observatory at the University of Missouri has run an annual event based on the fact that Astronomy is the only subject taught to both Muggles and Wizards. During the week before Halloween, we host the Haunted Observatory. The venue is decorated with a Halloween/Hogwarts theme and is open to the public. Our special guests include the ghosts of dead astronomers, such as

Newton, Galileo, Sagan, Hypatia; as well as characters from Harry Potter’s alma mater. Children must talk to all the ghosts before they can get candy. This event provides outreach to children of all ages, especially fans of the Harry Potter saga, whilst also providing an opportunity for students to develop outreach skills in a relatively easy, low intensity scenario (in cosplay with a very small audience).

**Author(s):** Angela Speck

**Institution(s):** University of Missouri

### **338 - Cosmology: Galaxy/Structure Evolution**

#### **338.01 - Simple experiments to understand the limits on reconstructing the cosmic initial conditions from galaxy redshift surveys(Matthew McQuinn)**

Some are running large numbers of cosmological simulations to reconstruct the initial modes that resulted in the observed galaxy distribution. Such reconstruction methods have the potential to back out more information about the cosmological initial conditions than possible with other methods. I will discuss simplified numerical experiments that shed light on how well the best reconstruction implementations can ever fair and that set bounds on the amount of primordial information that is accessible to galaxy redshift surveys.

**Author(s):** Matthew McQuinn

**Institution(s):** University of Washington

#### **338.02 - Understanding unrecognized galaxy blends with photometry(Melanie Simet)**

The existence of unrecognized galaxy blends (superpositions) is a pernicious problem for current and upcoming large-scale cosmological surveys from the ground, with expected blend rates of tens of percents (Dawson et al 2016). Such blends cause problems for many measurements, because a blended galaxy pair will be treated as a single galaxy at an incorrect redshift, impacting any measurement that uses redshift information. Here, we use toy-model simulations to investigate whether we can detect these previously-unrecognized blends through the use of galaxy photometry. We find that, for a Large Synoptic Survey Telescope (LSST)-like filter set, galaxy blends do not occupy a unique region of color space and so individual blended galaxy pairs cannot be detected or removed by a color-based selection. More promisingly, however, we show that a comparison of color-space density between a sample of known isolated galaxies and a sample including an unrecognized blend fraction can be used to estimate the overall level of blends and to build a prior on the fraction of detections that are blends at a given location in color space.

**Author(s):** Melanie Simet, Eric Huff

**Institution(s):** University of California Riverside, Jet Propulsion Laboratory

### **338.03 - Star-forming galaxies across cosmic history with COMAP(Patrick C Breysse)**

The CO Mapping Array Pathfinder (COMAP) is opening a new window on the high-redshift universe by mapping star-forming galaxies through CO emission lines. By operating in the intensity mapping regime, COMAP can quickly and efficiently probe large volumes of space in three dimensions while retaining sensitivity to the faintest sources. Phase I of COMAP, which is currently being commissioned, will target the Epoch of Galaxy Assembly from redshift  $z = 2.4$ - $3.4$ , and will allow measurement of the CO luminosity function in unprecedented detail. This can in turn constrain quantities such as the cosmic molecular gas abundance, or the star formation history, as well as provide many intriguing possibilities for cross-correlation. Phase II of the experiment will add significantly more sensitivity to this measurement and will add a lower-frequency receiver. This makes it possible to observe multiple CO lines from the Epoch of Reionization, offering a unique probe of the last great cosmic phase transition.

**Author(s):** Risa Wechsler, Hamsa Padmanabhan, George Stein, Gunjan Lakhiani, Todd C. Gaier, Marie Kristine Foss, Tzu-Ching Chang, James W. Lambo, Charles R. Lawrence, David P. Woodyo, Ingunn Katherine Wehus, Clive Dickinson, Hans Kristian Eriksen, Anthony C. S. Rea

**Institution(s):** Institute for Particle Physics and Astrophysics, ETH Zurich, Owens Valley Radio Observatory, California Institute of Technology, Department of Astronomy and Astrophysics, University of Toronto, CePIA, Departamento de Astronomia, FacCiencias Fisicas y M

### **338.04 - The WFIRST High Latitude Survey(Olivier Dore)**

Cosmic acceleration is the most surprising cosmological discovery in many decades. Testing and distinguishing among possible explanations requires cosmological measurements of extremely high precision probing the full history of cosmic expansion and structure growth and, ideally, compare and contrast matter and relativistic tracers of the gravity potential. This program is one of the defining objectives of the Wide-Field Infrared Survey Telescope (WFIRST). The WFIRST mission has the ability to improve these measurements by 1-2 orders of magnitude compared to the current state of the art, while simultaneously extending their redshift grasp, greatly improving control of systematic effects, and taking a unified approach to multiple probes that provide complementary physical information and cross-checks of cosmological results. We describe in this talk the activities of the Science Investigation Team (SIT) "Cosmology with the High Latitude Survey (HLS)" and present the current thinking on the design of the High Latitude Survey. WFIRST and the HLS in particular are designed to be able to deliver a definitive result on the origin of cosmic acceleration. They are not optimized for Figure of Merit sensitivity but for control of systematic uncertainties and for having multiple techniques each with

multiple cross-checks.

**Author(s):** Olivier Dore

**Institution(s):** JPL/Caltech Contributing Team(s): WFIRST Science Investigation Team "Cosmology with the High Latitude Survey"

### **338.06 - The 3D Spatial Distribution of Illustris-1 Satellite Galaxies(Tereasa Brainerd)**

Number density profiles are computed for the satellites of relatively isolated host galaxies in the Illustris-1 simulation. The mean total mass density of the hosts is well-fitted by a Navarro, Frenk & White (NFW) profile with concentration parameter  $c=11.9$ . The number density profile for the complete satellite sample is inconsistent with an NFW profile and, on scales  $< 0.5 r_{200}$ , the satellites do not trace the hosts' mass distribution. This differs substantially from previous results based on semi-analytic galaxy formation models, which generally show that satellite galaxies trace the mass of their host galaxies. The shape of the Illustris-1 satellite number density profile depends on the luminosities of both the hosts and the satellites. The number density profile for the faintest satellites ( $M_{\text{sat}} > -17$ ) is well-fitted by an NFW profile, but the concentration is a factor of  $\sim 6.5$  less than that of the host mass density. The number density profile for the brightest satellites ( $M_{\text{sat}} < -17$ ) exhibits a steep increase in slope for host-satellite distances  $< 0.1 r_{200}$ , in qualitative agreement with recent observational studies that find a steep increase in the satellite number density at small host-satellite distances. On scales  $> 0.1 r_{200}$  the satellites of the faintest hosts ( $M_{\text{host}} > -21.5$ ) trace the host mass reasonably well. On scales  $< 0.4 r_{200}$ , the satellites of the brightest hosts ( $M_{\text{host}} < -22.2$ ) do not trace the host mass and the satellite number density increases steeply for host-satellite distances  $< 0.1 r_{200}$ .

**Author(s):** Tereasa Brainerd

**Institution(s):** Boston University

### **338.05D - Modeling the non-linear universe using cosmological simulations(Joseph 17 DeRose)**

Current and upcoming cosmological surveys will map out the distribution of galaxies in our Universe in an attempt to answer fundamental questions about the constituents of our cosmos and the physical laws that govern it. The biggest limiting factor in the constraining power of current galaxy surveys is our inability to model the small scale physics associated with galaxy formation and evolution. The non-linear equations governing this physics cannot be accurately solved analytically, making simulations the only existing tool that promises to model it. My thesis has been focused on the creation of such simulations, and their application in contemporary survey science. In this talk I will discuss part of my thesis work focused on developing an efficient empirical model of galaxy formation, ADDGALS, allowing for the production of highly realistic galaxy simulations built on N-body simulations capable of

modeling the large cosmic volumes observed by modern surveys. I will present the framework that I have designed to model Dark Energy Survey (DES) observations using these simulations, including weak lensing effects and atmospheric and detector error models. Finally, I will discuss how these simulations are being used in DES, in particular work testing our full analysis pipeline for 3x2 point and cluster cosmology to high precision, setting the standard for systematics testing in future cosmology analyses.

**Author(s):** Joseph DeRose

**Institution(s):** Stanford University

### **338.07D - Measuring weak lensing magnification with the Fundamental Plane(Jenna Freudenburg)**

I present a framework for measuring weak lensing magnification using the fundamental plane in a DES-like dataset. Weak lensing has proved a powerful probe of cosmology, but shear measurements are sensitive to a number of significant systematic effects. To make the most of future cosmological surveys, new tools are needed to improve precision and constrain these systematics. Magnification, historically neglected in favor of shear, provides a promising way forward. In contrast to previous methods that rely on number counts, we instead exploit the fact that galaxies adhere with low intrinsic scatter to scaling relations among size, surface brightness, and light profile concentration. Given a sufficiently detailed model for systematic deviations from the fundamental plane defined by these scaling relations -- including deviations due to photo-z errors, sky subtraction and other instrument effects, and selection bias -- it is possible to develop an estimator for the magnification of individual galaxies, and by extension statistics such as the galaxy-magnification cross-correlation. The estimator is tested on an emulated dataset that includes realistic systematics models. In the future, we hope to apply this estimator to DES data in order to make a detection of the magnification signal that can be usefully compared to or combined with shear measurements.

**Author(s):** Jenna Freudenburg, Eric Huff, Christopher Hirata

**Institution(s):** Ohio State University, Jet Propulsion Laboratory

### **339 - Dwarf & Irregular Galaxies II: Satellites, Streams, and Other Halo Populations**

#### **339.01 - Dwarf Galaxies, Globular Clusters, and Ultra-compact Dwarfs: Getting to know the outer halo of NGC5128(Matthew Taylor)**

Populations of low-mass satellites like dwarf galaxies, globular clusters (GCs), and ultra-compact dwarf galaxies (UCDs) are common features of giant galaxies throughout the universe. Recent years have seen an acceleration in the discovery rate of such satellites in the Local Universe, with the subsequent unveiling of coherent satellite phase-space structures like groups and planes that are of great utility in near-field

cosmological studies. In an effort to push this field further, optical u'g'r'i'z' imaging of 22 sq. deg. centered on the nearby giant elliptical galaxy NGC5128, as part of the Survey of Centaurus A's Baryonic Structures campaign, has been searched for new low-mass satellites. We will present the early results, including a rich system of >3000 GCs, ~50 new dwarf galaxy candidates, and at least 20 UCDs all within ~225 kpc of their host galaxy. We will present their overall stellar mass and stellar population properties, spatial distributions in NGC5128's halo in relation to other known low-mass satellites, and highlight the potential utility of outer halo GCs to trace minor merging events in the recent past of giant galaxies. Looking toward the future, tracing giant galaxy kinematic profiles out to such large (100s of kpc) radii with next-generation wide-field multi-object spectrometers will constrain the ubiquity of so-called "satellite planes", reveal velocity substructure hinting at dwarf galaxy accretion events, with the overall potential to revolutionize observational near-field cosmological studies.

**Author(s):** Hong-Xin Zhang, Karen Ribbeck, Matthew Taylor, Yasna Ordenes-Briceno, Paul Eigenthaler, Thomas Puzia, Mia Sauda Bovill

**Institution(s):** Gemini Observatory, CAS Key Laboratory for Research in Galaxies and Cosmology, Pontificia Universidad Catolica de Chile, Texas Christian University

#### **339.03 - A Lonely Giant: The Sparse Satellite Population of M94 Challenges Galaxy Formation(Adam Smercina)**

The dwarf satellites of Milky Way (MW)-mass galaxies are important probes of galaxy formation. Satellites are predicted to live in the lowest-mass dark matter halos, which simulations predict are found in abundance around MW-mass galaxies. Recent observational advances have begun to allow us to place our own MW's satellite population in context with other galaxies, and compare to these model predictions. We have conducted a deep Subaru Hyper Suprime Cam (HSC) survey satellite population of the MW-mass galaxy M94. Our survey extends to an effective radius of 150 kpc in g-band. Surprisingly, we find that M94 hosts a satellite population unlike any other known galaxy: it possesses only two low-mass satellites, both  $< 10^6 M_{\odot}$ , compared to  $\sim 10$  around the MW. This is quite striking, as the current highest-resolution, limited-run hydrodynamical simulations such as FIRE fail to predict such broad scatter in the satellite populations of MW analogs. Using 'standard' halo occupation, we find that such a sparse satellite population occurs in  $< 0.1\%$  of MW-mass systems in the cosmological EAGLE simulation, which hosts thousands of MW-mass halos. In order to produce an M94-like system more frequently we find that satellite galaxy formation must be much more stochastic than is currently predicted, requiring a dramatic increase to the slope and scatter of the SMHM relation. Surprisingly, the SMHM relation must even be altered above the 'too big to fail' mass. The sparse satellite population of M94 thus advocates for a major modification to ideas of how the satellites around MW-mass galaxies form.

**Author(s):** Antonela Monachesi, Colin Slater, Adam

Smercina, Jeremy Bailin, Richard D'Souza, David Nidever, Eric Bell, Paul Price

**Institution(s):** University of Michigan, University of Washington, Princeton University, University of La Serena, University of Alabama, Instituto de Investigaci3n Multidisciplinar en Ciencia y Tecnolog3a, University of La Serena, Montana State University, Nation

### **339.04 - The Frequency of Stellar Streams Around Dwarf Galaxies(Sarah Pearson)**

ΛCDM predicts that the dark matter subhalo mass function is nearly self-similar. We therefore expect massive galaxies as well as smaller, dwarf galaxies to have a substantial amount of dark matter subhalos surrounding them. However, we expect the occurrence and nature of debris structures around dwarfs to be different than around larger galaxies, as their current accretion rate should be lower, they should have fewer subhalos and their baryon to dark matter fraction should be lower. As a consequence, we anticipate that observed differences in debris structures will offer new insights into hierarchical structure formation on small scales as well as how the baryons occupy dark matter structures around dwarfs, which is largely unexplored. Future surveys such as WFIRST and LSST will enable us to probe the stellar halos of dwarf galaxies and potentially detect substructure surrounding dwarfs. In this talk, I will discuss our expectations for the importance of stellar halos and the frequency of streams around LMC-type dwarf galaxies by estimating the merger rate and halo occupation from cosmological simulations. Additionally, I will compare the fraction of stars in these galaxies anticipated to be formed in-situ in the main halo progenitor vs accreted from other subhalos. Thus, I will assess whether we will find streams around dwarf galaxies with the next generation telescopes and discuss what we might learn if we find these structures.

**Author(s):** Kathryn V. Johnston, Sarah Pearson, Tjitske Starkenburg

**Institution(s):** Flatiron Institute, Columbia University

### **339.05 - Does NGC 2403 Have a Missing Satellites Problem?(Jeffrey L Carlin)**

We discuss results from the MADCASH (Magellanic Analog Dwarf Companions And Stellar Halos) survey, which will deliver the first census of the dwarf satellite populations and stellar halo properties within LMC-like environments in the Local Volume. We have mapped the halo of low-mass galaxy NGC 2403 ( $D = 3.2$  Mpc) to a projected radius of  $\sim 100$  kpc with deep Subaru+HyperSuprimeCam imaging reaching  $\sim 2$  magnitudes below the tip of its RGB. At these depths, we should be sensitive to dwarf galaxy companions of NGC 2403 having stellar masses of roughly  $10^5 M_{\odot}$  or higher. In early results, this program has already yielded the discovery of the faintest known dwarf galaxy satellite of an LMC stellar-mass host (i.e., NGC 2403) beyond the Local Group; we now report

our findings from a complete map covering the halo of NGC 2403. A previously known satellite, DDO 44, shows an extensive tidal stream in maps of resolved RGB stellar density. However, NGC 2403 appears to lack the 4-8 predicted satellites in the mass range we probe, suggesting that either physical processes in its halo have diminished the number of companions, or that cosmologically-motivated models are overpredicting the satellite populations of LMC-mass galaxies.

**Author(s):** Jeffrey L Carlin, Aaron J. Romanowsky, Duncan Forbes, Beth Willman, Annika Peter, Jean Brodie, Jay Strader, David Sand, Kristine Spekkens, Jonathan Hargis, Denija Crnojevic, Ragadeepika Pucha

**Institution(s):** Michigan State University, oRoyal Military College of Canada, LSST, AURA, University of Arizona/Steward Observatory, University of Tampa, UC Santa Cruz, Space Telescope Science Institute, Swinburne University, San Jose State University, Ohio State

### **339.07 - Can't start a fire without a spark: the dearth of ultra-faint galaxies far from the Milky Way(Elaad Applebaum)**

We have entered an unprecedented era of wide-field, deep surveys of the Universe. From these surveys, the number of known satellite galaxies of the Milky Way has grown more than five-fold, mostly owing to the discoveries of ultra-faint dwarf galaxies. However, it is still unknown how many galaxies remain to be discovered and where they will be located. To this end, we use high-resolution cosmological hydrodynamic simulations of Milky Way-like halos and analyze the distribution of galaxies within and beyond the virial radius. Differing from conventional expectations, we predict a steep decline in the number density of dwarf galaxies beyond the virial radius. Unique to this work, we additionally test the robustness of this prediction to differing star formation models. The radial dependence of luminous galaxies has significant implications for future surveys such as LSST.

**Author(s):** Elaad Applebaum, Alyson Brooks

**Institution(s):** Rutgers University

### **339.08 - Dark matter and binary population inference in dwarf galaxies using Bayesian hierarchical modeling(Quinn Eliot Minor)**

The estimated high dark matter content of ultra-faint dwarf galaxies hinges on an accurate measurement of the line-of-sight velocity dispersion of their constituent stars. However, their dispersions are low enough that the orbital motion of close binary systems can inflate them significantly. We demonstrate a Bayesian method to model multi-epoch radial velocity measurements in the ultra-faint dwarf Reticulum II, fully accounting for the effects of binary orbital motion and systematic offsets between spectroscopic datasets. In the process, we show that Ret II is indeed likely to be a very dark matter dominated object, but nevertheless seems to have a high

close binary fraction compared to Milky Way field binaries. This is consistent with recent results showing an anticorrelation between metallicity and close binary fraction. Finally, we demonstrate the binary population constraints that could be obtained with larger datasets using our hierarchical modeling approach.

**Author(s):** Louis Strigari, Quinn Eliot Minor, Jennifer Marshall, Andrew B Pace

**Institution(s):** CUNY Borough of Manhattan Community College, Texas A&M University, American Museum of Natural History

### **339.02D - Constraining the Physics of Low-Mass Satellite Galaxy Quenching(Sean P. Fillingham)**

Despite remarkable success at modeling the evolution of massive galaxies over cosmic time, modern hydrodynamic and semi-analytic models of galaxy formation fail to reproduce the properties of low-mass galaxies. This shortcoming in our theoretical picture is largely driven by an inability to understand the physical mechanisms by which star formation is suppressed (or “quenched”) in satellite galaxies. In an effort to address this shortcoming, I will present recent results to measure the efficiency of satellite quenching over more than 6 orders of magnitude in satellite stellar mass at  $z \sim 0$ . In particular, this work utilizes observations of galaxy groups identified in the Sloan Digital Sky Survey as well as detailed studies of dwarfs in the Local Volume to constrain the timescale upon which satellite quenching occurs following infall (and thus the physical mechanisms at play). By bringing together multiwavelength data across a broad range in satellite and host mass, this analysis has established a coherent physical picture of satellite quenching that addresses the most glaring deficiencies of current galaxy formation and evolution models.

**Author(s):** M. Katy Rodriguez Wimberly, Tyler Kelley, Coral Wheeler, James S. Bullock, Andrew B. Pace, Michael Boylan-Kolchin, Sean P. Fillingham, Michael C. Cooper, Shea Garrison-Kimmel

**Institution(s):** University of California, Irvine, California Institute of Technology, The University of Texas at Austin, Texas A&M University

## **340 - Circumstellar Disks II**

### **340.01 - Observing Circumstellar Disks with WFIRST/CGI(John Debes)**

The Wide Field Infrared Survey Telescope (WFIRST) coronagraphic instrument (CGI) will be capable of directly imaging a wide range of circumstellar disks in a combination of total intensity and polarized visible light, improving on previous high contrast imaging by orders of magnitude. A subsample of cold debris disks previously resolved in scattered light will likely be observed as part of the CGI technology demonstration phase, laying a foundation for the exploration of nearby planetary systems during the remainder of the WFIRST mission. We review the feasibility and potential scientific return for these

systems with the expected CGI complement of coronagraphic masks and observing modes, and identify key observations that could be proposed.

**Author(s):** Nikole Lewis, Vanessa Bailey, Charles Poteet, John Debes, Bin Ren, Ewan Douglas, Bertrand Mennesson, Bruce Macintosh, Bijan Nemati, Christine Chen

**Institution(s):** STScI, JHU, MIT, JPL, UA-Huntsville, Cornell, Stanford

### **340.03 - Sensitivity of WFIRST CGI to Exozodiacal Scattered Light(Ewan S Douglas)**

Measuring the surface brightness of visible light scattered by exozodiacal dust is key to understanding the diversity of circumstellar dust populations and optimizing future missions to image rocky exoplanets. The Wide Field Infrared Survey Telescope (WFIRST) coronagraph instrument (CGI) is expected to provide sensitivity to point sources at flux ratios smaller than  $5 \times 10^{-8}$ . This opens a new regime of visible light imaging of extended sources, particularly exozodiacal dust, around nearby bright stars. The WFIRST CGI technology demonstration is baselined to include two coronagraph modes with 360 degree dark holes of particular interest for imaging circumstellar dust, a shaped-pupil coronagraph (SPC) with a high-contrast field-of-view from 0.47 arcsec to 1.44 arcsec and a Hybrid-Lyot coronagraph (HLC) from 0.16 arcsec to 0.45 arcsec. We present analytical predictions of the imaging sensitivity to exozodiacal dust using the HLC, in the band from 546 nm to 604 nm, with preliminary estimates exceeding 22 magnitudes per square arcsecond around  $V = 5$  stars. We will also present 2D models used to validate the analytic sensitivity curve by running a range of physically plausible circumstellar disks through an end-to-end instrument model, including the effects of speckles and detector noise from the publicly available WFIRST CGI Observing Scenario 6 simulations.

**Author(s):** Ewan S Douglas, Nikole K Lewis, Vanessa Bailey, Yeyuan Xin, John Debes, John Krist, Bin Ren, Bruce Macintosh, Kerri L Cahoy, Bijan Nemati, Bertrand Mennesson

**Institution(s):** Massachusetts Institute of Technology, STScI, Jet Propulsion Laboratory, Cornell University, University of Alabama in Huntsville, Johns Hopkins University, Stanford University  
Contributing Team(s): WFIRST Coronagraph Science Instrument Team

### **340.05 - 28 Debris Disks Resolved on Solar System Scales with the Gemini Planet Imager(Thomas Esposito)**

We will summarize discoveries and results from our ~4-year circumstellar debris disk imaging campaign within the Gemini Planet Imager Exoplanet Survey (GPIS). Nearing completion after starting in November 2014, GPIS has surveyed over 500 young nearby stars to directly image giant planets in near-IR light with the extreme-AO, high-contrast GPI instrument on the Gemini South telescope. The complementary disk campaign is



itself a large, uniform survey that spatially resolved 28 debris disks using both polarimetric and spectroscopic observations of an 88 star GPIES subsample. For the first time for many of these planetary systems we are probing the  $\sim 10$ -200 au range with spatial resolutions of a few au; regions fundamental to planet formation. We will present the GPIES disk images showing multiple morphologies and extents, including several which represent the first scattered-light and/or polarized intensity detections. We will also discuss findings about the bulk properties of our debris disk sample and implications of our observational sensitivity to scattered-light disks for future imaging missions. This work benefited from NASA's NExSS (NNX15AD95G) research coordination network sponsored by NASA's Science Mission Directorate.

**Author(s):** Paul Kalas, Max Millar-Blanchaer, Justin Hom, Inseok Song, Ronald Lopez, Julien Rameau, Kevin Stahl, Christine Chen, Stanimir Metchev, Marshall Perrin, James Graham, Sebastian Bruzzone, Schuyler Wolff, Zachary H. Draper, Gaspard Duchene, Mike Fitzge

**Institution(s):** Université de Montréal, oAmherst College, National Research Council of Canada Herzberg, University of Victoria, Johns Hopkins University, Leiden University, University of Georgia, Yale University, UC Berkeley, Stanford University, UCLA, Space Tele

### **340.06 - Comet-like activity in the circumstellar debris disk surrounding the 1.4 Gyr-old F2V star HD 109085(Barry Welsh)**

Here, we present high signal-to-noise, medium-resolution spectral observations of the CaII K-line absorption ( $R\lambda \sim 60,000$ ) recorded towards the 1.4 Gyr-old F2V star HD 109085 (h Crv) on two sets of nights in 2017 and 2018. Variability of the circumstellar CaII K-line has been widely observed in the gas disks surrounding many fast rotating A-type stars with ages  $< 100$  Myr (Welsh & Montgomery 2018). This variability is attributed to the presence of evaporating gaseous material associated with comet /asteroid-like bodies as they fall towards the central star due to the gravitational perturbation of their orbits by exoplanets. Our present observations show that the circumstellar absorption of CaII K-line HD 109085 similarly varies over time-scales as short as 48 hours. To our knowledge, this is the first example of an (old) F-star with a known associated cold and dusty debris disk that also possesses warm (ionized) gas associated with evaporating 'exocomet' material. Organic material and water are thought to have been brought to the Earth via the bombardment by asteroids / comets. A similar process may still be operating after 1.4 Gyrs in the HD 109085 stellar system, which is thought to possess several exoplanets (Marino et al 2017).

**Author(s):** Barry Welsh, Sharon L. Montgomery

**Institution(s):** Eureka Scientific, Clarion University

### **340.02D - Millimeter/submillimeter Observations of Chemical Complexity in Protoplanetary Disks(Ryan A Loomis)**

Dust and gas rich protoplanetary disks are the formation sites of planets, and are virtually ubiquitous around young stars. Understanding these environments is crucial to determining future exoplanet compositions, as well as uncovering the origin of Earth's organic reservoir. In this talk, I present interferometric observations with the Atacama Large Millimeter Array (ALMA) designed to study the signatures of chemical complexity in protoplanetary disks. Connecting observations of gas-phase disk organics with the bulk icy reservoir responsible for comet formation requires constraints on abundance distributions (both radial and vertical) and formation/destruction chemistry. First, I present spatially resolved observations of the species  $H_2CO$  and  $CH_3CN$ , assessing the relative importance of gas-phase vs. grain-surface formation routes. I show that both processes contribute with distinct observational signatures, but grain-surface formation is the dominant pathway for both species. Comparing chemical model predictions of  $CH_3CN$  abundances with Solar System cometary measurements, I show that either vigorous vertical mixing or some degree of inheritance from interstellar ices likely occurred in the Solar Nebula. Second, a major challenge in analyzing observations of organics in disks is that their emission is often very weak, resulting in incomplete molecular inventories. I present a new method for detecting weak spectral lines in interferometric data through the use of matched filters, with possible SNR boosts of over 500%. Using this technique, I analyze an unbiased ALMA spectral line survey of two protoplanetary disks, comparing their molecular inventories and detect five new molecular species in disks, a 20% increase in the the number of known disk species.

**Author(s):** Kenji Furuya, Ian Czekala, Catherine Walsh, Jane Huang, Ryan A Loomis, Sean M. Andrews, Viviana V. Guzmán, Karin I Åberg, L. Ilseore Cleaves, Jennifer Bergner, Yuri Aikawa

**Institution(s):** National Radio Astronomy Observatory, University of Virginia, Harvard-Smithsonian Center for Astrophysics, University of Tokyo, University of Leeds, University of Tsukuba, Joint ALMA Observatory

### **340.04D - Effect of Variable Turbulent Viscosity $\hat{\nu}$ and Planet-Induced Gaps on Disk structure, Evolution and the Transport of Water(Anusha Kalyaan)**

The composition of planets and their volatile contents are intimately connected to the structure and evolution of the parent protoplanetary disks from which they form. How disks evolve has long been a mystery. Its angular momentum transport is often parameterized by a turbulent viscosity parameter  $\hat{\nu}$ , usually assumed to be spatially and temporally uniform across the disk. I show that variable  $\hat{\nu}(r,z)$  (where  $r$  is radius, and  $z$  is height from the midplane) resulting from angular momentum transport due to MRI can yield disks with significantly different structure, with mass piling up in the 1-10

AU region resulting in steep slopes of  $p > 2$  (where  $p$  is the power law exponent in  $\dot{M} \propto r^{-p}$ ) in these regions. I also show that the transition radius (where bulk mass flow switches from inward to outward) can move in as close as 3 AU; this effect (especially prominent in externally photoevaporated disks) may significantly influence the radial water content available during planet formation. I then investigate the transport of water in disks with different variable  $\dot{M}$  profiles. While radial temperature profile sets the location of the water snowline (i.e., inside of which water is present as vapor; outside of which, as ice on solids), it is the rates of diffusion and drift of small icy solids and diffusion of vapor across the snow line that determine the radial water distribution. All of these processes are highly sensitive to local  $\dot{M}$ . I calculate the effect of radially varying  $\dot{M}$  on water transport, by tracking the abundance of vapor in the inner disk, and fraction of ice in particles and larger asteroids beyond the snow line. I find one  $\dot{M}$  profile of a disk likely evolving due to winds and hydrodynamical instabilities, and motivated by meteoritic constraints, that appears consistent with inferred water contents observed in asteroids. Finally, I consider water transport in pre-transition disks, i.e., with gaps carved out by proto-planets, around M, G and A stars. I test how the water content of terrestrial planets that form inward of this gap is affected and may vary in disks around different stars.

**Author(s):** Steve Desch, Anusha Kalyaan

**Institution(s):** Arizona State University

## 341 - Stars, Stellar Evolution and Stellar Populations II

### 341.01 - Reproducing Stellar Rotation Periods in the Kepler Field via Magnetic Braking and Tidal Torques (David Fleming)

Stellar rotation period (Prot) studies have produced numerous insights into the angular momentum evolution of low-mass stars, but previous investigations have focused on single stars even though roughly half of Sun-like stars are in stellar binaries. We examine the impact of unresolved stellar binaries on the stellar Prot distribution of the Kepler field by performing Monte Carlo simulations of a population composed of single and double stars by modeling stellar evolution, magnetic braking, and tidal forces. We find that tides modify stellar rotations in all binaries with orbital periods less than 50 days, and up to 70 days in some cases. At short orbital periods, most stellar binaries tidally-lock into synchronous rotation, naturally explaining the observed population of fast rotators in the Kepler field that cannot be reproduced by single-star-only models. Many binaries with longer orbital periods, some up to orbital periods of 70 days, tidally-lock, synchronizing the stellar Prot with the binary orbital period, causing Prot to not be a valid proxy for age in all cases, i.e. gyrochronology methods must be applied carefully. We find the best match to the observations occurs when using an equilibrium tidal model with stellar tidal quality factor ranging from 105 - 108, coupled to the magnetic braking law of Matt et al. (2015). However, our assumed flat stellar age distribution over 1-4 Gyr underpredicts the number

of fast rotators in the Kepler field. If instead we assume a bimodal stellar age distribution in the Kepler field, hypothesized by Davenport (2017), composed of a young (100 Myr - 1 Gyr) and an old (1 - 4 Gyr) population, we successfully reproduce the Kepler Prot distribution. We show that tidal forces are important for binary stars at orbital periods longer than previously considered, the Kepler Prot distribution is significantly impacted by unresolved binaries, and that population synthesis models that couple stellar and tidal evolution can constrain the ages and physical properties of field stars.

**Author(s):** Rodrigo Luger, David Fleming, James Davenport, Rory Barnes

**Institution(s):** University of Washington, Center for Computational Astrophysics, Flatiron Institute

### 341.02 - Estimating the distances to Galactic carbon stars (Gregory C. Sloan)

While Gaia is revolutionizing our understanding of Galactic structure with precise parallaxes to stars 1 kpc or more from the Sun, a number of factors still conspire against accurate distances for stars on the asymptotic giant branch. The period-luminosity (P-L) relation for carbon stars is well calibrated in the Magellanic Clouds, but to apply it to stars in the Galaxy requires knowledge of their pulsation modes. We can estimate distances to Galactic carbon stars using multiple color-magnitude relations in the near-infrared and mid-infrared, and these estimates are accurate enough to separate stars pulsating in the fundamental mode from overtone pulsators. We also investigate whether the color-magnitude relations can be used to independently calibrate the Galactic P-L relation to test for possible effects from metallicity.

**Author(s):** Gregory C. Sloan, Kathleen Kraemer, Iain McDonald, Albert Zijlstra

**Institution(s):** Space Telescope Science Institute, Boston College, Univ of North Carolina Chapel Hill, Univ of Manchester

### 341.03 - The Non-Linear Initial-Final Mass Relation for Stars from 0.8 to 2.8 Msun (Jeffrey Cummings)

Spectroscopic analysis of white dwarfs can be used to determine each white dwarf's mass and cooling age. Focusing here on white dwarf members of older star clusters, comparison of this cooling age to the cluster's total age gives the evolutionary timescale of the white dwarf's progenitor, and hence its initial mass. This is the initial-final mass relation and is valuable for constraining stellar evolution. New white dwarf spectroscopy of confirmed members of both Ruprecht 147 and NGC 752 are combined with our uniform reanalysis of previous white dwarf data from M4, NGC 6819, and NGC 7789, and the recently published white dwarfs from M67. These data now more strongly argue that the low-mass IFMR is not a simple approximately linear relation from 0.8 to 2.8 Msun. The low-mass IFMR data show a rapid change to a steep slope near 1.5

Msun followed by a potentially non-monotonic but still poorly constrained IFMR between 1.8 to 2.8 Msun. Such a sharp rise in white dwarf masses from 1.5 to 1.8 Msun is consistent with independent estimates of where the efficiency of convective-core overshoot rapidly increases, which leads to higher mass stellar cores. For such a sharp rise of the IFMR to be consistent with the observed field white dwarf mass distribution, however, this further argues for a non-monotonic IFMR from 1.8 to 2.8 Msun.

**Author(s):** Enrico Ramirez-Ruiz, Jeffrey Cummings, Jason Kalirai, Jason Curtis, Pierre Bergeron, Pier-Emmanuel Tremblay

**Institution(s):** Johns Hopkins University, STScI, Columbia University, University of Warwick, University of Montreal, University of California - Santa Cruz

#### **341.04 - The Ultraviolet and X-ray Evolution of K Stars(Tyler Richey-Yowell)**

Knowing the high-energy radiation environment of a star over a planet's formation and evolution is critical in determining if that planet is potentially habitable and if any biosignatures will be detected, as UV radiation can severely change or destroy a planet's atmosphere. Current efforts for finding a potentially habitable planet lie with M stars, yet K stars may offer more habitable conditions due to decreased stellar activity and more distant and wider habitable zones. While M star stellar activity evolution has been observed photometrically and spectroscopically, there has been no complete study of K-star evolution. We present the first comprehensive study of the near-UV, far-UV, and X-ray evolution of K stars. We used members of young moving groups and clusters ranging in age from 10 - 625 Myr and field stars and their archived GALEX UV data and ROSAT X-ray data to determine how the UV and X-ray radiation evolve. We find that the UV and X-ray flux incident on a HZ planet is 5 - 50 times lower than that of HZ planets around early-M stars and 50 - 1000 times lower than those around late-M stars - the difference increasing with age. The UV and X-ray HZ flux of K stars decreases from the time of planet formation, thus allowing more suitable conditions for the development and detectability of life, perhaps garnering K dwarfs the "super-habitable" label.

**Author(s):** Victoria Meadows, Adam Schneider, Evgenya L. Shkolnik, Travis Barman, Ella Osby, Tyler Richey-Yowell

**Institution(s):** Arizona State University, University of Washington, University of Arizona

#### **341.05 - Chandra Survey of the Panchromatic Hubble Andromeda Treasury Area(Benjamin Williams)**

We have completed a Chandra survey of the northern disk of M31, matched to the Panchromatic Hubble Andromeda Treasury (PHAT). By combining the deep new Chandra ACIS-I observations with the extensive Hubble Space Telescope imaging, we detect 373 X-ray sources down to 0.35-8.0 keV flux

of 10-15 erg cm<sup>-2</sup> s<sup>-1</sup> over 0.4 square degrees, 170 of which are reported for the first time. We identify optical counterpart candidates for about half of the 373 sources, after using the HST data to correct the absolute astrometry of our Chandra imaging to 0.1". While 58 of the counterpart candidates are point sources potentially in M31, a greater number are extended background galaxies. Additionally there are several star clusters, foreground stars, and supernova remnants. Sources with no clear counterpart candidate are most likely to be undetected background galaxies and low-mass X-ray binaries in M31. All but 8 of the point sources have optical colors inconsistent with single stars, suggesting that many could be unresolved background galaxies or binary counterparts. For all optical point-like candidates, we examined the star formation history of the surrounding stellar populations to look for a young component that could be associated with a high mass X-ray binary (HMXB). The outcome of this population analysis, including possible age measurements for the best HMXB candidates, will be discussed.

**Author(s):** Alexia Lewis, Michael Eracleous, Knox Long, Breanna Binder, Neven Vulic, Benjamin Williams, Manami Sasaki, Valla Antoniou, Paul Plucinsky, Margaret Lazzarini, Dan Weisz, Julianne Dalcanton

**Institution(s):** University of Washington, Friedrich-Alexander University, Harvard-Smithsonian Center for Astrophysics, The Pennsylvania State University, NASA-GSFC, Cal Poly Pomona, Eureka Scientific, UC Berkeley, Ohio State University

#### **341.06 - Searching for Faint X-ray Emission from Galactic Stellar Wind Bow Shocks(Breanna Binder)**

Stellar wind bow shocks produced by runaway OB stars ( $M > 8$  Msun) are believed to be a major source of high-energy emission in the Milky Way. Faint ( $<10^{30}$  erg/s) non-thermal emission is expected to arise from relativistic particles (mainly electrons) being accelerated by a magnetic field at the shock front via first-order Fermi acceleration, but direct X-ray observations from bow shocks at  $>0.5$  kpc from the Sun require prohibitively long exposure times. We have used 3.45 Msec of archival Chandra X-ray observations containing 107 infrared bow shocks (selected from the Kobulnicky et al. 2016 catalog and the Milky Way Project DR2 release) to search for faint X-ray emission via stacking analysis. We do not detect significant X-ray emission from the location of the IR bow shocks. This implies an upper limit on the 0.5-7 keV luminosity of the average Galactic stellar wind bow shock of  $<2 \times 10^{29}$  erg/s. It is likely that the average ISM density and/or the mass loss rates of massive stars are, on average, too low to efficiently produce X-rays coincident with the infrared bow shock.

**Author(s):** Matthew Samuel Povich, Jose Barrios, Patrick Behr, Henry Kobulnicky, Breanna Binder

**Institution(s):** Cal Poly Pomona, University of Wyoming

### **341.08 - Predicting The Extreme Ultraviolet Radiation Environment Of The TRAPPIST-1 System(Sarah Peacock)**

TRAPPIST-1 is an ultra-cool M8 dwarf star that hosts seven transiting short-period terrestrial sized planets whose atmospheres will be probed by the James Webb Space Telescope. The high energy radiation that these close-in planets are exposed to strongly impacts the characteristics of their atmospheres, but these wavelengths are difficult to observe due to geocoronal contamination and interstellar attenuation. On account of these observational restrictions, a stellar atmosphere model may be used to compute the full ultraviolet stellar spectrum, including the extreme ultraviolet (EUV; 100 - 912 Å...). Here we present semi-empirical non-LTE model spectra of TRAPPIST-1 that span EUV to infrared wavelengths constructed using the atmosphere code PHOENIX. These upper-atmosphere models contain prescriptions for the chromosphere and transition region and include newly added partial frequency redistribution capabilities. In the absence of broadband UV spectral observations, we constrain our models using HST Ly $\alpha$  observations from TRAPPIST-1 and GALEX FUV and NUV photometric detections from a set of old M8 stars (>1 Gyr). We find that calibrating the models using both data sets separately yield similar FUV and NUV fluxes, but EUV fluxes that span two orders of magnitude. In this, we demonstrate that the EUV emission is very sensitive to the temperature structure in the transition region. Our lower activity models predict EUV fluxes similar to previously published estimates derived from semi-empirical scaling relationships, while the highest activity model predicts EUV fluxes an order of magnitude higher. Based on studies using the previously predicted radiation levels to analyze the stability of the TRAPPIST-1 planet atmospheres, results from this work further suggest that these planets likely do not have much liquid water on their surfaces.

**Author(s):** Travis Barman, Sarah Peacock, Evgenya L. Shkolnik

**Institution(s):** University of Arizona, LPL, Arizona State University

### **341.07D - Self-consistent radius and distance scales from red giant asteroseismology using K2, Kepler and Gaia(Joel C Zinn)**

In my dissertation I have developed a pipeline for performing asteroseismic analysis of evolved cool stars, applied it to a large K2 database, and performed critical tests of the accuracy and precision of both asteroseismic data and the astrometric data from the Gaia mission. Stellar astrophysics has benefitted enormously from time-domain space-based missions. CoRoT, Kepler, and K2, in addition to identifying thousands of planets, have enabled us to measure masses and radii of tens of thousands of red giant stars through asteroseismology, the study of stellar oscillations. The unexpected degrading of the Kepler satellite's pointing and its subsequently altered flight plan have opened up ten times more coverage of the sky than

Kepler did, revealing a variety of stellar populations across Galactic environments. I describe a new pipeline designed to extract stellar oscillations in the presence of increased noise present in K2 light curves, and I focus on its application on red giants as part of the K2 Galactic Archaeology Program. The resulting thousands of new red giant masses and radii across stellar environment establish a database for reconstructing the Galaxy's formation history. Red giant asteroseismic radii also offer an independent check of Gaia astrometry. I estimate the spatial correlations and the zero-point parallax offset in Gaia Data Releases 1 and 2 by comparing Gaia distances to distances derived from asteroseismic, spectroscopic, and photometric data, which have urgent implications for studies using Gaia parallaxes. With a corrected Gaia parallax scale, I also present the most stringent tests of the asteroseismic radius scale, finding it is accurate to at least 1% across the giant branch, for stars smaller than 30 times the radius of the Sun. Given asteroseismology will provide more precise measures of red giant radius and distance beyond 3kpc than will the predicted end-of-mission Gaia parallaxes, the program of asteroseismology-Gaia synergy introduced in this work promises to establish the most precise and accurate ages of the Galactic halo red giants to date.

**Author(s):** Joel C Zinn

**Institution(s):** Ohio State University

## **342 - Star Clusters Near and Far II**

### **342.01 - Tucana III, a Second r-Process Enhanced Ultra-Faint Dwarf Galaxy(Jennifer Marshall)**

We present detailed chemical abundance patterns of stars in the ultra-faint dwarf galaxy Tucana III, a Milky Way satellite galaxy candidate discovered by the Dark Energy Survey that is in the process of being tidally disrupted as it is accreted by the Galaxy. We show that four of five Tucana III member stars studied chemically to date are moderately enhanced in r-process elements and are classified as r-I stars. As is the case for the one other galaxy dominated by r-process enhanced stars, Reticulum II, Tucana III's stellar chemical abundances are consistent with early pollution from ejecta produced by a binary neutron star merger.

**Author(s):** Terese Hansen, Jennifer Marshall

**Institution(s):** Texas A&M University, Carnegie

### **342.02 - Tidal debris candidates from the Omega Cen accretion event in the APOGEE survey(Borja Anguiano)**

The “globular cluster” omega Centauri (oCen) has several peculiar features that set it apart from other Milky Way globular clusters, such as its large mass, extended size, oblate shape, internal rotation, large age and metallicity spreads, and retrograde orbit. Because of these properties, it is thought that oCen may be a heavily stripped remnant of a Milky Way-

captured dwarf spheroidal galaxy, now currently orbiting (backward) near the Galactic plane. As part of the SDSS-IV/APOGEE-2 survey, which has collected a half million high resolution ( $R \sim 22,500$ ), high S/N ( $>100$ ), infrared (1.51-1.70 microns) spectra for more than 300,000 stars in both hemispheres, APOGEE has included a dedicated oCen targeting campaign where around 1000 individual omega Cen red-giants are being observed. Because APOGEE spectra provide precise abundances for as many as 20 chemical elements, it is possible to build a detailed, multi-dimensional chemical distribution profile for the full mix of oCen populations. By using a multi-dimensional maximum likelihood technique we compute the probability that every other Milky Way field star observed in APOGEE has a chemical signature similar to that associated with any of the populations bound to the cluster. These chemical probabilities of whether a star is consistent with being oCen tidal debris will be combined with an orbital solution based on astrometric data from Gaia DR2 to test whether the stars also have kinematics matching those from a suit of oCen tidal disruption models. The best-matching oCen tidal stream candidates can, in turn, help to refine those models.

**Author(s):** Borja Anguiano, Verne Smith, Katia Cunha, Christian R Hayes, David Nidever, Jennifer Sobeck, Steve Majewski, Sten Hasselquist

**Institution(s):** University of Virginia, National Optical Astronomy Observatory, Montana State University, University of Washington, University of Utah Contributing Team(s): APOGEE team

### 342.03 - Selection and Identification of LEGUS Cluster Candidates(Hwihyun Kim)

The Legacy ExtraGalactic UV Survey (LEGUS) is a Cycle 21 Treasury program carried out by the Hubble Space Telescope to investigate star formation and evolution in 50 nearby star-forming galaxies. One of the high-level data products produced by the LEGUS project is a multi-band photometric catalog of star cluster candidates for each of the 50 LEGUS galaxies. Final star cluster catalogs contain the most comprehensive and extensive selection of cluster candidates and their properties, including morphological classifications determined by the team members after visually inspecting each cluster candidate. The visual inspection is performed after taking a semi-automated approach to extract cluster candidates using a set of SExtractor parameters and other selection criteria (concentration index,  $M_v$ , photometric error, etc). We introduce a custom-made, Python-based tool used to inspect individual cluster candidates, and describe the visual classification process in detail. We have inspected over 15,000 cluster candidates for 31 out of 50 LEGUS galaxies including 17 dwarf galaxies. We assign  $\sim 45,400$  ( $\sim 36\%$ ) candidates as Class 1 (compact and centrally concentrated) and Class 2 (slightly elongated and less symmetric) sources, and  $\sim 42,700$  ( $\sim 18\%$ ) candidates as Class 3 (extended and multi-peaked) sources. In this contribution we describe the process of constructing star cluster catalogs with the LEGUS datasets and discuss the correlation between the morphological classes and the properties of cluster candidates.

**Author(s):** Angela Adamo, Hwihyun Kim, David O Cook

**Institution(s):** Gemini Observatory, IPAC, Stockholm University Contributing Team(s): The LEGUS collaboration

### 342.04 - The GALAH survey: Co-orbiting stars and chemical tagging(Jeffrey Simpson)

We present a study using the second data release of the GALAH survey of stellar parameters and elemental abundances of 15 pairs of stars identified by Oh et al 2017. They identified these pairs as potentially co-moving pairs using proper motions and parallaxes from Gaia DR1. We find that 11 very wide ( $>1.7$  pc) pairs of stars do in fact have similar Galactic orbits, while a further four claimed co-moving pairs are not truly co-orbiting. Eight of the 11 co-orbiting pairs have reliable stellar parameters and abundances, and we find that three of those are quite similar in their abundance patterns, while five have significant [Fe/H] differences. For the latter, this indicates that they could be co-orbiting because of the general dynamical coldness of the thin disc, or perhaps resonances induced by the Galaxy, rather than a shared formation site. Stars such as these, wide binaries, debris of past star formation episodes, and coincidental co-orbiters, are crucial for exploring the limits of chemical tagging in the Milky Way.

**Author(s):** Jeffrey Simpson

**Institution(s):** University of New South Wales Contributing Team(s): The GALAH Collaboration

### 342.06 - On Open Cluster Disruption(Angus Beane)

Open clusters are loosely bound clusters of stars formed in the Milky Way disk from collapsed gas clouds. After the gas is expelled by stellar winds and supernovae, the cluster evaporates over a short period of time - typically hundreds of Myrs. Past studies of the dynamics of open clusters have made the assumption that the surrounding galaxy is smooth and axisymmetric. Recently, high resolution zoom-ins of Milky Way-mass galaxies have produced remarkable agreement with observation. These simulations reproduce features that are important to the gravitational potential of the Milky Way - mainly spiral arms, bars, and large gas clouds. We will report efforts to incorporate the gravitational potential of Milky Way zoom-ins from the FIRE collaboration in a direct n-body solver of open clusters. These controlled simulations allow us to track: 1.) the evolution of open clusters in realistic tidal environments and 2.) stars that have left the open cluster and have since moved 100s of pc away from the cluster. We will also report on searches of ejected members of known open clusters in Gaia DR2 based upon these simulations.

**Author(s):** Megan Bedell, Mordecai-Mark Mac Low, Daniel Anglés-Alcázar, Angus Beane, Melissa Ness, Robyn Sanderson,

**Institution(s):** University of Pennsylvania, American Museum of Natural History, Center for Computational Astrophysics, Columbia University

### **342.07 - Gaia's View of the Assembly and Dissolution of Young Star Clusters and Associations(Michael A. Kuhn)**

The second data release of ESA's Gaia mission has provided an unprecedented view into the internal kinematics of young star clusters and associations. We use Gaia astrometry to examine the motions of stars at the sub-km/s level in 28 clusters and associations (ages 1-5 Myr) using membership lists that were derived from previous X-ray, optical, and infrared studies of the regions. We find that at least 75% of the systems in our sample are in the process of expanding. Typical expansion velocities are on the order of  $\sim 0.5$  km/s, and, in several systems, expansion velocity has a positive radial gradient. One-dimensional velocity dispersions typically range from 1-3 km/s. The observed velocity dispersions imply that most of the systems in our sample are superviral and that some are unbound. We find that systems still embedded in molecular clouds are less likely to show expansion than systems that are partially or fully revealed. In star-forming regions that contain multiple clusters or subclusters, we find no evidence for ongoing coalescence of these groups, implying that hierarchical cluster assembly, if it occurs, must happen quickly while systems are still embedded.  
**Author(s):** Konstantin V. Getman, Eric Feigelson, Lynne Hillenbrand, Michael A. Kuhn, Alison Sills  
**Institution(s):** Caltech, Pennsylvania State University, McMaster University

### **342.05D - Light Element Inhomogeneities and Multiple Populations in Galactic Globular Clusters(Jeffrey M Gerber)**

Spectroscopic and photometric observations have shown that globular clusters are complex systems hosting multiple stellar populations showing variations in light elements such as C, N, O, and Na. However, while multiple populations have been found in every Galactic globular cluster studied, their formation is still not well understood. We present results from a project designed to increase the number of observational constraints on current formation theories and to better understand the chemical nature of multiple populations. We have obtained low-resolution spectra for 100-140 stars ranging in magnitude from the tip of the RGB down to the main sequence turn-off in each of three globular clusters covering a range in metallicity from  $[Fe/H] = -2.10$  to  $-0.78$ : M53, M10, and M71. Our observations come from the multi-object spectrograph, Hydra, on the WIYN-3.5m telescope. We measure the blue CN and CH bands around 3883 and 4300 angstroms, respectively, which allows us to derive C and N abundances, and determine populations based on both CN band strength and N abundance. The population determinations allow us to study the ratio of stars in each population, which can be used to constrain formation scenarios, and to make comparisons with other methods of classifying multiple populations such as those using the Na-O anti-correlation and HST UV photometry. Another necessary constraint for any formation theory of multiple populations is

the radial distribution of each population, and the extended radial coverage of our samples allows us to determine the radial distribution for each cluster studied. Finally, with C and N abundances for stars over much of the giant branch in the two lower metallicity clusters, we study and contrast the evolutionary effects on the surface abundances of these elements in each population.

**Author(s):** Eileen Friel, Jeffrey M Gerber, Enrico Vesperini  
**Institution(s):** Indiana University

### **343 - CMB, Dark Matter & Dark Energy I 343.01 -**

#### **SPT-3G: an optimized instrument for measuring the cosmic microwave background(Zhaodi Pan)**

The third generation camera for the South Pole Telescope (SPT-3G) is designed to map the cosmic microwave background (CMB) with unprecedented sensitivity and high angular resolution. To achieve a high mapping speed and be polarization-sensitive, we have developed multichroic dual-polarization detector modules integrated on silicon wafers. Ten such wafers with a total of 16,000 detectors populate our 400 mm-wide focal plane, which is coupled to the sky through a large-aperture optical system and read out using a frequency-domain multiplexing system. In this talk I will discuss the technology developments and performance of SPT-3G and the science goals. The technologies we have developed were demonstrated on SPT-3G and have implications for future CMB experiments, including the next generation CMB-S4. On the science side, SPT-3G will help improve measurements of the primordial B-mode by measuring and separating the lensing B-mode. The lensing map measured by SPT-3G will put improved constraints on the sum of the neutrino masses and probe the growth of structure, in particular when cross-correlated with optical surveys.

**Author(s):** Zhaodi Pan,

**Institution(s):** The University of Chicago, Kavli Institute for Cosmological Physics  
Contributing Team(s): SPT-3G collaboration

### **343.03 - New Methods for Multifrequency Component Separation: Reconstruction of Novel Thermal Sunyaev-Zel'dovich Maps from Planck Data(James Colin Hill)**

Component separation --- the isolation of particular signals from contaminants and noise --- is a widely encountered problem in the analysis of multifrequency microwave data sets. Signals of interest include the temperature and polarization anisotropies of the cosmic microwave background (CMB), as well as the thermal (tSZ) and kinematic Sunyaev-Zel'dovich (kSZ) effects. The internal linear combination (ILC) method has been frequently applied in this context to extract component-separated CMB and tSZ maps from multifrequency data, using the known spectral behavior of these signals. In its

simplest form, the ILC method preserves a known, specific signal while minimizing the variance due to residual contaminants and noise in the final map. However, the method can be modified with an additional constraint to "deproject" or "null" a particular contaminant whose spectral behavior is also known (or can be modeled). While this deprojection increases the noise in the resulting ILC map, it can nevertheless be useful to mitigate biases in measurements (e.g., cross-correlations) that make use of the map. I will present an extension of this method, termed "Multiply Constrained Monte Carlo ILC". In this approach, an arbitrary number of deprojection constraints can be imposed, relying on models for the spectral behavior of each component that is to be nulled. The method then samples over the parameters in these models, producing an ensemble of resulting ILC maps. Subsequent measurements can be performed on the ensemble of maps, allowing marginalization over the foreground parameters and thereby propagating the associated uncertainties in a Bayesian manner. Implementing the method on a needlet frame, I apply this algorithm to multifrequency data from the Planck satellite to obtain an ensemble of novel component-separated tSZ maps, with well-characterized extragalactic dust contamination (the major contaminant to tSZ reconstruction). I will discuss ongoing and future applications of these maps, as well as similar efforts toward robust CMB lensing and kSZ extraction.

**Author(s):** James Colin Hill,

**Institution(s):** Institute for Advanced Study, Flatiron Institute

### **343.06 - Dust as a Foreground for CMB Spectral Distortions(Ioana Zelko)**

Variations in dust size distribution may affect measurements of spectral distortions of the Cosmic Microwave Background. We examine the effect of improved dust modeling on the detectability of  $y$  and  $\tau_{1/4}$  distortions by experiments such as the Primordial Inflation Experiment (PIXIE, Kogut et al. 2011). The size distribution models proposed by Weingartner & Draine (2001a) are used to calculate extinctions, and an MCMC is used to explore the space of available parameters as constrained by known extinction laws (Schlafly et al. 2016). For the distribution of samples from the MCMC posterior, we calculate the principal components of the galactic dust emission for the range of frequencies used by PIXIE. In addition, the broad infrared emission from dust in other galaxies creates a foreground that is challenging to model in terms of few parameters. Such a simplified model could create a bias in the measurement of the spectral distortions. We will discuss the impact of including this galactic dust and cosmic infrared background modeling while still expecting PIXIE to constrain synchrotron, free-free emission, and the spectral distortion from the black body temperature deviation.

**Author(s):** Ioana Zelko, Douglas Finkbeiner,

**Institution(s):** Harvard University, Center for Astrophysics

### **343.02D - A measurement of E-mode polarization of the cosmic microwave background from the first year of the SPT-3G 1500 square degree survey(Daniel Dutcher)**

Over the last two decades the temperature and polarization properties of the cosmic microwave background (CMB) have been mapped across a wide range of angular scales with ever-increasing precision. Satellite missions such as WMAP and Planck have measured the CMB over the full sky across several frequencies, while ground-based and balloon-borne experiments have provided deep, high-resolution maps of select patches of sky. Recent  $\Lambda$ CDM parameter constraints derived from CMB datasets are in mild tension with parameters derived from other datasets; in particular, values of  $H_0$  calculated from the CMB are 2-3 sigma discrepant from those of Type Ia supernovae observations. Improved measurements of CMB power spectra at high multipoles are needed to further investigate the nature of this tension. SPT-3G, the most recent instrument to be installed on the South Pole Telescope, will conduct a 5-year survey of a 1500-square-degree patch of sky with arcminute-resolution, resulting in ultra-deep maps and power spectrum estimates an order of magnitude more sensitive than current results at small angular scales. These data will provide powerful consistency tests of  $\Lambda$ CDM and shed light on the extensions to the standard model proposed to resolve the  $H_0$  tension. In this talk I discuss the current status of SPT-3G and present measurements of the E-mode polarization and temperature-E-mode correlation angular power spectra of the CMB from the first year of the SPT-3G survey.

**Author(s):** Daniel Dutcher,

**Institution(s):** Department of Physics, University of Chicago, Kavli Institute for Cosmological Physics, University of Chicago  
Contributing Team(s): SPT-3G Collaboration

### **343.04D - Exploring the Diversity of Dark Matter Profiles in Dwarf Galaxies(Nicole C Relatores)**

Dark matter only simulations predict that dark matter halos have steep, cuspy inner density profiles, while observations of dwarf galaxies find a range of inner slopes that are typically much shallower. There is debate about whether this discrepancy can be explained by baryonic feedback or if it may require modified dark matter models. To explore this problem, we obtained high-resolution integral field HI observations for 26 dwarf galaxies with  $M^* \sim 109.3 \text{ M}_\odot$ , and CO kinematics with CARMA for a subsample of 11. We model the total mass distribution as the sum of a generalized Navarro-Frenk-White (NFW) dark matter halo and the stellar and gaseous components. Our analysis of the slope of the dark matter density profile focuses on the inner 300-800 pc, chosen based on the resolution of our data and the region that can be resolved by modern hydrodynamical simulations. The inner slope measured using ionized and molecular gas tracers is remarkably consistent, and it is additionally robust to the

choice of stellar mass-to-light ratio. We find a range of dark matter profiles, including both shallow and steep slopes, with an average slope of  $\rho_{DM} \sim r^{-0.8}$ , only moderately shallower than NFW. We find dark matter profiles that are typically steeper than those observed for lower mass galaxies with  $M^* \sim 107.5 M_\odot$ , and also steeper than simulations with baryonic feedback, such as FIRE.

**Author(s):** Richard Ellis, Alberto Bolatto, Phuongmai Truong, Joshua D. Simon, Nicole C. Relatores, Drew Newman, Leo Blitz  
**Institution(s):** University of Southern California, University College London, Observatories of the Carnegie

### **343.05D - Constraining Self-Interacting Dark Matter with Galaxy Warps (Kris Pardo)**

Dark matter and dark energy comprise most of the energy density of the universe; however, we know very little about either of them. We have only seen their effects on astrophysics and cosmology, and these remain the best ways to test these theories. I have focused my dissertation on testing various dark matter and dark energy theories with astrophysical data. This includes work testing Verlinde's Emergent Gravity theory with dwarf galaxies, higher-dimensional dark energy theories with gravitational waves, self-interacting dark matter with galaxy warps, and modified gravity theories of dark matter with baryonic acoustic oscillations. In this talk, I will focus on just one of these projects: how self-interacting dark matter can be constrained with galaxy warps. For some types of self-interactions, the passage of a galaxy through some background dark matter overdensity will cause a separation of centroids between the collisionless stars and the dark matter halo of the galaxy, which will be experiencing a drag force due to self-interactions. For stars arranged in a disk, this would cause a U-shaped warp of the disk. We have looked for these U-shaped warps in the Sloan Digital Sky Survey and have used this to place competitive constraints on the self-interaction cross section.

**Author(s):** Harry Desmond, Pedro Ferreira, Kris Pardo  
**Institution(s):** Princeton University, University of Oxford

### **344 - Plenary Prize Lecture: Annie Jump Cannon Award: Tracing the Astrochemical Origins of Familiar and Exotic Planets, Lauren Ilesdore Cleeves (Harvard University CfA)**

#### **344.01 - Tracing the Astrochemical Origins of Familiar and Exotic Planets (L. Ilesdore Cleeves)**

Historically, our theories of planet formation have been largely motivated by our Solar System. However, we are just one possible outcome, and with facilities like Kepler we are discovering a multitude of planet types and architectures, many unlike our own. How do we fit all of these systems into a unified theory? In the last five years, the Atacama Large Millimeter/Submillimeter Array (ALMA) has revolutionized our

understanding of planet formation by observing the earliest stages of the process at high spatial resolution on the sky, reaching in some cases  $\sim$  AU scales, with unprecedented sensitivity. In this presentation, I will discuss how observations of molecular emission from disks, such as those provided by ALMA, can answer two key questions in planet formation: 1) what are the possible initial planetary compositions inherited from the disk, and 2) what physical factors regulate the efficiency of planet formation, such as disk temperature, ionization fraction, and turbulence? Through such explorations, in concert with anticipated observations from upcoming facilities such as JWST, we can begin to put our Solar System's formation into context, working toward a more comprehensive picture of the planet formation process in the coming decade.

**Author(s):** L. Ilesdore Cleeves  
**Institution(s):** University of Virginia

### **345 - Plenary Prize Lecture: Henry Norris Russell Lecture: The Limits of Cosmology, Joseph Silk (Johns Hopkins University, Institut d'Astrophysique de Paris and Oxford University)**

#### **345.01 - The Limits of Cosmology (Joseph Silk)**

One of our greatest challenges in cosmology is understanding the origin of the structure of the universe, and in particular the formation of the galaxies. I will describe how the fossil radiation from the beginning of the universe, the cosmic microwave background, has provided a window for probing the initial conditions from which structure evolved and seeded the formation of the galaxies, and the outstanding issues that remain to be resolved, including the nature of dark matter and dark energy. I will address our optimal choice of future strategy in order to make further progress towards understanding our cosmic origins.

**Author(s):** Joseph Silk  
**Institution(s):** Johns Hopkins University

### **346 - Astrobiology Posters**

#### **346.01 - The Search for Extraterrestrial Life: An Astroecological Modeling Approach for Characterizing Exoplanet Habitability (Alma Yesenia Ceja)**

The field of astrobiology aims to determine whether life exists elsewhere in the Universe. A necessary first step in this endeavor is investigating the habitability of known exoplanets. We define the habitability of an exoplanet by its potential to sustain life. Here, an integrative approach is applied to explore the relationship between alien environments and terrestrial life. A probabilistic astro-ecology model is implemented in which the survivability of an organism is determined by its thermal response to local and global exoplanet temperatures. Exoplanet thermal environments are simulated using the climate model, Resolving Orbital and Climate Keys of Earth and Exoplanet Environments (ROCKE-3D). ROCKE-3D is a fully-coupled 3-dimensional oceanic-atmospheric general circulation model



(GCM, NASA-Goddard Institute for Space Studies). The GCM features interactive atmospheric chemistry, aerosols, the carbon cycle, vegetation, and other tracers, as well as the standard ocean, sea ice, and land surface components. It has been used to model Earth, Mars, ancient Venus, and the exoplanet Proxima Centauri b. The GCM output is coupled in the astro-ecology model with empirically-derived thermal performance curves of 1,627 cell strains representing extremophiles from all six Kingdoms, termed the biokinetic spectrum for temperature (Corkrey et al. 2016). The spectrum arises from a meta-analysis of cellular growth rate as a function of temperature. This work quantifies aspects of exoplanet habitability using terrestrial-based thermophysiology. Life, however, is dependent upon multiple variables including the presence of liquid water, nutrient content, and an energy source. Caveats of the methodology and application of our results are discussed with implications for extraterrestrial evolution. These results can be further applied to target selection for future missions designed for detecting biosignatures.

**Author(s):** Stephen Kane, Alma Yesenia Ceja

**Institution(s):** University of California, Riverside

### **346.02 - Revisiting the Early Earth's Methanogen Biosphere(Alia Wofford)**

Earth's geological history suggests that methane (CH<sub>4</sub>) concentrations were considerably higher billions of years ago, which would have significant effects on climate and atmospheric photochemistry. The largest source of Archean (2.5-4 billion years ago) CH<sub>4</sub> was probably biological production, as it is on Earth today (Kharecha et al 2005). Methanogenesis, a primitive methane-producing metabolism that evolved early in Earth's history (Ueno et al 2006), requires hydrogen (H<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) to generate energy, releasing methane as a byproduct. We have used an ecology model that tracks volcanically produced H<sub>2</sub> and dissolved oceanic CO<sub>2</sub> to estimate plausible biogenic CH<sub>4</sub> production rates during the Archean. Methane is then released into the water column and will eventually make its way into the atmosphere. We use biogenic methane fluxes out of the ocean as input to simulations using a 1-D photochemical-climate model of Archean Earth's atmosphere to test the implications for photochemistry and climate. High concentrations of methane can generate organic hazes, which can strongly impact habitability, climate, and planetary spectral appearance (Arney et al 2016). Preliminary analysis of our data shows haze formation when higher levels of methane are present. Hazy atmospheres produce temperature profiles that display strong temperature inversions in the upper stratosphere atmosphere and cooling at the surface level. Also, with thicker hazes there is less methane photolysis in the lower atmosphere which in turn decreases ethane formation, a byproduct of methane and important greenhouse gas. Lastly, we generate spectra from the results of these simulations using the Spectral Mapping and Atmospheric Radiative Transfer model (SMART; Meadows and Crisp 1996) to see what planets with similar spectra will look like to future telescopes. This work represents a self-consistent

synthesis of planetary processes from the biosphere, to the atmosphere, to the telescope.

**Author(s):** Shawn David Domagal-Goldman, Tori Hoehler, Sanjoy Som, Giada Arney, Alia Wofford, Andrew Rushby,

**Institution(s):** NASA Goddard Space Flight Center, Blue Marble Space Institute of Science, NASA AMES Research Center, University of California Irvine

### **346.03 - Water Activity of Thin Films in High Latitude Martian Ground Ice: A Preliminary Study(Vera Demchenko)**

Shallowly buried ground ice is nearly ubiquitous on Mars at high latitudes poleward of ~50° in both hemispheres. In the current climate, this ice is perennially cold, i.e., averaging ~190K at ~70° N latitude. Despite low temperatures, thin films of unfrozen water can exist due to interfacial and Gibbs-Thomson premelting at soil-ice interfaces. The presence of salts can further suppress the freezing point. Water activity is a thermodynamic measure of salinity and an indicator of the biological availability of water molecules. We carried out numerical simulations of subsurface temperatures and thin film occurrence over the last 10 Ma of Martian history. We then calculated the water activity in premelted films occurring ~1 m below the surface. In the current climate, peak mid-summer water activity in these films does not exceed 0.6, inconsistent with habitability for known terrestrial organisms. However, obliquity excursions over the past 10 Ma episodically produce mid-summer water activity ~0.7, consistent with metabolism in some species of Halobacteriaceae.

**Author(s):** Vera Demchenko, Hanna Sizemore,

**Institution(s):** University of Colorado Boulder, Green Bank Observatory, Planetary Science Institute

### **346.04 - Designing a Python Module for the Calculation of Molecular Parameters and Production Rates in Comets(Giannina Guzman)**

Presently, there is a lack of a generalized toolbox for the analysis of cometary observations. The upcoming influx of data stemming from the development of new technology will, then, prove to be a challenge for researchers to keep up with. As a solution to this problem, there is a NASA funded project to build "sbpy", an astropy affiliated and open source Python package for small body research. To further the development of sbpy, I have worked on various functionalities for the package. The first of these functionalities was an Astroquery module to allow the query of JPL's Molecular Spectroscopy catalog. This module provides the molecular constants needed for the production rate calculation. The second functionality is part of sbpy's spectroscopy module and it involves the calculation of molecular production rates following two specific models. This functionality was written with millimeter/sub-millimeter wavelength bands as the primary input, but is adaptable to other wavelengths. The first model I worked to recreate was a

simplification of the local thermal equilibrium (LTE) Haser model, which does not include photodissociation, as described in an existing publication (Drahus 2009). This functionality has already been compared to results calculated in the peer-reviewed literature (Drahus 2012) and have shown a 0.4% error at most. The error is suspected to stem from the difference in computations of molecular parameters. Drahus has also used the CDMS catalog for some of these parameters, while we calculated them from theoretical formulas. I also worked to recreate the LTE Haser model including photodissociation rates at the comet's distance from the Sun. This model calculates the number of molecules observed for an arbitrary production rate and also calculates the number of molecules observed from the input data. The production rate is then computed through the ratio of these results. The comparison between this model and existing data (Wierzchos et al., 2018) has yielded a 2.5% error or less. In the future, more computationally intensive models for the production rate can and will be added to sbpy's repertoire.

**Author(s):** Giannina Guzman, Miguel de Val-Borro

**Institution(s):** Villanova University, NASA GSFC  
Contributing Team(s): Astroquery team

#### **346.05 - Technosearch - Keeping Track of What Has Been Done(Andrew G Garcia)**

Technosearch is a web-based tool that keeps track of SETI searches from 1960 until the present day. This tool stays up to date as researchers report their new observations. Technosearch keeps track of the following fields of data: the title - or popular name-of the search paper, the name of the observers, the date of the search, the objects observed, the facility at which the search took place, the size of the telescope used, the observational sensitivity achieved, the resolving power of the instrument, the time that was spent observing each object, the reference where the search can be found in print, a link to the full paper in pdf format, and comments that explain the search strategy and a place where the observer can make note of whatever else they would like to report. This tool currently allows users to sort the data in ascending or descending order for the following fields: title, date, facility, and hours observed. Future upgrades will enable additional sortable fields including search frequency, search wavelength, and the flux limits. The website is split up into 3 separate but similar lists: Optical SETI, Radio SETI, and Other. The only difference between the lists is what part of the EM spectrum they observe in, and the attributes that define the searches. The tool is also capable of keeping track of which searches were smaller parts of a larger overarching strategy that is ongoing, or is important enough to the community to see how the project evolved with time. This website is maintained by the SETI Institute, and has the potential to be a very powerful tool for the entire SETI community. It will remain viable as the result of increasing use. Without community input these web pages will remain only a static snapshot of the state of SETI searches as of this date. Therefore, the next step in this project is to contact the observers responsible for existing entries on the list and request

that they make any necessary edits to correct current errors and submit future updates. We should also encourage these people to encourage widespread use of and update of Technosearch by the scientific community in the future.

**Author(s):** Andrew G Garcia, Jill Cornell Tarter

**Institution(s):** San Francisco State University, SETI Institute

### **347 - Astronomy Potpourri Posters**

#### **347.01 - Hyperlink preservation in astrophysics papers(PW Ryan)**

URLs have often been used as proxy citations for software and data. We extracted URLs from one journal's 2015 research articles, removed those from certain long-term reliable domains, and tested the remainder to determine what percentage of these URLs were accessible in September and October 2017. We repeated this test a year later to determine what percentage of these links were still accessible. We will present what we learned about software availability and URL accessibility in astronomy.

**Author(s):** PW Ryan

**Institution(s):** Astrophysics Source Code Library

#### **347.02 - Visualization Tools for Observation Planning(Tiffany Christian)**

A visualization tool was developed showing how resources for James Webb Space Telescope (JWST) long range plans are distributed across science observing programs. While the JWST long range planning system enables efficient usage of scarce telescope time by balancing observing time across year long observing cycles, the current system only has weak visualization capabilities that show total resource usage over time. A new visualization tool was developed that shows, via color coding, how each observing program (aka proposal) consumes observing resources in a JWST long range plan. The tool produces a standalone HTML file and allows operations staff to interactively diagnose resource problems in long range plans by highlighting program usage and providing numeric data for selected times. To help resolve resource issues, the tool shows if a selected program can be easily re-planned to alternative days.

**Author(s):** Tiffany Christian, Mark Giuliano

**Institution(s):** Smith College, Space Telescope Science Institute

#### **347.03 - A Simple Model for Radiative and Convective Fluxes in Planetary Atmospheres(Juan Tolento)**

One-dimensional (vertical) models of planetary atmospheres typically balance the net solar and internal energy fluxes against the net thermal radiative and convective heat fluxes to determine an equilibrium thermal structure. Thus, simple models of shortwave and long wave radiative transport can provide insight into key processes operating within planetary

atmospheres. We present a simple, analytic expression for both the downwelling thermal and net thermal radiative fluxes in a planetary troposphere. We assume that the atmosphere is non-scattering at thermal wavelengths and that opacities are grey at these same wavelengths. Additionally, we adopt an atmospheric thermal structure that follows a modified dry adiabat as well as a physically motivated power law relationship between grey thermal optical depth and atmospheric pressure. To verify the validity of our analytic treatment, we compare our model to more sophisticated full physics tools as applied to Venus, Earth, and a cloudfree Jupiter, thereby exploring a diversity of atmospheric conditions. Next, we seek to better understand our analytic model by exploring how thermal radiative flux profiles respond to variations in key physical parameters, such as the total grey thermal optical depth of the atmosphere. Adopting energy balance arguments, we derive convective flux profiles for the tropospheres of all Solar System worlds with thick atmospheres and propose a scaling that enables inter-comparison of these profiles. Lastly, we use our analytic treatment to discuss the validity of other simple models of convective fluxes in planetary atmospheres. Our new expressions build on decades of analytic modeling exercises in planetary atmospheres, and further prove the utility of simple, generalized tools in comparative planetology studies.

**Author(s):** Juan Tolento, Tyler Robinson

**Institution(s):** California Polytechnic State San Luis Obispo, Northern Arizona University

#### **347.04 - HERA Radio Frequency Interference(Erika Sanchez)**

The Epoch of Reionization (EoR) is a period of the universe history in which the intergalactic medium was ionized. HERA Hydrogen Epoch of Reionization is a radio telescope located in South Africa and an international collaboration that aims to understand EoR. This is accomplished by collecting the 21 cm emission of neutral hydrogen from EoR. Radio Frequency Interference (RFI) is human generated noise that limits our ability to see the radio sky. It is important to understand the statistics of RFI in our data to increase our sensitivity and therefore improve our chances of measuring the signal of Reionization. In order to extract the weak signal emitted by Hydrogen from EoR, a pipeline was designed. The pipeline completes all the file conversions necessary to utilize AOFlagger (a program that can be used to apply customized methods to identify RFI) and process our data. Here, we demonstrate the application of the AOFlagger pipeline to HERA data and present the insights it provides into the HERA RFI environment.

**Author(s):** Erika Sanchez,

**Institution(s):** Brown University, California State University San Bernardino  
Contributing Team(s): Joshua Kerrigan, DrPober

#### **347.05 - The Search for a Repeating Fast Radio Burst(Allison Marie McCarthy)**

Initially, Fast Radio Bursts (FRBs) were all one-off events. However, with the discovery of repeat bursts from FRB121102, it begs the question whether all FRBs repeat. Using data taken with the ALFA seven-beam receiver at the Arecibo Observatory, we present approximately 41 hours of follow up observations and analysis of the uncertainty region of FRB 110523. FRB 110523 is one of the few FRBs that can be observed with the Arecibo Telescope. More than that, FRB 110523 has unique characteristics such as its linear and circular polarization. Such characteristic differences from that of FRB 121102, and if FRB 110523 is shown to repeat, could show that FRBs have multiple origin populations. Here we report a possible second burst detection from FRB 110523, which was only seen in a single beam with a similar DM as the previously detected value.

**Author(s):** Allison Marie McCarthy

**Institution(s):** The University of Alabama

#### **347.06 - ZTF Asteroid Light Curve(Mercedes Sierra Thompson)**

The Zwicky Transient Factory (ZTF) survey, with its 47 square degree field of view, can cover 4200 square degrees per hour. The public portion of the survey serves as an excellent precursor to LSST, observing in  $r$  and  $g$  bands with an LSST-like cadence to  $\sim 21$ st magnitude. We have developed a pipeline to extract photometric measurements of known asteroids from the public (40%) and partnership (40%) portions of the survey, and use these data to fit their light curves using a multi-bandpass Lomb-Scargle method implemented in code package gatspy. ZTF has acquired data which can be used to fit light curves of over 500 asteroids. We demonstrate the fitting procedure, and show the distribution of measured rotation periods for these asteroids, cross-matched against previously measured rotation periods and their orbital distribution. We demonstrate how this pipeline could be used in the era of LSST to measure asteroid colors and rotation periods.

**Author(s):** Zeljko Ivezić, Andrew Connolly, R Lynne Jones, Mario Juric, Daniela Huppenkothen, Mercedes Sierra Thompson, Eric Bellm, Christina Willecke Lindberg

**Institution(s):** University of Washington, DIRAC

#### **347.07 - Arecibo Observatory Radar Observations: 2017-2018(Luisa Fernanda Zambrano Marin)**

The Arecibo Observatory in Puerto Rico has the world's most sensitive, most powerful, and most active planetary radar system. The Arecibo planetary radar science group focuses on the characterization of near-Earth objects (NEOs). Funded by the NASA NEO Observations program, our research group performs follow-up observations of both recently discovered and previously known objects and prioritizes observations of potentially hazardous asteroids (PHAs) and potential spacecraft

mission targets (NHATS objects). On average, we observe about 100 objects per year with the planetary radar system, roughly half of which were discovered only days or weeks earlier. Most of our observations use the S-band (2380 MHz, 12.6 cm) radar system, which transmits and receives circularly polarized light. When the transmitted signal is phase-coded, we can produce two-dimensional delay-Doppler radar images with range resolution as fine as 7.5 meters. Radar data provide highly accurate astrometry, directly measure the size, and strongly constrain the shape, spin, and surface properties of the objects. We also can do bistatic experiments with other radio telescopes such as Green Bank and Goldstone. Here, we summarize the targets observed since September 1, 2017, including: (3122) Florence, (3200) Phaethon, and 2017 YE<sub>5</sub>. Despite the damage caused by Hurricane Maria in September 2017, we have observed (as of October 10, 2018) 64 asteroids: 28 newly discovered NEAs, 27 PHAs, 12 NHATS objects, and 2 main belt asteroids. 50 asteroids were observed with radar for the first time, while 14 had been previously observed. This research was supported by NASA's Near-Earth Object Observations Program through grants NNX12AF24G and NNX13AQ46G awarded to Universities Space Research Association. After April 2018, Arecibo planetary radar operations were funded by NASA through grant 80NSSC18K1098 awarded to the University of Central Florida. The Arecibo Observatory is a facility of the National Science Foundation operated under cooperative agreement by the University of Central Florida in alliance with Yang Enterprises, Inc. and Universidad Metropolitana.

**Author(s):** Patrick A Taylor, Anne K Virkki, Betzaida Aponte, Flaviane Venditti, Edgard G Rivera Valentin, Sean Marshall, Sriram S Bhiravarasu, Luisa Fernanda Zambrano Marin,  
**Institution(s):** Arecibo Observatory, Lunar and Planetary Institute, Universities Space Research Association, University of Central Florida

### **347.08 - Geomorphologic Characterizations of Comet 67P/Churyumov-Gerasimenko (Alexandra Dobbs)**

Comets are capsules which preserve volatile and refractory material from our early solar system and may hold insights into mysteries regarding the interstellar medium, protoplanetary disks, and planet formation. Their composition may also provide information about the generation of organic molecules in extraterrestrial environments. Images taken by the Rosetta mission's optical, spectroscopic and infrared remote imaging system's narrow angle camera of comet 67P/Churyumov-Gerasimenko reveal a range of geologic features. The northern latitudes are dominated by smooth terrains which are active regions consisting of unconsolidated material that has fallen back to the nucleus following the sublimation of bedrock. Consolidated cliffs expose the base nucleus and are presumed to be the source of the smooth terrains. In this study the photometric properties of these features are modeled on a per-pixel basis. Phase curves are generated and may be fit using a Hapke model to characterize terrains across the comets surface. Additionally, these characterizations are important for comet sample return which is among NASA's highest priority in solar

system exploration. The proposed Comet Astrobiology Exploration Sample Return (CAESAR) mission's main goal is to touch the surface of 67P and collect at least 80 grams of material to bring back to Earth for analysis. The mission's success relies on the Touch-and-Go (TAG) sample acquisition event, targeting an area to maximize scientific value, while minimizing risk. Phase curves may provide information about the nature of favorable terrain types and can improve signal to noise ratio models for camera suites, ultimately adding context and precision to the current models of 67P. Phase curves for three of CAESAR's "Final Four" TAG sites reveal similarities between the smooth terrain types and how collectively they are fundamentally different in their scattering properties in comparison to a cliff face. These plots provide insights into the photometric properties of terrains on comet 67P which are relevant for geologic characterization and sample acquisition. This work was supported by the REU grant (NSF/AST-1659264).

**Author(s):** Alexander Hayes, Paul Corlies, Alexandra Dobbs, Samuel Birch

**Institution(s):** Fort Lewis College, Cornell University

## **348 - Binary Stars Posters**

### **348.01 - Finding Giant X-Ray Flares in M81 (Christina Moraitis)**

We have recently discovered a pair of energetic ( $>10^{40}$  ergs/s) X-ray sources in NGC4636 and NGC5128 that flare by factors of 100-200 on time scales of less than one minute that do not destroy the object. While the nature of these objects is unclear, they appear to represent a new class of X-ray flaring objects not previously observed in the local Universe. More recently, we have found a third source in the galaxy M81. Numerous X-ray flares have been detected in both Chandra and Swift observations. Unlike the other two flare sources, the M81 source does not reside in a globular cluster of the host galaxy. We present X-ray light curves and spectra of this new source from Swift and Chandra, and discuss constraints on the physical interpretation of the X-ray flares.

**Author(s):** Jimmy Irwin, Christina Moraitis

**Institution(s):** Samford University, University of Alabama

### **348.02 - VRCIC Observations and Analysis of the Totally Eclipsing Near-Contact Binary, NSVS 103152 (Ronald G Samec)**

NSVS 103152 is a  $F5V \pm 2$  type ( $T \sim 6500K$ ) eclipsing binary. It was observed in March 5, 6, 9, 2017 at Dark Sky Observatory in North Carolina with the 0.81-m reflector of Appalachian State University. Four times of minimum light were determined from our present observations, which include two primary eclipses and four secondary eclipses: HJD Min I =  $2457817.8376 \pm 0.0002$ ,  $2457818.6310 \pm 0.0001$ , HJD Min II =  $2457817.5742 \pm 0.0006$ ,  $2457821.5364 \pm 0.0007$ . In addition, two other timings were given in Hubscher et al. 2012 and one in VSX and one in Shaws list of Near Contact binaries

in <http://www.physast.uga.edu/~jss/ncb/>. The following quadratic ephemeris was determined from the available times of minimum light:  $J\text{D Hel Min I} = 2451419.95620 \pm 0.00048 \text{ d} + 0.52836783 \pm 0.00000016 \text{ X E} - 0.00000000276 \pm 0.00000000012 \text{ X E}^2$ . The rapid period decrease may indicate that the binary is undergoing magnetic braking and is approaching its contact configuration for the first time. VRC simultaneous Wilson-Devinney Program (WD) solutions give both a slightly underfilling (detached solution) and a mode 4 solution (semi-detached, primary filling its Roche Lobe). The detached solution gives slightly better sum of square residuals, 0.2593 vs. 0.2594. The first solution gives a mass ratio of  $0.3566 \pm 0.0006$ , and a component temperature difference of 1990 K. The large  $\dot{P}$  in the components verify that the binary is not in contact. A Binary Maker fitted dark spot altered slightly but was not eliminated in the WD synthetic light curve computations. The 16-degree cool spot is on the larger component above the equator with a T-factor of 0.95. The potentials indicate that the components are very near filling their respective Roche Lobes. The fill-out of our model is 99.95% for the primary component and 99.62% for the secondary component potential-wise. The inclination is  $\sim 85.4 (\pm 0.3)$  degrees, resulting in a total eclipse (secondary component) of 38 minutes duration. The systems distance is 798 ( $\pm 12$ ) pc as determined from GAIA DR2. Additional and more detailed information is given in this report.

**Author(s):** Daniel Bruce Caton, Ronald G Samec, Danny R. Faulkner

**Institution(s):** Pisgah Astronomical Research Institute, Dark Sky Observatory, Appalachian State University, Johnson Observatory

### 348.03 - An Atlas of Long-Term AAVSO Light Curves of Symbiotic Stars (Gobind S. Puniani)

Based on data collected by the American Association of Variable Star Observers (AAVSO), we have compiled a catalog of light curves of symbiotic binary star systems. These are long-term light curves, spanning years to decades. We present an atlas of plots of the light curves of 42 symbiotic star systems, with each characterized into one of three groups based on light curve continuity and data quality. The light curves are further categorized into the following, based on their physical properties: Classical Symbiotic Stars, Mira-like Component, Very Slow Novae, Irradiation Variations, Recurrent Novae, Peculiar, and Unclassified. Juxtaposing these light curves, along with some statistical analysis, may provide some key insights into the life cycles of symbiotic star systems.

**Author(s):** Frederick A. Ringwald, Gobind S. Puniani, Lorin G. Zozaya

**Institution(s):** California State University, Fresno

### 348.04 - Testing the Role of Strong Magnetic Fields in Stabilizing Radiation-Pressure-Dominated Thin Accretion Disks (Payden L Shaw)

We present results from two-dimensional, general relativistic, radiation, magnetohydrodynamic (GRRMHD) numerical simulations of radiation-pressure-dominated, Shakura-Sunyaev thin disks accreting onto a stellar-mass, Schwarzschild black hole. In previous work, we showed that such disks are thermally unstable. Here we test the idea that strong magnetic fields may stabilize the disk. We consider three different magnetic field configurations: a uniform, vertical magnetic field; a single, radially extended dipole field contained within the disk; and a series of alternating, small poloidal loops, distributed along the disk midplane. All three configurations start with initially weak magnetic fields. Differential winding (the so-called alpha dynamo) should increase the magnetic pressure relative to the gas pressure in both the vertical and radial field cases. The question is whether the fields can reach sufficient strength to stabilize the disks thermally before other processes (magnetic reconnection or the Parker instability) saturate their growth.

**Author(s):** Payden L Shaw, P. Chris Fragile, Bhupendra Mishra

**Institution(s):** College of Charleston, JILA, University of Colorado

### 348.05 - First Precision Photometric Observations and Analyses of Totally Eclipsing, Solar Type Binary, OR Leonis (Daniel Bruce Caton)

CCD, BVRI light curves of OR Leo were taken in 21, 22, 24 January and 11, 25 February, and 11, March 2018 at the Dark Sky Observatory in North Carolina with the 0.81-m reflector of Appalachian State University by D. Caton. OR Leo was discovered by the SAVS survey which classified it as a  $V = 0.51$  amplitude, EW variable. Ten times of minimum light were calculated, five primary eclipses and five secondary, from our present observations:  $HJD \text{ I} = 2458139.87973 \pm 0.00005$ ,  $2458142.8597 \pm 0.0005$ ,  $2458160.741430 \pm 0.000003$ ,  $2458174.8331 \pm 0.0002$ ,  $2458188.65290 \pm 0.0012$ ,  $HJD \text{ II} = 2458139.7442 \pm 0.0012$ ,  $2458142.9903 \pm 0.0037$ ,  $2458160.8800 \pm 0.0008$  and,  $2458188.78740 \pm 0.0011$ ,  $2458174.9709 \pm 0.0005$ . The following quadratic ephemeris was determined from all available times of minimum light:  $J\text{D Hel Min I} = 2458188.65373 \pm 0.00039 \text{ d} + 0.2709786 \pm 0.0000002 \text{ E} + 5.6(0.2)[\text{endif}] \rightarrow 10^{-10} \text{ E}^2$ . A 15-year period study ( $\sim 20,000$  orbits) reveals this orbital period is constant with high confidence. The mass ratio is found to be somewhat extreme,  $M_2/M_1 = 0.1827 \pm 0.0004$  ( $M_1/M_2 = 3.8$ ). The total eclipses assure this determination. Its Roche Lobe fill-out is  $\sim 25\%$ . The solution had no need of spots. The temperature difference of the component is about  $\sim 65$  K, with the more massive component as the hotter one, so it is a A-type W UMa Binary. The inclination is  $81.1 \pm 0.2$  degrees. Our secondary eclipse shows a time of constant light with an eclipse duration of 27 minutes. More information is given in this preliminary report.

**Author(s):** Daniel Bruce Caton, Ronald G Samec, Robert Hill, Danny R. Faulkner

**Institution(s):** Appalachian State University, Johnson Observatory, Pisgah Astronomical Research Institute, Bob

### **348.06 - Determining Fundamental Proprieties of Galaxies with X-ray Binary Correlations(Anthony Elijah Santini)**

Minor mergers and gravitational interactions of satellite galaxies with their host galaxies have a significant effect on the host galaxies themselves. These satellite galaxies can gravitationally interact and collide with their host galaxies and leave tidal streams in their wake. Because of this the tidal streams surrounding these host galaxies contain valuable information about the interaction history of these host galaxies. The tidal streams themselves are extremely faint “trails” of stars that are the product of the gravitational disruption of the satellite and host galaxy during their tidal interactions. Tidal streams are extremely difficult to detect due to how faint they are in comparison to the galaxy at optical wavelengths. However, tidal streams may also contain X-ray binaries, which are far easier to detect with telescopes such as the Chandra X-ray Observatory. The history of galaxy interaction could be studied by finding correlations between the X-ray binary population just outside the visible extent of the host galaxy and the tidal streams themselves. Additionally, the process of formation of intermediate mass black holes is theorized to be the result of mergers of stellar mass black holes in globular clusters. The practicality of this theory for intermediate mass black hole formation can be tested by determining the frequency with which luminous X-ray binaries, and thus probable black holes, are found in globular clusters. Using a volume-limited sample of galaxies within 15 Mpc observed by Chandra from 1999 to 2016, we examine the X-ray source populations outside D25 to look for correlations between X-ray binaries and tidal streams, and to examine the possibility of forming intermediate mass black holes in globular clusters.  
**Author(s):** Roy Kilgard, Anthony Elijah Santini  
**Institution(s):** Wesleyan

### **348.07 - Spectropolarimetry of WR 113 and other WR + O binaries with SALT(Andrew Fullard)**

Gamma-ray bursts (GRBs) are enigmatic events that allow us to obtain information about distant galaxies and exotic physics due to their high energy. The precise progenitors of GRBs are unknown, but supernovae produced by massive stars are the primary candidates. Like other massive stars, WR stars often occur in binaries, where interaction can affect their mass loss rates and provide the rapid rotation thought to be required for GRB production. The diagnostic tool of spectropolarimetry, along with the potentially eclipsing nature of a binary system, helps us to better characterize the CSM created by the stars' colliding winds. Thus, we can constrain mass loss rates, probe wind interactions, and infer rapid rotation. I present spectropolarimetric results for a sample of WR+O binary systems, obtained with the Robert Stobie Spectrograph at the

South African Large Telescope, between April 2017 and October 2018. The precisely phased observations we obtain with RSS/SALT allow us to map both continuum and emission line polarization variations over the binary cycle, and so potentially reconstruct the shapes and locations of the emitting and scattering regions within the system. I discuss our initial findings and interpretations of the polarimetric variability in several of the sampled binary systems. I analyze one system in particular, the WC8d+O8-9IV binary WR 113 (CV Ser), in light of recently published models of the system, and discuss its status as a possible GRB progenitor.

**Author(s):** Jennifer L. Hoffman, Kenneth Nordsieck, Andrew Fullard

**Institution(s):** University of Denver, University of Wisconsin  
**Contributing Team(s):** SALT observing team

### **348.08 - Constraining Tidal Quality Factor Through Tidal Synchronization in Binary Stars(RUSKIN PATEL)**

Tidal interaction in binary systems is known to change the spin of the stars. The spin state of the stars at the current age is used here to constrain the value of tidal quality factor ( $Q^*$ ). A Monte Carlo Markov Chain method is proposed to sample the parameters required to run a binary system evolution module which calculates the spin of the star at current age. The proposed method is applied to several binary systems in the open cluster M35. I present here the results and analysis thus obtained for the corresponding values of  $Q^*$  for the selected systems. This research is directed towards sampling a large number of binary systems from various open clusters to find the possible relationship between  $Q^*$  and various observed parameters.

**Author(s):** Kaloyan Penev, RUSKIN PATEL

**Institution(s):** University of Texas at Dallas

### **348.09 - Investigating the Possible Mechanisms Powering the Radio Pulsations in AR Scorpii(Kelly Nicole Sanderson)**

The radio pulsations emitted from the binary system AR Scorpii were found to be of interest to many scientists because of the unusual nature of the compact source powering the variable emission from the system. This emission oscillates on a period of 3.56 hours, exactly matching the orbital period of this system, but is also accompanied by two other variable signals with periods of 117.1 and 118.2 seconds. These are thought to be due to the spin of the compact object of the system as well as the beat period between this spin and the orbital period of the system respectively. These three signals, previously observed by the VLA, tell us that the radio emission is emanating from the radio star but is likely being powered by the compact source's interaction with this M star. Multiple models have been predicted to describe how the compact object is actually powering the pulsations. Using VLBA observations of this

system, we would like to determine which of the proposed models is the best at describing the interactions of this system. Determining which model best fit the system was proven difficult for the VLBA because of the lack of a nearby calibrator source combined with the sensitivity of the long baselines provided by this instrument. However, the VLBA was able to confirm two of the three periodic signals detected by the VLA. In addition, the dependence of the polarization of these signals on the orbital period was also confirmed.

**Author(s):** Kelly Nicole Sanderson, Anthony Beasley

**Institution(s):** New Mexico State University, National Radio Astronomy Observatory

### **348.10 - Recombination Energy and Common Envelope Ejection(Jingyao Zhu)**

Hydrodynamical simulations of binary systems undergoing common envelope evolution have generally failed to achieve the levels of envelope ejection and orbital inspiral needed to produce observed post-common envelope binaries, particularly binary white dwarfs. Energy released by hydrogen and/or helium recombination in the expanding envelope has been invoked as a potential source of energy, and recently Nandez and Ivanova have found using smoothed particle hydrodynamics (SPH) simulations that this mechanism may work if the energy can be trapped and used to do work. However, it is not clear whether this condition actually obtains in real systems. To gain insight into this question, we are conducting adaptive mesh refinement (AMR) simulations of common envelopes with radiation diffusion and an equation of state that includes hydrogen and helium partial ionization. We present simulations of red giant-white dwarf systems with parameters similar to those studied by Nandez et al. and discuss the efficiency of envelope ejection in these systems, examining its connection to the relative locations of the photosphere and partial ionization zones.

**Author(s):** Ronald E. Taam, Paul M. Ricker, Jingyao Zhu, Ronald F. Webbink, Frank X. Timmes

**Institution(s):** University of Illinois at Urbana Champaign, Northwestern University, Arizona State University, Academia Sinica Institute for Astronomy and Astrophysics

### **348.11 - Common Envelope Evolution of Massive Binaries(Paul M. Ricker)**

The discovery via gravitational waves of binary black hole systems with total masses greater than  $60 M_{\odot}$  has raised interesting questions for stellar evolution theory. Among the most promising formation channels for these systems is one involving a common envelope binary containing a low metallicity, core helium burning star with mass  $\sim 80 - 90 M_{\odot}$  and a black hole with mass  $\sim 30 - 40 M_{\odot}$ . For this channel to be viable, the common envelope binary must eject more than half the giant star's mass and reduce its orbital separation by as much as a factor of 80. I will discuss issues

faced in numerically simulating the common envelope evolution of such systems and present a 3D AMR simulation of the dynamical inspiral of a low-metallicity red supergiant with a massive black hole companion.

**Author(s):** Ronald E. Taam, Paul M. Ricker, Ronald F. Webbink, Aaron M. Holgado, Frank X. Timmes

**Institution(s):** University of Illinois at Urbana-Champaign, Academia Sinica Institute for Astronomy and Astrophysics, Northwestern University, Arizona State University

### **348.12 - Optical and Infrared Observations of the T Tauri Binary KH 15D(Aleezah Ali)**

We present VRIJHK photometry of the T Tauri binary KH 15D acquired in the 2017/2018 observing season. The data were obtained from the ANDICAM instrument on the 1.3m telescope operated by the Small Moderate Aperture Research Telescope System (SMARTS) at the Cerro-Tololo Inter-American Observatory (CTIO). This T Tauri system includes two young low-mass stars (primary and secondary components designed A and B) on a 48d period surrounded by an inclined, precessing circumbinary disk, which periodically occults the stellar companions. The recent data reveals Star B gradually emerging from the trailing “fuzzy” edge of the disk and is now completely unocculted for the first time since the system's discovery in 1995. From this photometry, we create lightcurves used to probe the composition of the disk, derive the magnitude of Star B, and demonstrate the overall mechanics of the system. In particular, the recent data shows reddening during egress of the last eclipse, indicating that the trailing edge of the disk is transparent and consists of dust-sized particles. Additionally, the most recent data displays Star B at a brighter magnitude than previously observed, allowing us to calculate an apparent I magnitude of 14.079, or 0.12 times brighter than previously computed.

**Author(s):** Aleezah Ali, William Herbst, Amanda Newmark, Joshua Winn, Aylin Garcia Soto, Diana Windemuth

**Institution(s):** University of Washington, Wesleyan University, Massachusetts Institute of Technology, Princeton University

### **348.13 - Identifying Intrinsic X-ray Source Population Groupings in External Galaxies: Astronomical Uses for Machine Learning(Karina Cooper)**

This study examines the X-ray and optical properties of X-ray sources in order to perform classification and clustering with machine learning algorithms. We used an archival survey of X-ray emitting sources in galaxies within 15 Mpc, excluding the Milky Way and its satellites, as detected by the Chandra X-ray Observatory. The purpose of our research was to develop a grouping scheme and discover patterns related to X-ray color. We experimented with variables such as X-ray color, luminosity, and galaxy morphological type as dimensions for unsupervised machine learning algorithms and achieved the

best results with just X-ray Hard and Soft color ratios. We also began to explore adding optical color as another variable. We applied supervised learning with a small training set in order to look at model performances with respect to known classification labels. While we were unable to identify a perfect algorithm, both K-Neighbors and Gaussian Mixture Modeling produced promising results.

**Author(s):** Sadie Coffin, Roy Kilgard, Karina Cooper

**Institution(s):** Swarthmore College, Wesleyan University, Middlebury College

#### **348.14 - Double-lined Spectroscopic binaries in the SDSS/APOGEE DR14 dataset(Kevin Covey)**

Double-lined spectroscopic binaries (SB2s) are useful laboratories for determining precise stellar properties, and multiple systems are important sites for planet formation and key components of stellar populations. SB2s challenge automated stellar parameter pipelines, however, such as the Automated Stellar Parameters and Chemical Abundances Pipeline (ASPCAP) developed for the APOGEE survey. We aim to validate a method of identifying and flagging candidate SB2s with APOGEE spectra by analyzing cross correlation functions (CCFs) computed by the APOGEE reduction pipeline. We calculate metrics that quantify the degree of asymmetry present in each CCF, enabling the selection of sources which show evidence for multiple components in at least one spectral epoch. We also perform a singular spectrum analysis (SSA) to identify sources whose CCFs show significant temporal variability, and utilize machine learning techniques to assign each source a probabilistic SB2 likelihood. Visually classifying thousands of SB2 candidates, we quantify the fidelity and false positive rate as a function of each metric, and identify thresholds that optimize the balance between the purity and completeness of the selected sample. We plan to integrate this SB2 detection algorithm into future SDSS/APOGEE data releases, enabling the community to identify or exclude candidate SB2s in future analyses of the APOGEE catalog.

**Author(s):** Marina Kounkel, Nicholas Troup, Adela Reyna, Kevin Matheson, Carlos Badenes, Nathan Michael De Lee, Kevin Covey, Kimihiro Noguchi

**Institution(s):** Western Washington Univ., Univ of Pittsburgh, Northern Kentucky University, Salisbury University  
**Contributing Team(s):** APOGEE- RV Working Group

#### **348.15 - Constraining Natal Kicks of Binary Neutron Star Systems(Isaac Rivera)**

We use the projected offsets of localized short gamma-ray bursts (sGRBs) to constrain properties of their progenitor binary neutron star (BNS) systems. We perform a 3-dimensional kinematic evolution of systems through the galactic potential of their host galaxy beginning at BNS formation and ending with the merger of the two neutron stars due to gravitational wave emission, provided a merger occurs.

The simulations depend on various input parameters; however, we focus on the mass of the second star and the semi-major axis of the system's orbit prior to its supernova, the natal velocity kick given imparted by the second supernova, and the location at which the second supernova occurred in the galaxy. Using various prescriptions for these input parameters, we investigate the progenitor properties of systems which match the observed offset of the sGRB, providing more information on their formation. Trends emerge that reveal that the higher the mass of the helium star, the higher the velocity kick must be in order for the system to survive, creating a minimum required velocity. We also see fewer surviving systems with a higher semi-major axis, as it is difficult to receive a large kick and remain bound. Finally, we place constraints on the location of the supernova with respect to its host galaxy. This further constrains the properties of surviving systems and constrains the natal kicks required to cause systems to merge at their observed offsets to larger values.

**Author(s):** Michael Zevin, Isaac Rivera, Chase Kimball

**Institution(s):** Northwestern University

#### **348.16 - New spectroscopic orbits for binaries in the Kepler open cluster NGC 6811(Stephanie T. Douglas)**

NGC 6811 is a crucial benchmark cluster for studying the evolution of stellar rotation, multiplicity, and tidal effects. With an age of 1 Gyr, it fills a gap in studies of tidal evolution in binary stars. We have surveyed NGC 6811 and the surrounding region with the Hectochelle spectrograph on MMT from 2007-2018. In total we have >8300 spectra of >3400 stars, and we identify >300 new binaries, many of which are likely cluster members. We constrain the orbits of these binaries using a rejection sampling methodology that robustly handles multimodal orbital parameter distributions. Where rejection sampling yields a unimodal posterior probability distribution over the orbital elements, we fit a final orbit using Markov Chain monte carlo. We present partially or fully constrained orbits for binaries in NGC 6811, as well as preliminary results on tidal circularization in the cluster.

**Author(s):** Stephanie T. Douglas, Søren Meibom, Adrian Price-Whelan

**Institution(s):** Princeton University, Harvard-Smithsonian Center for Astrophysics

#### **348.17 - High Mass X-ray Binary System Merger Rates(Sophia Haight)**

High mass X-ray binary systems are candidates for compact object mergers detectable by laser-interferometers. To evolve the system Cygnus X-1 over a range of metallicities and mass ratios, we use Modules for Experiments in Stellar Astrophysics (MESA). MESA outputs final parameters which suggest the final evolution of the main sequence is a neutron star. Thus we assume a neutron star and black hole system (a type which LIGO has never detected before). We aim to determine a



merger rate for this system post supernova. We build a Monte Carlo simulation to generate a supernova kick which accompanies the birth of a neutron star. Using equations which express the relationship between pre and post supernova parameters, we determine the fraction of systems that are not disrupted and also those that merge. Then, with equations which determine the time-to-merge of non disrupted systems, we collect inspiral times for systems that merge to determine a merger rate for all systems merging within Hubble time. We find that approximately 15 percent of systems remain bound and, of these, about 8 percent of systems will coalesce in Hubble time. From this, we derive a fraction of systems which merge (within Hubble time) of about 1.4 out of 100 HMXB systems with parameters similar to that of Cygnus-X1. Additionally, we are able to collect the distribution of system properties for disrupted systems, systems that merge, and systems that merge in Hubble time.

**Author(s):** Sophia Haight, Christopher Pankow, Vasiliki Kalogera

**Institution(s):** Columbia University, Northwestern University's Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA)

### **348.18 - Refining the Link between Star Formation and Ultraluminous X-ray Sources(Marshall Tickner)**

Ultraluminous X-ray Sources (ULXs) are off-nuclear sources with X-ray power output in excess of the Eddington limit of typical stellar-mass black holes. It has been shown that ULXs are often found in galaxies with overall high star-formation rates (SFR), but the SFR varies widely throughout a galaxy. Little work has been done to quantify the link between ULXs and local star formation rates, and we employ the normalized cumulative rank pixel value function (NCRPVF) to better understand that link. We present the first results of our study using a population of 50 ULXs and the SFR maps of their host galaxies. We find that there is no "threshold" local SFR for the occurrence of a ULX; a small region of high SFR and large regions of low SFR are both conducive to producing ULXs. We also present the first results of our uncertainty analysis of the NCRPVF method.

**Author(s):** Marshall Tickner, David Pooley

**Institution(s):** Trinity University

### **348.19 - The COBAIN code. Basic principles and geometrical considerations(Angela Kochoska)**

The COBAIN (COnTact Binary Atmospheres with INterpolation) code is a generalized three-dimensional radiative transfer code, developed to correctly model contact binary atmospheres. The initial implementation and testing phase (Kochoska et al. 2018, AAS 231, 244.09) demonstrated COBAIN's performance on single, differentially-rotating stars. Here we present the progress that has been made towards modeling contact binary atmospheres in both spherical and cylindrical geometry, the

advantages and disadvantages associated with the chosen geometry, as well as the optimal numerical setup for a variety of system parameters. We also discuss the final goal of this ambitious project, which is the computation of model atmosphere tables to be interfaced with modern binary star analysis codes such as PHOEBE 2 (<http://phoebe-project.org>).

**Author(s):** Kyle Conroy, Andrej Prsa, Martin Horvat, Angela Kochoska, Tomaz Zwitter

**Institution(s):** Villanova University, University of Ljubljana

### **348.20 - Variability of Hundreds of X-ray Binaries(Tenley Hutchinson-Smith)**

X-ray binaries are a fascinating class of astrophysical objects. They tend to be highly variable over both short and long time scales, and can experience sudden flares and long intervals of quiescence. Several physical phenomena, including eclipses, can produce periodic behavior. It has even been hypothesized that some X-ray binaries are orbited by planets. If this is the case, dips in the observed X-ray emission may occur. Here we report on our study of archived Chandra data from several hundred X-ray sources in the galaxies M51, M101, and M104. We analyzed the data by searching for interesting time signatures in the light curves of the X-ray sources, most of which are X-ray binaries, and have found flares, dips, and periodic signatures. We present the results and consider their implications, including the prospects for planet detection and for the search of X-ray triples. This research was made possible by the SAO REU program and is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs.

**Author(s):** Julia Berndtsson, Daniel D'Orazio, Rosanne di Stefano, Ryan Urquhart, Tenley Hutchinson-Smith,

**Institution(s):** Spelman College, ICRAR's Curtin University Node, Harvard University

### **348.21 - Improved Large-Scale 3D Smoothed Particle Hydrodynamics Simulations of Eta Carinae's Colliding Stellar Winds(Javier Bustamante)**

We present results from a series of new full-3D Smoothed Particle Hydrodynamics (SPH) simulations of the colliding stellar winds in the massive binary Eta Carinae. The radius of the computational domain of these simulations is 3,875 AU, making them the largest hydrodynamic simulations to date of Eta Carinae's colliding stellar winds. Such large simulations are crucial for generating synthetic observables for direct comparison to detailed spectral mapping data obtained at multiple epochs with the Hubble Space Telescope/Space Telescope Imaging Spectrograph (HST/STIS). Famous for the largest non-terminal stellar explosion ever recorded, Eta Carinae is the most massive (~120 M<sub>Sun</sub>) active binary within 10,000 light-years of Earth, containing a Luminous Blue Variable and either a Wolf-Rayet or an extreme O star in a highly eccentric ( $e \sim 0.9$ ), 5.54-year orbit. Eta Carinae also

drives the strongest colliding stellar wind shock in the solar neighborhood. Dramatic changes across multiple wavelengths are routinely observed as the stars move about in their highly elliptical orbits, however, several important stellar, wind, and orbital parameters remain uncertain despite decades of close observation. These new SPH simulations are being coupled to 3D time-dependent radiative-transfer simulations with the goal of producing synthetic data cubes for comparison to available and upcoming HST/STIS observations. Comparison of the models and observations will reveal key details about the binary's orbital motion, photoionization properties, and recent mass loss history, which are essential for understanding the late-stage evolution of this nearby supernova progenitor. Our methods can also be adapted to other colliding wind binaries (e.g. WR 140) that will be the subject of future observations with e.g. the James Webb Space Telescope.

**Author(s):** Javier Bustamante, Thomas Madura, Christopher Russell, Theodore Gull

**Institution(s):** San Jose State University, NASA Goddard Space Flight Center, Pontificia Universidad Católica de Chile

### **348.22 - The Mass Transfer Geometry of V367 Cyg(Aislynn Wallach)**

Companion-affected mass loss complicates our understanding of evolved stars; for example, theoretical models predict up to 70% of all main-sequence O stars interact with companions at some point during their lifetimes, but the details of mass loss and transfer in binary systems is poorly understood. V367 Cyg is an eclipsing, low-mass binary system with a complex geometry that offers a unique opportunity to better understand mass transfer processes; the primary star has overflowed its Roche lobe, resulting in an accretion disk that surrounds the secondary star. Here, we will present an analysis of new spectropolarimetric data of V367 Cyg taken with the University of Wisconsin's Half-Wave Polarimeter (HPOL) at the Pine Bluff Observatory and discuss their implications for the mass-loss geometry of the system.

**Author(s):** Jamie L Lomax, Emily Levesque, John Wisniewski, Marilyn R. Meade, Jennifer L. Hoffman, Brian Babler, Kenneth Nordsieck, Aislynn Wallach

**Institution(s):** University of Washington, University of Wisconsin, United States Naval Academy, University of Oklahoma, University of Denver

### **348.23 - The Eclipsing Binary KR Persei(Emily Hollingworth)**

KR Persei is a partially eclipsing system with a 0.996-day orbit. Prior work has determined general characteristics of this binary. We have recently obtained high-precision radial velocities from the Fairborn Observatory (AZ). We used the Wilson-Devinney program with these RV measurements and with existing UBVR differential photometry to determine an improved orbital solution and absolute dimensions of this

binary. We find that the two stars have comparable masses (~1.45 solar), radii (~1.8 solar), and temperatures (~6500 K). Both components have non-spherical shapes, and the orbital period is slightly lengthening. Additional spectroscopic observations will continue throughout the coming year.

**Author(s):** Francis Fekel, Gregory W Henry, James R Sowell, Emily Hollingworth

**Institution(s):** Georgia Institute of Technology, Tennessee State University

### **348.24 - The Tidal Apsidal Structure Constant for a Low-Mass Star(Jerome Orosz)**

The orbit of a binary star will precess if tides and/or rotation cause the stars to deviate from spherical symmetry. The rate of this "apsidal motion" depends on the stellar radii relative to the orbital separation, the orbital eccentricity, the stellar mass ratio, and the apsidal-motion constant  $k$  of each star. The apsidal motion constant depends on the central condensation of the star and indicates how easy it is to deform it. For main sequence solar-mass stars and larger,  $k < 0.02$ , while for low-mass stars with deep convective envelopes,  $k \gtrsim 0.15$ . In some cases,  $k$  for stars in eclipsing binaries can be measured, leading to clues about the internal structure of the stars. To date, stars with measured  $k$ -constants are more massive than the Sun. The apsidal motion constant  $k$ , and hence the internal mass distribution, has never before been measured for a low-mass star. We present here a detailed photo-dynamical model of KIC 7289157. This multi-star system, discovered by NASA's Kepler mission, consists of a 5.26 day eccentric ( $e=0.08$ ) eclipsing binary with stars of 1.10 and 0.57  $M_{\odot}$ . A third star with 1.11  $M_{\odot}$  orbits the binary with a period of 243.6 days and an eccentricity of 0.30. Several tertiary eclipse and occultation events are observed. Finally, there is a fourth star with a mass of 0.56  $M_{\odot}$  in an inclined, wide orbit about the first three stars, with a period of  $\sim 27,000$  days. The third star causes precession of the inner orbit. Owing to the tertiary events, the precession rate of the binary can be precisely measured, allowing us to measure the  $k$ -constants for both stars. For the smaller, 0.57  $M_{\odot}$  star in the binary, our initial results give  $k < 0.03$  at the 68% confidence level, and  $< 0.07$  at the 90% confidence level. The value of  $k$  expected from theory for this star is 0.08. Taken at face value, our results suggest this star is more centrally condensed than what is expected from evolutionary models. We acknowledge data contributions from the KELT network. We acknowledge funding from the NSF (award AST-1617004) and from NASA (award NNX14AB91G). We are also grateful to John Hood, Jr. for his generous support of our research at San Diego State University.

**Author(s):** Gur Windmiller, Quentin J. Socia, Donald R. Short, Jerome Orosz, William F. Welsh, Mitchell E. Yenawine

**Institution(s):** San Diego State University

### **348.25 - The Kepler/APOGEE project. Fundamental parameters for 7 benchmark-grade eclipsing binary systems.(Andrej Prsa)**

Fundamental stellar parameters (masses and radii) with uncertainties smaller than  $\sim 1\%$  are exceedingly rare, yet they allow us to critically probe the physical processes that govern stellar evolution. The Kepler/APOGEE project couples ultra-precise light curves from NASA's Kepler mission with the high-resolution spectroscopic data acquired by the APOGEE instrument within the Sloan Digital Sky Survey. Modeling these data with sophisticated tools such as PHOEBE (Prsa et al. 2016; <http://phoebe-project.org>) enables us to determine fundamental stellar parameters to better than  $1\%$ . In this contribution we present the data and the results on 7 benchmark-grade eclipsing binary systems: KIC 3247294, KIC 4281895, KIC 4931073, KIC 2308957, KIC 4076952, KIC 5193386 and KIC 5288543. The first three systems are highly eccentric, and the remaining four systems feature total eclipses.

**Author(s):** Andrej Prsa, Kelly Hambleton, Blaz Leban, Suvrath Mahadevan, Chad Bender, Scott W. Fleming

**Institution(s):** Villanova University, Space Telescope Science Institute, University of Ljubljana, Penn State University, University of Arizona

### **348.26 - Synthesizing a Sample of Detached Binary Stars in the Kepler Field to Probe the Underlying Stellar Population(Mark Wells)**

Stellar formation and evolution, as they apply to binary stars, reveal their underlying physical mechanisms through the properties of the observed binary star samples. By analyzing populations of binaries, we can study these processes in detail. In the era of large-scale time domain surveys, the acquisition of large samples of eclipsing binaries is all but guaranteed. The Kepler Eclipsing Binary Catalog (KEBC; Kirk et al 2016) provides a glimpse of what these large scale surveys will produce and offers an opportunity to develop extensible methodologies as we prepare for the massive influx of data from the Large Synoptic Survey Telescope (LSST). In this contribution we forward-model the underlying Kepler binary population using the state-of-the-art in synthetic survey generation code and constraints provided by binary population studies (Raghavan et al. 2010, Duchene & Kraus 2013, Moe & Di Stefano 2017). We simulate Kepler observations of the underlying synthetic binary population to obtain a synthetic eclipsing binary survey. These synthetic eclipsing binaries are compared to the  $\sim 90\%$  complete KEBC. Using the catalog as a baseline, we iteratively modify the input distributions from which we generate binary orbital parameters and re-synthesize the binary population until the discrepancy between the synthetic and observed reference population is minimized. Comparing the adjusted population with the initial input model, we are able to provide a quantitative assessment of how well our input assumptions are able to account for the observed population. In this pilot study we focus only on the observed period distribution of detached eclipsing binaries; other

observables, most notably mass-ratio or eccentricity, will also be used to tune the synthetic binary population in future work.

**Author(s):** Mark Wells, Andrej Prsa

**Institution(s):** The Pennsylvania State University, Villanova University

### **348.27 - Considerations and Design Principles for the 2.1 Release of the PHOEBE Eclipsing Binary Modeling Code(Kyle Conroy)**

PHOEBE 2.0 (<http://phoebe-project.org>) was released in early 2017 (Prsa et al, 2016), introducing the next-generation of modeling eclipsing systems with increased precision, triangulated meshing, light travel time effects, Doppler boosting, and improved atmospheric and passband treatments. The recent 2.1 release builds upon this with support for misalignment between the rotational and orbital axes, built-in MPI parallelization, as well as support for creating synthetic spectral line profiles. Here we discuss the implementation and use cases of these new features as well as the parameterization change from polar to equivalent radius and redesign of the plotting framework made between the 2.0 and 2.1 releases of PHOEBE.

**Author(s):** Joseph Giammarco, Andrej Prsa, Kelly Hambleton, Martin Horvat, Herbert Pablo, Kyle Conroy, Angela Kochoska

**Institution(s):** Villanova University, University of Ljubljana, AAVSO, Eastern University

### **348.28 - NuSTAR Analysis of a Low-Frequency QPO in the Black Hole MAXI J1535-571(Liam Dowling Jones)**

MAXI J1535-571 is a recently discovered transient X-ray black hole candidate that exhibited strong low-frequency quasi-periodic oscillations in its bright 2017-2018 outburst, as indicated by observations from the Neutron Star Interior Composition Explorer (NICER) (e.g., Stevens et al. 2018). To follow up on the behavior of these QPOs and their energy dependence, we present X-ray timing results from 12 observations obtained by the Nuclear Spectroscopic Telescope Array (NuSTAR). Due to NuSTAR's deadtime properties, we analyze the cospectra of MAXI J1535-571, rather than the power spectra, using tools developed by Bachetti and Huppenkothen (2018). The feature varies in frequency, with the peak occurring at an average frequency across observations of approximately 2.5 Hz; the QPO appears to be relatively broad and weak. We explore the energy dependence of the QPO and its lag behavior in the NuSTAR data, for comparison to NICER and the Type B QPO discovered by Stevens et al. (2018).

**Author(s):** Joseph Neilsen, Abigail L. Stevens, Phil Uttley, Liam Dowling Jones

**Institution(s):** Villanova, Michigan State University, University of Amsterdam

### **348.29 - Searching for Binaries in the Praesepe Open Cluster(Valeria J Villegas-Medina)**

We examine the Praesepe open cluster in search of close Solar-type binaries. Open clusters are groups of hundreds to thousands of stars, all with the same age. In observing the young (~600 Myr) Praesepe cluster we obtain a snapshot where all the stars in the cluster have the same age and composition, allowing us to hone in on the characteristics of the systems themselves. By searching for binaries in open clusters of different ages and with the same composition we can eventually piece together the life of a binary. We have observed Praesepe members using the Tillinghast Reflector Echelle Spectrograph (TRES) on the 1.5m telescope at the Whipple Observatory from 2012-2018. TRES yields spectra with  $R \sim 44,000$  and we can achieve velocity precision of 100 m/s for stars as faint as  $V \sim 12.5$ . We look for high variations in radial velocity for stars in our sample as a test for a companion star. We use the Python package RadVel to carry out a maximum likelihood fit for each binary's orbital parameters. We present preliminary orbits for new binaries in Praesepe as well as plans for future work.

**Author(s):** Valeria J Villegas-Medina, Samuel N Quinn, Mercedes Lopez-Morales, Stephanie Douglas,

**Institution(s):** Westminster College, Columbia University, Harvard-Smithsonian Center for Astrophysics  
**Contributing Team(s):** Harvard-Smithsonian Center for Astrophysics

### **348.30 - Constructing Orbits: Peculiarities in Period Finders and the Resulting Orbital Fits(Nathan Michael De Lee)**

The APO Galactic Evolution Experiment (APOGEE-1) survey took high-resolution H-Band spectroscopy of 146,000 stars (as of Data Release 12). Of these, 14,840 stars had at least 8 radial velocity (RV) epochs with baselines up to 3 years (~1000 days) making them suitable for orbit fitting. In Troup (2016), 382 of the 14,840 orbits were selected as a gold sample of stars with well-characterized orbits. In our project, we analyzed the orbit fitting code used in Troup (2016) to understand what areas of orbital parameter space are more or less likely to be recovered using those techniques and other fitting methods. We did this by generating a catalog of mock RV curves that resembles the APOGEE survey and analyzing the results of different Keplerian orbit fitting methods. In particular, we will investigate how different period finding algorithms affect our recovery rate. We will also look at how using Markov Chain Monte Carlo (MCMC) techniques can help us improve our recovery rate.

**Author(s):** Nicholas Troup, Kendra Herweck, Steve Majewski, Kyle Houston, Nathan Michael De Lee, Kevin Covey, Joleen K Carlberg

**Institution(s):** Northern Kentucky University, Salisbury University, Vanderbilt University, Space Telescope Science Institute, Western Washington University, University of Virginia  
**Contributing Team(s):** APOGEE- RV Working Group

### **348.31 - A Novel Algorithm for Detrending Systematic Artifacts in Kepler Light Curves of Periodic Variable Stars(Moses Zhang)**

The Kepler Mission has been pivotal to our modern understanding of planetary transits and host stellar properties, such as population and asteroseismic parameter modeling, ever since its launch in March 2009. Eclipsing binaries (EBs) within the Kepler dataset, which make up 1.3% of all targets, have contributed to our understanding of fundamental stellar parameters and stellar evolutionary models. Both modeling and population analysis, however, have been hindered by processing artifacts embedded during data reduction, which introduced extrinsic noise to the Kepler light curves. We present a python-based algorithm that introduces a novel detrending technique that relies on strict signal periodicity. The algorithm disentangles the periodic signal using a discrete probability function in an iterative, self-correcting manner through heuristic minimization of the cost function. In addition, we present the optimally extracted periodic signals of EBs for all objects in the Kepler Eclipsing Binary Catalogue as a demonstration of the algorithm. One strength of this application is its independence of any model-fitting assumptions, overcoming the limits of the Singular Value Decomposition (SVD) method of NASA's Pre-Data Conditioning Bayesian maximum a posteriori (PDC-MAP) pipeline. This algorithm is the first to target systematic noise detrending based on strictly periodic signals, which allows for more efficient light curve extraction, and also allows for unbiased noise analysis, providing insight into the nature of variable sources and the corresponding systematic errors.

**Author(s):** Moses Zhang, Andrej Prsa, Mark Wells

**Institution(s):** Byram Hills High School, Villanova University, The Pennsylvania State University

## **349 - Cosmology -- Posters**

### **349.01 - Supernova Cosmology with Luminous Red Galaxies(Hannah McCall)**

Upcoming Type Ia supernova analyses must overcome several challenges to improve their measurements of dark energy. Without the resources for spectroscopic follow-up of every transient, it is necessary to find alternative methods of determining supernova type, obtaining supernova or host galaxy redshift, and navigating systematic uncertainties due to correlations with host galaxy properties. We present here a new approach that addresses each of these obstacles. From the 3,000 supernovae discovered by the Dark Energy Survey, we take the sample of supernovae hosted in luminous red galaxies (LRGs). These galaxies host exclusively type Ia supernovae, so no spectroscopy is required for supernova classification. Furthermore, we are able to measure precise photometric redshifts for these types of galaxies ( $\bar{f}_z / (1+z) \sim 0.02$ ), eliminating the need of spectroscopy for determination of redshift. In addition, as SNe can be found in LRGs from low to high redshift, use of supernovae located in this galaxy subset ensures a consistent host galaxy demographic. We use the

redshifts of the host galaxies to help ascertain distances of supernovae, and combine this information to create a Hubble diagram. In the future, we can utilize the Hubble diagram to measure cosmological parameters and continue to refine our method for use in upcoming surveys like LSST.

**Author(s):** Eduardo Rozo, Hannah McCall, Daniel Scolnic, Rick Kessler, Eli Rykoff

**Institution(s):** Washington University in StLouis, Stanford University, Kavli Institute for Cosmological Physics at the University of Chicago, University of Arizona

### **349.02 - Photometric Calibration of the Pan-STARRS Survey to Improve Cosmological Measurements with Type Ia Supernovae(Joseph Manuel)**

Photometric calibration is the dominant systematic uncertainty in the analysis of type Ia supernovae (SNIa) for precision cosmology (Scolnic, 2018). Recent studies have shown that 1% level uncertainties in the calibration can propagate to up to 5% level systematic uncertainties in measurements of the equation-of-state of dark energy. The Pan-STARRS survey (PS1) is critical in this pursuit as it has discovered and measured a large fraction of the SNIa used to measure dark energy, and the PS1 calibration has been used to recalibrate almost every other SN survey. Here, we revisit the calibration of PS1 to address percent-level discrepancies in measurements between the Point-Spread Function (PSF) versus aperture photometry of calibration stars. We find a significant discrepancy in g passband, likely due to the PSF-shape dependence on color. We correct for this discrepancy by changing the effective passband and then redetermine the absolute calibration of the PS1 survey. We measure the calibration of each filter to 3 mmag, paving the path to the next best measurements of dark energy with even bigger samples of SNe in the future.

**Author(s):** Joseph Manuel, Daniel Scolnic

**Institution(s):** Villanova University, Kavli Institute of Cosmological Physics, University of Chicago

### **349.03 - Finding Galaxies That Hosted Multiple Type Ia Supernovae(Aisha Massiah)**

One of the most puzzling aspects about cosmological analyses with Type Ia is that the luminosity of these SNe appears to correlate with the properties of the galaxies that host them. To better understand this issue, we search the largest samples of SNIa to find galaxies that have hosted multiple SNIa over the last decade. Looking at the Pan-STARRS and Dark Energy Survey SN samples, we find ~10 galaxies that host multiple likely SNIa. We compare the light-curves and measured luminosities of the SNe, and discuss implications about their consistency. Finally, we predict how many galaxies that host multiple SNIa will be found by LSST and WFIRST.

**Author(s):** Daniel Scolnic, Aisha Massiah

**Institution(s):** Kavli Institute for Cosmological Physics, The

University of Connecticut

### **349.04 - High-Redshift SNe with Subaru and HST(David Rubin)**

High-redshift type Ia supernovae are crucial for constraining any time variation in dark energy. Here, we present the first discoveries and light curves from the Subaru Supernovae with Hubble Infrared (SUSHI) program, which combines high-redshift SN discoveries from the Subaru Strategic Program (SSP, as well as other Subaru time) with HST WFC3 IR followup. This program efficiently uses the wide field and high collecting area of Subaru Hyper Suprime-Cam for optical light curves, but still obtains a precision NIR color. We are on track to double the number of well-measured SNe Ia at  $z > 1.1$ , triggering on 23 SNe Ia in our first season.

**Author(s):** Nozomu Tominaga, Pierre Astier, Saul Perlmutter, Jakob Nordino, Eric Linder, David Rubin, Clare Myers Saunders, Reynald Pain, Masaomi Tanaka, Susana Deustua, Ariel Goobar, Kyle Barbary, Francois Hazenberg, Rahman Amanullah, Takahiro Kato, Nicolas Regnault

**Institution(s):** NAOJ, oHumboldt University of Berlin, USF, Konan University, UPenn, DESY, Barcelona, Space Telescope Science Institute, INP3, IPMU, LBNL, University of Stockholm, Lancaster University, University of Tokyo, Kyoto University, Australian Astronom

### **349.05 - Automated REcognition of Transients with a Convolutional Neural Network(Miles Currie)**

In the past, transient detection was largely dependent on the efficiency of the human eye to distinguish remnants in image subtractions. Modern techniques utilize the efficiency and automation of computers and machine learning. The current state of the art relies on a machine learning technique known as random-forest classification to distinguish defining features of a type Ia supernova through a large decision tree with comparable performance to a human eye as well as preliminary convolutional neural networks. We begin to replace the random forest technique with a machine learning technique known as convolutional neural networks. A convolutional neural network increases the efficiency and accuracy of the random forest by creating an array of filters that the image is passed through multiple times in parallel, in contrast to the random forest method of passing through the filter pipeline once in series. Preliminary studies show that using a simple neural network is already competitive with the current state of the art methods. A more complex neural network system exceeds today's models. As the network is trained to look for the features of a real transient, it is able to distinguish between subtraction artifacts and a transient. This screens out unwanted artifacts that have no scientific value. The efficiency of the network is rigorously tested with simulated transients, allowing selection effects to be controlled. Our network is the first of its kind, trained to handle undersampled HST WFC3-IR observations and eventually

WFIRST observations.

**Author(s):** Miles Currie, David Rubin

**Institution(s):** Space Telescope Science Institute, University of Washington

### **349.06 - Supernova Cosmology Inference with Probabilistic Photometric Redshifts(Christina Peters)**

This work, SCIPPR, employs probabilistic supernova type classifications and photometric redshift probability density functions to do supernova (SN) Ia cosmology. An extension of the Bayesian Estimation Applied to Multiple Species (BEAMS) framework of Hlozek et al. 2012, SCIPPR's incorporation of host galaxy photometric redshifts will be valuable for SN Ia cosmology in the era of the Large Synoptic Survey Telescope and other future photometric surveys where it will not be possible to perform spectroscopic follow up on every SN. We present a Bayesian hierarchical model for constraining the cosmological parameters from photometric lightcurves and host galaxy photometry, which includes selection effects and uncertainty in the redshift-dependent supernova type proportions. We create a pair of realistic simulated catalogs informed by existing photometric data: the first of probabilities over supernova type, redshift, and distance modulus from fitting lightcurves with supernova templates and the second of probabilities over redshift from fitting simulated host galaxy photometry with galaxy templates. We perform inference to obtain a probability distribution over cosmological parameters and compare performance with other methods and typical selection criteria: a spectroscopic subset, a subset of high probability photometrically classified supernovae, and reducing the photometric redshift probability to a single measurement and error bar. When comparing to the performance of SCIPPR, we find making cuts on classification probability typically introduces bias due to contamination and using a strictly spectroscopic sample (of either SNe or host galaxies) constrains the cosmological parameters less due to smaller data sets.

**Author(s):** Alex Malz, Christina Peters, Renée Hlozek,

**Institution(s):** Dunlap Institute for Astronomy and Astrophysics, University of Toronto, Department of Astronomy and Astrophysics, University of Toronto, Center for Cosmology and Particle Physics, New York University, Department of Physics, New York University

### **349.07 - Optimizing Magnitude-Limited Supernova Surveys for Cosmology(Jesse Han)**

In optimizing a supernova survey, there is an inevitable tradeoff between the number of SNe observed and the signal-to-noise ratio of each individual SN. Given a fixed total observing time, an improvement in the uncertainty of one of these parameters results in a proportional degradation of the other. These two effects roughly cancel each other out if the survey is limited by statistical uncertainty. In the presence of selection effects, however, the two effects do not cancel out, which we investigate

using a Bayesian hierarchical model. Our work has applications for optimizing future surveys such as LSST and WFIRST.

**Author(s):** Jesse Han, Andrew Fruchter, Susana Deustua, David Rubin

**Institution(s):** University of Virginia, Space Telescope Science Institute

### **349.08 - Cosmological implications of a degenerate antineutrino star(Tom F Neiser)**

The  $\Lambda$ CDM model successfully models the expansion of matter with an expansion of the underlying metric. However, it does not address the nature of dark energy and the big bang, which give rise to the accelerating and inertial components of the metric expansion respectively. At the time of the big bang, the observable universe with an estimated mass-energy content of  $\sim 10^{55}$  g was in a collective state of high energy density of mysterious origin. A model of cosmology will be presented, where this big bang state was created by the collapse of an antineutrino star that has exceeded its Chandrasekhar limit ( $M_{\text{ch}}$ ). For example, an effective neutrino mass of  $m_{\nu}^{1/2} = 10$  meV/c<sup>2</sup> corresponds to a mass limit of  $M_{\text{ch}}^{1/2} = 1.44 - 1056$  g. To allow the first neutrino stars and antineutrino stars to form naturally from an initial quantum vacuum state, it is necessary to assume that matter and antimatter gravitationally repel, which is currently being tested at CERN. While it may prove incorrect, this assumption may also be helpful for a description of dark energy in the late universe. For example, when solving Chandrasekhar's equation of state for a degenerate gas of antineutrinos of mass  $m_{\nu}^{1/2} = 10$  meV/c<sup>2</sup> and with a central density comparable to the dark energy density of the  $\Lambda$ CDM model ( $\rho_{\Lambda}$ ), we get an antineutrino star of cosmological radius  $R = 15$  Gly and mass  $M/M_{\text{ch}}^{1/2} = 0.12$ . If viewed from the core, a degenerate antineutrino star remnant could today emit the isothermal cosmic microwave background (CMB) radiation and radially accelerate matter, and thus mimic the metric expansion with a minimum of new physics. This model and the  $\Lambda$ CDM model are in similar quantitative agreement with distance-redshift data. The above model is also in qualitative agreement with observations of CMB anisotropies and large structures that challenge the assumption of homogeneity and isotropy of the  $\Lambda$ CDM model. Future work is required to further develop and test the above model while relying on the  $\Lambda$ CDM model as a benchmark. Details of the above model are found in a forthcoming publication [Neiser, 2018, doi: 10.20944/preprints201806.0175.v2].

**Author(s):** Tom F Neiser

**Institution(s):** University of California, Los Angeles

### **349.09 - Validation and Application of the Bayesian Fourier Domain (BFD) Shear Measurement Method(Kathleen Eckert)**

Shear measurement for weak lensing studies relies on the ability to precisely and accurately measure galaxy shapes. Both moment- and model-based methods are sensitive to many forms of bias including model bias, noise bias, and selection bias and require calibration using simulations or "meta-calibration" from the data itself. The Bayesian Fourier Domain (BFD) shear measurement algorithm is rigorously derived to be unbiased for background-limited observations of low S/N galaxies, typical of the galaxies used for weak lensing analyses. Using validation simulations of a simplified galaxy population, we show that the BFD shear measurement algorithm is unbiased to within  $|m| < 1e-3$ , the target of next generation weak lensing surveys such as Euclid, LSST, and WFIRST. We also describe extension of the method to perform a joint measurement of shear and magnification, demonstrating the power of BFD to measure both weak lensing effects. Finally, we report on efforts to develop BFD for the Euclid and Dark Energy Surveys, including additional testing and application to real data.

**Author(s):** Gary Bernstein, Kathleen Eckert

**Institution(s):** University of Pennsylvania

### **349.10 - A More Direct Method for Calculating the Cosmic Velocity Correlation Function from Peculiar Velocity Data(Sarah Peery)**

We study a novel method for calculating the cosmic velocity correlation function proposed by Nick Kaiser in the 1980s. Unlike the commonly used method introduced by Gorski, the Kaiser method estimates the three-dimensional velocity correlation functions directly from radial peculiar velocities, allowing for a more accurate comparison with linear theory. After testing the method using mock catalogs drawn from simulations, we apply it to the CosmicFlows3 compendium of over 10,000 measured peculiar velocities.

**Author(s):** Sarah Peery, Richard Watkins

**Institution(s):** Willamette University

### **349.11 - Density Split Statistics: Data From the Dark Energy Survey(Alessa Ibrahim)**

Density split statistics (DSS) is a method in cosmology that is used to measure the joint distribution of galaxy and matter densities of different patches of the sky, with counts-in-cells and lensing (Gruen+18, Friedrich+18). My work is built on these previous works. However, the catalog we use in this work contains data of a different galaxy sample that is denser. We demonstrate the feasibility of using a dense galaxy sample, selected by  $i < 22.5$  and a color-cut to constrain galaxy redshift, for a cosmology analysis with Dark Energy Survey Data. We do this by a step-by-step analysis of these statistics in the Buzzard suite of N-body simulations. The goal of this project is to find

out whether we can get improved constraints on cosmology from DSS with dense galaxy samples, and as a result, present the validation of the overall model and the effect of the denser galaxy sample on cosmological constraints.

**Author(s):** Daniel Gruen, Alessa Ibrahim, Joe DeRose, Risa Wechsler, Oliver Friedrich

**Institution(s):** California State University San Bernardino, Stanford University Contributing Team(s): Galaxy Formation & Cosmology Group (GFC), and X-ray Astronomy and Observational Cosmology (XOC)

### **349.12 - Constraints on the Dark Energy Survey's Photometric Galaxy Redshifts(Rodrigo Eduardo Lope C rdova Rosado)**

Dark energy, a force that counteracts gravity and accelerates the expansion of the universe on the grandest of scales, continues to confound the astrophysicists. In order to constrain its behavior in the universe, cosmologists are undertaking large surveys to understand its effects. The Dark Energy Survey (DES) is surveying an eighth of the sky for galaxies with redshift 0.2 to 1.5 to observe weak lensing effects and analyze cosmic shear. DES measures galaxy photometry in the four distinct  $g r i z$  bands, and hope to constrain their redshift from these photometric measurements. The error associated with these photo- $z$ 's contribute significantly to the DES cosmological parameters' error from weak lensing. Invoking Self Organized Maps (SOM), we establish a novel method of estimating the  $N(z)$  associated with the tomographic bins created to organize the SOM cells which capture galaxies with discreet color properties, based on the photometric measurements. By using a better constrained photometric survey for a smaller subset of the sky, we can leverage the few known redshifts to inform our color measurements across the SOM, and estimate  $N(z)$  for the full survey sample. This method has proven to constrain the mean difference between estimated and true  $N(z)$  for a simulated survey within 4%.

**Author(s):** Jason Rhodes, Daniel C Masters, Rodrigo Eduardo Lope C rdova Rosado,

**Institution(s):** Harvard University, Jet Propulsion Laboratory, California Institute of Technology Contributing Team(s): Dark Energy Survey (DES)

### **349.13 - Constraining Cosmological Parameters through the kSZ effect(Jonathan Davis)**

This project focuses on code development to calculate galaxy cluster peculiar momentum correlations derived from the kinetic Sunyaev-Zel'dovich(kSZ) effect. Our code builds the Core Cosmology Library (LSST DESC, in preparation) to model pairwise cluster correlations, as outlined Mueller et. al 2015. These measurements facilitate forecasting of the cosmological constraining potential of the kSZ measurements from upcoming CMB and large scale structure surveys. Care has been taken to ensure maintainability and reusability of the code by using an

object oriented structure. Code optimization and parallelization was undertaken, moderately improving single thread calculations while drastically improving performance on larger multi-core processors, compared to previous FORTRAN 90 software.

**Author(s):** Jonathan Davis, Rachel Esther Bean

**Institution(s):** Cornell University, Utah Valley University

#### **349.14 - A Simple Model for the Extragalactic Background Light(Jessica Gillcrist)**

We find that it is possible to match observational limits on the spectral intensity of the extragalactic background light (EBL) with a surprisingly simple theoretical model. We use a combination of blackbody spectral energy distributions (SEDs) in a standard LambdaCDM background, normalized so that the overall luminosity density evolves with redshift in agreement with constraints on cosmic star formation history from Nagamine et al. Our results suggest that the “Fossil model” of luminosity density evolution best fits the observations (others produce either too much or too little light in the bolometric sense). Four blackbodies are sufficient to provide an excellent fit. We associate these four peaks physically with starlight and re-emission of that light at longer wavelengths by dust in both normal and starburst galaxies. We plan to use this simple model in numerical studies of the role of extinction by dust in the intergalactic medium.

**Author(s):** James Overduin, Jessica Gillcrist, Maegan Jennings

**Institution(s):** Towson University

#### **349.15 - Calculation of the Ostriker-Vishniac Effect for Cosmological Models with Ultra-light Axions(Gerrit Simon Farren)**

We extend the formalism for computing the Ostriker-Vishniac effect which probes density-velocity correlations at small angular scales to cosmological models with scale-dependent growth arising in the context of ultra-light axions (ULAs). Such scalar particles with masses in the range  $10^{-33} < m_a < 10^{-20}$  eV are motivated in string theory and were originally proposed to solve the CP violation problem. The axion field initially evolves slowly in time and has equation of state  $w \approx -1$ . Once  $m_a$  is approximately greater or equal to  $3H$  the field starts oscillating rapidly and the effective equation of state is  $w_{\text{eff}} \approx 0$ , leading to the ULA number density approximately diluting with matter. The oscillatory nature of the axion field gives rise to a scale-dependent perturbation sound speed, leading perturbations on small scales to oscillate rather than grow, suppressing the growth of structure. Using the angular power spectrum of the Ostriker-Vishniac effect one would be able to probe the growth of structure during the period of reionization, sharpening the constraints on axion abundance already derived from primary CMB anisotropies and large-scale structure surveys. We present numerical calculations showing how the

modifications to the growth of structure as a function of time and scale effect the Ostriker-Vishniac angular power spectrum in the presence of ULAs.

**Author(s):** Gerrit Simon Farren, Andrew Jaffe, Daniel Grin

**Institution(s):** Haverford College, Imperial College London

#### **349.16 - Creating Tools for Modeling Gain Calibrations of 21 cm Interferometers(Chad McDermott)**

High precision gain calibration is required for 21 cm cosmology. Finding what could be the gain error for each antenna of any interferometer, however, is very challenging. Due to the multiple variables at play, it can change at every measurement. The exact effects of gain errors are being researched as well. To partially counteract this, a model must be made. Using this program, we try to simulate possible gain errors of any data set given, by simply generating them from a normal distribution, and convolving them across time and frequency. Researchers can use these simulations reveal possible relationships of, or between, gain corrections at a specific time and frequency.

**Author(s):** Chad McDermott, Jonathan Pober

**Institution(s):** San Jose State University, Brown University

#### **349.17 - The Effects of RFI on 21-cm Measurements of the Epoch of Reionization(Lily R Whitler)**

The redshifted 21-cm line from neutral hydrogen shows great promise as a probe of the Epoch of Reionization (EoR) and Cosmic Dawn. However, detecting the 21-cm signal from the EoR requires meticulous precision to overcome challenges such as bright galactic and extragalactic radio foregrounds, ionospheric distortion, and instrumental and environmental contaminants, including radio frequency interference (RFI). RFI can manifest as either broadband (spanning a wide range of frequencies) or narrowband (confined to a small frequency range) signals, and originates from a variety of known and unknown sources ranging from aircraft and orbital communications to FM radio transmissions. Using data from the Hydrogen Epoch of Reionization Array (HERA), we present an investigation of the effects of RFI on the 21-cm power spectrum from the EoR. We use real and simulated HERA data to examine the impact of errors introduced by RFI on the power spectrum, and explore various excision strategies to improve the final cosmological measurement.

**Author(s):** Daniel Jacobs, Adam Beardsley, Lily R Whitler

**Institution(s):** Arizona State University Contributing Team(s): HERA Collaboration

#### **349.18 - Measuring HERA's Primary Beam Using Extragalactic Radio Sources(Tyler Cox)**

Observations of redshifted 21-cm emission of neutral hydrogen in the intergalactic medium have the potential to give insight into the unobserved Dark Ages and the Epoch of Reionization.



Radio interferometers such as the wide-field array, HERA, look to observe and characterize reionization through the detection of the 21-cm power spectrum. One of the challenges of making this detection is separating bright radio foregrounds from the much weaker 21-cm signal, which can be achieved through a precise understanding of HERA's primary beam. Much of the work that has already been conducted to constrain HERA's primary beam has only been done at 137 MHz using the Orbcomm satellite constellation. However, knowledge of the response of the beam across frequencies is needed for complete foreground separation. Using observations made by HERA, bright foreground radio sources within one degree of zenith are tracked and their intensities are measured as they transit across the array's field of view. These individual measurements are compiled into a single beam measurement which is then compared to the primary beam model. These measurements are taken in 10 MHz and 20 MHz bandwidths across the HERA's frequency range (100-200 MHz) to find HERA's primary beam response across different frequencies. It is found that these frequency-dependent beam measurements closely match the beam models out to a zenith angle of roughly 15 degrees.

**Author(s):** Tyler Cox, Daniel Jacobs, Adam Beardsley

**Institution(s):** Arizona State University

#### **349.19 - Hydrogen Epoch of Reionization Array 2017-2018 Observational Season Reporting(David Lewis)**

As the Hydrogen Epoch of Reionization Array (HERA) continues to add baselines, it has been making observations through the 2017-2018 season. Though the array has not yet reached full size, the amount of data obtained means that the season's observations would make a suitable Internal Data Release (IDR). During this season HERA observed for 182 nights, applying Radio Frequency Interference (RFI) flags to each baseline visibility and recording this information in flag data files. As part of an undergraduate summer research program, RFI flag data from the season's observations was collected and analyzed to assist with the selection of IDR data. Flag data was compiled, as well as information from each night (observer flags), and various analysis used to assemble a report on the entire season's observations. The resulting report describes the data flagging process and shows some of the typical RFI seen throughout the season, as well as providing a condensed view of the entire season's observations and trends in antenna flagging. Out of the original 182 observations, 131 had no observer flags, and 107 were included in the IDR based on data quality.

**Author(s):** Daniel Jacobs, David Lewis, Adam Beardsley

**Institution(s):** Arizona State University

#### **349.20 - Using Non-Redundancy as an Antenna Metric for HERA Data(Shane Kirkpatrick Bechtel)**

The HERA Radio Telescope is an interferometric array composed of many regularly spaced antennas. The repetition of

baselines within this array allows for redundant data comparisons which could be used to identify antennas behaving non-ideally. A controllable simulation of sky-like signals, designed to emulate time and frequency behavior of HERA-like foregrounds, was constructed to have a certain amount of non-redundancy. Using many of these simulations, we test a metric which calculates antenna redundancy from the median of the time-averaged frequency data. Applying this statistic to HERA 2017 data, we find that the metric identified nearly all the antenna flagged by another well understood indicator of low-quality measurement (power level), as well as several flagged purely on the basis of redundancy. From the simulation, we find that the metric accurately flags antenna behaving non-redundantly when only a small number are doing so, but fails when more do so as well. Furthermore, we note that North-South aligned baselines, as a group have a much higher level of redundancy than other orientations.

**Author(s):** Shane Kirkpatrick Bechtel, Daniel Jacobs, Adam Beardsley

**Institution(s):** Arizona State University

#### **349.21 - Identifying and Modeling Constant Additive Offset in HERA Visibility Data(Katherine Elder)**

The Hydrogen Epoch of Reionization Array (HERA) radio telescope, currently under construction, is designed to detect redshifted 21cm hydrogen from the neutral intergalactic medium which traces the first stars and galaxies in the Universe. Observation of the signal redshifted to meter wavelengths is challenging because it is faint and viewed through contributions from Galactic and Intergalactic foregrounds, which are orders of magnitude stronger by instrumental errors. Any introduction of chromaticity raises the potential for adding error to the background measurement. The galactic signal is highly polarized on the largest scales with a strongly frequency dependent polarization angle. Leakage of these polarized signals into the total power has the potential to add an additional foreground bias term. An imaging analysis of HERA observations recorded in the 2017-2018 identified signals which did not vary with time and therefore did not correspond to a source which could be calibrated or cleaned out of the data. Here are reported efforts to identify what was causing the constant additive offset in our instrument and to build a physical model of the effect. Contributions identified include a component dependent on baseline length and another with a spectral signature consistent with a cable reflection. A simplified physical model is constructed where in one component a radio signal bounces out of one antenna and into another and in the second the radio signal bounces within the cables connecting the antenna to the receivers. The data are used to fit for unknown reflection and cable couple parameters and residuals inspected to assess the quality of this simplified model.

**Author(s):** Katherine Elder, Daniel Jacobs

**Institution(s):** California State University Fresno, Arizona State University

### **349.22 - Calibration and imaging with HERA Outriggers(Sean Morgan)**

The Hydrogen Epoch of Reionization Array (HERA) is a radio telescope in South Africa designed to observe Hydrogen via the 21 cm line at redshifts 6 to 20. It is an array of stationary radio dishes currently being built and observing while dishes are being added. Almost all the HERA dishes are face-packed into a hexagonal array, however, there are dishes being built around the array that are farther away to improve foreground imaging. This year saw the completion of the first two such outriggers. The core HERA antennas have been calibrated with a mixture of redundant and sky-based algorithms and the outriggers are arranged to provide redundant baselines suitable for both methods, however, the two outriggers currently available must use sky model-based methods. Calibration of these antennas presented difficulties. A method of iteratively selecting reference antennas, using known redundancy of some baselines was used to obtain a reasonable first solution. This calibration is demonstrated in an image of Fornax A.

**Author(s):** Daniel Jacobs, Sean Morgan, Adam Beardsley

**Institution(s):** San Francisco State University, Arizona State University

### **349.23 - Exploring the Moon over HERA as a Source of Radio Frequency Interference(Jean Donet)**

The Hydrogen Epoch of Reionization Array (HERA) is a radio interferometer located in South Africa. This array seeks to detect the Epoch of Reionization, an event in the early Universe when the neutral intergalactic medium became ionized with the emergence of the first stars. This detection relies on extremely faint background radio signals, which are dwarfed by the strong foregrounds of local radio communications. The Moon is the closest celestial body to Earth. Its reflection of light, while helpful illuminating nightly darkness, has historically affected astronomical measurements as a bright foreground polluting the dark sky. HERA's location is helpful with this since the Moon rarely comes close to HERA's zenith at -30 degrees. However, the Moon's orbital plane oscillates relative to the ecliptic over a period of 18.6 years, resulting in a maximum declination of +/-28.5 degrees. This presents the issue of the Moon's flux density being detected by HERA as it approaches its zenith. Additionally, transmissions can be reflected by the Moon and be picked up by HERA. These can include Earth-Moon-Earth communications (EME), transmissions that use the Moon's reflective property to bounce signals back to Earth. This investigation approaches this problem by tracking the Moon's path along the sky and simulating radio communications using specifications for a traditional EME at 144MHz.

**Author(s):** Jean Donet,

**Institution(s):** San Jose State University, Arizona State University Contributing Team(s): HERA

### **349.25 - Where do Population III Stars Form? The Effects of Radiative Feedback and Self-Shielding on the Host Halo Mass Distribution(Danielle Ruth Skinner)**

We perform a cosmological simulation with a comoving volume of 1 Mpc<sup>3</sup> to study the birthplaces of Population III stars, using the adaptive mesh refinement code Enzo. We investigate the distribution of host halo masses and its relationship to the Lyman-Werner background intensity. In our sample of 697 host halos, we find that 84% of them have masses below the Machacek et al. (2001) relation because of the inclusion of H<sub>2</sub> self-shielding. In our simulation above a redshift of 12.5, the mean halo mass is time-independent and ~105.8 solar masses. Afterwards, it steadily rises above the Machacek et al. relation to a mean value of ~106.6 solar masses. Most of these halos form multiple Population III stars, with a median number of four, up to a maximum of 16. We also find that a few halos do form stars below the Machacek et al. relation but in a high Lyman-Werner radiation field with values up to ~50 J<sub>21</sub>. Our results suggest that Population III star formation may be less affected by Lyman-Werner radiation feedback than previously thought and that Population III multiple systems are common.

**Author(s):** John Wise, Danielle Ruth Skinner

**Institution(s):** Georgia Institute of Technology

## **350 - Dark Matter & Dark Energy --Posters**

### **350.01 - Selection of Milky Way Analogs Using the Dark Energy Survey(Silvana Carolina Delgado)**

The study of satellite galaxies around Milky Way (MW) analogs is crucial for understanding the structure of galaxies and their dark matter halos. We present the methods used to select a sample of MW analogs using Dark Energy Survey's (DES) Year-Three Release, investigating MW analog galaxies in this footprint for the first time. Our results are compared to a study done with the Sloan Digital Sky Survey (SDSS) on the abundance of satellite galaxies around MW-like hosts. We identify candidates as nearby galaxies ( $z < 0.055$ ) with color  $g - r > 0$ , apparent magnitude ranging from  $11 < r < 17.8$ , and an absolute magnitude within +/- 0.25 of the MW. Additionally, we develop a method to remove candidates that have objects brighter than the MW and lie within a chosen angular distance of the candidate galaxy. As a result, we have identified 5894 MW analogs, in comparison to the 8388 from the SDSS study. This will be used to statistically identify the number of satellites around MW-like hosts, an important measurement for classifying dwarf spheroidal galaxies and dark matter subhalos.

**Author(s):** Silvana Carolina Delgado,

**Institution(s):** University of Massachusetts Amherst, Texas A&M University Contributing Team(s): Silvana Delgado, Louis EStrigari, Jennifer LMarshall, Andrew BPace, Katelyn MStringer

### **350.02 - Dark Matter Annihilation in the Galactic Center(Yasmeen Asali)**

The Weakly Interacting Massive Particle model considers the hypothetical dark matter (DM) particle to be its own antiparticle, and thus we can expect annihilation in high density regions, such as the Galactic Center (GC). Working under these assumptions, the gamma ray emission from annihilation events can be modelled with spectral and spatial components. We use simulated data from the Cherenkov Telescope Array (CTA) for a first look analysis that can be performed within a year of data collection using a spatial analysis method with gammapy, a python package for CTA data currently in development. Collapsing the data over the spectral dimension into one energy bin allows us to increase the event count with fewer observations. Using this stacked counts image, we performed iterative fitting and source subtraction to generate a residual image representing the diffuse gamma ray emission in the GC. We show that this type of analysis is highly dependent on the choice of background model since the region has many overlapping sources, and that the best estimator is an adaptive ring background algorithm. We were not able to recover the spatial signal from DM annihilation using just the first year of data, but a similar analysis with a greater number of observations, a more rigorous method of source subtraction, or a more refined background model may recover a statistically significant signal.

**Author(s):** Germán Gomez-Vargas, Andreas Reisenegger, Yasmeen Asali

**Institution(s):** Columbia University, Pontificia Universidad Católica de Chile

### **350.03 - Probing Dark Matter Models through the Halo Mass Function(Nicholas A. Sweeney)**

As dark matter clusters over time, it collapses to form objects known as dark matter halos. The Halo Mass Function (HMF) is defined as the number density of these halos per unit mass. A semi-analytic formalism known as the Halo Model has been used to plot the HMF for a variety of thermally-produced dark matter candidates, most notably Cold Dark Matter (CDM) and Warm Dark Matter (WDM). It is of interest to apply such a semi-analytic approach to Ultralight Axion (ULA) dark matter, a model proposing that Ultralight Axions (10-24 eV  $\approx$  10<sup>-20</sup> eV) either partially or fully contribute to the dark matter density of the Universe. The existing semi-analytic code "WarmAndFuzzy" (Marsh 2016) is extended to present plots of the HMF in the ULA model for a variety of ULA masses and redshifts. These plots are compared under different smoothing filter prescriptions and address the viability of using the HMF to distinguish between ULA dark matter and thermally produced candidates for each filter prescription. For a sharp-k filter, the ULA mass function exhibits a turnover at small-scales, similar to WDM, but may be distinguishable observationally due to its oscillatory modes. For Spherical Top-hat and Gaussian filters, the ULA mass function is indistinguishable from that of CDM or WDM.

**Author(s):** Daniel Grin, Tristan Smith, Nicholas A. Sweeney  
**Institution(s):** Haverford College, Swarthmore College

### **350.04 - Modeling 8B Solar Neutrino Detection with CEvNS(Nikko John Cleri)**

In the continuing search for dark matter and information about the energy density of the universe, it is becoming increasingly evident that many answers may come from the study of neutrinos. This work discusses methods used to create models for the observation of coherent elastic neutrino-nucleus scattering (CE $\nu$ NS) events in search of Weakly Interacting Massive Particles (WIMPs), a leading dark matter candidate. We focus on the 8B produced solar neutrinos, which represent the most abundant background source in dark matter searches. Eliminating this background using threshold recoil energy cuts is essential to increasing the likelihood of detecting WIMPs. For our two nuclear targets, xenon and argon, our model predicts a flux of  $\sim 10^3$  and  $\sim 10^2$  events per year respectively over all threshold energies for a ton-scale detector. Introducing a threshold recoil energy of  $\sim 5$  keV will eliminate the 8B neutrino background in xenon and argon detectors, meaning the likelihood of detection of WIMPs scales linearly with the detector.

**Author(s):** Louis Strigari, Nikko John Cleri

**Institution(s):** University of Connecticut, Texas A&M University

### **350.05 - Distinguishing CDM dwarfs from SIDM dwarfs in baryonic simulations(Emily Strickland)**

Dwarf galaxies in the nearby Universe are the most dark-matter-dominated systems known. They are therefore natural probes of the nature of dark matter, which remains unknown. Our collaboration has performed several high-resolution cosmological zoom-in simulations of isolated dwarf galaxies. We simulate each galaxy in standard cold dark matter ( $\Lambda$ CDM) as well as self-interacting dark matter (SIDM, with a cross section of  $\sigma/m \sim 1$  cm<sup>2</sup>/g), both with and without baryons, in order to identify distinguishing characteristics between the two. The simulations are run using GIZMO, a meshless-finite-mass hydrodynamical code, and are part of the Feedback in Realistic Environments (FIRE) project. By analyzing both the global properties and inner structure of the dwarfs in varying dark matter prescriptions, we provide a side-by-side comparison of isolated, dark-matter-dominated galaxies at the mass scale where differences in the two models of dark matter are thought to be the most obvious. We find that the edge of classical dwarfs and ultra-faint dwarfs (at stellar masses of  $\sim 10^5$  solar masses) provides the clearest window for distinguishing between the two theories. At these low masses, our SIDM galaxies have a cored inner density profile, while their CDM counterparts have "cuspy" centers. Comparing the core formation over time shows strong similarities between CDM with hydrodynamics and SIDM with and without hydrodynamics. Future

observations of ultra faint dwarfs with JWST and 30-m telescopes will be able to discern whether such alternate theories of dark matter are viable.

**Author(s):** Alex Fitts, Emily Strickland, Michael Boylan-Kolchin

**Institution(s):** University of Texas at Austin

### **350.06 - Dark Matter Halo Reshaping Energy Budget(Jason Young)**

One of the outstanding issues facing dark matter halo formation is the "core/cusp problem", wherein dark-matter-only simulations predict halo density profiles with a central "cusp", whereas real galaxies appear to have a constant density "cores" in their mass profiles. With low baryonic densities, low surface brightness (LSB) spirals have density fields dominated by dark matter at all radii, making them excellent laboratories for the study of dark matter halo formation. One class of solutions to this mystery is the reshaping of the dark matter halo by bursts of star formation near the galaxy's center. In this scenario, feedback pushes gas out of the central region, which gravitationally drags dark matter, creating a cored profile. The MUSCEL program (MULTIwavelength observations of the Structure, Chemistry and Evolution of LSB galaxies) uses combined ground-based/space-based data to determine the spatially resolved star-formation histories of LSB spirals. Here we present a comparison between the energy released via star formation, as determined from the fitted star formation histories, and the energy required for cusp-to-core reshaping. The current structure of the dark matter halo is determined from radial velocity field measurements, while the original cuspy dark matter halo is derived from theoretical models available in the literature.

**Author(s):** Sharon Xuesong Wang, Rachel Kuzio de Naray, Jason Young

**Institution(s):** Mount Holyoke College, Carnegie DTM, Georgia State

### **350.07 - Charcoal Chromatography to Purify Xenon for the LZ Dark Matter Experiment(Rene Mora Padilla)**

The LZ collaboration is a project aimed to find dark matter. The detector is a dual-phase time projection chamber with 10 tonnes of liquefied xenon (Xe) that allows us to detect particle interactions with the Xe target. To decrease the radioactive background, krypton (Kr-85) must be removed from the Xe prior to the experiment. This has to be done because Kr is a beta emitter and its isotope causes a background in the detector. To reduce the concentration of Kr, LZ uses a purification process of charcoal chromatography. This process separates the two noble gases using the difference in the time constant in their elution curves. The charcoal column is filled with 500 kg of activated charcoal which is baked and washed in situ. The baking process is controlled using an interface program called Ignition. Both

the temperature and the heaters are monitoring and controlled using Ignition. Once this procedure is complete, the charcoal is ready to start the Kr removal.

**Author(s):** Daniel Akerib, Rene Mora Padilla, Tomas Gonda, Philip Weigel

**Institution(s):** California State University, Stanislaus, SLAC National Accelerator Laboratory Contributing Team(s): LZ Collaboration

### **350.08 - Direct Detection of Dark Energy Scalar Fields through Space Laboratory Experiments(Sheng-wei Chiow)**

Dark energy constitutes ~70% of the universe, which explains the observed accelerated expansion. While little is known about the nature of dark energy, it is conjectured to be a new scalar field interacting with normal matter at the cosmological scale. To be consistent with solar system observations, such interactions are highly environment dependent and screened locally. Possible scalar fields are in the forms of chameleon, symmetron, and galileon models. Recently, cold atom experiments in laboratories have contributed significantly to the constraints of chameleon and symmetron parameters, thanks to the "thin-shell" effect of these two models. Galileon is described by the Vainshtein screening model and cannot be tested with the ground laboratory-scale experiments. It is therefore largely unconstrained. We will describe measurement concepts for all three categories of dark energy scalar fields. We will report an experimental concept study of using atom interferometry in microgravity to improve the sensitivity to chameleon and symmetron by orders of magnitude from the state-of-the-art, without precise knowledge of gravity forces. In this scheme, spatially modulated dark energy forces are introduced with a periodic geometry of the local mass distribution. Gravitational forces of the mass structure will be minimized at the spatial frequency using trim masses. Multiloop atom interferometers will measure the periodic acceleration while largely reject forces at other spatial frequencies. We will show that parameters of interest of chameleon and symmetron will be tested at high confidence levels. We will also present a space experiment concept in the solar system to directly measure the signals predicted by the galileon model. The experiment is expected to be able to gather sufficient data in three years of operation to provide a definitive statement of the validity of the galileon model. We thank Jérôme Gleyzes and Jason Rhodes for discussions and encouragement. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

**Author(s):** Nan Yu, Sheng-wei Chiow

**Institution(s):** Jet Propulsion Laboratory

### **350.09 - In Search of a Dynamical Dark Energy Equation of State(Islam Khan)**

Investigating the nature of dark energy in our universe is one of the main challenges of modern cosmology. This exotic source of stress-energy with negative pressure is responsible for the late cosmic acceleration but lacks a fundamental and well-defined theory. The simplest extension to the  $\Lambda$ CDM model is offered by dynamical dark energy models in which the cosmic acceleration is driven by an evolving scalar field, dubbed quintessence, slowly rolling down a flat potential. Given their similarity in nature, there is a possibility that the inflation and quintessence fields are the same field, dominating the universe at different times. We describe an approach for unifying the two phases of accelerated expansions of the universe under one general evolving potential, consequently obtaining a general evolving dark energy equation of state. We use the Code for Anisotropies in the Microwave Background (CAMB) to analyze the effects of quintessence models with various forms of scalar field potentials. We particularly focus on “tracker” models such as the one with Raatra-Peebles potential. Results of the analysis include CMB anisotropy power spectra, and E- and B-mode polarizations. These are tested against 2018 Planck mission data to assess observability.

**Author(s):** Guy Worthey, Michael McNeil Forbes, Islam Khan

**Institution(s):** Washington State University

### **351 - Dwarf & Irregular Galaxies -- Posters**

#### **351.01 - Satellite Galaxy Characteristics in the SAGA Survey(Danielle Rowland)**

Extensive studies of the Local Group, which includes the Milky Way and its neighbors, have greatly increased our understanding of galaxy formation and evolution. However, it is unknown if these results are applicable to other similar galaxy groupings throughout the larger universe. To test the representative nature of the Local Group, the on-going SAGA Survey seeks to find and then characterize satellites of 100 Milky Way analogs for a statistically significant comparison. Initial candidates were identified with photometry then confirmed using spectroscopic redshifts leading to a sample in Geha et al. 2017 that found 29 satellites around 8 Milky Way analogs. Further follow-up data was taken on these satellites at Palomar Observatory using the Double Spectrograph instrument. This poster will detail the reduction techniques used to produce 1D spectra and rotation curves of these targeted satellites. I will also discuss preliminary results of the dark matter content for these targets. Determination of each target's characteristics, such as dark matter content, provides a direct means of comparison to bring the satellites of the Local Group into a broader context.

**Author(s):** Laura L Watkins, Erik Tollerud, Danielle Rowland,

**Institution(s):** Columbia University , Space Telescope Science Institute

#### **351.02 - A New Catalogue of Ring Galaxies from the Hyper Suprime-Cam(Benjamin Rosenwasser)**

We present results of a search for collisional and polar ring galaxies (PRG) in a 40 deg<sup>2</sup> survey using the Hyper Suprime-Cam (HSC) on the Subaru Telescope. A visual classification was made for 48,207 galaxies down to  $r \sim 19$  by a team of REU summer research students. In total 3152 galaxies (6.5%) were flagged as having a polar ring, collisional ring, or something otherwise peculiar. Sixteen, and probably more, galaxies are PRGs, a rare class of galaxy that comprises a few percent of the So population. The surface density of the new PRGs is  $\sim$ two orders of magnitude larger than the value found in SDSS imaging, due in part to probing  $\sim$ 2 magnitudes deeper with HSC. The rings, both polar and collisional, are generally very blue compared to the central galaxy, and are likely short lived structures associated with the accretion of satellite galaxies and gas from the intergalactic medium.

**Author(s):** Alexis Arsenault, C.W. Robertson, Ralf Kotulla, Amy Barger, Allison Erena, Amy Griffin, Taylor Spoo, Samantha Lucia Garza, Andrew Mizener, Benjamin Rosenwasser

**Institution(s):** University of Wisconsin-Madison

#### **351.03 - Identifying Faint Galaxies in the Nearby Universe(Christian Juarez)**

It is difficult to survey large numbers of faint galaxies that are nearby because the observations need to be both deep and wide. We developed a method to look for faint galaxies in the Sloan Digital Sky Survey (SDSS), which is both sensitive to nearby star-forming galaxies and covers a very large sky area. Specifically, we aim to find low mass galaxies in the foreground to galaxies that were targeted for spectroscopy with SDSS. We determined that the effective volume covered by the SDSS fibers, and the sensitivity to the H $\alpha$  emission line, is comparable to the best dedicated surveys, and is significantly better in that it samples large, independent pieces of the sky. Our method involves identifying additional, unexplained emission lines after a model spectrum for the target galaxy is subtracted. In this way, we can find additional low-mass, star-forming galaxies along the line of sight to the target galaxies. Our method successfully identified known foreground, emission-line emitting galaxies in SDSS quasar spectra. We test the algorithm on a sub-sample of 16,000 galaxies as a proof of concept. Remarkably, the first galaxy we detected is not a faint, foreground galaxy, but rather a lensed, Lyman-alpha emitting galaxy at  $z \sim 5.6$ .

**Author(s):** Christian Juarez, Brian Siana

**Institution(s):** San Diego State University, University of California Riverside

### **351.04 - Dynamical Histories of the Crater II and Hercules Dwarf Galaxies(Sal Wanying Fu)**

We investigate the likelihood that the dwarf galaxies Hercules and Crater II have previously been tidally stripped by the Milky Way. We present Magellan/IMACS spectra of stars in Crater II. From 37 members, we measure a velocity dispersion of 2.6 km/s, which corresponds to a mass-to-light-ratio of 43 within the half-light radius of Crater II. We measure a mean metallicity of -1.97, with a metallicity dispersion of 0.15 dex. Our velocity dispersion and metallicity dispersion measurements agree with previous measurements for Crater II, and confirm that the galaxy resides in a kinematically cold dark matter halo. By comparing repeat measurements of 24 Crater II members, we assess the impact of binaries on the velocity dispersion measurement of the dwarf. We also search for spectroscopic members stripped from Hercules in the extratidal stellar overdensities surrounding the dwarf. For both galaxies, we calculate proper motions from Gaia DR2, and use their full 6D phase space information to evaluate the possibility that their orbits approach sufficiently close to the Milky Way to experience tidal stripping. We find that the proper motion of Crater II is consistent with a tidal stripping scenario. However, it is unlikely that Hercules has undergone tidal interactions with the Milky Way, suggesting that elongated morphologies of dwarf galaxies like Hercules are not necessarily related to tidal disruption.

**Author(s):** Alex G Alarcon Jara, Joshua D. Simon, Sal Wanying Fu,

**Institution(s):** Pomona College, Universidad de Concepción, Carnegie Observatories

### **351.05 - An Examination of the APOGEE-2 Survey Data for the Draco Dwarf Spheroidal Galaxy(Jennifer Sobeck)**

Since 2011, the Apache Point Observatory Galactic Evolution Experiment (APOGEE) has performed a large-scale, high-resolution stellar spectroscopic survey of the Galaxy in the near-infrared wavelength regime. The second stage of the APOGEE Survey, APOGEE-2, has expanded beyond the Milky Way and targeted stars in eight Local Group satellite galaxies: the Large and Small Magellanic Clouds (LMC, SMC) and six dwarf spheroidal galaxies (Draco, Ursa Minor, Bootes I, Sextans, Sculptor, and Carina). The current work presents an abundance analysis of several tens of stars that approximately span the full metallicity range of the Draco dwarf spheroidal (dSph) galaxy. Confirmation of Draco membership was done via several criteria including the recently-published Gaia DR2 proper motions and the results from Helmi et al. (2018). The performance of the APOGEE automated data reduction and data product generation pipelines (DRP and ASPCAP, respectively) is evaluated for these faint, low metallicity Draco stars. With this comparatively large Draco stellar sample from APOGEE, robust trends in the individual alpha elements are established and the abundance distributions for heavier elements are examined. Comparisons are made of the APOGEE

element abundance ratios to those from literature. These Draco results are then discussed in the context of galactic star formation history and chemical enrichment.

**Author(s):** Jennifer Sobeck, Sal Wanying Fu, George Schafer, Joshua Simon, Matthew Shetrone

**Institution(s):** University of Washington, Carnegie Observatories, University of Texas at Austin, Pomona College  
**Contributing Team(s):** SDSS-IV APOGEE- Survey Team

### **351.06 - Mapping Abundances Across the Core of the Sagittarius dSph Galaxy using The Cannon(Matthew Melendez)**

The Sagittarius (Sgr) dwarf galaxy, a dwarf spheroidal galaxy that is a satellite to the Milky Way, has been identified as being in the process of being tidally torn apart by the Milky Way. To study the kinematical and chemical distribution and history of Sgr we have taken spectra for thousands of stars in the large area of the dwarf galaxy. Previous studies have constrained the membership of stars in Sgr based on radial velocity. We will now explore the chemical history of the galaxy by analyzing the stellar component of Sgr using The Cannon, a data-driven method for determining stellar parameters such as temperature, surface gravity, and chemical abundances from stellar spectra. A subset ~150 of our stars have previously been observed as part of SDSS/APOGEE survey, at higher resolution and signal-to-noise, which will allow us to use these spectra to train The Cannon in this spectral region in order to obtain accurate abundances for the remaining data set of ~1100 Sgr member stars. This study will allow us to identify chemical subgroups of Sgr which will allow us to confidently study the history and evolution of the Sgr dwarf galaxy.

**Author(s):** John Donor, Matthew Melendez, Peter Frinchaboy, Amy Elaine Ray

**Institution(s):** Texas Christian University

### **351.07 - A Search For Young Stars in the Magellanic Stream(Joshua Povick)**

In 1990, Irwin and collaborators discovered blue stars in the InterCloud region (ICR) between the Magellanic Clouds. However, it has been a challenge to conclude how these young stars formed ~10 kpc away from the main bodies of the Clouds, until now. We present results of the first nearly-complete spectroscopic survey of these stars using the SMARTS-1.5m telescope + R-C Spectrograph (RC), and high-resolution follow-up with the Magellan 6.5m telescope + MIKE spectrograph (MIKE), which we combine with Gaia DR2 data. Both the RC and MIKE spectra were compared to synthetic spectra to derive Teff,logg, [Fe/H], vsini, and radial velocity for each star. We used the spectroscopic parameters and Gaia proper motions and parallaxes to help determine if the blue stars came from the Large Magellanic Cloud (LMC), the Small Magellanic Cloud, the LMC filament of the Magellanic Stream (MS), or are foreground contaminants. Among the blue stars, a group of seven stars

were identified as rapid rotators and Magellanic-like RVs. Of these stars, two are associated with the outer LMC and three are part of a foreground moving group at a heliocentric distance of 7 kpc. One star, with an age  $\sim 65$  Myr based on the spectroscopic parameters, is consistent with having formed in the gas of the LMC filament of the Magellanic Stream. This interesting star could help place constraints on star formation in low density, metal-poor gas, and provide a detailed chemical composition of the MS gas, an important clue to its origin.

**Author(s):** Jeffrey L Carlin, Joshua Povick, Steve Majewski, David Nidever

**Institution(s):** Montana State University, Large Synoptic Survey Telescope, University of Virginia

### **351.08 - Photometric Metallicities of the Small and Large Magellanic Clouds(Amy Elizabeth Miller)**

The Small and Large Magellanic Clouds are of particular interest as nearby exemplars of interacting, gas-rich dwarf galaxies under the influence of a large spiral that provide the opportunity to explore the evolution of such systems at the resolved stellar level. The distribution of stellar metallicities across the Clouds is a key ingredient to understanding the processes that have shaped their evolution, and remains a rich ground for exploration. I use data from the Survey of Magellanic Stellar History (SMASH), a photometric survey of the Magellanic Clouds that contains approximately 400 million objects in 197 fields that were obtained with DECam on the CTIO Blanco 4m telescope. SMASH covers 2400 square degrees to 24th magnitude in ugriz, encompassing a depth of  $\sim 2$  magnitudes below the oldest main-sequence turnoff stars. The DECam u-band is sensitive to metallicity for main-sequence turn-off stars, which is calibrated using SDSS and GALAH spectroscopy in overlapping regions. This analysis is used to make accurate metallicity maps of the main bodies of the Clouds, their peripheries, and the Milky Way halo. Ultimately, these metallicity maps will help us trace out population gradients in the Clouds, uncover the origin of their very extended stellar peripheries, and elucidate the consequences of stripping stars and gas off the Clouds when they fall into the Milky Way halo.

**Author(s):** Amy Elizabeth Miller

**Institution(s):** Montana State University Contributing Team(s): DrDavid Nidever, SMASH

### **351.09 - Space Velocities of Dwarf Galaxies in the Local Group from HST Proper Motions(S. Tony Tony Sohn)**

The Local Group has been the benchmark for testing and calibrating many aspects of cosmological and galaxy formation theories. Thanks to the advancements in both observational and theoretical areas, our understanding about the galaxy formation and evolution in the Local Group has greatly improved in the last decade. Nonetheless, many fundamental parameters (e.g., total mass of the Local Group) still remain poorly constrained

due to the limited information on the transverse motions of galaxies in the Local Group. Accurate proper motion measurements are required to resolve this issue, and the HSTPROMO (High-resolution Space Telescope Proper Motion) collaboration has been in the forefront of providing them for many galaxies, star clusters, and individual stars in the Local Group. In this contribution, I will present results from our recent HST study to measure proper motions of dwarf galaxies in the Local Group, and discuss implications.

**Author(s):** S. Tony Tony Sohn

**Institution(s):** Space Telescope Science Institute

### **351.10 - Hubble Space Telescope Imaging of the Nearby Dwarf Irregular Galaxy Antlia B: Star Formation History and a New TRGB Distance(Jonathan Hargis)**

The population of dwarf galaxies in the local universe provide important astrophysical constraints on models of both low-mass galaxy formation and small-scale cosmological structure. We present Hubble Space Telescope imaging of the dwarf irregular galaxy Antlia B, a recently discovered member of the NGC 3109 dwarf association ( $d \sim 1.3$  Mpc). Using ACS/WFC imaging, we resolve individual stars in Antlia B down to nearly two magnitudes below the red clump. The resulting color-magnitude diagram is dominated by an old, metal-poor stellar population (ages  $> 7$  Gyr) and a smaller population of young, more metal-rich stars (ages  $\sim 300 - 700$  Myr). We find no evidence of very recent ( $t < 300$  Myr) star formation. We derive the detailed star formation history (SFH) using the methods of Weisz et al. (2011, 2014) and find that Antlia B has a SFH consistent with other Local Volume dwarf irregulars. A qualitative comparison of the Antlia B SFH to the other galaxies in the NGC 3109 association suggests that more stellar mass growth occurred at early times ( $t \sim 7 - 13$  Gyr) for the more massive dwarfs (NGC 3109, Sex A, Sex B) relative to the smaller dwarfs (Antlia, Antlia B, Leo P). However, given the large systematic uncertainties in the SFH results, the derived SFHs for all galaxies in the NGC 3109 are broadly consistent. Lastly, we present a new TRGB distance derived from the HST imaging and discuss the likelihood of Antlia B as a satellite of NGC 3109.

**Author(s):** Dan Weisz, Beth Willman, David Sand, Sandra Albers, Kristine Spekkens, Jonathan Hargis, Denija Crnojevic

**Institution(s):** Space Telescope Science Institute, Steward Observatory/University of Arizona, University of California Berkeley, Royal Military College of Canada, University of Tampa

### **351.11 - "The Neutral ISM of the Extremely Metal-Deficient Galaxy Leoncino"(Josh Bartz)**

We present new multi-configuration VLA HI spectral line imaging of the dwarf galaxies AGC 198691 (hereafter, Leoncino) and UGC 5186. Leoncino is one of 82 galaxies in the "Survey of HI in Extremely Low-mass Dwarfs" ("SHIELD"), a multi-wavelength investigation of low-mass galaxies that were

cataloged by the Arecibo Legacy Fast ALFA (ALFALFA) survey. Leoncino is one of the lowest metallicity galaxies known in the local universe (Hirschauer et al. 2016). A single pointing with the VLA allows us to study the HI morphology and dynamics of both galaxies simultaneously. We present HI images at a variety of angular resolutions in order to explore both the global and the resolved properties of the neutral ISM.

**Author(s):** Evan Skillman, John M. Cannon, Elizabeth Adams, Andrew Dolphin, Danielle Berg, Alex J. R. Gordon, Martha P Haynes, Tylyn Page, Riccardo Giovanelli, Kristen B. W. McQuinn, Steven Janowiecki, Alec Seth Hirschauer, Josh Bartz, Katherine Rhode, John Salzer

**Institution(s):** Macalester College, Ohio State University, ASTRON, Cornell University, Raytheon Company, University of Texas, Space Telescope Institute, University of Minnesota, Indiana University

### **351.12 - Delayed Stellar Mass Assembly in the Low Surface Brightness Dwarf Galaxy KDG 215(Lilly Bralts-Kelly)**

We present HI spectral line and optical broadband images of the nearby low surface brightness dwarf galaxy KDG 215. The HI images, acquired with the Karl G. Jansky Very Large Array, reveal a dispersion-dominated interstellar medium with only weak signatures of coherent rotation. The HI gas reaches a peak mass surface density of  $6 \text{ M}_{\odot} \text{ pc}^{-2}$  at the location of the peak surface brightness in the optical and the ultraviolet. Although KDG 215 is gas-rich, the  $\text{H}\alpha$  non-detection implies a very low current massive star formation rate. In order to investigate the recent evolution of this system, we have derived the recent and lifetime star formation histories from archival Hubble Space Telescope images. The recent star formation history shows a peak star formation rate  $\sim 1$  Gyr ago, followed by a decreasing star formation rate to the present day quiescent state. The cumulative star formation history indicates that a significant fraction of the stellar mass assembly in KDG 215 has occurred within the last 1.25 Gyr. KDG 215 is one of only a few known galaxies that demonstrates such a delayed star formation history. While the ancient stellar population (predominantly red giants) is prominent, the look-back time by which 50% of the mass of all stars ever formed had been created is among the youngest of any known galaxy.

**Author(s):** Igor Karachentsev, John M. Cannon, Sarah Chinski, Greta Helmel, Andrew Dolphin, Moritz Rusch, Joshua Bartz, Alex J. R. Gordon, Zili Shen, Tylyn Page, Andrew Mizener, Sam Hollenbach, Sarah Taft, Riley A. McGlasson, William Retza, Kristen B. W. McQuinn, Lil

**Institution(s):** Macalester College, Special Astrophysical Observatory of RAS, University of Texas at Austin, Raytheon Company, Indiana University

### **351.13 - HI Spectral Line Imaging of Three SHIELD Galaxies(Jacob Hetrick)**

The ALFALFA blind HI survey has populated the low-mass end of the HI mass function for the first time, allowing an unprecedented opportunity to explore the physical properties of the galaxies that inhabit this extreme portion of parameter space. Using the now-complete ALFALFA dataset, we have constructed the "Survey of HI in Extremely Low-mass Dwarfs" ("SHIELD"), a complete sample of 82 galaxies that provides a unique opportunity to further our understanding of these cosmologically important systems. Here we present new VLA imaging of the final 3 of the 82 sources to be observed at low angular resolution in the HI spectral line: AGC215284, AGC731448, and AGC732041 (program VLA/18A-177). We compare the HI images to ground-based H-alpha imaging in order to examine the star formation properties of each system.

**Author(s):** Evan Skillman, John M. Cannon, Jacob Hetrick, Elizabeth Adams, Lukas Leisman, Steven Janowiecki, Michael Jones, Martha P Haynes, Riccardo Giovanelli, Kristen B. W. McQuinn, Katherine Rhode, John Salzer

**Institution(s):** Macalester College, Cornell University, ASTRON, Instituto de Astrofísica de Andalucía, University of Texas, Indiana University, Valparaiso University, University of Minnesota

### **351.14 - The Enigmatic ALFALFA (Almost) Dark Galaxy AGC 229101(Lukas Leisman)**

We present deep HI and optical imaging of AGC 229101, an enigmatic and potentially unique source detected in the ALFALFA survey. Though it has an HI mass  $>109$  solar masses, it is not detected in SDSS imaging, and has a very narrow HI line width. Deep follow up imaging with pODI on the WIYN 3.5m at KPNO detects a very blue, very low surface brightness optical counterpart with a stellar mass  $<107$  solar masses, giving a gas fraction of  $\text{MHI}/\text{M}^*$  in excess of 200. Low resolution WSRT HI imaging and higher resolution VLA B-array imaging reveal that AGC 229101 appears to consist of two connected HI components, with the optical counterpart associated with the peak column density in the northern component. The two components have approximately equal mass and radii, and together stretch over  $>80$  kpc as projected on the sky. We compare the properties of AGC 229101 to other extreme HI-rich sources, and demonstrate that its properties appear to be unique relative to others sources in ALFALFA. We discuss potential explanations, including a tidal encounter between neighboring sources, a merger of two independent, almost dark sources, and gas in-fall along a filament.

**Author(s):** John M. Cannon, Elizabeth Adams, Hannah Pagel, Martha P Haynes, Gyula Józsa, William Janesh, Lukas Leisman, Steven Janowiecki, Catherine Ball, Katherine Rhode, John Salzer

**Institution(s):** Valparaiso University, Indiana University, Cornell University, Case Western Reserve University, Macalester College, ASTRON, Cornell University, SKA South



**351.15 - HI-Bearing Ultra-Diffuse Galaxies: VLA Imaging of AGC 749290 and AGC 238764(Lexi Gault)**

Ultra-diffuse galaxies (UDGs) are galaxies with a very low optical surface brightness; they have very few stars for their given radius. Since UDGs are thus difficult to study in visible light, we observe radio emission from neutral hydrogen gas (HI) in these galaxies. Here we present observations of the HI gas in the UDGs AGC 749290 and AGC 238764. Initially selected from a sample of Ultra-Diffuse Galaxies detected in the ALFALFA survey, these sources were imaged as a part of a follow up program using the Jansky Very Large Array (VLA) in both C and D configurations. We reduce the data using the CASA software suite, removing radio interference, applying calibration, and creating images. From these data we obtain spectra and maps of the galaxies' HI distribution and radial velocities. We find that both sources show ordered gas distributions and rotation, and that the HI gas extends well beyond the already extended optical emission. Further, we estimate inclinations and plot these sources on the Baryonic Tully-Fisher relation, providing tentative evidence that these sources are rotating too slowly for their given mass. This work has been supported by NSF grant AST-1637339.

**Author(s):** Lexi Gault, Lukas Leisman

**Institution(s):** Valparaiso University Contributing Team(s): The ALFALFA Team, The Undergraduate ALFALFA Team

**351.16 - Using Very Large Array Data to Image the Ultra-Diffuse Galaxy AGC 749251(Kameron Reiter)**

Ultra-diffuse galaxies (UDGs) have generated significant interest in recent years, as their stars appear too spread out relative to typical galaxies, and because some UDGs appear to have more than typical amounts of dark matter. The ALFALFA Survey has detected a number of UDGs in the field that are rich with neutral hydrogen (HI). We use the Karl G. Jansky Very Large Array (VLA) to image one of these HI-rich UDG, AGC 749251. We manually remove radio frequency interference, and reduce it using standard procedures in CASA. From the resulting data cubes we created 2D maps (moment 0 maps) and maps of the radial velocities of the HI gas. We find that the HI in AGC 749251 shows reasonably ordered morphology and rotation, and extends beyond the already extended optical emission. We estimate the source's inclination and rotation velocity, constraining the source's dark matter content. We also compare our results to other, non-ultra diffuse galaxies, and suggest that the rotation velocity seems low compared with other sources of similar mass. This work has been supported by NSF grant AST-1637339.

**Author(s):** Lukas Leisman, Kameron Reiter

**Institution(s):** Valparaiso University Contributing Team(s): The ALFALFA Team

**351.17 - An Analysis of the Dark Matter Distributions of Low Mass Galaxies(Kathryn Bowen)**

We report dark matter decompositions for five low mass galaxies: NGC4068, NGC6789, UGC4483, UGC8651, and UGC9240. Using new and archival neutral hydrogen (HI) observations from the Very Large Array combined with archival optical and infrared imaging observations from the WIYN 0.9m and Spitzer Space Telescope, a rotation curve decomposition was created for each galaxy, producing a fit for the dark matter halo of each galaxy. The dark matter fraction was calculated at three separate radii of interest for each galaxy: 2.2 scale lengths, the optical radius of the galaxy, and at the last measured point of the HI gas. For most of these galaxies, dark matter was confirmed to be dominant at all radii. This study was made possible by the NSF REU Grant PHY- 1757646.

**Author(s):** Kathryn Bowen, Liese van Zee

**Institution(s):** Purdue University, Indiana University

**351.18 - Mechanisms for Inducing Star Formation in the Dwarf Irregular Galaxy DDO 133(Lauren Laufman)**

Dwarf irregular galaxies are important to study for several reasons. First, they are the most abundant galaxy in the universe; in the Local Group we have more than fifty dwarfs and just three spirals. In addition to being the most common, they are the closest analogue to the building blocks of the early universe and their lack of heavy elements imitates early universe star formation conditions. However, the models say that dwarf irregulars shouldn't be able to continuously form stars; they aren't dense enough to reach the critical density for gravitational instabilities to form and collapse the gas clouds. We present a study of peculiar gas motions and their connection with star formation in the dwarf irregular galaxy DDO 133. Using primarily HI data cubes from the VLA, we build moment maps to identify the motion and location of the gas, and use previously written code to deconvolve these moment maps into bulk and peculiar motions. We identify a stellar bar in DDO 133 with characteristic streaming motions of HI around said bar, likely causing the significant amounts of HI and star formation observed at the ends of the bar. This research was funded by NSF grant 1461200 to Northern Arizona University to support the 2018 Research Experiences for Undergraduates program.

**Author(s):** Deidre Hunter, Se-Heon Oh, Lauren Laufman

**Institution(s):** University of Wisconsin-Madison, Korea Astronomy and Space Science Institute, Lowell Observatory

### **351.19 - HST STIS Observations of the Central Radio/X-Ray Source in the Compact Starburst Galaxy Henize 2-10 (Eric Rohr)**

Based on radio and X-ray observations, it has been suggested that a black hole of mass  $\sim 106 M_{\odot}$  resides in the dwarf starburst galaxy Henize 2-10. This unusual finding has important implications for the formation of massive black holes in the early universe since Henize 2-10 can be viewed as a low redshift analog to the first high- $z$  galaxies. We present long-slit HST STIS spectra that include the central radio/X-ray source. While recent VLT-MUSE spectroscopic observations with 0.7" seeing show no change in ionization near the central source, our higher spatial resolution STIS observations identify a distinct compact region at the location of the radio/X-ray source. Initial analysis reveals broader (FWHM  $\sim 380 \text{ km s}^{-1}$ ) blue-shifted lines of low ionization. Our analysis focuses on testing two scenarios: a LINER-like AGN and a young (few decades) SNR.

**Author(s):** Mark Whittle, Amy Reines, K. E. Johnson, Eric Rohr

**Institution(s):** University of Virginia, Montana State University

### **351.20 - Displaced by Mergers: Wandering Black Holes in MARVEL-ous Dwarf Galaxies (Jillian Bellovary)**

Recent discoveries of dwarf galaxies hosting active galactic nuclei (AGN) suggest that massive black holes (MBHs) may be a common occurrence in such low-mass systems. We examine the occupation and characteristics of MBHs in dwarf galaxies using the MARVEL-ous Dwarfs sample of high resolution cosmological simulations. We describe in detail the properties of seven dwarfs hosting MBHs, although none of them are AGN at any point during their histories. Approximately 50% of MBHs in the dwarfs are off-center, as a result of being perturbed by a merger with another dwarf galaxy. Our simulations include a subgrid model for dynamical friction; thus these off-center MBHs are a true dynamical consequence of mergers, and not a numerical effect. Since not every MBH in a dwarf is centrally located, some presupposed MBH-MBH mergers may not actually occur, which will affect the gravitational wave signal detected by LISA.

**Author(s):** Sarra Hayoune, Jillian Bellovary, Michael Josef Tremmel, Michelle Luzuriaga, Ferah Munshi

**Institution(s):** Queensborough Community College, Hudson County Community College, American Museum of Natural History, Yale University, University of Oklahoma

### **351.21 - Into Darkness: what the MARVEL-ous dwarf simulations can tell us about the physics of first star formation (Ferah Munshi)**

The existence of ultra-faint dwarf (UFD) galaxies highlights the need to push our theoretical understanding of galaxies to extremely low mass. Using two identical volumes from the high-resolution, fully cosmological MARVEL-ous dwarf galaxy

simulation suite, we examine the formation of dwarf galaxies and their UFD satellites. The volumes have identical initial conditions, and vary only in how they form stars: one uses a temperature-density threshold for star formation in combination with metal line cooling, while the other replaces the temperature-density threshold with an  $H_{2}$ -based sub-grid star formation model. We find that the total number of dwarf galaxies that form is different by a factor of 2 between the two runs, but most of these are satellites, leading to a factor of 5 difference in the number of luminous UFD companions around more massive, isolated dwarfs. These results emphasize that predictions for UFD properties made using hydrodynamic simulations, in particular regarding the frequency of satellites around dwarf galaxies, the slope of the stellar mass function at low masses, as well as the properties of ultra-faint galaxies occupying the smallest halos, are extremely sensitive to the subgrid physics of star formation contained within the simulation.

**Author(s):** Elia Applebaum, Ferah Munshi, Thomas Quinn, Alyson Brooks, Charlotte Christensen

**Institution(s):** University of Oklahoma, Grinnell College, Rutgers, University of Washington

### **351.22 - The Star Formation Law in Dwarf Galaxies (Jaimee-Ian Rodriguez)**

Despite being the most numerous galaxy type in the universe, little is understood about dwarf galaxies due to their small size, which impedes observation, and their irregular patterns of star formation. Yet, their low metallicities and high gas fractions make them excellent laboratories to test theories of the Interstellar Medium originally developed for more massive galaxies, in particular the role of supernovae-driven feedback and the processes that drive and regulate star formation. We attempted to recreate these conditions by incorporating precise physics into high-resolution simulations of isolated dwarf galaxies using the adaptive mesh refinement code Enzo. We analyzed the star formation law, namely the relationship between star formation rate surface density and gas surface density in several simulations in order to characterize the patterns of star formation in environments of varying turbulence and feedback. We then compared these results to the existing analytic models which attempt to predict this behavior in larger systems, in particular, those proposed by Eve Ostriker (2010), Mark Krumholz (2013) and Claude-Andre Faucher-Giguere (2013), the first of which aligns most closely with our computationally generated results.

**Author(s):** Jaimee-Ian Rodriguez, John Forbes

**Institution(s):** Hunter College, Harvard-Smithsonian Center for Astrophysics, Banneker & Aztlán Institute

### **351.23 - Locations of Illustris-1 Satellite Galaxies(Masaya Yamamoto)**

We use the Illustris-1 simulation to study the locations of satellite galaxies, measured relative to the major axes of their host galaxies' dark matter halos and stellar mass distributions. The host galaxies are selected to be relatively isolated and, therefore, the dynamics of the systems are dominated by the hosts. Overall, when the locations of the satellites are measured relative to the hosts' dark matter halos, the satellites of high-mass, high-luminosity hosts do not show a preferred location. The satellites of low-mass, low-luminous hosts are more likely to live close to the major axes of the hosts' dark matter halos. When measured with respect to the hosts' stellar mass distributions, however, the satellite locations are largely independent of host mass and luminosity. This disagrees with a previous theoretical result from the Millenium Run simulation (Agustsson & Brainerd 2010) where the locations of the satellites were found to be a strong function of the physical properties of the hosts. The discrepancy between our results for Illustris-1 satellites and Millenium Run satellites appears to originate with a large population of low mass, isotropically-distributed satellites at large host-satellite distances that are not found in the Millennium Run.

**Author(s):** Masaya Yamamoto, Tereasa Brainerd

**Institution(s):** Boston University

### **352 - Engaging Learners in Research & with Content: Education Practices Across the Human Continuum -- Posters**

#### **352.01 - Providing an Immersive Undergraduate Research Class Experience in the Five College Astronomy Department(Kimberly Ward-Duong)**

Beyond introduction within an upper-level observational techniques course, astronomy undergraduates often do not encounter training in astronomical research methods as part of standard major coursework. In order to develop research and observing experience as part of curriculum available to students, the Five College Astronomy Department (FCAD) has implemented an astronomy capstone course over the past four years (AST 341; Observational Techniques II). This course aims to provide real-life experience with a professional facility and complex data analyses that prepare students for dedicated internships, REU programs, graduate school, and work outside of astronomy in STEM-related fields. In AST 341, students complete novel astronomy research projects over the course of one semester, in areas that have ranged from deep extragalactic observations to studies of nearby star forming regions. The course begins with an 8-night observing run on the WIYN 0.9m Telescope at Kitt Peak National Observatory, and concludes with research poster presentations at an FCAD-wide symposium with all member institutions. We present results from the latest iteration of the course in Spring 2018, which focused on variability of young stellar objects and an introduction to time domain astronomy. We provide an overview of the student projects and their results, pedagogical

approaches to developing student research skills, and previous course outcomes (including presentations at professional conferences, student thesis and independent study projects, and graduate school placement).

**Author(s):** Kimberly Ward-Duong, Anne Jaskot, Michael Petersen, Todd Tripp, James D. Lowenthal, Katherine Follette, Suzan Edwards

**Institution(s):** Amherst College, Smith College, University of Massachusetts Amherst, Amherst College

#### **352.02 - Data Science education through astronomical sky surveys(Lior Shamir)**

Data Science is an emerging discipline that combines computer science, statistics, and mathematics for the purpose of turning data into insights and knowledge. The training of data scientists should include research experience, as the job of the data scientist, whether in academia or industry, includes a substantial research component. Astronomy is an engaging way to provide data science students with authentic research experience. Ground-based and space-based missions generate some of the largest and most productive scientific databases, providing numerous opportunities for data science research that can be done by students. Activities can include basic supervised machine learning such as automatic classification of astronomical objects, but also discovery-driven data science tasks such as novelty detection, identification of peculiar objects, and unsupervised analysis of spectroscopic, photometric, and visual data. These research tasks can be prepared in a way that simplifies the research activities, so that the research can be done by undergraduate students as part of courses. The activities expose students to authentic research by working with real-world data, while providing engaging activities that can lead to meaningful discoveries or data products.

**Author(s):** Lior Shamir

**Institution(s):** Lawrence Technological University

#### **352.03 - Developing a Sophomore level Astronomy Class for Physics and Astronomy Majors(Denise C Stephens)**

One of the challenges we face in undergraduate education is finding strong textbooks and materials for sophomore level courses in astronomy for our majors. While many of the 100 level textbooks contain basic equations and problems, they are lacking in rigor and in their connections between the physics and the observations. The demand for a textbook at this level is not great enough to drive publishers to invest time and energy in the creation of textbooks at the appropriate level. Our current solution has been to use Carroll and Ostlie's Introduction to Modern Astrophysics and adapt the material to a level that our students can understand. But it is still a work in progress. The goal of this poster is to share what we have accomplished thus far and spark communication between instructors at different universities to share ideas on how we

can better meet the education needs of our undergraduate astronomy majors.

**Author(s):** Denise C Stephens, Nicholas Van Alfen

**Institution(s):** Brigham Young University

### **352.04 - Designing Solutions For Technology Based STEM Education(Edwin Dely)**

It requires innovative technological and engineering solutions to bring high quality astronomy programming to youth across the country. Two such efforts of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics include the Spectrum Lab and the MicroObservatory Robotic Telescope Network. The Spectrum Lab, in addition to an online tool for analyzing and understanding spectroscopic data, aims to engage students in hands-on exploration of spectra through the use of a 3D printed, educational spectrometer for mobile devices. Reaching the broadest audience possible required iterating on an existing, limited design to deliver a device (and 3D printable model) universally compatible with current cell phones. The MicroObservatory Robotic Telescope Network collects astronomical images for naive and advanced users on a nightly basis. To further calibrate the data collected from the telescopes an evenly illuminated exposure, known as a flat field, was needed. A device compatible with MicroObservatory's specifications was designed and built to evenly illuminate the telescope's field of view, allowing users to characterize the signal response of the digital detector of the telescopes, and perform higher-level calibration and analysis. In addition, to provide full day solar viewing to MicroObservatory users, a solar tracking telescope was designed and built with housing to protect it from the weather. These efforts each require unique solutions to reach a national audience and accomplish their educational goals of providing underserved youth with frequent and unlimited access to the skies.

**Author(s):** Edwin Dely, Frank Sienkiewicz, Erika Wright

**Institution(s):** UMASS Lowell, Harvard-Smithsonian Center for Astrophysics

### **352.06 - AstroCom NYC: A Partnership between New York City Astronomers(Timothy Paglione)**

AstroCom NYC is an undergraduate mentoring program designed to improve urban minority student access to opportunities in astrophysical research by greatly enhancing partnerships between research astronomers in New York City (City University of New York - an MSI, American Museum of Natural History, and Flatiron Institute Center of Computational Astrophysics). New York City now has one of the largest concentrations of professional astronomers in the country, so we provide exciting and unique opportunities for students in all five boroughs, fostering an expanding mentor network throughout the city. We provide centralized, personalized mentoring as well as financial, academic, and now also mental

health support, to CUNY undergraduates throughout their studies, plus the resources and opportunities to further CUNY faculty research with students. The goal is that students' residency in the unique research environments at AMNH and the CCA helps them build a sense of belonging in the field, and readies and inspires them for graduate study. We welcomed our sixth cohort last year, and had our largest graduating class move to grad school and bridge programs.

**Author(s):** Ariyeh Maller, Kelle Cruz, K.E. Saavik Ford, Charles T Liu, Mordecai-Mark Mac Low, Luis Anchordoquio, Quinn Minor, Dennis Robbins, Joshua Tan, Jillian Bellovary, Allyson Sheffield, Viviana Acquaviva, Matthew O'Dowdo, Barry McKernan, ,

**Institution(s):** CUNY LaGuardia CommColl., oCUNY Lehman College, CUNY York College, CUNY BMCC, AMNH, Columbia Univ., CUNY Hunter College, CUNY City Tech, Flatiron InstCCA, CUNY Collof Staten Island, CUNY Queensborough CommColl

### **352.07 - A Way to Categorize Programs that Bring Data to the Classroom(Luisa Rebull)**

Getting high-quality astronomical data in the grade 7-12 classroom has become much easier than ever before as a result of wide availability of the Internet in schools, easily accessible professional astronomy archives, and research-grade robotic telescopes. Especially in the context of new science standards in the US, schools need to be moving towards more project-based learning and incorporating more authentic scientific inquiry, so demand for programs that use real data is only expected to grow. In this poster, I suggest a funnel as a way to think about the "ecosystem" of projects getting astronomical data into the hands of teachers, students, and the public.

**Author(s):** Luisa Rebull

**Institution(s):** Caltech-IPAC

### **352.08 - Alignment of NITARP components to Next Generation Science Standards(David Friedlander-Holm)**

The NASA/IPAC Teacher Archive Research Program (NITARP) provides a year-long research experience for secondary educators and their students. High school students work alongside educators and research scientists to formulate research proposals, analyze NASA archival data, and present their findings at an academic conference. NITARP is one of the few programs that allows secondary students to conduct real astronomical research in an authentic research setting. The Next Generation Science Standards (NGSS), developed in 2013, provide a national framework for forward-thinking science education in the United States. By aligning the NITARP experience and goals with the NGSS, we present how NITARP provides an authentic and engaging application of the these standards for secondary students. We show through analysis of skills used by secondary science students that through

participation in NITARP, students make progress on a broad range of standards. Combined with self-reported student surveys, we are also able show that student views toward science and science research change when students have worked for approximately a year as NITARP participants. This research was made possible through NITARP and funded by NASA Astrophysics Data Program

**Author(s):** David Friedlander-Holm, Matt Nowinski, Thomas Rutherford, Nicholas K Goeldi, Alissa Sperling, Varoujan Gorjian

**Institution(s):** The Bay School of San Francisco, Loudoun County Public Schools, Ripon High School, Sullivan South High School, The Boeing Company, Caltech/Jet Propulsion Laboratory, Springside Chestnut Hill Academy

### **352.09 - Using IRSA's Tools in the Secondary Classroom(Laura Orr)**

IRSA's tools are very powerful and wide reaching and provide tools for anyone to access "real" data from a huge range of instruments and satellites. While the tools are useful for professional astronomers, they also can be an effective tools for educators to use in the classroom. In the poster, we look at the ways that our team uses IRSA's tools for research as well as in classroom education. We highlight that the public access and usability of the tools create a platform for a wide range of exploration. The correlation to educational standards and curriculum can be supported by IRSA in an engaging ways that use technology, real world information and problem solving inquiry - cornerstones of STEM and effective science education (as well as the NGSS). The IRSA tool suite is also very adaptable, can be mastered with minimal training, and is easily accessible. They are useful to both professional educators and students. This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by the NASA Astrophysics Data Program.

**Author(s):** Deborah Morgan, Luisa Rebull, Nancy Coster, Laura Wommack, Laura Orr

**Institution(s):** Ukiah High School, South Sevier High School, Kankakee Valley High School, Caltech/IPAC, Lakeside Jr-Sr High School

### **352.10 - New Database Access to the Astronomical Photographic Data Archive at PARI(J. Donald Cline)**

A diverse set of photometric, astrometric, spectral and surface brightness data exist on decades of photographic glass plates. The Astronomical Photographic Data Archive (APDA) at the Pisgah Astronomical Research Institute (PARI) was established in November 2007 and is dedicated to the task of collecting, restoring, preserving and storing astronomical photographic data and PARI continues to accept collections. APDA is also tasked with scanning each image and establishing a database of images that can be accessed via the Internet by the global community of scientists, researchers and students. APDA is a

new type of astronomical observatory - one that harnesses analog data of the night sky taken for more than a century and making that data available in a digital format. The Astronomical Photographic Data Archive Database Project improves access and discovery. Our objectives include the creation of a PostgreSQL database that allows access to all APDA plate collections, building the database from logbooks and spreadsheets of collections, providing finding aids; i.e., physical location in APDA (e.g. room, storage unit, and shelf, drawer or box) for each plate and if available, scanned images of plates, envelopes, and other metadata. This project provides open-access to astronomical plate collections obtained from many sources to benefit scientists and science historians providing the opportunities for multi-disciplinary research. The development of the database was funded, in part, by the Institute of Museum and Library Services.

**Author(s):** J. Donald Cline, Michael Castelaz, Thurburn Barker

**Institution(s):** Pisgah Astronomical Research Institute, Brevard College

### **352.11 - The Universe of Learning's Authentic Ground-based Observing and Research Experience(Robert Thomas Zellem)**

The NASA's Universe of Learning program creates and delivers science-driven, audience-driven resources and experiences designed to engage and immerse learners of all ages and backgrounds in exploring the universe for themselves. The project is the result of a unique partnership between the Space Telescope Science Institute, Caltech/IPAC, Jet Propulsion Laboratory, Smithsonian Astrophysical Observatory, and Sonoma State University, and is one of 25 competitively-selected cooperative agreements within the NASA Science Mission Directorate STEM Activation program. The NASA's Universe of Learning team draws upon cutting-edge science and works closely with Subject Matter Experts (scientists and engineers) from across the NASA Astrophysics Physics of the Cosmos, Cosmic Origins, and Exoplanet Exploration themes. The NASA's Universe of Learning program aims to increase learners' understanding of the process of science, and key topics in astronomy and increase the role of NASA Astrophysics science experts as partners. Within NASA's Universe of Learning is the Authentic Ground-based observing and Research Experience (AGRE), a subgroup consisting of the MicroObservatory, Global Telescope Network, and Project PANOPTES. Both individually and working in concert, these participatory experiences for learners of all ages provide opportunities for realistic and authentic astronomical observing experiences. Examples of such activities are producing color images of cosmological phenomena (nebulae, clusters, galaxies, etc.) and observing, reducing, and analyzing transiting exoplanet lightcurves. These data tools and participatory experiences not only engage learners in these phenomena outside of a formal classroom setting, but also make scientific processes and practices tractable and understandable. In addition to these authentic experiences, by taking advantage of

pathways to engaging with NASA science within and exterior to the NASA's Universe of Learning framework, our audiences come into these experiences excited to learn more about astrophysics and engage with the process of science, thus helping to build their identities as scientists.

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**Institution(s):** Jet Propulsion Laboratory - California Institute of Technology, Space Telescope Science Institute, Harvard-Smithsonian Center for Astrophysics, Caltech/IPAC, Sonoma State University, Smithsonian Astrophysical Observatory

### **353 - Evolved Stars, Cataclysmic Variables and Friends Posters**

#### **353.01 - A Modern Search for Wolf-Rayet (WR) Stars in the Magellanic Clouds: A Final Census(Philip Massey)**

Wolf-Rayet (WR) stars evolved from massive OB stars, where the outer hydrogen-rich layers have been stripped away by some mechanism: stellar winds, close binary companions, episodic mass-loss during a Luminous Blue Variable phase, or all of the above. We have recently carried out a new survey of the Small and Large Magellanic Clouds (SMC, LMC) discovering 15 new WR in the LMC, bringing the total known to 154. We also found 12 Of-type stars, including rare Onfp and Of?p stars, and a variety of other interesting emission-lined stars. Most exciting, however, has been our discovery of new class of WRs, which we are calling WN3/O3s. These have the typical emission lines of a high-excitation nitrogen-rich (WN) Wolf-Rayet, but the absorption lines of a hot O-type star. However, they are many magnitudes too faint to be WN3+O3 binaries. Rather, the emission and absorption originate from the same object. Detailed analysis of our Magellan spectra have shown that the physical properties of these stars are similar to normal WNs, but with the presence of more hydrogen and much lower mass-loss rates. About 8% of the LMC's WN-type population is made up of these newly found objects, and so these are not a consequence of some rare and special process. The question then is how did these WN3/O3s evolve? Are they simply a short-lived phase in the normal evolution of WRs, a "missing link" between O-type stars and WRs that occurs only in certain metallicity regimes? Or have they evolved by binary evolution? Drop by our poster and hear what we have to say on the issue! This work was supported by the National Science Foundation through AST-1612874.

**Author(s):** Desmond John Hillier, Nidia Morrell, Kathryn Neugent, Philip Massey,

**Institution(s):** Lowell Observatory, University of Washington, Northern Arizona University, University of Pittsburgh, Las Campanas Observatory

#### **353.02 - Recent Evolution of the Mass Loss Rate for Eta Carinae(Greta Helm)**

We present analysis of recent spectra from the supernova imposter Eta Carinae. Observations were taken as a part of the Hubble Space Telescope's Treasury Program on Eta Carinae, using the STIS CCD. Recent changes in these spectra from 2012 to 2018 confirm the continuation of certain trends in the star's behavior, including both an overall brightening and the related decrease in the mass loss rate and stellar wind density. As a result, [N II] absorption continues to deepen significantly. In addition, one [N II] emission feature has recently resolved in an unprecedented way, and shows significant variation over the course of a spectroscopic cycle. This research was done as a part of the University of Minnesota's summer 2018 Physics and Astronomy Research for Undergraduates program.

**Author(s):** K. Ishibashi, John Martin, Greta Helm, Roberta Humphreys, Kris Davidson

**Institution(s):** Macalester College, University of Illinois Springfield, University of Minnesota, Nagoya University

#### **353.03 - HIDING IN PLAIN SIGHT: SERENDIPITOUS DISCOVERY OF A RARE, VERY LOW-EXCITATION [WC] STAR NEAR THE LMC(Catherine Manea)**

We report the chance discovery of an unusual V~15 emission-line star, UVQS J060819.93-715737.4 (hereafter "J0608"). With a spectrum dominated by extremely intense, narrow C II emission, J0608 resembles the small handful of current members of the rare [WC11] subclass of low-mass, cool Wolf-Rayet stars. The spectrum reveals many C II and He I P Cygni profiles, signifying mass loss, and a population of numerous C II autoionizing levels, signifying that both dielectronic recombination and a very high C abundance play a key role in the extraordinary C II emission of this star. All previously known [WC11]'s are central stars of planetary nebulae, also implied in J0608 by the presence of [O II] 3727. However, a variety of direct-imaging observations fail to resolve the object: it may be quite compact. The spectrum also reveals a distinct lack of higher-ionization C transitions, indicating very low excitation, even lower than that of the prototype [WC11] star CPD -56° 8032, for which we also present a modern spectrum. Oddly, despite the lower excitation, J0608 is strongly detected in the FUV/NUV by GALEX and displays a peculiar blue optical continuum, perhaps implying the presence of a hot companion. Extensive OGLE photometry shows flickering at the level of a few tenths of magnitude, but no periodic variations, suggesting that this companion, if present, might be at low orbital inclination. J0608 is superposed near the outskirts of the LMC, and the observed radial velocity and Gaia DR2 proper motion suggest it is likely a member. If indeed a member, this is the first late-type WC in the LMC, and the first accurate determination of a [WC11] luminosity. Regardless of membership, the serendipitous discovery of this object leads us to question the true rarity of this [WC11] subclass: J0608 fails normal Wolf-Rayet selection techniques. There may be a

substantial number of these very cool WRs waiting to be identified, both Galactic and in the Local Group.

**Author(s):** Robert E. Williams, Catherine Manea, Michal K. Szymanski, J. Xavier Prochaska, Bruce Margon, Howard E. Bond,

**Institution(s):** University of California, Santa Cruz, Penn State, STScI, Warsaw University Obs

### **353.04 - AKARI Mission Program: Excavating Mass Loss History in Extended Dust Shells of Evolved Stars (MLHES) II. Detailed Analysis of the Circumstellar Shell Structures.(Andrew Torres)**

We performed a far-IR imaging survey of the circumstellar dust shells around 144 evolved stars as a mission programme of the AKARI infrared astronomical satellite, dubbed as “Excavating Mass Loss History in Extended Dust Shells of Evolved Stars” (MLHES), using the Far-Infrared Surveyor (FIS) instrument. Our objective is to reveal the mass-loss history of these stars empirically by characterizing the distributions of the cold dust component in the circumstellar dust shells via AKARI/FIS images in the far-IR. Previously, we delivered far-IR surface brightness distributions of these circumstellar dust shells in roughly  $10''$ – $30''$  areas of the sky around the target evolved stars in the AKARI/FIS bands at 65, 90, 140, and  $160\ \mu\text{m}$  and compiled the results of photometric measurements. In this work, we perform a detailed analysis of the structures of the circumstellar shells by removing the effects of the central emission source. To remove the effects of the central emission source, we (1) subtract a scaled point source calibrator image from the image of our target evolved star and (2) deconvolve the target sources using the point source calibrator image. We will describe these methods, assess their effectiveness, present the results and discuss the mass-loss history results.

**Author(s):** Toshiya Ueta, Hideyuki Izumiura, Satoshi Takita, Issei Yamamura, Andrew Torres, Rachael Tomasino

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### **353.05 - Shedding Light on the Isolation of Luminous Blue Variables(Erin Aadland)**

In the traditional view of massive star evolution, luminous blue variables (LBVs) are a transitional phase between massive O-type stars and Wolf-Rayet stars (WRs). A debate has sprouted over whether this single star evolution is flawed and perhaps a binary evolutionary track describes the LBV phase better. The root of this debate has been the question of isolation (projected angular separation) of LBVs from their nearest neighboring O-type star. LBVs, traditionally, have relatively short lifetimes, and as a result they should not disperse far from their birthplace or be isolated. A recent study found that LBVs have

an isolation more similar to that of red supergiants (RSGs) than traditionally thought possible given single star evolution. A similar study, however, found the opposite result. Both of these studies used spectroscopically identified O-type stars, which for the Large Magellanic Cloud is extremely incomplete, and does not necessarily represent the high mass stars we expect to be LBV progenitors in any event. Therefore, we re-examined the question of isolation using photometric criteria to select the highest mass unevolved stars (“bright blue stars” or BBSs) to use as our comparison sample. We find that LBVs are no more isolated than BBSs or WRs, and were able to statistically rule out the possibility of LBVs coming from the same distribution as the RSGs. We also note the number of LBVs in or near OB associations is comparable to the number of BBSs or WRs, and not to that of RSGs. Therefore, we conclude that the isolation of LBVs is consistent with the traditional picture of massive single star evolution. This work was supported by the National Science Foundation through AST-1612874.

**Author(s):** Maria Drout, Erin Aadland, Kathryn Neugent, Philip Massey,

**Institution(s):** Northern Arizona University, University of Washington, Lowell Observatory, The Observatories of the Carnegie

### **353.06 - Infrared light curves of dusty & metal-poor AGB stars(Steven Robert Goldman)**

The effects of metallicity on both the dust production and mass loss of evolved stars have consequences for stellar masses, stellar lifetimes, the progenitors of core-collapse supernovae, and the origin of dust in the ISM. With the DUST in Nearby Galaxies with Spitzer (DUSTiNGS) survey, we have discovered samples of dusty evolved AGB stars out to the edge of the Local Group, reaching metallicities down to 0.6% solar. This makes them the nearest analogs of AGB stars in high-redshift galaxies. We present new infrared light curves of the dustiest AGB stars in 10 galaxies from the DUSTiNGS survey and show how the infrared Period-Luminosity (PL) relation is affected by dust and by metallicity. These results have implications for the efficiency of AGB dust production at high-redshift and for the use of the Mira PL relation as a potential distance indicator.

**Author(s):** Steven Robert Goldman, Martha Boyer

**Institution(s):** Space Telescope Science Institute

### **353.07 - Long-Term Evolution of Post-Eruption Novae(Katherine Bruce)**

Classical novae (CNe) are eruptions that occur in cataclysmic variable systems that are made up of a white dwarf (WD) accreting from a companion star. The accreted material builds up onto the WD’s surface until the pressure causes runaway thermonuclear reactions. This eruption causes a peak in brightness then decreases back down to quiescence. The Hibernation Theory (Shara et al. 1986) predicts that a post-eruption nova should decrease in brightness by  $\sim 1$  magnitude

per century and the orbital separation should increase. This decrease in brightness is caused by a decrease in accretion rate due to the greater orbital separation. Novae are generally heavily observed during their eruption, however that coverage nearly stops after the eruption is over. Because of this, not much is known about the evolution of novae. To evaluate the predictions of the Hibernation Model, we must be able to understand the long-term behavior of post-eruption CNe. To determine their trends in brightness, we collected data from the Harvard College Observatory plate archives, literature, and modern telescope observations. We constructed long-term light curves for the novae V630 Sgr, V841 Oph, X Ser, V1016 Sgr, and others.

**Author(s):** Bridget Ierace, Katherine Bruce, Ashley Pagnotta

**Institution(s):** College of Charleston

### **353.08 - Observations of PTFS1623al, a Magnetic Cataclysmic Variable(Ryan Jackim)**

We have identified a variable optical counterpart, PTFS1623al, within the error circle of the ROSAT X-ray source 1RXS J235728.5+671600. The source varies by 2.5 magnitudes over a 96 minute period. Swift XRT imaging confirms the association between the optical counterpart and the ROSAT source. Keck-LRIS spectroscopy shows strong double-peaked Hydrogen and Helium emission lines with a complex, phase-dependent morphology. These features are consistent with a magnetic cataclysmic variable. We present our observations and discuss their implications for our understanding of the system parameters.

**Author(s):** Thomas Prince, Eric Bellm, Thomas Kupfer, Ryan Jackim

**Institution(s):** University of Washington, California Institute of Technology, University of California

### **353.09 - Pulsation Study of Proto-Planetary Nebulae Based on ASAS-SN Data(Matthew Bremer)**

Proto-planetary nebulae (PPNe) are objects in transition between the AGB and planetary nebulae phases in the evolution of low- and intermediate-mass (1-8 Msun) stars. Previous studies have shown that these objects vary in brightness due to pulsations, with periods ranging from 35 to 160 days for objects in the Milky Way Galaxy and the Magellanic Clouds. We have expanded these studies using publically available data from the All-Sky Automated Survey for Supernovae data set. They cover the years 2014 - 2018 with high-density coverage. Based on this data set alone, we have determined significant periods for ~25 PPNe, some of which do not have published values. This has allowed us to find objects with even shorter periods, ranging from 24 to 30 days. These new ASAS-SN period values are compared with previously published ones to investigate changes in period. We find correlations between light curve periods and both light curve amplitudes and stellar temperatures, in accord with previous studies (cf. Hrivnak et al.

2015, AJ, 149, 184). This research is supported by the NSF (most recently AST-1413660).

**Author(s):** Matthew Bremer, Bruce Hrivnak

**Institution(s):** Valparaiso University

### **353.10 - Spectroscopic Classification of Post-AGB Candidates: Searching for Proto-Planetary Nebulae(Michael Battipaglia)**

We have determined the spectral classification of approximately 50 candidates for post-AGB, proto-planetary nebula (PPN) objects. The candidates were chosen based on their infrared excesses as seen in the IRAS data. The spectra are of low-resolution (R~550) and were obtained with the Kitt Peak National Observatory 2.1-m and the Steward Observatory 2.3-m telescopes. Spectroscopy has permitted us to discriminate between PPNe and other objects with dust, such as pre-main sequence stars and planetary nebulae. Most of the objects appear to be PPNe, ranging in spectral type from K to B, with some of the hotter ones showing hydrogen emission lines. A number of the objects have published classifications, which we list for comparison. Some were previously classified as PPNe but a few are new identifications. We are also carrying on a photometric monitoring program of many of these objects to study light variability. This research is supported by the NSF (most recently AST-1413660).

**Author(s):** Michael Battipaglia, Bruce Hrivnak, Kate Su, Wen Lu, Kevin Volk

**Institution(s):** Valparaiso University, Space Telescope Science Institute, University of Arizona

### **353.11 - High Contrast Coronagraphic Imaging of Two RSG Stars(Jamie R. Lomax)**

Coronagraphic imaging has been used for years by a variety of astronomical fields to combat contrast problems that prevent the direct detection or imaging of companions and circumstellar material. We have recently undertaken a pilot study to better understand how the newest generation high contrast coronagraphic systems might be used to probe the nearby environments around massive stars. In particular, we present analysis of GPI data taken of two red supergiant stars; CD -31 4916 and CPD -53 7344. We report on follow-up HST/STIS BAR5 data of CD -31 4916 used to produce a high-fidelity image of the RSG's circumstellar material and the possible detection of a low-luminosity stellar companion around CPD -53 7344.

**Author(s):** Emily Levesque, John Wisniewski, Jamie R. Lomax

**Institution(s):** University of Washington, University of Oklahoma, United States Naval Academy



### **353.12 - Spectroscopy of a Candidate Eta Carinae Analog in M33(Michael Scott Gordon)**

We present optical LBT/MODS and near-IR IRTF/SpeX spectroscopy of a possible eta Carinae analog in M33. Object M33-8 was first flagged as a candidate Luminous Blue Variable (LBV) based on its near- to far-IR colors by Khan et al. 2013, though later not considered a point source by Khan et al. 2015. This source is revealed in preliminary spectroscopy to show nebular, helium, and possible [Fe II] emission consistent with historical data of eta Car. We discuss the derived parameters and possible evolutionary state of M33-8 in the context of LBVs and the massive star population of M33.

**Author(s):** Terry J. Jones, John Martin, Rubab Khan, Michael Scott Gordon, Roberta Humphreys

**Institution(s):** Minnesota Institute for Astrophysics, University of Illinois Springfield, NASA Ames/SOFIA Science Center, University of Washington Seattle

### **353.13 - Analysis of a Century's Worth of AR Scorpii Photometry from DASCH and ASAS-SN(Erik Peterson)**

AR Scorpii (AR Sco) is a binary star system with the only known white dwarf pulsar. The system pulsates with a period of 1.97 minutes due to a rapidly spinning magnetized white dwarf. The binary system has an orbital period of about 3.56 hours (Marsh et al. 2016). One of the Katz (2017) models tries to describe the orbital variation and predicts a precessional period of 20 - 200 years that could be observed within a decade of observation. A previous study (Littlefield et al. 2017) attempted a verification of Katz's model for AR Sco but lacked the baseline to rigorously test it because the study analyzed data only as far back as 2005. We investigate Katz's hypothesis by compiling observations from the Digitized Harvard Astronomical Plate Collection (DASCH) and the All-Sky Automated Survey for Supernovae (ASAS-SN) spanning from the 1800s to present. By studying the orbital waveform across our baseline, we find that the average brightness of AR Sco remained constant over this time span, and we constrain the rate of change of the orbital period.

**Author(s):** Erik Peterson, Peter Garnavich, Colin Littlefield

**Institution(s):** University of Notre Dame

### **353.14 - 13 Years of Spectropolarimetry of P Cygni(Keyan Gootkin)**

We present a study on 13 years of HPOL optical linear spectropolarimetry of P Cygni. With a set of 19 additional spectropolarimetric observations, we revisit previous findings on the nature and variability of P Cygni's observed linear polarization and report on discrete features in P Cygni's observed polarization spectrum. Using this expanded dataset we also test the assumption that line blanketing effects suppress all intrinsic polarization from strong emission lines. This assumption is vital in determining the wavelength dependence of P Cygni's intrinsic polarization. Our results allow us to constrain the geometry of the polarizing region to better

understand the circumstellar material around P Cygni.

**Author(s):** Jamie L Lomax, Emily Levesque, Trevor Dorn-Wallenstein, Keyan Gootkin

**Institution(s):** United States Naval Academy, University of Washington

### **354 - Exploring our Cosmic Origins: New Results from the Atacama Large Millimeter/submillimeter Array -- Posters** **354.01 - ALMA Observations of Polarization from Dust Scattering in the IM Lup Protoplanetary Disk(Charles Hull)**

We present 870  $\mu$ m ALMA observations of polarized dust emission toward the Class II protoplanetary disk IM Lup. We find that the orientation of the polarized emission is along the minor axis of the disk, and that the value of the polarization fraction increases steadily toward the center of the disk, reaching a peak value of  $\sim 1.1\%$ . All of these characteristics are consistent with models of self-scattering of submillimeter-wave emission from an optically thin inclined disk. The distribution of the polarization position angles across the IM Lup disk reveals that while the average orientation is along the minor axis, the polarization orientations show a significant spread in angles; this can also be explained by models of pure scattering. We compare the polarization with that of the Class I/II source HL Tau. A comparison of cuts of the polarization fraction across the major and minor axes of both sources reveals that IM Lup has a substantially higher polarization fraction than HL Tau toward the center of the disk. This enhanced polarization fraction could be due a number of factors, including scattering by larger dust grains in the more evolved IM Lup disk. However, our models yield similar maximum grain sizes for both HL Tau and IM Lup: on the order of 70  $\mu$ m in both cases. This reveals continued tension between grain-size estimates from scattering models and from models of the dust emission spectrum, which find that the bulk of the (unpolarized) emission in disks is most likely due to millimeter (or even centimeter) sized grains.

**Author(s):** Charles Hull

**Institution(s):** NAOJ/ALMA

### **354.02 - ALMA Detections of the Youngest Protostars in Ophiuchus(Rachel Friesen)**

We present Atacama Large Millimeter/submillimeter Array (ALMA) observations of 1.1 mm dust continuum and CO 2-1 emission toward six dense cores within the Ophiuchus molecular cloud. We detect compact, sub-arcsecond continuum structures toward four targets, three of which (Oph A N6, SM1, and SM1N) are located in the Ophiuchus A ridge. Several of the sources are compact ( $R < 80$  au) accretion disks around young protostars, as evidenced by their resolved, elongated structure and clear bipolar outflows in the CO data. We show that the dust spectral index toward these objects suggests that the disks are either optically thick at 1.1 mm, or that significant grain

growth has already occurred. Both SM1N and N6 contain a single compact continuum source ( $R \sim 75 - 110$  au) embedded within a larger continuum structure, but show no clear bipolar outflows with velocities greater than a few km/s from the cloud velocity. These sources are candidates to be the youngest protostars or first hydrostatic cores in the Ophiuchus molecular cloud.

**Author(s):** Tyler Bourke, Andy Pon, Paola Caselli, Jes Jorgensen, Jaime Pineda, James Di Francesco, Rachel Friesen

**Institution(s):** National Radio Astronomy Observatory, Max-Planck-Institut für extraterrestrische Physik, University of Western Ontario, SKA Organization, Niels Bohr Institute & Natural History Museum of Denmark, Herzberg Astronomy and Astrophysics

### **354.03 - Correcting ALMA 12-m Array Data for Missing Short Spacings Using the Green Bank Telescope (Melissa Hoffman)**

The Atacama Large Millimeter/submillimeter Array (ALMA) offers astronomers high resolution and exceptional point source sensitivity via its main array of fifty 12-m antennas that can be configured on baselines as long as 16.2 km. These capabilities come at the cost of reduced sensitivity to extended emission and an inability to measure total power. The Atacama Compact Array (ACA) component of ALMA is designed to capture extended emission and measure the total power via an array of eleven 7-m antennas and four 12-m total power antennas. The total power antennas in ACA are designed to measure the total flux from a source; their resolution is comparable to the primary beam of the 12-m array. The 100 m Green Bank Telescope (GBT) offers a complementary way to obtain short-spacing and total power data for ALMA observations for observations within their overlapping sky coverage  $\hat{r} = -40^\circ$  to  $\hat{r} = +40^\circ$  and frequency ranges (84 GHz to 116 GHz). Since the GBT has a diameter  $\sim 10$  times greater than the ALMA total power antennas, it has more overlap in  $u$ - $v$  space with the ALMA 12-m baselines than the total power antennas. These characteristics may provide improved reconstruction of the large-spatial scales in the images. Our goal is to answer two questions: Can we map out a way in CASA to use the GBT in place of the Total Power (TP) array when combining with ALMA interferometric data? How does the flux reconstruction of a GBT+ALMA combination compare to TP+ALMA combination?

**Author(s):** Melissa Hoffman, Amanda Kepley

**Institution(s):** NRAO

### **354.04 - North American ALMA Development Projects: On the Path to Doubling the ALMA Bandwidth (Crystal Brogan)**

The ALMA 2030 Development Roadmap recommends that the top development priority is to broaden the receiver bandwidth by at least a factor of two, and to upgrade the associated

electronics and correlator. When fully implemented, ALMA data will have at least  $\sqrt{2}$  better continuum sensitivity (for the same observing time), and its simultaneous spectral grasp will be doubled. The North American ALMA Science Center together with the NRAO Central Development Lab is pursuing two key aspects of the ALMA 2030 vision: (1) to significantly upgrade the 1.3 mm (Band 6) receiver in order to (at minimum) double its IF bandwidth, and significantly improve its noise performance across its entire IF range; and (2) to significantly upgrade the Baseline Correlator (used for 12m-array observations) via the Correlator Upgrade Project (CUP). In Phase 1 of the CUP, an approved ALMA development project, the correlator will have eight times more channels available for each baseband, and the downstream subsystems will be upgraded to handle the increased data rates. In Phase 2 of the CUP, the correlator would also be able to handle the increase in receiver bandwidth. I will present key science benefits from these two development projects, along with their anticipated timelines.

**Author(s):** Crystal Brogan, Al Wootten

**Institution(s):** NRAO Contributing Team(s): NAASC, CDL, ALMA

### **354.05 - Data combination and imaging of mm-wave interferometric and single dish datasets: science cases and techniques (Adele Plunkett)**

Millimeter-wavelength interferometric observations -- like those from ALMA, VLA, and others -- are providing high-sensitivity and high-resolution data to detect and often resolve complex astronomical morphologies. For a number of science cases, the combination of interferometry data with single dish observations is required, including (but not limited to): protostellar outflows and their environment, dense clumps and prestellar cores in molecular clouds (MCs), the interplay between giant MCs and galactic structures in nearby galaxies, the evolution of AGB stars, planetary nebulae and their winds, and any analysis of the probability distribution function (PDF) from diffuse emission to dense, clumpy emission. What these have in common are both compact and extended structures spanning spatial scales over several orders of magnitude, appearing as less than a few arcseconds to several arcminutes, or more. Various methods have been developed to combine multi-scale mm-wave datasets; the combination can occur before, during, or after (imaging) deconvolution, and can be done in the Fourier and/or image plane. Our team has especially focused on development of a new tool TP2VIS for CASA that generates pseudo-visibilitys of single dish data for combination of UV data. Here we will summarize the combination methods, present a case study of a protostellar outflow observed with ALMA to test the methods, and discuss the relative merits of each method.

**Author(s):** Adele Plunkett, Ed Fomalont, Jin Koda, Tsuyoshi Sawada, Peter Teuben

**Institution(s):** National Radio Astronomy Observatory, Joint ALMA Observatory, Stony Brook University, University of Maryland Contributing Team(s): Data Combination Working

Group

**354.07 - High resolution ALMA observations of molecular gas in the ram pressure stripped galaxy NGC 4402(William Joseph Cramer)**

Our high resolution ALMA CO(2-1) and CO(3-2) observations of the ram pressure stripped galaxy NGC 4402 in the Virgo cluster show some of the clearest signatures yet of the impact of ram pressure on the ISM of galaxies. The side of the galaxy upon which ram pressure is incident shows isolated molecular clouds in the part of the disk which has been otherwise stripped of lower density gas. These decoupled clouds have the kinematics of normal disk rotation, indicating that they have not been accelerated much by ram pressure. However a large plume of molecular gas above these clouds extends into the halo of the galaxy, and has velocities as much as 60 km/s higher than the maximum rotational velocity of the galaxy, clearly indicating acceleration by ram pressure. This plume is presumably formed by more diffuse molecular gas, which gets directly stripped. Furthermore, we have detected molecular gas in the 1-2 kpc long decoupled dust filaments seen in HST observations of NGC 4402, that are kinematically distinct from the surrounding regions of the disk. The surface densities and the kinematics of the filaments provide constraints on the type of clouds which resist stripping and therefore decouple from the stripped gas, as well as the physical mechanisms that act to form the filaments.

**Author(s):** Juan Cortes, Paulo Cortes, William Joseph Cramer, Jeffrey Kenney

**Institution(s):** Yale University, JAO-ALMA

**354.08 - An ALMA Development Roadmap(Al Wootten)**

Input on new scientific directions and technical feasibility of future developments from the ALMA Science Advisory Committee (ASAC), the community, and technical studies have helped define a roadmap, ALMA Memo No 612, for future development that will significantly expand ALMA's capabilities and enable it to produce even more exciting science in the coming decades. Top development priorities more efficiently enable a wide range of scientific studies by significantly reducing the time required for their execution by increasing sensitivity and throughput. The prioritized plan is commensurate within the anticipated ALMA development budget. Fundamental science drivers include: Investigation of the Origins of Planets, through imaging protoplanetary disks in nearby (150pc) star formation regions to resolve the Earth formation zone (~1AU) in the dust continuum at wavelengths shorter than 1mm, enabling detection of the tidal gaps and inner holes created by planets undergoing formation. Tracing the evolution from simple to complex organic molecules through the process of star and planet formation down to solar system scales (~10-100AU) by performing full-band spectral

scans at a rate of 2-4 protostars per day. Tracing the cosmic evolution of key elements from the first galaxies ( $z > 10$ ) through the peak of star formation ( $z = 2-4$ ) by imaging their cooling lines, both atomic ([CII], [OIII]) and molecular (CO), and dust continuum at a rate of 1-2 galaxies per hour. Achieving these ambitious goals is currently impossible even with the outstanding capabilities of the current ALMA array. The ALMA Development Roadmap identifies: -upgrading the correlator to provide up to eight times more channels, providing increased spectral grasp for line work, -upgrading the processed data bits, equivalent to adding 6 antennas to a 48-antenna array, doubling processed bandwidth and -upgrading receivers in bandwidth and sensitivity as high priorities. These upgrades enable the science goals, making ALMA even more efficient and powerful. They keep it at the forefront of astronomy by continuing to produce transformational science and enabling fundamental advances in our understanding of the universe for the decades to come.

**Author(s):** Sean Dougherty, Leonardo Testi, Nick Whyborn, John M. Carpenter, Neal J. Evans, Daisuke Iono, Al Wootten,

**Institution(s):** NRAO, Joint ALMA Observatory (JAO), University of Virginia, National Astronomical Observatory of Japan, University of Texas at Austin, Joint ALMA Observatory, ESO Contributing Team(s): ALMA Development Working Group

**354.09 - After The Fall: The Dust and Gas in E+A Post-Starburst Galaxies(Adam Smercina)**

Recent detections of a significant interstellar medium (ISM) in many post-starburst galaxies challenges their traditional classification as dust- and gas-poor merger remnants, rapidly transitioning to quiescence. We have conducted a multi-wavelength survey of 33 E+A post-starbursts selected from SDSS, including Spitzer, Herschel, and ALMA. We find compact, warm dust reservoirs with high polycyclic aromatic hydrocarbon (PAH) abundances. Their infrared spectral properties are unique, with dominant PAH emission, very weak nebular lines, and deep [C II] deficits - the aging burst populations provide an unusual "high-soft" radiation field that seemingly dominates the post-starbursts' ISM energetics. We also find unusually strong H<sub>2</sub> rotational emission, among the brightest, relative to infrared luminosity, of any known galaxy - indicating a highly turbulent ISM. High-resolution ALMA CO(2-1) follow-up observations reveal that the molecular gas in these post-starbursts is exceptionally dense - rivaling the gas found in ULIRGs - and is concentrated in turbulent, rotating nuclear reservoirs. Coupled with modest SFRs from a range of infrared tracers, the post-starbursts' high gas densities indicate highly inefficient star formation - they lie more than an order of magnitude below the Kennicutt-Schmidt star-forming relation. These results paint a coherent picture of systems in which star formation was, indeed, rapidly truncated, but in which the ISM was not completely expelled. High-density nuclear reservoirs of molecular fuel remain but are supported against collapse by some form of continual turbulent heating.

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Yujin Yang, Tom Jarretto, Adam Smercina, JD Smith, Svitlana Zhukovska, Decker French, Daniel Dale, Ann Zabludoff, Aditya Togi, Fabian Walter, Kevin Croxall, Christy Tremonti, Eric Bell  
**Institution(s):** University of Wisconsin-Madison, oUniversity of Cape Town, University of Arizona, Korea Astronomy and Space Science Institute, Illumination Works LLC, University of Helsinki, University of Michigan, Max-Planck-Institut für Astronomie, University of

### **354.10 - Measuring protoplanetary disk alignment in young binary systems(Aaron S Hersch)**

Many of the known planetary systems are unlike our Solar System, containing hot Jupiters or planets orbiting their host stars on eccentric or inclined orbits. One possible explanation for producing such orbits is migration driven by Kozai-Lidov oscillations, which can be induced by a companion on a sufficiently inclined orbit. Observations of protoplanetary disks can help determine whether young binary companions are inclined relative to the individual stars' nascent planetary systems and thus could induce such migration. We used ALMA to observe continuum and CO(3-2) emission from a sample of young binary systems in Taurus-Auriga, Ophiuchus, and Lupus. The kinematics of the CO emission allows us to deduce the spatial orientation of the disks, even for disks that are near our resolution limit. Comparing the orientations of the two disks within a given binary, we find examples of both well-aligned and significantly misaligned systems. Overall, our sample shows more tendency toward alignment than would be expected from a random distribution of disk inclinations, suggesting that binary formation favors aligned systems and/or that evolution toward relative alignment has occurred within 1-2 Myr of formation. This work makes use of the following ALMA data: ADS/JAO.ALMA#2015.1.00637.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

**Author(s):** Rachel Akeson, Eric L. N. Jensen, Aaron S Hersch  
**Institution(s):** Swarthmore College, Caltech/IPAC, NExSci

### **354.11 - ALMA Observations of Mass Loss from OH/IR Stars in the Inner Galactic Bulge(Benjamin Sargent)**

Asymptotic giant branch (AGB) stars are intermediate mass (0.8-8 solar mass) evolved stars that contribute significantly to galactic interstellar medium (ISM) chemical enrichment. OH/IR stars are thought to be high mass-loss rate (MLR) AGB stars, so their contributions of mass, most of which is gas, to their host galaxy are significant. As such, it is important to determine if and how OH/IR circumstellar gas-to-dust ratio

varies with metallicity, so that the dust MLR for an AGB star can be determined from modeling its optical and infrared spectral energy distribution (SED) and used with its inferred gas-to-dust ratio to determine its gas MLR. This requires measurements of emission from gas, such as CO, at submillimeter/millimeter wavelengths in combination with photometry at optical and infrared wavelengths. We have used ALMA to observe the 12CO J=2-1, 12CO J=3-2, and 13CO J=3-2 lines from the envelopes of 22 OH/IR stars in the inner Galactic bulge. We will use the data to determine these stars' gas MLRs to help measure the inner Bulge's ISM replenishment; in addition, in combination with radiative transfer modeling of the optical and infrared SEDs to determine dust MLRs, we will be able to compare the current dust output with the gas ejection at scales probed by the CO measurements. We have also obtained near-infrared spectra to determine the metallicities of the stars in our sample, in order to seek any possible relations between gas-to-dust ratio and metallicity. In addition, by observing the 12CO J=3-2 and 13CO J=3-2 emission from these stars, we can place constraints on the carbon isotope ratios of our sample. Funding from NASA ADAP grant 80NSSC17K0057 is acknowledged.

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**Institution(s):** Space Telescope Science Institute, Lund University, Chalmers University of Technology, Harvard-Smithsonian Center for Astrophysics, Universidad Nacional Autonoma de Mexico, Rochester Institute of Technology

### **354.12 - ALMA measurement of the masses and densities of dwarf planet satellites(Michael Brown)**

The high occurrence rate of satellites around the largest dwarf planets in the Kuiper belt has substantially increased our understanding of the mass distribution in the Kuiper belt. While the adaptive optics and HST observations required for resolving the satellites and measuring their positions provide precise relative astrometry, absolute astrometry is difficult because of the small fields-of-view and the large motion across the sky of the targets between observations. Because of these difficulties, we have knowledge of only the total masses of these systems, rather than the individual masses of the components. Observations with ALMA solves this issue. ALMA can make precise absolute astrometric observations over the tens-of-arcminutes scales of the motions of objects in the Kuiper belt. We have exploited this capability to measure the satellite masses and densities of two systems. For the Orcus-Vanth system we clearly detect both components of the system and the barycentric wobble as Vanth orbits Orcus. The barycentric wobble allows us to measure the relative masses, while the resolved thermal detection of Vanth allows a measurement of the size and thus density of both components. For the Eris-Dysnomia system we have a tentative detection of the much fainter Dysnomia. Forthcoming observations should confirm this detection. An upper limit on the barycentric wobble puts a stringent upper limit on the mass of Dysnomia which, if the

large size inferred from the tentative detection is correct, suggests a much lower density for Dysnomia than for Eris.

**Author(s):** Michael Brown, Bryan Butler

**Institution(s):** Caltech, NRAO

### **354.13 - Exciting phenomena powered by the ongoing accretion outburst in the massive protostar NGC6334I-MM1B(Todd Russell Hunter)**

In January 2015, something unprecedented began to happen in the deeply-embedded massive protostellar cluster NGC6334I. Ten maser transitions from three molecular species (water, methanol and hydroxyl) began to flare contemporaneously reaching an initial peak in August 2015 (MacLeod et al. 2018, MNRAS 478, 1077). At that time, previously planned observations with ALMA revealed a factor of four increase in the millimeter dust continuum emission from source MM1 compared to SMA images obtained in 2008, consistent with a factor of 70 increase in luminosity (Hunter et al. 2017, ApJL 837, 29). Using the VLA, we found that the dense, methanol-rich gas surrounding MM1 now emits strong 6.7 GHz Class II methanol maser emission, in stark contrast to all previous interferometric observations since the 1980s (Hunter et al. 2018, ApJ 854, 170). At the center of the outburst is the protostar/hypercompact HII region MM1B, which drives a highly-collimated bipolar molecular outflow traced by thermal CS and HDO emission in ALMA Band 10 (McGuire et al. 2018, ApJL 863, 35) and 22 GHz water masers (Brogan et al. 2018, ApJ, in press, arXiv:1809.04178). The outflow timescale of 170 years suggests that it was initially formed in a similar previous outburst, allowing the radiative energy of the current outburst to propagate up the outflow cavity to its northern tip causing flaring of the water masers there in the form of a bowshock co-located with a non-thermal centimeter continuum point source (Brogan et al. 2018). In contrast, the water masers previously detected toward MM1B have mostly disappeared due to the reduction in the collisional pump efficiency by the higher mid-infrared radiation field there (Brogan et al. 2018). We will present our latest, highest resolution images from ALMA and VLA which confirm MM1B as the dominant point source in millimeter continuum, and reveal a drop in its free-free continuum emission, presumably in response to the elevated accretion rate.

**Author(s):** Rachel Friesen, James Chibueze, Brett McGuire, Fanie van den Heever, Todd Russell Hunter, Gordon MacLeod, Claudia J. Cyganowski, Crystal Brogan

**Institution(s):** NRAO, University of Western Ontario, University of St Andrews, SKA South Africa, Hartebeesthoek Radio Observatory

### **354.14 - An ALMA Study of Disk and Wind Kinematics Using Hydrogen Recombination Masers in MWC 349A(Deanna Lily Emery)**

The kinematics of circumstellar disks and disk winds are poorly understood due to the difficulty of obtaining well-resolved observational data. However, the bright hydrogen recombination-line maser emission originating from the circumstellar disk of MWC 349A, offers a unique opportunity to study the disk at milli-arcsecond precision. We carried out observations of MWC 349A in hydrogen recombination line H<sub>30</sub>α and 1.3 mm continuum in Band 6 of ALMA using its most extended array configuration of ~16 km baseline. With a beam size of 80 mas × 30 mas at a position angle of 24°, the high angular resolution observations resolved the disk in the east-west direction (along the plane of the disk) in both continuum and the line emission for the first time. With spatially resolved images of the maser emission, we are able to produce and analyze rotation curves for the H<sub>30</sub>α transition with greater precision than before. We will report the new constraint on the stellar mass and the spatial distributions of the hydrogen masers, as well as a study of the kinematics of the circumstellar disk.

**Author(s):** Deanna Lily Emery, Alejandro Baez-Rubio, James Moran, Qizhou Zhang, Izaskun Jimenez-Serra, Jesus Martin-Pintado

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Centro de Astrobiologia

### **354.15 - HIRMES - High Resolution Mid-infrared Spectrometer for SOFIA(Alexander Kutryv)**

HIRMES is a third generation SOFIA instrument designed to cover the gap in the middle infrared region with a broad range of spectra resolution from very low (300-600) to high resolving power of 105. With its high resolving power modes (R from 50,000 to 100,000), HIRMES will provide unique access to HD in protoplanetary disks, and allows velocity resolved spectroscopy of water at temperatures characteristic of the snow line. HIRMES measures the velocities of orbiting gas in [OI] 63 μm line, one of the strongest fine structure lines, a tracer of spatial structure that is not available from direct imaging. HIRMES uses its grating mode (R ~ 600) to determine the mass of water ice in the system and to explore the crystalline mass fraction of the ice, providing information about its thermal evolution. HIRMES observations of the distribution of water ice, water vapor (including heavy isotopologues), and oxygen in planet-forming disks will illuminate the fossil record of these components in our own Solar System, as preserved in comets and asteroids. HIRMES is a direct photon detecting spectrometer, thus it achieves the sensitivity necessary to be in the discovery space which is fundamentally inaccessible to heterodyne receiver instruments. Hundreds of protoplanetary disks in associations within 500 parsecs (pc) of our Solar System, including well over 100 in the three nearest Young Stellar Object (YSO) associations 140-160 pc away, are within HIRMES grasp.

**Author(s):** Wen-Ting Hsieh, Edwin Bergin, Gary Melnick, Thomas Nikola, Gordon Stacey, Stefanie N Milam, Dan Watson, Samuel Richards, Richard Arendt, Gordon Bjoraker, David Neufeld, Aki Roberge, S. Harvey Moseley, Edward Wollack, Klaus Martin Pontoppidan, Alexander K

**Institution(s):** oUMBC, UMD / NASA GSFC, SAO, NASA GSFC, STScI, Johns Hopkins, University of Michigan, University of Rochester, USRA NASA Ames Research Center, Cornell University  
**Contributing Team(s):** TCazeau, DFixsen, JKellog, LSparr, EMentzel, CEngler, ESharp, PNag

### **355 - Intergalactic Medium, QSO Absorption Line Systems**

#### **355.01 - 3D IGM Tomography Visualization of the LATIS Survey (Sunny Rhoades)**

Lyman-alpha forest absorption from diffuse neutral hydrogen in the intergalactic medium (IGM) can be used as a tracer of large-scale cosmological structure. In addition to quasars, faint star-forming galaxies at  $z \sim 2-3$  can be used as background sources to probe the Lyman-alpha forest, yielding much higher sightline densities. With background sources separated by only several transverse Mpc, it then becomes possible to carry out a tomographic reconstruction to recover the 3D Lyman-alpha forest absorption field on spatial resolutions of  $\sim 1.4$  pMpc that resolve the cosmic web. We present initial results from the Lyman-alpha Tomography IMACS Survey (LATIS), including a tomographic reconstruction over a comoving volume of  $4 \times 10^5$  h<sup>-3</sup> Mpc<sup>3</sup> that covers  $0.15$  deg<sup>2</sup> and spans  $z=2.2-2.8$ . We used the Mayavi interactive environment to create three-dimensional renderings of the tomographic map, in which we can see that the IGM absorption and galaxy sources generally appear to trace the same structures. We detect large matter overdensities and underdensities that match the distribution of sources from redshift surveys in the same field, including overdensities associated with several recently-discovered galaxy protoclusters in the volume.

**Author(s):** Sunny Rhoades, Drew Newman, Gwen C Rudie

**Institution(s):** Pomona College, Carnegie Observatories

#### **355.02 - The Temperature and Turbulence of Circumgalactic C IV Absorbers at $z \sim 0.07$ (Andrew Mizener)**

Understanding gas flows in the circumgalactic medium (CGM) around galaxies is an important aspect of galaxy formation and evolution over cosmic time. In particular, the thermal and dynamical properties of the CGM will constrain the feedback mechanisms and outflow properties of these galaxies driven by supernovae and/or OB stars. In this work, we use  $\sim 150$  COS AGN archival spectra to obtain new measurements of the temperature and turbulence of the CGM, derived from HI+C IV pairs at  $z \sim 0.07$ . We combine our results with measurements made using the same observables at higher redshifts around  $z \sim 2.5$ , constraining the thermal/dynamical evolution of the CGM. Our preliminary results suggest that the CGM

temperature probed by HI+C IV pairs does not change within errors, but the non-thermal motion increases by a factor of  $\sim 2.5$  at  $z \sim 0.07$ .

**Author(s):** Tae-Sun Kim, Andrew Mizener, Bastian Wakker

**Institution(s):** Macalester College, University of Wisconsin, Madison

#### **355.03 - Exploring the CRAG: Strong HI Absorption in the CGM of ALFALFA Galaxies (Chelsey McMichael)**

As part of our Survey of the Circumgalactic Regions of the ALFALFA Galaxies (CRAG), we report on the identification and analysis of strong HI absorption in the circumgalactic medium (CGM) of the ALFALFA galaxies as identified in archival HST/COS G130M QSO spectroscopic observations. We characterize the HI and metal content of these strong absorbers and explore the physical distribution of the CGM for these galaxies. Using photometric, spectroscopic, and imaging observations from the Sloan Digital Sky Survey, we analyze the environments of these galaxies. We also summarize the gas-galaxy connection for this sample of strong HI absorbers and HI-rich galaxies. This work has been supported by NSF grant AST-1716569.

**Author(s):** Joseph N. Burchett, Chelsey McMichael, Liam Patterson, Joseph Ribaudo

**Institution(s):** Utica College, University of California Santa Cruz

#### **355.04 - Photometric redshifts of galaxies in quasar fields (Elizabeth Ann Apala)**

We present photometric redshifts of the galaxies in the fields of 12 bright low redshift ( $0.06 < z < 0.37$ ) broad line active galactic nuclei. The redshifts are calculated using a Bayesian scheme from Sloan Digital Sky Survey (SDSS) u, g, r, and i magnitudes derived from deep imaging using the wide-field 90Prime camera on the Steward Observatory Bok 2.3-meter telescope. Most of the sample fields overlap with the SDSS, but our data are 2-3 magnitudes deeper. Spectra of the sample quasars have also been obtained with the Cosmic Origins Spectrograph on the Hubble Space Telescope, so we will use these spectroscopic data and our calculated photometric redshifts in the context of our recent efforts to match galaxies and line of sight absorbers using statistical techniques.

**Author(s):** Elizabeth Ann Apala, Jennifer Scott

**Institution(s):** Towson University, Towson University

### **355.05 - Exploring the CRAG: The Missing CGM of the ALFALFA Galaxies(Liam Patterson)**

As part of our Survey of the Circumgalactic Regions of the ALFALFA Galaxies (CRAG), we report on the analysis of QSO sightlines that pass within  $\sim 100$  kpc of ALFALFA galaxies that show no discernable evidence of a circumgalactic medium (CGM) as probed by the presence of Ly $\lambda$  absorption. Many of these corresponding galaxies reside in group or cluster environments, in agreement with recent studies that indicate the nearby galaxy environment plays a significant role in determining the physical conditions of the CGM. However, we also identify a sample of isolated ALFALFA galaxies that show no evidence of HI within  $\sim 100$  kpc - suggesting the physical distribution of the CGM around these galaxies is patchy and non-uniform, even within relatively small volumes around the galaxies. We explore photometric, spectroscopic, and imaging observations from the Sloan Digital Sky Survey in an attempt to characterize the properties these galaxies and the environments in which they reside. This work has been supported by NSF grant AST-1716569.

**Author(s):** Joseph N. Burchett, Chelsey McMichael, Liam Patterson, Joseph Ribaud

**Institution(s):** Utica College, University of California - Santa Cruz

### **355.06 - Probing Galaxy Evolution Back to 1 Billion Years After the Big Bang Using Quasar Absorption Line Spectroscopy(Alexandra Mannings)**

Triply-ionized carbon (C IV) is an ideal candidate for probing galactic metal enrichment in the early Universe because of its ubiquitous presence in the circumgalactic medium (CGM) of galaxies. Here we use a large, high redshift ( $z > 5$ ) quasar survey to search for intervening C IV systems. We compare our results with previous works, such as Cooksey (2013) and Mas-Ribas (2018), that focused on intermediate redshift quasar samples, as well as Codoreanu (2018). We created automated code to search the largest sample of high redshift ( $z > 5$ ) VLT/X-Shooter quasar spectra - creating a high redshift, high-resolution extension to the previous work. We identify 122 C IV systems with a redshift range of  $3.7 < z < 5.5$  in the sightlines towards 41  $z > 5$  quasars. This sample includes systems with equivalent width ranging from 0.14 to 3.8 Angstroms, corresponding to a column density range of  $\log N(\text{C IV}) = 12.6 - 14.5 \text{ cm}^{-2}$ . A paucity of  $z > 5$  quasars with high-resolution spectra and related analyses underscores the necessity of this survey in order to better understand enrichment processes and their cosmological timeline. This project was supported in part by the NSF REU grant AST-1757321 and by the Nantucket Maria Mitchell Association.

**Author(s):** Regina A. Jorgenson, Alexandra Mannings, Marc Rafelski

**Institution(s):** The University of Alabama, Space Telescope Science Institute, Maria Mitchell Observatory

### **355.07 - Studying Metals in the Circumgalactic Medium by Post-Processing Cosmological Galaxy Simulations(Bryan Wang)**

In recent decades, cosmological simulations have played an increasing role in the expert understanding of galaxy formation, but while simulations have improved dramatically, many parameters such as the strength of stellar and supernova feedback are not well determined. The circumgalactic medium (CGM), the gas outside of the galaxy disc but within the dark matter halo, could be an effective probe of feedback models due to its high ionization level and low density. However, since the CGM does not form stars and is usually detected in absorption spectra, instead of simulated telescope image comparisons, a more specialized methodology is needed. This work analyzes the CGM of many simulated galaxies using the random sampling of sightlines throughout a spherical volume surrounding them, emulating absorption spectra. We determine each sightline using two points: the starting location is chosen uniformly over the surface of the sphere and the midpoint is uniformly distributed throughout the bulk of a smaller concentric sphere. We project along this line of sight and use ionization calculation software TRIDENT to determine the column densities of ions situated in the line. Since we can make a large number of individual sightlines, many statistical properties can be examined, covering the full spectrum of redshifts, star formation histories, masses, and other macroscopic parameters of the simulated galaxies. These properties can be directly compared to observed absorption data, and can therefore help constrain the parameters of these simulations and either improve confidence in their predictions or determine what physical models need to be adjusted.

**Author(s):** Rishi Dange, Joel Primack, Clayton Strawn, Bryan Wang,

**Institution(s):** The Harker School, University of California, Santa Cruz

### **355.08 - Broad and Narrow Intrinsic Absorption in Quasars as it Relates to Outflows, Orientation, and Radio Properties(Robert B Stone)**

This work provides evidence that a large fraction of narrow absorption lines (NALs) seen along the line of sight to distant quasars are due to accretion disk winds, while also seeking to understand the relationship between NALs and certain quasar-intrinsic properties. We extend the results from past work in the literature with velocity distributions ( $dN/dV$ ) of  $\sim 108,000$  NALs from a sample of  $\sim 58,000$  SDSS quasars. The primary results of this work are summarized as follows: (1) the velocity distribution of NALs is not a function of radio loudness (or even detection) once marginalized by optical/UV luminosity; (2) there are significant differences in the number and distribution of NALs as a function of both radio spectral index and optical/UV luminosity and these two findings are not entirely inter dependent; (3) improvements in quasar systemic redshift measurements, analysis of NALs in broad absorption line

quasars, and differences in the NAL distribution as a combined function of optical luminosity and radio spectral index---together provide evidence that a significant portion of NALs are due to outflows; (4) the results are consistent with standard models of accretion disk winds governed by the LUV- $\dot{M}$  relationship and line-of-sight orientation indicated by radio spectral index, and (5) possibly supports the magnetically arrested disk model as an explanation for the semi-stochastic nature of strong radio emission in a fraction of quasars.

**Author(s):** Gordon Richards, Robert B Stone

**Institution(s):** Drexel University

### **355.09 - Studies of the lowest-redshift IGM**

**(Bart Wakker)**

We are studying the Lyman alpha forest at the lowest redshifts ( $cz < 10000$  km/s) to constrain the ionizing UV background, and understand the location and physical properties of the absorbers. We present a detailed study of 25 absorbers in which both CIII and CIV absorption is seen and compare the derived physical parameters using 4 published models for the local UV background; we show that models with relatively low ionizing flux yield unrealistic physical properties for the absorbing clouds. Using data from NED we have created a catalogue of nearby galaxies, homogenizing the available data to derive physical properties such as diameters and luminosities. Using this catalogue we can define 25 isolated local galaxy filaments. We then study the distribution and properties of detection/non-detections of Lyman-alpha absorption in 450 sightlines. From this we find that the absorbers trace the Cosmic Web. Their distribution can be compared to predictions of cosmological simulations, which depend on a combination of the distribution of dark matter and the average ionizing background.

**Author(s):** Tae-Sun Kim, Audra Hernandez, David M French, Bart Wakker

**Institution(s):** University of Wisconsin-Madison

### **355.10 - The Lyman-beta Power Spectrum(Bayu J Wilson)**

The Lyman-alpha power spectrum has previously been used to constrain the Universe's initial conditions and particle constituents (such as the amount and mass of the dark matter) and the temperature of intergalactic gas (which constrains reionization processes). To further improve these constraints, we use another Lyman series transition (Lyman-beta). The Lyman-beta absorption cross-section is lower than that of Lyman-alpha so it probes the intergalactic medium at higher densities where Lyman-alpha features are saturated. Therefore, the Lyman-beta forest allows for a better measurement of the slope of the temperature-density relation, allowing additional constraints on reionization and the subsequent thermal evolution. In this work, we present an analysis of the Lyman-beta power spectrum using the VLT/XSHOOTER XQ-100 Legacy Survey.

**Author(s):** Bayu J Wilson, Vid Irsic, Matthew McQuinn

**Institution(s):** University of Washington

### **355.11 - A Model for Intergalactic Dust and its Impact on the Extragalactic Background Light(Maegan Jennings)**

Observations of quasar reddening demonstrate that extinction by dust in the intergalactic medium is significant at optical wavelengths, but the impact of this extinction on the spectral intensity of the extragalactic background light (EBL) has not yet been assessed in a quantitative way. We use an interstellar dust extinction model of Weingartner and Draine and combine this with simple but physically reasonable expressions for dust evolution to arrive at an intergalactic dust model with two adjustable parameters. The resulting opacities closely match observational constraints from Imara and Loeb at near-optical wavelengths. We convolve this intergalactic dust model with a simple EBL model (described elsewhere in this meeting) to determine that optical EBL intensity is reduced by approximately 3% due to intergalactic dust. The "missing" light is of course shifted to longer wavelengths. Nevertheless, this result is a partial vindication for H.W.M. Olbers and his predecessor, J.P.L. de Cheseaux, who were the first to speculate that an absorbing medium might help to explain the darkness of the night sky.

**Author(s):** James Overduin, Jessica Gillcrist, Maegan Jennings

**Institution(s):** Towson University

### **355.12 - Evolution of Neutral Oxygen Absorbers in the Circumgalactic Medium During the Epoch of Reionization(Caitlin Doughty)**

We use cosmological radiation hydrodynamic simulations of hydrogen reionization to investigate whether the statistics of neutral oxygen absorbers can be used as a complementary probe of the progress of hydrogen reionization. Neutral oxygen (O I) is characterized by an ionization energy that is nearly identical to that of neutral hydrogen (H I), a fact which has been noted to implicate a sensitivity to changes in the ionizing background during the epoch of hydrogen reionization. Further, the decreased abundance of oxygen compared to that of hydrogen places this low ionization state in a unique position to be sensitive to the background while simultaneously tending to be unsaturated when observed through quasar absorption spectra. We present results from the Technicolor Dawn simulations, which incorporate on-the-fly radiation transport calculations, examining the evolution of O I via absorption line system abundances viewed through synthetic sightlines cast through the simulation volume. We analyze equivalent width distributions, relationships between system characteristics and apparent host galaxies, and covering fractions to establish how O I systems are evolving during the epoch of reionization and which systems are most sensitive to the changes in the ionizing



background. We find that neutral hydrogen fractions of  $>0.1$  are roughly linearly correlated with the neutral oxygen fraction obtainable through quasar sightline observations, thus the latter value constitutes a good predictor of the local neutral hydrogen fraction. Further, we find that low equivalent width O I systems located physically far from their hosts are preferentially affected during this regime, showing a sharp decline in abundance.

**Author(s):** Kristian Finlator, Caitlin Doughty

**Institution(s):** New Mexico State University

### **355.13 - CGM-GRB: Studying the CircumGalactic Medium around GRB hosts at $z > 2$ (Pradip Gatkine)**

The circumgalactic medium (CGM) is the site of various galactic phenomena such as galactic winds, outflows, accretion flows, and recycling flows. Recent space- and ground-based studies of the circumgalactic medium (CGM) using bright background quasars have revealed a dynamic interplay between the galaxy ecosystem and surrounding CGM. In this study, we extend this investigation of the CGM to higher redshifts ( $z > 2$ ) by using the bright afterglows of gamma-ray bursts as background sources. Thanks to their bright UV/optical/NIR afterglows, promptly acquired spectroscopic data show exquisite absorption lines from both the CGM and interstellar medium (ISM) of the GRB host galaxy along the line of sight traced by the afterglow light. We compiled a sample of 27 high-resolution ( $R > 8000$ ) and high signal-to-noise (typical  $S/N \sim 15$ ) spectra of GRB afterglows covering a redshift range of  $z \sim 2$  to 6, with six of them at  $z > 4$ . The column densities (N), Doppler parameters (b) and line-centroids of both high-ionization (O VI, C IV, Si IV, N V) and low-ionization species (Si II, C II\*, Fe II, etc) are extracted to study the kinematics of different phases in the CGM. We observed an excess absorption in the blue wings of high-ion absorption features, unlike the typical symmetrical distribution of the low-ion absorption features. In addition, the column density ratios of high- to low-ion lines clearly show the existence of three absorption regimes: a) blueward of  $-100$  km/s, b) within  $\pm 100$  km/s and c) redward of  $100$  km/s. We hypothesize that these populations are: a) predominantly warm CGM outflows at high velocity, b) a combination of CGM at low-velocity and galaxy ISM, and c) cool CGM inflows, respectively. We use a toy-model to corroborate the outflow signatures in GRB afterglow spectra and estimate the CGM mass, assuming a typical GRB host galaxy. Through this study, we establish that GRB afterglows are crucial probes of CGM evolution at high redshifts.

**Author(s):** Sylvain Veilleux, Antonino Cucchiara, Pradip Gatkine

**Institution(s):** University of Maryland College Park, University of The Virgin Islands

### **355.14 - CGM2: COS+Gemini Mapping of the Circumgalactic Medium (Matthew Wilde)**

The Circumgalactic Medium (CGM) - the gas filling a galaxy's dark matter halo out to the viral radius - is where accretion flows feeding star formation meet enriched feedback, where satellites are stripped and disrupted, and where ejected gas is recycled. These processes appear to have a strong influence on galaxy formation and thus an understanding of the CGM is necessary for our holistic model of galaxy formation and evolution. By combining absorption-line system information from the line-of-sight quasar spectra with a redshift survey of galaxies in the field of each quasar, one can gain insight into the CGM as a function of the projected radial distance from the galaxies. Here, we introduce the COS+Gemini Mapping of the Circumgalactic Medium Survey, CGM2. The survey combines 24 far-UV bright,  $z \sim 1$ , quasar spectra taken with the COS instrument on the Hubble Space Telescope, with a large ground based galaxy survey of galaxies  $m_{AB} \leq 23$  within  $\sim 10$  comoving-Mpc of the quasar sightlines. Each galaxy in the survey has spectra obtained using the multiobject spectrograph GMOS on both the Gemini-North and Gemini-South telescopes as well as deep multiband photometry from the twin Gemini telescopes and the DESI project. We report redshifts and stellar masses for  $\sim 4,000$  galaxies in our survey as well as first results.

**Author(s):** J. Xavier Prochaska, Jessica Werk, Matthew Wilde

**Institution(s):** University of Washington, University of California Santa Cruz

### **355.15 - Associated Absorbers and Galaxies in the Sloan Digital Sky Survey (Elizabeth Fletcher)**

We present the results of 44 low redshift quasars ( $0.06 < z < 0.85$ ) observed with the Cosmic Origins Spectrograph on the Hubble Space Telescope that lie within the footprint of the Sloan Digital Sky Survey. We use photometric data of galaxies from the SDSS DR12 to match galaxies with absorption systems of a similar redshift. Within this data set of quasars, we focused upon associated absorbers. An associated absorber is loosely defined as an absorption system with a velocity separation of less than  $5,000$  km/s of its background quasar. We will compare the COS sample of possible associated absorber - galaxy pairs to the known anticorrelation between absorber equivalent width and galaxy impact parameter. We will investigate trends with quasar luminosity in this sample and in a control sample of possible non-associated absorber - galaxy pairs in order to examine the galaxy proximity effect.

**Author(s):** Elizabeth Fletcher, Jennifer Scott, Elizabeth Apala

**Institution(s):** Towson University

### **355.16 - Exploring the missing baryons using absorption studies(Orsolya Kovacs)**

In the low-redshift ( $z < 2$ ) universe, about one-third of the baryons remain unaccounted for, which poses the long-standing missing baryon problem. The missing baryons are believed to reside in filaments connecting galaxies in the form of warm-hot intergalactic medium (WHIM). Although UV absorption studies explored the warm phase ( $T < \sim 10^5$  K) of the WHIM, it is hypothesized that notable fraction of the missing baryons is in the hot (X-ray) phase ( $T > \sim 5 \times 10^5$  K). However, X-ray spectroscopy is limited by the low effective area of currently available instrumentation, thus the conclusive observational evidence is still lacking. In this work, we utilize Chandra LETG spectra of luminous AGN, along with previous redshift measurements of UV absorption line systems, and apply a stacking method to gain unparalleled sensitivity. Based on the stacked data, we probe the most abundant helium-like and hydrogen-like metal lines in the spectra of AGN. In addition, we constrain the contribution of the WHIM to the overall baryon budget.

**Author(s):** William Forman, Ralph Kraft, Akos Bogdan, Randall Smith, Orsolya Kovacs

**Institution(s):** Smithsonian Astrophysical Observatory

### **356 - Large Scale Structure, Cosmic Distance Scale -- Posters**

#### **356.01 - Looking for the BAO Signal in the 2MRS Using the Wavelet Transformation(William Kwako)**

We analyze the density field of the 2MASS redshift survey using a wavelet transform designed to find the baryon acoustic oscillation (BAO) signal. The wavelet we use in our analysis is a shell of variable radius and thickness, thus mimicking the form of the BAO signal we are looking for. We found that a wavelet with radius  $117h^{-1}\text{Mpc}$  with thickness  $30h^{-1}\text{Mpc}$  gives the largest response, matching both theoretical predictions and observational results found using much deeper surveys. The wavelet transform is also used to find the most likely locations of BAO shells in the local volume.

**Author(s):** Brent Tully, William Kwako, Richard Watkins

**Institution(s):** Willamette University, IfA, University of Hawaii

#### **356.02 - Sounds Discordant: Classical Distance Ladder and $\Lambda$ CDM Determinations of the Cosmological Sound Horizon(Mackenzie Joy)**

The comoving size of the sound horizon,  $r_s$  can be determined in two ways. It can be found empirically with Cepheid-calibrated Type Ia Supernovae or calculated within the standard model of cosmology. The first method is independent of assumptions about the components of the universe while the second uses data to constrain cosmological parameters according to the  $\Lambda$ CDM model. This poster presents constraints on the empirically-determined sound horizon using Cepheid-

calibrated Supernovae and BAO data both using the  $\Lambda$ CDM model as a basis for the behavior of the universe's expansion and using a non-parametric method. Both of these values of the sound horizon are significantly smaller than the  $\Lambda$ CDM-calculated value at a level of 2 to  $3\sigma$ . We argue that the best way to decrease the value of the model calculated sound horizon is to increase the expansion rate before recombination. This could be accomplished by adding a dark radiation component in early times.

**Author(s):** Mackenzie Joy, Lloyd Knox, Kevin Aylor

**Institution(s):** University of Georgia, UC Davis

#### **356.03 - Probing Large Scale Power in the Universe using the Galaxy Peculiar Velocity Covariance Matrix(Jilliann Peery)**

We develop a method to analyze galaxy peculiar velocity data using a Bayesian approach based around the radial velocity covariance matrix. Our method is designed to utilize more information from velocity measurements than other commonly used probes, such as the bulk flow, while still being insensitive to small-scale, nonlinear motions. Using data from the CosmicFlows3 compendium of measured peculiar velocities, we are able to use our method to put constraints on the amplitude of the density power spectrum on large scales, thus providing a test of the cosmological standard model.

**Author(s):** Kristian Barajas, Jillian Peery, Richard Watkins

**Institution(s):** Willamette University, University of California, Los Angeles

#### **356.04 - Comparing Spectroscopic Distance Calculations of Different Supernova Types(Robert Mitchell)**

The Expanding Photosphere Method (EPM) models a supernova's photosphere as a spherically-symmetric diluted blackbody to compute its luminosity from the photospheric temperature and velocity, and therefore calculate its distance. The version of the EPM used in this study utilizes the calculations of Hamuy et al. (2001) and Dessart and Hillier (2005), which were empirically derived only for Type II-P supernovae. Previous work indicated that Fe II-derived velocities and V-I color temperatures were the best choices to yield reasonably accurate distance calculations. Our current study examines whether this version of EPM can also be used with other types of core-collapse supernovae. We determine that the empirical calculations of Hamuy et al. and Dessart and Hillier can successfully estimate distances for Type IIb, Ib, and Ic supernovae as well as Type II-P, also using Fe-line velocities and V-I color temperatures, provided the total photometric extinction and its uncertainty are low.

**Author(s):** Krishna Acharya, Roshan Khadka, Biraj Silwal, Robert Mitchell

**Institution(s):** StAmbrose University, University of Texas at

Arlington

### **356.05 - Measuring Photometric Redshift for Galaxies with 0.01(Jackson Steele)**

Broadband photometric redshifts, effective for many uses, have resolutions in  $z$  on the order of 0.01-0.02, which is too coarse for detailed large-scale structure mapping, particularly in the lowest-density volumes. Noting that the percentage of galaxies having  $H\text{I}\pm$  emission tends to rise as number density decreases, we have designed a filter system to photometrically measure the redshifts of such galaxies with the intent of using them to map emission-line galaxies in the near universe. The filter system consists of two oppositely-sloped filters covering the same wavelength range and centered on the  $H\text{I}\pm$  emission line, together with a continuum-measuring filter. We find from photometry of a small number of AGN and computational modeling of spectra from 197 emission-line galaxies from SDSS, that we can photometrically measure redshifts with an accuracy of 572 km s<sup>-1</sup> for emission-line galaxies with 3000 km s<sup>-1</sup> <  $cz$  < 9000 km s<sup>-1</sup>. The accuracy depends significantly on the line strength of  $H\text{I}\pm$ . When the equivalent width of  $H\text{I}\pm$  is greater than 40 Angstroms, the errors are less than 300 km s<sup>-1</sup>.

**Author(s):** J. Moody, Michael Joner, Jackson Steele, Ryan William Lesser, Matthew McNeff, Jonathan Barnes, John Bowman

**Institution(s):** Brigham Young University, Salt Lake Community College, Purdue University

### **356.06 - Analysis of a large number of spiral galaxies shows asymmetry between clockwise and counterclockwise galaxies(Lior Shamir)**

Face-on spiral galaxies observed from Earth can have clockwise or counterclockwise spin patterns. Because the direction of the spin pattern of a galaxy is a matter of the perspective of the observer, it is expected that the measured physical properties of clockwise galaxies are similar to the properties of galaxies with counterclockwise spin patterns. However, a comprehensive analysis using a large number of spiral galaxies shows statistically significant differences between the photometry of galaxies with clockwise patterns and galaxies with counterclockwise patterns. That asymmetry is oriented around an axis, such that the asymmetry in one hemisphere is inverse to the asymmetry observed in the opposite hemisphere. That is, galaxies with counterclockwise patterns are brighter by  $\sim 0.05$  magnitude than galaxies with clockwise patterns in one hemisphere, and that difference is inverted when observing the opposite hemisphere. That observation is consistent across telescopes (SDSS and PanSTARRS), and analysis methods (automatic classification or manual classification of the galaxies). The most probable axis of the asymmetry is at ( $ra=172$ ,  $dec=50$ ), which is relatively close to the galactic pole. The proximity to the galactic pole suggests that the source of the observed asymmetry could be relativistic beaming.

**Author(s):** Lior Shamir

**Institution(s):** Lawrence Technological University

### **356.07 - The Arecibo Pisces-Perseus Survey: Goals, data reduction, and initial results from declination strips 23 and 33(Omar Luna)**

The Arecibo Pisces-Perseus Supercluster Survey (APPSS) attempts to detect the infall of galaxies onto the Pisces-Perseus Supercluster (PPS). The ALFALFA survey has greatly augmented the known redshifts across the region. APPSS sources will complement the ALFALFA sources, with the goal of building a large enough sample to make a high confidence measurement of infall and backflow onto the PSS filament via peculiar velocity estimates from the Tully-Fisher (TFR) and Baryonic Tully-Fisher (BTFR) relations. APPSS galaxies are selected using photometric data from the Sloan Digital Sky Survey (SDSS), aimed to detect low-mass, nearby gas-rich objects below the ALFALFA detection limit. The L-band wide receiver at Arecibo Observatory in Puerto Rico is used to obtain a five-minute ON-OFF measurement for each galaxy. Since the candidate galaxy redshifts are unknown, the receiver and spectrograph system are used in a search mode that spans the expected frequencies of HI emission from PPS galaxies. We will describe the goals, target selection, and data reduction process for the survey. Our collaboration has divided the PPS into two-degree wide declination strips for data reduction; we report preliminary results for strips 23 and 33. We have made the initial data reduction on more than 200 targets, and determined the systemic velocity, line width, integrated flux density, and HI mass for each candidate detection. We will compare results on our two declination strips, and point out interesting detections found along the way as examples of the data reduction process. This work has been supported by NSF grants AST-1211005 and AST-1637339.

**Author(s):** Omar Luna, Martha P Haynes, David W Craig, Rebecca Koopmann, Michael Jones

**Institution(s):** West Texas A&M University, Cornell University, Instituto de Astrofísica de Andalucía-a, Union College  
**Contributing Team(s):** APPSS Team, Undergraduate ALFALFA Team, ALFALFA Team

### **356.08 - The Arecibo Pisces-Perseus Supercluster Survey: Declination Strips 27 and 29, and Comparison to Cosmological Simulations(Thomas Cane)**

The Arecibo Pisces-Perseus Supercluster Survey (APPSS) will provide strong observational constraints on the infall rate onto the main filament of the Pisces-Perseus Supercluster. The survey data consist of HI emission-line galaxies in the PPS region, obtained primarily at the Arecibo Observatory. Here we present data from Declination strips 27 and 29, which include 308 target galaxies, and describe our method for deducing the dark matter distribution in the filament from galaxy peculiar velocities by comparison to similar filaments in the Millennium

simulation. This work has been supported by NSF grants AST-1211005 and AST-1637339.

**Author(s):** Jesse Kelley-Derzon, Michael Jones, Mary Crone Odekon, Martha P Haynes, Rebecca Koopmann, Sam Gartenstein, Thomas Cane, Trevor Viscardi, Veronica Mierzejewski

**Institution(s):** Skidmore College, Cornell University, Union College, Instituto Astrofisica Andalucia Contributing Team(s): APPSS Team, Undergraduate ALFALFA Team

### **356.09 - Surveying for void galaxies with new photometric methods(Rochelle Steele)**

The presence or absence of dwarf galaxies having  $M_r' > -14$  in large intergalactic voids is a test of galaxy formation models and how they treat dark matter. Unfortunately, surveys such as SDSS and 2dFGRS do not go deep enough to find such objects in the nearest large voids. We have surveyed for dwarf galaxies as faint as  $M_r' = -13$  within a nearby void tabulated by Foster and Nelson (2009, termed FN 8), using the KPNO 4-m telescope and redshifted  $H\text{I}\pm$  filters. Ratios of counts in these filters uniquely determine the wavelength and equivalent width of any emission line detected. Broadband photometry, calibrated by Gemini spectra, is used to separate OII and OIII emission from the desired  $H\text{I}\pm$ . After careful calibration, we find that the void dwarf population is not more than a few percent of the cosmic mean, and may very well be absent, although there is one reasonable candidate for being in the void center. We present our survey method, scope, and analysis.

**Author(s):** J. Moody, Michael Joner, Rochelle Steele, Jackson Steele, Christian Draper, Stephen McNeil

**Institution(s):** Brigham Young University, Brigham Young University Idaho, Utah Valley University

### **357 - Modern Morphologies - Galaxy Zoo and Beyond -- Posters**

#### **357.01 - The growth of bars from $0.25 < z < 1$ : analysis of galactic bar lengths and strengths with Galaxy Zoo: Bar Lengths(Brooke Simmons)**

Using bar lengths measured from Hubble Space Telescope legacy extragalactic survey images of  $\sim 8,000$  galaxies, we examine the growth of kpc-scale galactic bars in the COSMOS field from  $0.25 < z < 1$ . Bar lengths and widths were measured from Galaxy Zoo: Hubble and Galaxy Zoo: CANDELS images using a custom citizen science project, Galaxy Zoo: Bar Lengths. Each galaxy was classified and marked by at least 20 volunteers from the project, and the results are aggregated using agglomerative clustering. We examine the growth of bars in the context of their host galaxies' star formation properties and bulge strengths, and compare with results of low-redshift studies of bar lengths and how the strength of bars relates to other dynamical properties of their host disks.

**Author(s):** Karen Masters, Brooke Simmons, Chris Lintott, Alison Coil, Tenley Hutchinson-Smith,

**Institution(s):** UC San Diego, Spelman College, Lancaster

University, University of Oxford, Haverford College

Contributing Team(s): the Galaxy Zoo team and volunteers

### **358 - Resources for Education & Public Outreach -- Posters**

#### **358.01 - A New Catalog of 250+ Pieces of Music Inspired by Serious Astronomy(Andrew Fraknoi)**

I have collected more than 250 examples of music that are seriously influenced by astronomical ideas. I don't include songs that just happened to have a cute title like "Blue Moon" or "Supermassive Black Hole." Some significant astronomical concept has to be described in the piece, or -- in the case of instrumental music -- has to have been part of the composer's intent. Newly discovered pieces include: \* an opera about Galileo, \* a musical setting of Walt Whitman's "When I Heard the Learned Astronomer," \* a pop song about astronomy and falling in love, whose official video is all about going to a star party, \* chamber music about wormholes, \* "The Hubble Cantata," with narration and images by Mario Livio, \* a piano piece which uses "sonification" of Type Ia supernova data. These days almost all the pieces are available free on YouTube, Vimeo or other web channels, and thus can easily be downloaded or played in class. I will show some of the music that is most useful for astronomy education and outreach. You can access the full guide (with links to each piece on the Web) directly by going to: <http://bit.ly/astronomymusic> The collection of resource guides, including one on plays inspired by astronomy, is at: <http://www.fraknoi.com/resource-guides-on-astronomy-education/>

**Author(s):** Andrew Fraknoi

**Institution(s):** University of San Francisco

#### **358.02 - Educationally Rich Images and Videos Appearing on APOD in 2018(Robert Nemiroff)**

The Astronomy Picture of the Day (APOD: main NASA site: <https://apod.nasa.gov/>) featured many images and videos in 2018 that were both topical and educational. As usual, the APOD editors created a brief hyperlinked explanation for each entry. Topics included astronomy-oriented rocket launches, Earth, Earth's night sky, the space station, Moon, Sun, Solar System planets, Solar System moons, asteroids, comets, exoplanets, absorption nebulae, emission nebulae, reflection nebulae, open star clusters, globular star clusters, galaxies, galaxy groups, clusters of galaxies, and cosmology. A selection of particularly educationally-rich APODs is presented, as well as a brief review of methods that teachers from grade school to college have used to incorporate APODs into their classrooms.

**Author(s):** Robert Nemiroff, Jerry Bonnell,

**Institution(s):** Michigan Technological University, University of Maryland, NASA's GSFC

### **358.03 - Development of a Contained Raspberry-Pi-based Pulsar-Timing Outreach Device(Michael T Lam)**

We are developing a low-cost Raspberry-Pi-based device to contain various pulsar timing outreach demonstrations. The device is aimed to be easily usable by astronomers knowledgeable in the field but will contain easily installable packages so that professors and teachers can use them in school laboratory exercises. We highlight the five intended modes of operations. While the interaction between software packages and hardware has been found to be troublesome, the standardization of hardware and software for the Raspberry Pi will make it easy to develop and maintain these codebases.

**Author(s):** Michael T Lam, Nathaniel Garver-Daniels, Adam Brazier

**Institution(s):** West Virginia University, Cornell University  
**Contributing Team(s):** NANOGrav Physics Frontiers Center

### **358.04 - An Acoustical Analogue of a Galactic-scale Gravitational-Wave Detector(Michael T Lam)**

By precisely monitoring the "ticks" of Nature's most precise clocks (millisecond pulsars), scientists are trying to detect the "ripples in spacetime" (gravitational waves) produced by the inspirals of supermassive black holes in the centers of distant merging galaxies. Here we describe a relatively simple demonstration that uses two metronomes and a microphone to illustrate several techniques used by pulsar astronomers to search for and detect gravitational waves. An adapted version of this demonstration could be used as an instructional laboratory investigation at the undergraduate level.

**Author(s):** Michael T Lam, Joey Shapiro Key, Jeffrey Shafiq Hazboun, Joseph D Romano, Marc Normandin

**Institution(s):** West Virginia University, University of Washington Bothell, Texas Tech University, University of Texas Rio Grande Valley  
**Contributing Team(s):** NANOGrav Physics Frontiers Center

### **358.05 - The Great American Eclipse Weather Phenomena(Anthony Papol)**

For the first time in nearly 40 years, a total solar eclipse passed over the continental United States on August 21, 2017. Using observations gathered while on-site in Long Creek, Oregon, and from over seven hundred other sites within the path of totality from across the United States, it was determined that the total solar eclipse caused a decrease in temperature of  $5.8 \pm 10.2$  minutes after totality ended. These observations also showed that the wind speed decreased by 1.6 mph 25.1 minutes after totality ended, and that if a change in wind direction occurred, it shifted 7.4 minutes before totality began.

**Author(s):** Anthony Papol

**Institution(s):** Brown University

## **359 - The Sun -- Posters**

### **359.01 - Where's That Flare: A Comprehensive Hard X-Ray Solar Flare Catalog(Maya Merhi)**

We have created a hard x-ray solar flare catalog using short channel wavelength bands of 0.5 to 4 Å... from NOAA's Geostationary Operational Environmental Satellites (GOES) X-Ray Sensor (XRS) data for 2003 to 2018. The Where's That Flare (WTF) catalog was developed using an automated algorithm designed to use changes in the derivative of the hard X-ray flux to identify flares. Intended to provide a complete archive of all hard X-ray solar flare events in GOES XRS data, the WTF catalog (novelty for the hard X-ray) distinguishes between "simple" single peak flare events and "complex" multi-peak flare events and is sensitive to small flares near the background level. To account for the varying background level of the hard X-ray flux, the detection algorithm dynamically adapts to the local background to detect flares of all sizes and complexities. A statistical analysis of flare characteristics was performed on the WTF catalog investigating correlations between total energy, flare duration, peak flux, peak time, rise time, decay time, as well as characteristics of complex events such as number of peaks per complex event. Frequency distributions of total energy, flare duration, and number of peaks per complex event were also investigated and fit with power laws where applicable. Our catalog is complete to approximately  $10^{-7.5}$  W/m<sup>2</sup> peak flux. In the future, we will run our algorithm on all available GOES data and use this catalog in conjunction with NOAA GOES SXI data and NASA Hinode image data to give spatial locations of solar flares in our catalog. This work is supported by NSF-REU Solar Physics program at SAO, grant number AGS-1560313. Keywords: Catalogs, Solar flares, X-ray flares

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Smithsonian Center for Astrophysics  
**Contributing Team(s):** Solar and Stellar X-Ray Group

### **359.02 - Exploring Sunspot Emergence with the Helioseismic and Magnetic Imager(Vidya Venkatesan)**

The physics behind sunspot emergence is still not well understood. One of the goals of the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamic Observatory (SDO) is to explore the science behind active region emergence. With HMI's virtually continuous 45-sec data sampling, it has become possible for the first time to view the detailed evolution of active regions at high cadence and with reasonably high resolution. We have made a series of movies to visualize the initial phases of sunspot emergence. We found evidence of the classic picture of magnetic flux tubes developing into sunspots as their tops broke through the photosphere in some of the data sets. We also found that spots often appear well before their active regions are identified. With this and additional data, we hope to extract information leading to improvements in automated and unbiased detection of spot emergence and to help understand

some of the conundrums of spot emergence, including their non-random longitudinal distribution which cannot be explained by visibility alone.

**Author(s):** Phil Scherrer, Almee Norton, Vidya Venkatesan, Charles Baldner, Rick Bogart

**Institution(s):** California State University, Northridge, Stanford University

### 359.03 -

#### **The Sun in Time Updated: Magnetic Activity of the Sun Over Time and Changes in X-ray, Coronal, and Chromospheric UV Emissions and Their Effects on Hosted Planets(Briana Josephine Dalton)**

Since its birth nearly 4.6 Gyr ago, our Sun has been undergoing drastic changes in magnetic activity, resulting in changes in its coronal X-ray and chromospheric UV emissions, as well as in its star spot activity. We report on the magnetic evolution of the Sun and related solar-type stars by utilizing solar-proxies with spectral types from G0-5V and ages ~50 Myr to 8 Gyr. This program builds on the Villanova Sun in Time program started over 25 years ago and utilizes X-ray data from ROSAT, XMM-Newton, Chandra and FUV-UV data from the IUE and the HST. Additional stellar rotation-age determinations from Kepler and K2 Mission are also used to better define the loss of angular momentum with time from magnetic braking effects and to calibrate rotation vs. age. For the first time, we added new data for the strong FUV emission fluxes from HI Lyman  $\hat{I}$ ± (1216 Å...). The Ly $\hat{I}$ ± emission line dominates the EUVE-FUV flux, contributing ~80-90% of the stellar or solar flux from ~400 - 1500 Å.... It is a major source for photo-dissociation of important molecules including H<sub>2</sub>O, CH<sub>4</sub>, and CO<sub>2</sub> in planetary atmospheres, including the Earth. The Ly $\hat{I}$ ± flux measures were obtained from Linsky et al. 2013 (ApJ. 766, 69) while we determined the corresponding stellar ages. We have also added measures of the strong chromospheric Mg II HK 2800 Å... emission line fluxes. We developed relations between Mg II HK flux vs. Age, as well as vs. Ly $\hat{I}$ ± flux. We present the updated results as improved relations among rotation period, age, and X-ray as well as (FUV) Ly $\hat{I}$ ± and Mg II HK 2800 Å... fluxes and irradiances at a standardized distance of 1AU from the host stars. This research is sponsored by NASA grants HST GO-13861 & GO-13020 and Chandra GO5-16002X that we gratefully acknowledge.

**Author(s):** Edward Francis Guinan, Scott Engle, Briana Josephine Dalton

**Institution(s):** Villanova University

#### **359.04 - Comparative Study of the Solar Wind: Modeling Charge State Distributions in the Heliosphere(Marcus DuPont)**

Non-equilibrium ionization (NEI) is a key process often times ignored when modeling astrophysical plasmas whose thermodynamical timescales are much shorter than the

timescales for ionization and recombination. In this paper, we use magnetohydrodynamics (MHD) models alongside the post NEI analysis to calculate synthetic charge state distributions during the Whole Sun Month interval (CR)-1913 (1996 August 22 to 1996 September 18), and compare them with in-situ measurements made with the Ulysses Solar Wind Ion Spectrometer Composition (SWICS) instrument. In our analysis, we: (1) show that the solar wind speeds at 20 solar radii calculated by the Magnetohydrodynamics Around a Sphere (MAS) model were not in agreement with the Ulysses observations; (2) measure the "freeze-in" distance for several ions observed by the SWICS instrument to determine a possible correlation between when the ionization states become fixed and their expansion into the solar wind; (3) obtain charge state densities and abundance ratios for slow and fast winds based on the NEI model, and compared them with in-situ observations.

**Author(s):** Nicholas Murphy, Marcus DuPont, Chengcai Shen

**Institution(s):** Florida State University, Harvard-Smithsonian Center for Astrophysics

#### **359.05 - Angular Response Characterization of the REgolith X-ray Imaging Spectrometer (REXIS) Solar X-ray Monitor (SXM)(Christian J Nieves)**

The OSIRIS-REx spacecraft was launched on September 2016 as part of the New Frontiers program to precisely characterize and collect a sample (>60 g) from the near-Earth asteroid 101955 Bennu. The REgolith X-ray Imaging Spectrometer (REXIS) was built by students at MIT and Harvard to measure elemental abundance distributions across the surface of the asteroid in order to characterize Bennu within analog meteorite groups. The REXIS instrument consists of two primary parts: the coded aperture telescope with a CCD detector plane, which will observe X-ray fluorescence lines induced by incident solar X-ray flux, and the Solar X-ray Monitor (SXM): mounted on the Sun-facing side of the spacecraft to measure the spectrum of solar X-rays incident on the surface of Bennu. The data gathered by these two instruments will enable us to measure the elemental abundances of the surface of the asteroid. In order to assess the angular response of the flight instrument and to evaluate potential sources of systematic error in the fitting of solar spectra, we carried out a laboratory calibration of the SXM flight spare. We evaluated the SXM response over the entire field of view expected during operations around the asteroid using an Fe-55 source and analyzed the count rate and energy resolution as a function of position within the unocculted field of view. Our analysis excludes significant deviation in all samples points at the  $\hat{I}$ ± in detector efficiency, energy resolution, and gain beyond that expected as a result of the incidence angle and SXM collimator and detector geometry.

**Author(s):** Jae Sub Hong, Christian J Nieves, Branden Allen

**Institution(s):** University of Puerto Rico, Mayagüez Campus, Harvard-Smithsonian Center for Astrophysics  
Contributing Team(s): REXIS Team

### **359.06 - First Steps Investigating the Relationship between Solar Surface Magnetic Field and Coronal Soft X-Ray Spectra(Sierra Garza)**

How the solar atmosphere is heated from roughly 5,700 K at the photosphere to over 1 MK up in the corona is still under debate, but there is strong evidence that the heating process involves magnetic phenomena. We present the initial steps of investigating the relationship between the photospheric magnetic and coronal soft x-ray spectral flux. We reaffirm the positive correlation between from the spectrally integrated soft x-ray data number signal from the Hinode X-ray Telescope (Hinode/XRT) Al-Mesh, Al-Poly and Be-Thin filters, and the 94 angstrom filter data number signals from the Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO/AIA) full Sun images, to the unsigned line-of-sight magnetic field strength from the SDO Helioseismic Magnetic Imager (SDO/HMI) within 0.9 solar radii. This is consistent with the investigations of Fischer et al. 1998, Petsov et al. 2003 and Warren et al. 2012. This data set includes observations from June 2016 to April 2017. We set threshold values of 316 and 1000 gauss for the SDO/HMI line-of-sight (los) data to emphasize the stronger field strengths. In future work, we will compare these results with the spectrally resolved soft X-ray measurements of the Miniature X-ray Solar Spectrometer (MinXSS) CubeSats. MinXSS data will provide more details on the coronal temperature structure, and elemental abundance variation with the photospheric magnetic field. This work is supported by the NSF-REU Solar Physics program at SAO, grant number AGS-1560313. The MinXSS-1 CubeSat mission is supported by NASA Grant NNX14AN84G.

**Author(s):** Katharine Reeves, Christopher Moore, Sierra Garza,

**Institution(s):** California State Polytechnic University, Pomona, Harvard-Smithsonian Center for Astrophysics

## **360 - Variable Stars -- Posters**

### **360.01 - Looking at Flare Stars Below 100 MHz with the LWA(Ivey Davis)**

Flare stars are objects of major astrophysical interest as their flares are visible from X-rays to decametric radio waves. While most are M-type dwarfs and primarily convective, properties of the emission suggests a similarity to type III solar flares. This similarity implies that these flares occur due to magnetic reconnection events; however, the flares are much more powerful than what is observed from the Sun and generally are unpredictable in terms of power and occurrence. The wide range of regimes in which the events are visible allows for inspection of the properties of the stars from multiple parts of the spectrum, allowing for insightful analyses of the processes that drive such intense events. There is considerable interest in these objects at radio wavelengths due to the relationship between radio power and frequency with the strength of the magnetic field of the object; making confident detections of flare stars in low frequencies would provide insight into the magnetic fields, and consequently the interior structure and

dynamics of these stars. Low frequency observations are particularly helpful in measuring the characteristic field strengths. However, currently, the literature on flare stars below 100 MHz is conflicting in terms of many qualities like frequency of occurrence of the flare events, the frequency drift of the flares, and the power of the flares. In order to better understand these discrepancies, observations of these types of objects are being conducted with the Long Wavelength Array (LWA), a dipole array with a single, 70 km baseline between sites in the central square mile of the Very Large Array (VLA) and Sevilleta, New Mexico. These observations were done in the frequency range of 63 to 83 MHz and focused on nearby stars known to flare below 100 MHz, namely the stars AD Leonis, EQ Pegasi, Wolf 424 A, and EV Lacertae. We will present the results from several, week-long campaigns where these flare stars were regularly observed for three hour intervals with the LWA interferometer.

**Author(s):** Ivey Davis, Greg B Taylor, Jayce Dowell

**Institution(s):** University of New Mexico

### **360.02 - Characterizing Stellar Variables in the Time Domain Spectroscopic Survey(Sierra Dodd)**

The Time-Domain Spectroscopic Survey (TDSS) is the largest spectroscopic survey ever carried out specifically targeting variable objects. In this paper we consider the subsample of some 22,000 TDSS variables characterized spectroscopically as stars, and evaluate best methods for retrieval and analysis of light curve data from the Palomar and Catalina surveys. We analyze light curves using Python and the VARTOOLS code of Hartman & Bakos (2016). A combination of the VARTOOLS output, spectroscopic information from Sloan, and classification of periodic variables in Catalina from Drake et al. (2014) is used to guide future classification of the entire TDSS sample, including some discussion of the larger variable sample for which no significant periodicity is found. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1659473, and by the Smithsonian Institution.

**Author(s):** Paul Green, Sierra Dodd, Rachael Christina Amaro, Benjamin Roulston

**Institution(s):** University of Washington, Harvard Smithsonian Center for Astrophysics Contributing Team(s): TDSS, SDSS

### **360.04 - The Search for Variable Stars in DES Ultra-faint Galaxies - the RR Lyrae Star population of Reticulum III(Morgan McCarthy)**

The Reticulum III Ultra-Faint Dwarf Spheroidal galaxy is a satellite galaxy of the Milky Way lying at a loosely-constrained heliocentric distance  $D = 92 \pm 13$  kpc. To better constrain the distance, we searched the galaxy for RR Lyrae stars and other periodic variables. Using the Goodman imager at the SOAR telescope, we observed the galaxy over four consecutive nights

in November of 2016, gathering data in the Sloan Digital Sky Survey g, r, and i filters. We built a 627-star catalog for Reticulum III, from which we identified 17 candidate variable stars using the large standard deviation in their magnitudes. We did not identify any periodic variable stars, however, this non-discovery is consistent with the RR Lyrae population observed among galaxies of absolute magnitude  $M_V \approx -3$  mag. Additionally, we observe the general positive correlation between absolute magnitude and RR Lyrae population size breaks down for galaxies  $M_V < -6$  mag.

**Author(s):** Morgan McCarthy, Katherina Vivas, Clara Mart  nez-V  izquez

**Institution(s):** University of Rochester, Cerro Tololo Inter-American Observatory  
**Contributing Team(s):** Dark Energy Survey Collaboration

### **360.05 - Connecting Starspots and Flares on Main-Sequence Stars(Rachael Roettenbacher)**

Strong magnetic fields in low-mass stars give rise to a variety of stellar activity, including starspots and flares. The connection between the flares and starspots remains unclear, as a number of studies of M dwarfs have shown no correlation between the two magnetic phenomena. Using the flare-finding algorithm FLATWRM and the spot-analysis algorithms SAUCES, we investigated over 100 spotted, flaring, main-sequence stars with long-cadence Kepler light curves. We analyzed the phase difference between the timing of a starspot feature facing Kepler and a flare occurrence. For the most energetic flares, we found no correlation between the flares and starspots. However, for weaker flares, we found that they preferentially occur when the starspot was visible to Kepler.

**Author(s):** Rachael Roettenbacher, Kriszti  n Vida

**Institution(s):** Yale University , Konkoly Observatory

### **360.06 - Constructing an all-sky catalog of bright variable stars with ASAS-SN(Tharindu Jayasinghe)**

The All-Sky Automated Survey for SuperNovae (ASAS-SN, Shappee et al. 2014; Kochanek et al. 2017) has monitored the entire visible sky to a depth of  $\sim 17$  mag in the V-band since 2014. In addition to the detection of transients in real-time, ASAS-SN data are well suited for the discovery and characterization of variable stars (Jayasinghe et al. 2018a; Shields et al. 2018). In Jayasinghe et al. (2018a), we reported the discovery of  $\sim 66,000$  new variable stars in ASAS-SN V-band data. In Jayasinghe et al. (2018b), we uniformly analyzed the ASAS-SN light curves of  $\sim 412,000$  known variables from the AAVSO's VSX catalog (Watson et al. 2006), providing the first all-sky, homogeneously classified catalog of variable stars. All the light curves for these sources are made available to the public. We are currently conducting a systematic, all-sky variability analysis of the  $\sim 50$  million bright ( $V < 17$  mag) APASS sources using ASAS-SN V-band data, which is likely to yield numerous additional variable stars.

**Author(s):** Tharindu Jayasinghe, Krzysztof Stanek, Christopher Kochanek

**Institution(s):** The Ohio State University  
**Contributing Team(s):** ASAS-SN

### **360.07 - Monitoring Pulsating Variable Stars with Five Robotic Telescopes(Adam Garth Bugg)**

In Spring 2017, Brigham Young University (BYU) implemented an 8-inch robotic telescope on the observation deck of the Eyring Science Center. In Summer of 2018, a 10-inch telescope was installed and tested. Using those two telescopes, and a set of filters modeled after those reported in Joner & Hintz (2015), we have gathered photometric observations of a group of Cepheid variables. We present the preliminary results of this research, including H-alpha index and Johnson V light curves. A few of our targets are compared to results from spectroscopic data obtained with the 1.2-m telescope of the Dominion Astrophysical Observatory. We note that several of the Cepheids had no published periods, and preliminary period measurements for those stars are also presented.

**Author(s):** Adam Garth Bugg, Eric G Hintz, Michael D. Joner

**Institution(s):** Brigham Young University

### **360.08 - Identifying Photometrically Variable Stars in the Andromeda Galaxy(Gautam Chawla)**

Photometrically variable stars are those that pulsate, causing their luminosity to vary with time. Studying such stars can help astronomers improve their understanding of the physics of stellar pulsation (and, more generally, stellar evolution). Certain classes of variable stars can serve as standard candles that can be used to measure the line of sight distance and foreground dust extinction. This project focuses on developing a few new methods to identify variable stars. The PHAT survey of the M31 (Andromeda) galaxy was key to our project because of the availability of multi-band time domain photometric data for a very large number of stars at a common distance. The PHAT data were used to construct color-color diagrams (2CDs), which were then used to statistically isolate photometrically variable stars. A set of about a hundred known variable stars found in the POMME and iPTF ground-based surveys was used as a training set throughout the 2CD analysis. This analysis was continued with the time-epoch portion of the PHAT survey. From the time-epoch data, cumulative histograms of the time baseline of measurement in each star were constructed to determine the amount of usable data. A variability statistic for each star was constructed based on this data. This was applied to sets of HST stars and simulations were used to classify whether a star was variable or not. In future work we will apply this method to AGB stars and candidate RR Lyrae stars in M31.

**Author(s):** Ruchi Maheshwari, Ryan Dudschus, Puragra Guhathakurta, Gautam Chawla, Monika Soraisam, Brianna McCollm

**Institution(s):** Princeton High School, Westmont High



School, Saratoga High School, National Optical Astronomy Observatory, University of California Santa Cruz

### **360.09 - Time Series Observations of the delta Scuti Variable GW Draconis(Alexandra T Nelson)**

GW Draconis is a delta Scuti variable that has received limited attention. However, its high declination makes it a target that can be observed for a larger portion of the year and for longer sequences on any given night. This makes GW Dra a very interesting target. We have gathered photometric observations of GW Dra which were previously taken, but not published, starting in 2000. Using newly installed robotic telescopes we have extended the baseline up to the present day. From this photometric data we will present an examination of the pulsational characteristics of GW Dra. Beyond the photometric data we also examined previously unpublished radial velocity data from the Dominion Astrophysical Observatory 1.2-m Radial Velocity Speedometer. We will also present spectra also obtained with the DAO 1.2-m telescope.

**Author(s):** Aubrie A. Maxwell, Alexandra T Nelson, Michael Joner, Eric G Hintz

**Institution(s):** Brigham Young University, Utah Valley University

### **360.10 - The Identification and Characterization of RR Lyrae Stars in M53(Suzanna Officer)**

Often abundant in globular clusters, RR Lyrae variables are valuable standard candles and can be used to study stellar structure. In this project, images of Messier 53 (NGC 5024) were used to identify and characterize RR Lyrae variable stars. The data set consists of five nights of observations with an approximately 10 minute cadence using the Hiltner 2.4m telescope at the MDM Observatory at Kitt Peak. The project's goal is to not only characterize variable stars in M53, but to formulate an effective procedure for finding variable stars in similar data sets. With the established methodology, 63 variable stars were found in M53; 45 of the variable stars were confirmed in literature as variable, and 18 of the stars were newly discovered variables.

**Author(s):** Brian Chaboyer, Nathaniel Paust, Suzanna Officer, Lucas Napalitano

**Institution(s):** Whitman College, Dartmouth College

### **360.11 - An Analysis of the delta Scuti Variable V402 Cephei(Jason B Trump)**

We present an analysis of photometric observations of the delta Scuti, V402 Cephei, secured between the years 2000 and 2005. To extend the baseline, we have obtained recent observations using our newly established robotic telescope facilities on the BYU campus. The current photometric data will be supplemented with spectroscopic data taken with the 1.2-m

telescope of the Dominion Astrophysical Observatory. A preliminary analysis of the present data set suggests a variety of potential interpretations beyond those currently published. We will present our observations for this star and explore possible interpretations based on an examination of the entire data set.

**Author(s):** Jason B Trump, Eric G Hintz, Michael Joner

**Institution(s):** Brigham Young University

### **360.12 - Calibrating Mass Accretion Rates in Pre-Main Sequence Stars using Brackett Alpha Emission, and Pitfalls in Low Accretion Rate Systems(Dakotah Tyler)**

Using calibrations derived from correlations between luminosities of Hydrogen Line emissions, we can calculate Mass Accretion Rates for particular stars. Correlations for the emission line strengths and their relationship to Mass Accretion Rates for Paschen Beta (1.28 microns) and Brackett Gamma (2.16 microns) are well known and have been calibrated by Fairlamb et al. By analyzing correlations between the relative strengths of these emission lines and that of Br A (4.06 microns) we can calibrate Br A emission for producing Mass Accretion Rates as well. This is useful when extracting data from an observation that does not contain Pa B or Br G, but does contain Br A, which can be common. It is important to be able to produce Accretion Rates on all observations, as variability in Low Accretion Rate Systems is a point of interest. In this presentation, we also look at some pitfalls associated with analyzing emission in these Low Accretion Rate Systems. Variability is defining characteristic of these systems, but this high level of variability can result in massive fluctuations in observations made in as little as weeks apart. Some of these observations even reveal negative fluxes at times when absorption seems to be stronger than emission from certain Hydrogen Lines.

**Author(s):** Dakotah Tyler

**Institution(s):** University of Cincinnati

### **360.13 - K2 observations of UY Sex and V1405 Ori: Two pulsating hot horizontal branch (subdwarf B) stars.(Matthew Yeager)**

The short period (p-mode) pulsators UY Sex and V1405 Ori were discovered with ground-based observations in 1997 and 1999, respectively. They both also received follow-up ground-based observations in attempts to resolve their pulsations and apply asteroseismic techniques to understand their structure. During K2's campaigns 14 and 13, short-cadence data were obtained. In this poster, we present a preliminary analysis of the K2 data and compare the results with what were obtained from the previous ground-based efforts. Subdwarf B stars are hot horizontal branch stars with  $20,000 < T_{\text{eff}} < 40,000$  K and  $5.0 < \log g < 6.0$  dex (cgs). They have masses near  $0.5 M_{\odot}$  and radii near  $0.2 R_{\odot}$  with thin, inert H envelopes. The hotter stars tend to pulsate in pressure (p) modes with periods of a few minutes, the cooler ones in gravity (g) modes with

periods of about 45 minutes to a few hours, yet there are several hybrid pulsators which can span the entire temperature range. UY Sex is purely a p-mode pulsator while V1405 Ori is a p-mode-dominated hybrid pulsator.

**Author(s):** Alyssa Slayton, Michael Reed, Matthew Yeager

**Institution(s):** Missouri State University

### **360.14 - A 7-Day, Multiwavelength Flare Monitoring Campaign on AU Mic(Adam F Kowalski)**

M dwarf flares exhibit a strong response in the X-ray and NUV, in line with the standard Neupert effect observed in ~80% of (less energetic) solar flares. However, some stellar flares produce only bright X-rays and others only a bright NUV response. The detailed properties and causes of each of these types of flares are not well constrained because the vast majority of data of M dwarf flares in the past have been in the optical without information at other wavelengths. Our fundamental understanding of stellar flares has been hampered by a lack of a large multi-wavelength dataset covering many types of flares (Neupert vs. non-Neupert). We present first results from a large flare campaign over ~7 days (Oct 10 - Oct 17, 2018) in which we characterize AU Mic's flaring properties at X-ray, UV, optical, and radio wavelengths. AU Mic is the brightest M dwarf flare star in the sky, has a well-constrained (young) age, and is known to produce very energetic flares on occasion. The flare monitoring was done with a large fleet of ground and space-based observatories, including XMM-Newton, Swift, the VLA, the ATCA, the SMARTS 0.9m and 1.5m telescopes at CTIO, MINERVA-Australis, the ARC 3.5m at APO, and several sites in the LCO Global Telescope Network. In each wavelength regime, we have devised and made new measurements to probe the physics of flaring atmospheres from the photosphere and/or low chromosphere through the corona. We show how these data provide new constraints on radiative-hydrodynamic flare models, and we discuss implications for the space weather in the system.

**Author(s):** Jamie L Lomax, Todd Henry, Glenn Schneider, Graeme White, Rachel Osten, John Wisniewski, Wei-Chun Jao, Roy Axelson, James E Neff, Adam F Kowalski, Eliot Halley Vrijmoet, Rodrigo Hinojosa, Brad Carter, Leonardo Paredes, Joel Allred, Alexander Brown, Jack

**Institution(s):** USQ/AmateurAstronomer, oCTIO/NOAO, USQ/Western Sydney University, NSF, University of Colorado, University of Oklahoma, Eureka Scientific, STScI, USNA, University of Arizona, GSU/RECONS, University of Southern Queensland, NASA/GSFC

### **360.15 - Variable star classification with crowd sourcing(Nicholas Easton)**

We present a Zooniverse citizen science project in development aimed at classifying variable stars in the LSST Big Data era. Currently we make use of data from the Atlas and PTF catalogs, mapped to Gaia DR2. We plan to expand to additional data sets

(including that of LSST) in the near future. The addition of Gaia data enables Zooniverse volunteers to not only view the light curve for an individual source, but also an H-R diagram showing a particular star's location relative to all stars in the catalog. This, in combination with the shape of the light curve and the inferred variability period and amplitude, provides volunteers with information necessary to classify variable stars into a finer grid than with the light curve alone. On the back end, we will use volunteer classifications to train a machine learning algorithm to help vet the (large) catalog of available variable stars prior to entry into the Zooniverse workflow. In this poster we present our current Zooniverse workflow, initial results, and our plans for the future.

**Author(s):** Aaron Geller, Nicholas Easton, Adam Miller,

**Institution(s):** Case Western Reserve University, Adler Planetarium, Northwestern University

### **360.16 - Evryscope Observations of Post-Common-Envelope Hot Subdwarf Systems(Kyle A Corcoran)**

Evryscope is an array of twenty-four individual telescopes built by UNC and deployed on Cerro Tololo with the purpose of imaging the entire Southern sky once every two minutes. Now having operated for more than three years, the Evryscope has produced insurmountable data on most Southern targets brighter than 16th magnitude. Many of the helium-fusing hot subdwarf stars are members of post-common-envelope binaries with white dwarfs or low-mass stellar/substellar companions. These systems are typically bright with characteristically short periods, often exhibiting eclipses, ellipsoidal modulation, or a reflection effect. Evryscope is an unparalleled tool for studying these post-common-envelope systems in many interesting ways. While the raw light curves are noisy due to the small aperture size, phase folding the data over such a large number of orbital cycles produces high signal-to-noise light curves suitable for model fitting. Additionally, we can monitor small drifts or oscillations in the arrival times of photons which may reveal secular evolution of the binary, gravitational wave emission, or reflex motion due to circumbinary objects. Perhaps most exciting is our ability to detect previously-unknown variability in hot subdwarf systems. Here we present several years of Evryscope photometry and discuss our analyses of several interesting hot subdwarf binaries. This material is based in part upon work supported by the National Science Foundation under Grant No. AST-1812874.

**Author(s):** Sam Mycroft, Stephen Walser, Octavi Fors, Henry T Corbett, Nicholas Law, Brad Barlow, Ward S Howard, Kyle A Corcoran, John Aube, Jeff Ratzloff

**Institution(s):** High Point University, UNC Chapel Hill

### **360.17 - A Search For Variables Stars in NGC6134(Melvin Blake)**

Data collected over a week long period from the PROMPT telescopes was analyzed to study the variable stars in the old

open star cluster NGC6134. V and I-band observations were obtained with the objective was to observe the known  $\dot{I}'$ -Scuti Stars in NGC6134 and to search for other variable stars in the cluster. we present the results of this investigation and suggest future observations of this cluster.

**Author(s):** Melvin Blake, Lauren Wigginton

**Institution(s):** University of North Alabama

### **360.18 - Classical Cepheid Evolution in and Around the Galaxy: Comparing the Milky Way, LMC and SMC(Scott Engle)**

Classical Cepheids have long been of fundamental importance to Astronomy and Cosmology, even moreso in after Gaia DR2. One of the most interesting aspects of Cepheids, though, is that they present cases of stellar evolution in real-time. As part of the Secret Lives of Cepheids program, we have been monitoring the evolution of Cepheids as indicated by their rates of period change. To investigate how these rates are influenced by metallicity, we have systematically calculated/refined and compared rates of Cepheid period change for galactic Cepheids, LMC Cepheids and SMC Cepheids.

**Author(s):** Joseph M. Michail, Hilding Neilson, Edward Francis Guinan, Scott Engle, Mary Erickson

**Institution(s):** Villanova University, Univof Toronto

### **360.19 - Inferring the Spectrum of Accretion onto the Pre-Main Sequence Star LkCa 15(Joseph Murphy)**

The final stage of pre-main sequence star formation is defined by the magnetospheric accretion of gas from a circumstellar disk onto the stellar surface. The combination of the time-variable emission of the accretion shock and the (possibly) time-variable extinction from orbiting circumstellar dust severely complicates measurements of the accretion rate and the fundamental stellar parameters of the system. The presence of the accretion flux acts to reduce the contrast of the stellar photospheric absorption features in high resolution spectroscopic observations ("veiling" them). Traditional analysis methods which assume the spectrum of the accretion flux to be continuum-like in nature can yield artificially high accretion rate estimates if in fact the accretion flux is significantly concentrated in wavelength, e.g., in emission lines coincident with photospheric absorption features. To examine the influence of these effects on accretion rate estimates, we obtained 20 epochs of high resolution optical spectra and near-simultaneous ugriz photometry of the K5 T Tauri stars LkCa 14 and LkCa 15, which comprise a non-accreting "template" star and a moderately accreting "target" star, respectively. We develop a Gaussian process framework to construct a high-fidelity template of the stellar photosphere, and use this to infer the spectrum of the accretion flux on a per-epoch basis. In combination with the broad-band photometry, we use this framework to disentangle the flux changes due to accretion events and variable dimming from circumstellar dust

obscuration. We find that the accretion spectrum is not well-described by a continuum source, and indeed contains low amplitude but numerous emission lines, which would otherwise bias accretion rates obtained via traditional methods.

**Author(s):** Ian Czekala, Joseph Murphy, Bruce Macintosh, David W Latham, Sean M. Andrews

**Institution(s):** Stanford University, Harvard-Smithsonian Center for Astrophysics, University of California, Berkeley

### **361 - Theoretical Advances Guided by Radio-Millimeter-Submillimeter Arrays -- Posters**

#### **361.01 - Science with a next-generation Very Large Array(Eric Joseph Murphy)**

Inspired by dramatic discoveries from the Jansky VLA, VLBA, and ALMA, a plan to pursue a large collecting area radio interferometer that will open new discovery space from protoplanetary disks to distant galaxies is being developed by NRAO and the science community. Building on the superb cm observing conditions and existing infrastructure of the VLA site in the U.S. Southwest, the current vision of the ngVLA will be an interferometric array with more than 10 times the sensitivity and spatial resolution of the current VLA and ALMA, operating at frequencies spanning  $\sim 1.2$  - 116 GHz with baselines extending across North America and beyond. The ngVLA will be optimized for observations at wavelengths between the exquisite performance of ALMA at submm wavelengths, and the future SKA-1 at decimeter to meter wavelengths, thus lending itself to be highly complementary with these facilities. As such, the ngVLA will open a new window on the universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcsecond resolution, as well as deliver unprecedented broad band continuum polarimetric imaging of non-thermal processes. The ngVLA will be the only facility in the world that can tackle a broad range of outstanding scientific questions in modern astronomy by simultaneously delivering the capability to: unveil the formation of Solar System analogues; probe the initial conditions for planetary systems and life with astrochemistry; characterize the assembly, structure, and evolution of galaxies from the first billion years to the present; use pulsars in the Galactic center as fundamental tests of gravity; and understand the formation and evolution of stellar and supermassive blackholes in the era of multi-messenger astronomy.

**Author(s):** Eric Joseph Murphy

**Institution(s):** National Radio Astronomy Observatory  
Contributing Team(s): the ngVLA Science Advisory Council, the ngVLA Science Working Groups

#### **361.02 - The Next-Generation Very Large Array Technical Overview(Mark McKinnon)**

As part of its mandate as a national observatory, the NRAO is looking toward the long range future of radio astronomy and fostering the long term growth of the US astronomical community. NRAO has sponsored a series of science and

technical community meetings to consider the science mission and design of a next-generation Very Large Array (ngVLA), building on the legacies of the Atacama Large Millimeter/submillimeter Array (ALMA) and the Very Large Array (VLA). The basic ngVLA design emerging from these discussions is an interferometric array with approximately ten times the sensitivity and ten times higher spatial resolution than the VLA and ALMA radio telescopes, optimized for operation in the wavelength range 0.3cm to 3cm. The ngVLA will open a new window on the Universe through ultra-sensitive imaging of thermal line and continuum emission down to sub-milliarc-second resolution, as well as unprecedented broadband continuum polarimetric imaging of non-thermal processes. The specifications and concepts for major ngVLA system elements have converged into a Reference Design, which forms the technical and cost basis of the project Astro2020 Decadal proposal. We will provide an overview of the Reference Design of the ngVLA. The concepts for major system elements such as the antenna, receiving electronics, and central signal processing will be presented. We will also describe the major development activities that are presently underway to advance the design.

**Author(s):** Robert Selina, Mark McKinnon

**Institution(s):** NRAO

### **361.03 - Antenna Concept for the Next-Generation Very Large Array (Dana Scott Dunbar)**

The Karl Jansky Very Large Array (VLA) has proven to be one of the most productive radio telescopes at centimeter wavelengths. The NRAO is now investigating the future of centimeter wavelength astronomy in the northern hemisphere, spanning the gap between thermal and non-thermal emission mechanisms, and bridging the capabilities of ALMA and SKA. The scientific mission, specifications and technical concept of a next-generation VLA (ngVLA) are presently being developed. Preliminary goals for the ngVLA are to increase both the system sensitivity and angular resolution of the VLA and ALMA tenfold for frequencies spanning 1.2 GHz to 116 GHz. Specifications and costing for the ngVLA system, and major components such as the antennas, are in development in anticipation of the Astro2020 Decadal Survey and a facility design and construction proposal to the NSF. The design of the antenna will be a major construction and operations cost driver for the facility. The antennas must have acceptable aperture efficiency and pointing for operation up to 116 GHz, with five to ten times the total collecting area of the VLA. Unblocked apertures are preferred, with wide subreflector subtended angles for compact feed and receiver packages. Improved reliability, and ease of access to the receiver and servo electronics packages, will be required to meet the operations cost requirement. We present the high-level design for the antenna, which includes the antenna concept, specifications, initial surface analysis and deflections of the back-up-structure. We will also highlight further studies and design work that will contribute to the baseline design. The presentation will also discuss areas of technical risk, and where technical advances may be required for successful antenna production and

assembly.

**Author(s):** Dana Scott Dunbar, Brad McCreight, Robert Selina

**Institution(s):** NRAO, General Dynamics Mission Systems  
Contributing Team(s): General Dynamics Mission Systems

### **361.04 - Composite 18-m Antenna Reflector for the ngVLA (James Di Francesco)**

The ngVLA reference design calls for 244 18-m diameter antennas and 19 6-m diameter antennas which constitute >50% of the overall project cost. Canada, through National Research Council of Canada - Herzberg Astronomy and Astrophysics (NRC-HAA), is contributing to the reference design with studies of both antenna sizes based on the Single-piece Rim-supported Composite (SRC) technology developed by NRC-HAA. This presentation will provide an overview of the development that NRC-HAA has performed to meet the ngVLA requirements with SRC technology. The SRC technology was developed as a means of producing high performance radio reflectors using advanced materials and mass production techniques to meet the challenge of new large radio astronomy arrays. Repeatable production through application of standard industrial quality control techniques with the mould-based technology and the use of advanced composite materials enables light, stiff, thermally stable structures to be achieved at competitive costs. To date, NRC-HAA has produced 15-m diameter reflectors capable of operation up to 50 GHz. The ngVLA requirement to operate up to a maximum frequency of 116 GHz requires much higher surface accuracy and pointing performance. To meet these requirements, development has involved all aspects of the technology: structural design, materials selection (RF and structural), manufacturing process and tooling design. In addition, the feed-low offset Gregorian configuration selected for the ngVLA presents some challenge for the mount design as well. With an alt-az configuration needed to get down to low elevation angles, the elevation axis must be offset, resulting in increased cantilevered loads. This poster presents an overview of the design developed by NRC-HAA and its partners with emphasis on the novel design features and analysis results.

**Author(s):** Lynn Baker, Richard Hellyer, Dean R. Chalmers, Matt Fleming, Gordon E. Lacy, Mohammed Islam, Matt Wessel, James Di Francesco, Joe Jeff Fitzsimmons

**Institution(s):** National Research Council of Canada, Private Consultant, Minex Engineering Corporation, SED Systems

### **361.05 - The ngVLA Front End Reference Design (Sivasankaran Srikanth)**

The ngVLA will provide near-continuous frequency coverage from 1.2 - 116 GHz in multiple bands, with a gap at the atmospheric absorption band between ~50 - 70 GHz. Maximizing sensitivity for each band, while also minimizing the overall operating cost are the primary design goals. Therefore, receivers and feeds are cryogenically cooled, with multiple bands integrated into common cryostats. The proposed ngVLA

Front End design consists of six separate bands, each having an integrated feed. The upper five bands (2 - 6) are co-located within a single compact cryostat, while the lowest-frequency band (1) occupies a second cryostat of similar volume and mass. The Band 1 feed is cooled to 80K, while all other feeds are cooled to 20K. For optimum performance at higher frequencies, waveguide-bandwidth ( $\sim 1.66:1$ ) receivers are proposed for Band 3 (12.3 - 20.5 GHz), Band 4 (20.5 - 34 GHz), Band 5 (30.5 - 50.5 GHz) and Band 6 (70 - 116 GHz). Excellent low noise performance is achievable, without adding undue size or weight. An axially-corrugated conical feed horn design with wide opening angle ( $\sim 55^\circ$ ) is adopted. Aperture efficiency is comparable to traditional corrugated feed horns, but is simpler to fabricate, and very compact in size. Simulated and measured radiation patterns from a representative horn scaled for 4-8 GHz are presented. For continuous coverage between 1.2 - 12.3 GHz, waveguide or octave-bandwidth receivers are not cost-effective, given the  $> 10:1$  frequency range. In Band 1 (1.2 - 3.5 GHz) and Band 2 (3.5 - 12.3 GHz), wideband LNAs mated to a quad-ridge feed horn (QRFH) are used. Aperture efficiency and receiver noise temperature are not as optimum compared to the other bands: on the other hand, very significant cost savings are realized, by effectively halving the number of receivers and cryostats required per antenna. The cryostats incorporate Gifford-McMahon (G-M) cryocoolers, run at variable speed to reduce both the average running cost and mechanical wear. The helium compressor supplying the cryocoolers will also be a modern variable-speed scroll-type unit for the same reasons. This combination substantially reduces the overall operating cost of the cryogenic system.

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**Institution(s):** National Radio Astronomy Observatory  
 Contributing Team(s): WGrammer, DUrbain, SSturgis

### **361.06 - Trident Frequency Slice Architecture Correlator/Beamformer Reference Design for ngVLA (Michael P. Rupen)**

The Trident Frequency Slice Architecture Correlator/Beamformer (CBF) Reference Design describes a digital correlator/beamformer system that meets the science requirements of the ngVLA synthesis radio telescope - specifically, processing 28 GHz of aggregate bandwidth per polarization for 263 antennas with baselines up to 10,000 km. The reference design uses the Frequency Slice Architecture (FSA) developed by NRC which aims to minimize cost by reducing the processing hardware requirements while increasing modularity. The architecture is highly flexible, delivering many independent Frequency Slice Processors (FSPs) which can be allocated to continuum, spectral line (zoom), or beamforming work depending on the needs of an observation. The reference design implements an FSA CBF using NRC's TALON technology currently under development for the Square Kilometer Array Mid Frequency Telescope Correlator/Beamformer. The TALON technology is fiber-connected Intel Stratix 10 FPGA based signal processing boards in 2U (air-cooled) or 1U (liquid cooled) rack mount

server boxes. Key requirements for the correlator and beamformer and planned FSP function modes are discussed. FSP function modes include correlation, VLBI beamforming, and several flavors of pulsar beamforming. Pulsar beamforming FSP function modes include: true-delay beamforming using all antennas, true-delay beamforming using a fixed set of 130 antennas, and phase-delay beamforming using up to 168 antennas with a beamforming aperture diameter of up to 30 km. Each pulsar beamforming function mode provides trade-offs between sensitivity, channelization, and number of beams. Finally, a description of the high level signal processing architecture and physical architecture/technology is presented. While ngVLA will use future FPGA technology still in development, the reference design represents a low-risk solution using currently available technology that can be accurately costed. Cost, power consumption, and rack space requirements can be extrapolated to future technology nodes based on industry projections.

**Author(s):** Mike Pleasance, Michael P. Rupen, Brent Carlson  
**Institution(s):** National Research Council of Canada

### **361.07 - The ngVLA Reference Array Configuration (Viviana Rosero)**

The next generation Very Large Array (ngVLA) is a project of the National Radio Astronomy Observatory (NRAO) to design and build an astronomical observatory that will operate in a frequency coverage of  $\sim 1.2 - 116$  GHz with up to 20 GHz of instantaneous sampled bandwidth. The observatory will be a non-reconfigurable synthesis radio telescope operating in a phased or interferometric mode. The ngVLA is designed to accommodate a wide variety of scientific observations at centimeter-to-millimeter wavelengths aiming to deliver high sensitivity over a wide range of resolutions. The ngVLA array design includes three fundamental subarrays: the main interferometric array, the short baseline array and the long baseline array. Antennas within the main array are distributed over a range of physical scales and with different geometries: i) a dense core which provides high surface brightness sensitivity at  $\sim 1,000$  mas resolution; b) a multi-arm spiral capable of high-fidelity imaging at  $\sim 10$  mas scales; c) longer arms which provide mid-scale baselines for imaging at  $\sim 1$  mas. The main array will be augmented by a very compact array of smaller antennas which will provide sensitivity on larger angular scales, and four antennas of the main array will be equipped to measure total power in order to fill in the center of the (u,v)-plane. Additionally, a long baseline array (LBA) consisting of several outlying stations will provide intercontinental-scale baselines for achieving resolutions of  $\sim 0.1$  mas. The design of the array configuration is practical, accounting for logistic limitations such as topography, utility access, local RFI sources and land managements/availability. For each of the components of the array we investigate the image sensitivity, which depends on the required resolution and imaging fidelity.

**Author(s):** Alan Erickson, Eric Joseph Murphy, Viviana Rosero, Robert Selina, Eric Greisen, Chris Carilli, Brian Scott Mason

**Institution(s):** National Radio Astronomy Observatory,  
National Radio Astronomy Observatory

### **361.08 - The NGVLA Short Baseline Array(Brian Scott Mason)**

The Next Generation VLA (NGVLA) aims to provide excellent image fidelity for a broad spectrum of science cases. At the same time, in order to keep construction and operations cost as low as possible, the NGVLA antennas will not be reconfigurable. The NGVLA reference design calls for 214 18m diameter antennas distributed in a spiral pattern with baselines out to ~1,000 km. A 1-km diameter ``core" contains 94 of the 214 antennas, with baselines as short as 31m (set by antenna clearance requirements). Roughly 30% of identified NGVLA science cases require measuring larger spatial structures than the NGVLA main array will measure, i.e., they need shorter spacings than the NGVLA main array will provide. To meet this need, an NGVLA Short Baseline Array (SBA) has been designed and incorporated into the NGVLA reference design. The SBA consists of 19 6m antennas with baselines as short as 11m. In order to provide information on yet larger spatial scales, the SBA also includes four 18m total power antennas. This poster describes the SBA requirements and design. We are conducting simulations to quantify the SBA performance. Preliminary results from these simulations are also presented.

**Author(s):** Eric Joseph Murphy, Dean R. Chalmers, Brian Scott Mason, Robert Selina, Alan Erickson

**Institution(s):** NRAO, Herzberg Institute

### **361.09 - Long Baseline Capabilities of the next-generation VLA(James Braatz)**

As part of the current reference design, the ngVLA will include a Long Baseline Array (LBA) consisting of 30 18-m dishes that will extend across North America and beyond. The ngVLA LBA antennas will be grouped into 10 clusters of two to four each, located at sites with existing infrastructure (e.g., current VLBA sites and radio observatories), providing continental-scale baselines ( $B_{\text{max}} \sim 8860$  km). The LBA is designed to sample a broad range of angular scales for stand-alone use as a sub-array, as well as for integrated operations with the main array. The current configuration and number of antennas for the LBA has been chosen to ensure a  $S/N > 10$  detection at 10 GHz with a 0.6 mas beam of a source like the recent NS-NS merger gravitational wave event (GW170817) at the Advanced LIGO horizon distance of 200 Mpc, which will in turn allow for measurements (movies) of its expansion.

**Author(s):** Walter Briskin, Alan Erickson, Eric Joseph Murphy, Viviana Rosero, Robert Selina, Eric Greisen, T. J. Maccarone, Chris Carilli, James Braatz, Mark Reid

**Institution(s):** NRAO, Texas Tech University, NRAO, Smithsonian Astrophysical Observatory

### **361.10 - The Sensitivity of the Next Generation Very Large Array (ngVLA)(Bryan Butler)**

The design for the Next Generation Very Large Array (ngVLA) is now mature enough to make a much more detailed calculation of sensitivity than has been possible before. Previous estimates have suffered from uncertainties in design specifics, many of which have been reduced through further development. We use a more detailed model of antenna and feed design to estimate the aperture efficiency, and receiver designs that in some cases have been prototyped to estimate the receiver temperature. This is the most accurate estimate we have made to date, based on these updates. The atmospheric contribution to the system temperature is calculated using the most current measurements of atmospheric conditions at the Karl G. Jansky Very Large Array (VLA) site and in the surrounding region. Given this information an estimate of the point source sensitivity is calculated with much more confidence than previously. We compare these ngVLA sensitivity numbers directly with existing and near-future instruments in the frequency range of ngVLA (1.2 to 116 GHz), namely the current VLA, the Atacama Large Millimeter/submillimeter Array (ALMA) and the Square Kilometer Array phase 1 for Mid frequencies (SKA1-Mid). We find that the ngVLA, with its current design, is roughly a factor of 10 more sensitive than VLA and ALMA, and factor of 6-7 more sensitive than SKA1-Mid (current deployment baseline) for spectral line observations, and almost a factor of 20 more sensitive than all three for continuum observations due to increased collecting area and bandwidth above 20 GHz (should SKA1-Mid eventually include receivers above the 14 GHz max frequency in the current deployment baseline design). These calculations will remain under investigation as the project matures. The values presented herein represent the state of the project as it stands today, and can be used to inform studies of the scientific potential of the ngVLA.

**Author(s):** Eric Joseph Murphy, Wes Grammer, Chris Carilli, Bryan Butler, Robert Selina

**Institution(s):** National Radio Astronomy Observatory

### **361.11 - The Next Generation Very Large Array Operations Concept(Amanda Kepley)**

The Next Generation Very Large Array (ngVLA) will consist of approximately 263 reflector antennas operating from 1.2 to 116GHz in either phased or interferometric mode with approximately 214 18m antennas in the main array, 19 6m antennas in a short baseline array, co-located near the core, and 30 18m in a long baseline array to provide continental scale baselines. It will be operated as a proposal-driven instrument with the science program determined by PI-led proposals. Proposals will be peer reviewed and ranked based on scientific merit and technical feasibility. The scientific program for the telescope will be scheduled dynamically based on environmental conditions and array status, in accordance with the user's scientific requirements. The data will generally be

delivered to the PIs and the broader scientific community as Science Ready Data Products, i.e., automated pipelines will deliver calibrated raw data and higher level data products. Through the delivery of quality-assured Science Ready Data Products, and the provision of standard observing strategies, the Observatory will aim to support both a broad community of scientific users and to facilitate multi-wavelength and multi-messenger astronomy. The operation and maintenance of the array will be supported by three primary centers to minimize staff at the array core. These will include a Maintenance Center located near the array core, an Array Operations and Repair Center near Socorro, NM, and a Science Operations Center and Data Center likely co-located in a large metropolitan area. The array will be operated primarily in sub-array mode, which will allow array maintenance and science to occur simultaneously. To minimize maintenance costs, the design of the ngVLA will focus on maintenance efficiency, including using modularized components, minimizing preventative maintenance and repair visits, and automating diagnostics.

**Author(s):** Amanda Kepley

**Institution(s):** National Radio Astronomy Observatory  
Contributing Team(s): ngVLA Operations Working Group

### **361.12 - Reaching Communities and Creating New Opportunities with the ngVLA(Lyndelee Von Schill)**

The National Radio Astronomy Observatory (NRAO) recognizes that the next generation Very Large Array (ngVLA) project will span more than 10 years in development. This longevity offers a unique opportunity for the Observatory to build a pipeline for future employees from the regions in which the ngVLA will be present. Our Broader Impact and Broadening Participation efforts, then, include a proactive, intentional plan to include workforce development as an integral part of the entire ngVLA project, from beginning construction through and beyond first science. The NRAO acknowledges that there are multiple approaches to workforce pipeline development, and has embraced coordinated efforts and strategies, built around the concepts of Broader Impacts and Broadening Participation principles. The NRAO maintains a coordinated approach towards building a diverse, well-prepared workforce includes K-12 education, public outreach, higher education and research opportunities, and post-doc and professional development programs. The NRAO Office of Diversity and Inclusion (ODI) and the Education and Public Outreach (EPO) Department serve the strategic goal of the Observatory to broaden public awareness of, support for, and participation in Science, Technology, Engineering, and Mathematics (STEM). ODI operates a suite of programs, including the National Astronomy Consortium (NAC), designed to support underrepresented minority undergraduate and graduate students in pursuit of careers in STEM. EPO highlights the discoveries, technologies, and careers pioneered and exemplified by the NRAO via multipurpose engagement strategies that include face-to-face and standalone learning programs, products, and public services for the general public and K-12 students, with attention to reaching diverse audiences. This poster describes some

identified opportunities for new, substantial, outcome-oriented Broader Impact (BI) and Broadening Participation (BP) activities, enabled by the development and realization of a next-generation Very Large Array (ngVLA). NRAO expects to continue to ask the community for input into this important component of the ngVLA project.

**Author(s):** Lyndelee Von Schill, Suzanne Gurton

**Institution(s):** National Radio Astronomy Observatory

### **361.13 - The Green Bank Array's Contribution To Very Long Baseline Interferometry(Anthony Minter)**

The Green Bank Array (GBA) is a proposed array of radio telescopes located at the Green Bank Observatory in the National Radio Quiet Zone which will operate as a stand-alone instrument or in combination with the Green Bank Telescope (GBT). It could be used for pulsar timing, transients, star formation research and Very Long Baseline Interferometry (VLBI). The array will consist of ten 18-m antennas (based on the ngVLA design) and will operate over 1.2 - 116 GHz. By itself, the GBA will have the collecting area of the Parkes telescope and will operate with good sensitivity at all of its operational frequencies. In the configuration that is currently being studied, most of the GBA will be within ~1 km of the GBT. The GBA's sensitivity at 3mm will be comparable to the LMT. The GBA+GBT will offer exceptional sensitivity from 1.2 - 50 GHz and will match or exceed the sensitivity of ALMA over most of their overlapping frequency coverage. The GBA's location and sensitivity will allow it to provide significant contributions to long baseline interferometry, especially at 3mm. For the first time the community would have sufficient sensitivity at 3mm to expand long baseline science beyond its traditional study of bright AGN. We will highlight how the GBA will enhance VLBI performed with the ngVLA, global VLBI sessions and Global mm-wave VLBI (GMVA) observations. The Green Bank Observatory is a facility of the National Science Foundation operated under a cooperative agreement by Associated Universities, Inc.

**Author(s):** Tapasi Ghosh, Joy Skipper, Natalie Butterfield, Ryan S Lynch, Anthony Minter, Ronald Maddalena, David Frayer, Felix Lockman, Andrew Seymour, Amber Bonsall, Frank Ghigo, William Armentrout, Karen O'Neil

**Institution(s):** Green Bank Observatory

### **361.14 - The GBT as the Short-Spacing Instrument for the ngVLA(David Frayer)**

The next generation Very Large Array project (ngVLA) would represent a major step forward in sensitivity and resolution for radio astronomy, with the ability to achieve 1 milli-arcsec resolution at 100 GHz. However, the trade-off between spatial resolution and surface-brightness sensitivity is unavoidable for interferometers. Large single-dishes complement interferometers by enabling science on spatial scales which are resolved out by interferometers. The Green Bank Telescope

(GBT) is the only facility currently operating over the full range of proposed ngVLA frequencies (1-116 GHz). I discuss the ability of the GBT to serve as a short-spacing instrument for the ngVLA.

**Author(s):** David Frayer

**Institution(s):** Green Bank Observatory

### **361.15 - Low-Frequency Commensal Systems: from VLITE to LOBO to ngLOBO (Wendy Peters)**

The VLA Low-band Ionosphere and Transient Experiment (VLITE, <<http://vlite.nrao.edu/>>) is a commensal observing system on the NRAO Karl G. Jansky Very Large Array (VLA). The separate optical path of the prime-focus sub-GHz dipole feeds and the Cassegrain-focus GHz feeds allows for simultaneous observations during most standard GHz frequency VLA observations. Currently, 16 VLA antennas are outfitted with dedicated samplers and use spare fibers to transport the 320-384 MHz band to the VLITE CPU-based correlator. VLITE operates at nearly 70% wall time with roughly 6200 hours of VLA time recorded each year. Initial goals for the system included exploring the scientific potential of a commensal low frequency system for ionospheric remote sensing, astrophysics and transients. In the short term, we are working to expand VLITE to all 27 VLA antennas and to the maximum available low band receiver bandwidth (224-480 MHz). The correlator for this Low Band Observatory (LOBO) would have the flexibility to also incorporate lower frequency signals from the new VLA 74 MHz system, including from VLA dishes (60-80 MHz) and stand-alone Long Wavelength Array (LWA) aperture array stations (20-80 MHz). In the longer term, we look towards leveraging the vast infrastructure of the ngVLA to include a commensal low frequency capability, called ngLOBO. As described in our community white paper (Taylor et al. 2018; arXiv:1708.00090), ngLOBO has three primary scientific observing missions: (1) Radio Large Synoptic Survey Telescope (Radio-LSST): one beam that is commensal with the ngVLA will conduct a continuous synoptic survey of large swaths of the sky for both slow and fast transients; (2) This same commensal beam will provide complementary low frequency images of all ngVLA targets when such data enhances their value. (3) Independent beams from the ngLOBO-Low aperture array will conduct targeted research in astrophysics, Earth science and space weather applications, engaging new communities and attracting independent resources.

**Author(s):** Jason Kooi, Walter Briske, Matthew Kerr, Jayce Dowell, Scott David Hyman, Frank Schinzel, Greg B Taylor, Julia Deneva, Namir E Kassim, Wendy Peters, Tracy Clarke, Kristina Nyland, Simona Giacintucci, Paul S Ray, Brian Hicks, Joseph Helmboldt, Emil Po

**Institution(s):** Naval Research Laboratory, Long Baseline Observatory, National Radio Astronomy Observatory, Sweet Briar College, University of New Mexico, National Research Council, George Mason University

### **361.16 - Peering into planet formation: from ALMA and JVLA to the ngVLA (Andrea Isella)**

In the last five years, ALMA and JVLA have delivered images of the environment surrounding young stars that transformed our understanding of planet formation. A major discovery is that circumstellar dust and pebbles are not smoothly distributed around the star but they instead accumulate in narrow circular rings that are created by the radial motion of solid particles towards local maxima of the gas pressure. These structures are thought to originate from the gravitational interaction between the circumstellar material and giant planets, and might be the place where most of the rocky planets form. In my poster, I will present results from the ALMA "Disk Substructures at High Angular Resolution Project" and from recent JVLA observations that probe the formation of giant planets as close as 10 au from the central star. I will further discuss how the next generation of long-baseline interferometers (e.g., the next generation VLA) will enable us to extend the study of planet formation in the region where most of the planets are expected to form (<10 au) and probe the presence of planets as small as a few Earth masses.

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**Institution(s):** Rice University, Cal State Northridge, CfA-Harvard, University of Nevada, Las Vegas, University of Heidelberg, Los Alamos National Lab, Ludwig-Maximilians University

### **361.17 - Surveying the Protostellar Population Powering Extended Green Objects (EGOs) with the VLA (Allison Towner)**

We present 3.6 cm and 1.3 cm (C- and K-band) JVLA observations of 10 nascent massive protoclusters in the Milky Way. These protoclusters are typical young, massive objects with total FIR luminosities ranging from 1,000 to 40,000  $L_{\text{sun}}$ , and exist in a specific evolutionary state that is a) prior to the onset of significant ionization feedback and b) in which active outflows dominate their infrared appearance. These VLA observations cover known 6.7 GHz Class II CH<sub>3</sub>OH and 22 GHz H<sub>2</sub>O masers in these objects, as well as 3.6 cm and 1.3 cm continuum observations with sensitivities of tens of micro-Janskys at an angular resolution of ~0.4-arcseconds. These observations address two key areas of massive protocluster research: 1) Well-sampled SEDs for the individual protostars in these sources will allow us to disentangle the various types of centimeter-wavelength continuum emission (dust, free-free, synchrotron, etc.) that may be present for each protostar, and the high angular resolution enables us to further refine the specific physical emission mechanisms (e.g. gravitationally-trapped HC HII region, ionized jet, stellar wind, etc.) in each MYSO. 2) These SEDs will also allow us to examine the demographics (evolutionary stage, mass, clustering, mass segregation if any) of each protocluster. In addition to



characterizing the unique properties of each individual protocluster, we will also be able to compare our data to the predictions of current theories of massive star formation.

**Author(s):** Todd Russell Hunter, Crystal Brogan, Allison Towner,

**Institution(s):** University of Virginia, National Radio Astronomy Observatory

### **361.18 - Stellar Emission as a Source of Flux Bias in Debris Disks(Jacob White)**

Our understanding of stellar atmospheres and our ability to infer architectures of extrasolar planetary systems rely on understanding the emission of stars at sub-millimeter to centimeter wavelengths. Observations of debris-poor stars at these wavelengths, however, are largely non-existent. In this presentation we describe how unconstrained stellar emission can interfere with the search for and accurate characterization of circumstellar debris, how recent ALMA and VLA observations are working to solve this issue, and how the ngVLA is the only facility that can properly build a thorough catalog of radio observations of debris poor stars. The sensitivity of ALMA and VLA has only recently allowed for observations of some nearby debris-poor, intermediate mass stars and enable a preliminary analysis of their stellar atmospheres (White et al. 2018). In order to study unresolved debris around a range of various types of stars, which will be a key science goal of the ngVLA, a large catalog of the radio spectra of various stellar types is imperative. The ngVLA, with its unprecedented  $< 10^{-24}$  W m<sup>-2</sup> Hz<sup>-1</sup> sensitivity, is the only facility with the that will allow for the observations of a broad range of stellar spectral types in a feasible amount of time. The observations will enable the building and testing of accurate models of stellar emission (e.g., PHOENIX), which in turn are required for evaluating both the occurrence and abundance of debris over the proposed wavelength range of the ngVLA.

**Author(s):** Jacob White

**Institution(s):** Konkoly Observatory

### **361.19 - ngVLA Key Science Goal 2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry(Brett McGuire)**

One of the most challenging aspects in understanding the origin and evolution of planets and planetary systems is tracing the influence of chemistry on the physical evolution of a system from a molecular cloud to a solar system. Existing facilities have already shown the stunning degree of molecular complexity present in these systems. The unique combination of sensitivity and spatial resolution offered by the ngVLA will permit the observation of both highly complex and very low-abundance chemical species that are exquisitely sensitive to the physical conditions and evolutionary history of their sources, which are out of reach of current observatories. In turn, by understanding the chemical evolution of these complex molecules,

unprecedentedly detailed astrophysical insight can be gleaned from these astrochemical observations. This poster will overview a number of key science goals in astrochemistry which will be enabled by the ngVLA, including: 1) imaging of the deepest, densest regions in protoplanetary disks and unveiling the physical history through isotopic ratios 2) probing the ammonia snow line in these disks, thought to be the only viable tracer of the water snowline 3) observations of the molecular content of giant planet atmospheres 4) detections of new, complex molecules, potentially including the simplest amino acids and sugars 5) tracing the origin of chiral excess in star-forming regions

**Author(s):** Brett McGuire

**Institution(s):** National Radio Astronomy Observatory

**Contributing Team(s):** ngVLA Science Working Group

### **361.20 - Zeeman Splitting Opportunities with the ngVLA(Timothy Robishaw)**

There are over 30 astrophysically significant atomic and molecular radio transitions that are capable of exhibiting the Zeeman effect. While only ten of these transitions will occur in the optimized ngVLA band covering 10-50 GHz, all but three will be observable in the full 1.2-116 GHz bandpass. The collecting area and angular resolution of the ngVLA will allow for new and exciting opportunities to study magnetic fields via Zeeman splitting. Potentially fruitful transitions and targets will be presented along with a discussion of antenna optics design considerations that could minimize the instrumental polarization effects that have previously hindered Zeeman measurements in diffuse gas.

**Author(s):** Timothy Robishaw

**Institution(s):** Dominion Radio Astrophysical Observatory

### **361.21 - ngVLA Key Science Goal 3: Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time(Daniel Dale)**

The Next Generation Very Large Array (ngVLA) will fundamentally advance our understanding of the formation processes that lead to the assembly of galaxies throughout cosmic history. The combination of large bandwidth with unprecedented sensitivity to the critical low-level CO lines over virtually the entire redshift range will open up the opportunity to conduct large-scale, deep cold molecular gas surveys, mapping the fuel for star formation in galaxies over substantial cosmic volumes. Imaging of the sub-kiloparsec scale distribution and kinematic structure of molecular gas in both normal main-sequence and starburst galaxies back to early cosmic epochs will reveal the physical processes responsible for star formation and black hole growth in galaxies. In the nearby universe, the ngVLA has the capability to survey the structure of the cold, star-forming interstellar medium at parsec-resolution out to the Virgo cluster. A range of molecular tracers will be accessible to map the kinematical, physical, and chemical state

of the gas as it flows in from the outer disk, assembles into clouds, and experiences feedback due to star formation or accretion into central super-massive black holes. These investigations will crucially complement studies of the star formation and stellar mass histories with the Large UV/Optical/Infrared Surveyor and the Origins Space Telescope, providing the means to obtain a comprehensive picture of galaxy evolution through cosmic times.

**Author(s):** Roberto Decarli, Alberto Bolatto, Desika Narayanan, Dominik A Riechers, Caitlin M Casey, Chris Carilli, Eric Joseph Murphy, Daniel Dale, Fabian Walter

**Institution(s):** University of Wyoming, NRAO, Cornell University, University of Texas, University of Maryland, University of Florida, INAF, MPIA Contributing Team(s): ngVLA Galaxy Assembly through Cosmic Time Science Working Group, ngVLA Galaxy Ecosystems Science Workin

### **361.22 - AGN life cycles, SMBH Masses, and Galactic Winds: Advancing our Understanding of SMBH-Galaxy Co-evolution with the ngVLA(Kristina Nyland)**

A key missing element in our understanding of cosmic assembly is the nature of energetic feedback from supermassive black holes (SMBHs) and the impact of active galactic nuclei (AGN) on galaxy evolution. The next-generation Very Large Array (ngVLA), which will provide a ten-fold improvement in sensitivity and angular resolution compared to the current VLA, will serve as a transformational new tool in our understanding of AGN feedback as a function of redshift and environment. By combining broadband continuum data with spectral line measurements of the cold gas contents and kinematics of galaxies, the ngVLA will probe the evolution and life cycles of the radio-quiet and radio-loud AGN populations in unprecedented detail, quantify the energetic impact of AGN feedback on the star-forming reservoirs of gas-rich galaxies, and place constraints on SMBH formation and growth. Here, we present an overview of how the current reference design of the ngVLA will facilitate these advancements in our understanding of SMBH-galaxy co-evolution, with an emphasis on prospects for continuum surveys, the detection of molecular outflows out to high redshifts, and precision CO-dynamics-based SMBH mass measurements. We also discuss the importance of the next-generation Low-band Observatory (ngLOBO), a commensal low-frequency enhancement to the main ngVLA design, to maximize the utility of the ngVLA for AGN science.

**Author(s):** Isabella Prandoni, Mark Lacy, Tracy Clarke, Justin Spilker, Wiphu Rujopakarn, Kristina Nyland, Dipanjan Mukherjee, Allison Kirkpatrick, Katherine Alataloo, Benjamin Boizelle, Pallavi Patil, Amy Kimball, Jeremy Harwood, Kirsten R Hall

**Institution(s):** University of Hertfordshire, oSpace Telescope Science Institute, National Radio Astronomy Observatory, Naval Research Laboratory, Chulalongkorn University, National Research Council, University of Texas, University of Kansas, Johns Hopkins University

### **361.23 -**

#### **Evidence of Complex B-field Structures in the ICM surrounding Cygnus A(Makhuduga Lerato Sebokolodi)**

A new high sensitivity polarization study of Cygnus A using 2-18 GHz JVLA data shows significant depolarization below 6 GHz with 0.75" (750 pc) resolution, as well as complicated polarization structures. The newly measured rotation measures (RM) are consistent with those obtained from previous studies [1, 2]; with RMs ranging from -3000 to +1300 rad/m/m in the western lobe and -5500 to +3000 rad/m/m in the eastern lobe. Our preliminary analysis indicates multi-scale B-fields with scales > 120 kpc and < 300 pc in the vicinity of Cygnus A. There is also a strong evidence that these large RMs originate from the large-scale uniform B-fields in the ambient ICM -- in agreement with [1, 2]. We show that the observed depolarizations and polarization structures at our optimum resolution (750 pc) may result from small-scale fluctuations across the beam. However, it still remains a mystery whether all these complex B-fields are in the ambient ICM, or whether some are in compressed gas local to the source. But we are confident that internal effects due to a mixing of thermal and synchrotron gas are minor. Ideal observations for addressing this problem would be those that can achieve high resolutions < 0.3" while preserving the spectral resolution (2-18 GHz). Achieving this requires an instrument with a minimum baseline that is 3x longer than the current JVLA longest baseline. Such baseline lengths are typical of the ngVLA (180-300 km) and the SKA (200 km). We present the above ongoing analysis, and the different techniques utilised including RM Synthesis [3] and direct fitting to Stokes Q and U data. References[1] Perley R.A., & Carilli C.L. 1996, Cygnus A -- Study of a Radio Galaxy, 168[2] Dreher et.al., 1987, APJ, 316, 611[3] Brentjens M.A., & de Bruyn., A.G. 2005, A&A, 441, 1217

**Author(s):** Makhuduga Lerato Sebokolodi,  
**Institution(s):** NRAO, SKA SA

### **361.24 - ngVLA searches for pulsars at the Galactic center(Paul Demorest)**

Detection of one or more pulsars in orbit about our galaxy's central supermassive black hole (Sgr A\*) is a long-standing, yet still elusive, goal in physics and astrophysics. Timing observations of a pulsar as it orbits Sgr A\* would provide high-precision measurements of the black hole properties (mass, spin), and new tests of fundamental predictions of general relativity such as the no-hair theorem and cosmic censorship conjecture. Characterizing a population of pulsars at the Galactic center would also give new astrophysical insight into the mass distribution, interstellar medium (ISM) properties, magnetic field, and star formation history of this complex and interesting region. The presence of young massive stars in the region leads to predictions of large numbers of neutron stars. However despite many observational attempts, only a handful of pulsars have been detected in the central ~degree, and none

close enough to Sgr A\* to have orbital timescales of ~years or faster. The conventional explanation for this is that strong scattering in the ISM broadens pulsed radio signals in time, to the point that they become undetectable; observing at higher frequencies reduces this effect, but the steep spectrum of most radio pulsars means the signals also become much fainter. The 2013 discovery of the magnetar J1745-2900 only 0.1 pc in projection from Sgr A\* challenged this viewpoint, leading to some claims of a "missing pulsar" problem. However even with the reduced scattering strength inferred from this source, no existing radio telescopes have yet had the sensitivity to detect faint millisecond pulsars (MSPs) at the Galactic center. The proposed next-generation Very Large Array (ngVLA) will have nearly an order of magnitude more sensitivity than any current telescope in the ~5--30 GHz range that is expected to be the sweet spot for detection of pulsars -- including MSPs -- at the Galactic center. In this presentation we will outline the motivations, current knowledge, and predictions for a pulsar search in the Galactic center using the ngVLA, one of the key science goals for the instrument.

**Author(s):** Michael Kramer, T. Joseph W Lazio, Norbert Wex, Scott M. Ransom, Julia Deneva, James Cordes, Shami Chatterjee, Jason Dexter, Geoffrey C. Bower, Paul Demorest, Robert Wharton, Lijing Shao

**Institution(s):** National Radio Astronomy Observatory, Cornell University, ASIAA, Max Planck Institute for Extraterrestrial Physics, George Mason University, JPL, Caltech, Max Planck Institute for Radio Astronomy, National Radio Astronomy Observatory

### 361.25 - ngVLA Key Science Goal 5

#### Understanding the Formation and Evolution of Black Holes in the Era of Multi-Messenger Astronomy (T. Joseph W Lazio)

The next-generation Very Large Array (ngVLA) will be a powerful telescope for finding and studying black holes across the entire mass range. High-resolution imaging abilities will allow the separation of low-luminosity black holes in the local Universe from background sources, thereby providing critical constraints on the mass function, formation, and growth of black holes. Its combination of sensitivity and angular resolution will provide new constraints on the physics of black hole accretion and jet formation. Combined with facilities across the spectrum and gravitational wave observatories, the ngVLA will provide crucial constraints on the interaction of black holes with their environments, with specific implications for the relationship between evolution of galaxies and the emission of gravitational waves from in-spiraling supermassive black holes and potential implications for stellar mass and intermediate mass black holes. The ngVLA will identify the radio counterparts to transient sources discovered by electromagnetic, gravitational wave, and neutrino observatories, and its high-resolution, fast-mapping capabilities will make it the preferred instrument to pinpoint electromagnetic counterparts to events such as supermassive

black hole mergers. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

**Author(s):** E G Kording, Joseph Simon, Sarah Burke-Spolaor, Jeremiah K Darling, Mark Reid, Laura Chomiuk, Dario Carbone, Gregory R Sivakoff, Brian Metzger, Davide Lazzati, Xin Liu, J. C. A. Miller-Jones, Pallavi Patil, Vikram Ravi, Katherine Alatalo, Preeti Kharb,

**Institution(s):** International Centre for Radio Astronomy Research-Curtin University, Rochester Institute of Technology, Univ degli Studi di Torino, INAF-Istituto di Radioastronomia, Oregon State University, Purdue University, University of Illinois Urbana-Champaign,

### 361.26 - VLBA Observations of the Structure and Motions of the Inner Parsec of the M87 Jet (Robert Craig Walker)

Walker et al (2018, Ap.J. 855, 128) reported results from Very Long Baseline Array (VLBA) observations of M87 at 43 GHz which include intensive monitoring in 2007 and 2008 plus 17 years of roughly annual observations, for a total of 50 individual observations. The results from that study are reviewed in this poster. The central radio source in M87 provides the best opportunity to study jet formation because it has a large angular size for the gravitational radius of the black hole and has a bright jet that is well resolved by VLBI observations. The 43 GHz VLBA observations have a resolution of about  $0.21 \times 0.43$  milli-arcseconds (mas) which is about 30 by 60 Schwarzschild radii ( $R_s$ ) for  $D = 16.7$  Mpc and  $M_{bh} = 6.1 \times 10^9 M_{sun}$ . Our high-dynamic-range images clearly show the wide-opening-angle structure of the jet and show the counter-jet. The jet and counter-jet are nearly symmetric in the inner 1.5 milli-arcseconds (0.12 pc in projection) with both being edge brightened. Both show deviations from parabolic shape in the form of an initial rapid expansion in width and subsequent contraction followed by further rapid expansion and, beyond the visible counter-jet, subsequent collimation. Proper motions and counter-jet/jet intensity ratios both indicate acceleration from apparent speeds of less than about  $0.5c$  to greater than about  $2c$  in the inner about 2 mas (0.16 pc or 240  $R_s$  in projection) and suggest a helical flow. The jet displays a sideways shift with an approximately 8 to 10 year quasi-periodicity. The shift propagates outwards non-ballistically and significantly more slowly than the flow speed revealed by the fastest moving components. Polarization data show a systematic structure with magnetic field vectors that suggest a toroidal field close to the core.

**Author(s):** Frederick B. Davies, Chun Ly, William Junor, Robert Craig Walker, Philip E. Hardee

**Institution(s):** National Radio Astronomy Observatory, Steward Observatory, University of Arizona, University of Alabama, Los Alamos National Laboratory, University of

California, Santa Barbara

### **361.27 - Intermediate-Mass Black Holes in Globular Cluster Systems(J. M. Wrobel)**

Using the Next Generation Very Large Array (ngVLA), we will make a comprehensive inventory of intermediate-mass black holes (IMBHs) in hundreds of globular cluster (GC) systems out to a distance of 25 Mpc. These systems hold tens of thousands of GCs in total. We describe how to convert an ngVLA signal from a GC to an IMBH mass according to a semi-empirical accretion model. Simulations of gas flows in GCs would help to improve the robustness of the conversion. Our IMBH inventory is well suited for ngVLA Early Science. IMBHs have masses of about 100 to 100,000 solar masses. Finding them in GCs would validate a formation channel for seed black holes in the early universe and inform event predictions for gravitational wave facilities. Reaching a large number of GCs is key, as Fragione et al. (2018) predict that only a few percent will have retained their gravitational-wave fostering IMBHs. The NRAO is a facility of the NSF, operated under cooperative agreement by Associated Universities, Inc.

**Author(s):** J. M. Wrobel, K. E. Nyland, T. J. Maccarone, J. C. A. Miller-Jones

**Institution(s):** NRAO-NM, NRAO-CV, Curtin University, Texas Tech University

## **362 - The CMB Posters**

### **362.01 - Using 3-Dimensional Fast Fourier Transforms to Simulate Cosmic Microwave Background Maps on a Spherical Cap(Eric Goetz)**

The current methods of simulating the Cosmic Microwave Background (CMB) involve either simulating the entire sky using spherical transforms or simulating a flat patch with fast Fourier transforms (FFTs). For patches that are too large to be considered flat but much less than the full sky, the former method is inefficient and the latter is inaccurate. One alternative method of CMB simulation is to simulate the random processes behind the CMB in a 3-dimensional box that contains the part of the sphere that we want to measure. Then, we can select the points we want from the box. This method should be more efficient than previous methods because it performs simulations over a box instead of a sphere, allowing for the use of FFTs in place of much slower spherical harmonic transforms. For this method to work, there must be a 3-dimensional power spectrum defined on the box that has the same correlation function as the angular power spectrum. Since the angular power spectrum is known, this becomes a linear programming problem, where the constraints for the 3-D power spectrum are that it matches the angular power spectrum over the observed region and that it be non-negative. If a power spectrum satisfying these constraints exists, we can use it to create maps of the CMB with the same statistical properties as the observed CMB. These maps can then be used to test theories about the early universe. We have solved this linear

programming problem for a variety of realistic scenarios. We have performed extensive statistical tests comparing the statistics of maps produced via FFT simulation with maps produced via standard spherical harmonic methods, and found the two methods to be statistically indistinguishable.

**Author(s):** Eric Goetz, Emory Bunn

**Institution(s):** University of Richmond

### **362.02 - BICEP Array: a multi-frequency degree-scale CMB Polarimeter(Howard Hui)**

Bicep Array is the newest multi-frequency instrument in the Bicep/Keck Array program. It is comprised of four 550mm aperture refractive telescopes observing the polarization of the cosmic microwave background (CMB) at 30/40, 95, 150 and 220/270 GHz with over 30,000 detectors. We present an overview of the receiver, detailing the optics, thermal, mechanical, and magnetic shielding design. Bicep Array follows Bicep3's modular focal plane concept, and upgrades to 6" wafer to reduce fabrication with higher detector count per module. The first receiver at 30/40GHz is expected to start observing at the South Pole during the 2019-20 season. By the end of the planned Bicep Array program, we project  $0.002 \leq \hat{f}(r) \leq 0.006$ , assuming current modeling of polarized Galactic foreground and depending on the level of delensing that can be achieved with higher resolution maps from the South Pole Telescope.

**Author(s):** Howard Hui

**Institution(s):** California Institute of Technology

### **362.03 - Weak gravitational lensing & CMB probes of spatially varying fine-structure constant and baryon/dark-matter relative abundances.(Daniel Grin)**

Cosmic microwave background (CMB) anisotropies are Gaussian and isotropic at linear order. The presence of long wavelength modulating fields, however, can introduce non-Gaussianity and statistical anisotropy in the CMB. For example, the dark matter present along the line of sight between observers and the last-scattering surface gravitationally lenses the background CMB. Weak gravitational lensing of the CMB has already been detected at  $\sim 40 \sigma$  in Planck satellite data! There are discrepancies between the observed CMB lensing signal and expectations from  $\Lambda$ CDM theory, offering the opportunity to explore the possibility of other long wavelength modulating field, which might be able to relieve the tension between the predicted and observed amplitude of CMB weak lensing. A variety of particle-physics models for the origin of the baryon asymmetry and density fluctuations in the universe predict compensated isocurvature perturbations, spatial fluctuations in the relative densities of baryons and cold dark matter. It is also possible that the strength of the electromagnetic interaction is set by a novel scalar field with couplings to the standard model, sourcing spatial fluctuations in the fine structure constant. Here, the observational

motivation for these models is reviewed and the imprint of both these possibilities on CMB statistics (and weak lensing observables in particular) is computed. Current data are used to probe these models, forecasts are made for the sensitivity of upcoming efforts like CMB Stage IV and the Simons Array, and a variety of other theoretical considerations are explored.

**Author(s):** Tristan Smith, David Robinson, Davy Qi, Julian Munoz, Daniel Grin, Ely Kovetz, Rhiannon Smith, Kyle Yee  
**Institution(s):** Haverford College, Johns Hopkins University, Harvard University, Swarthmore College

### **362.04 - Polychromatic Map Reconstruction from Time-Ordered Data of Telescopes with Asymmetric and Wavelength-Dependent Antenna Patterns(Connor Mooney)**

Imaging telescopes with asymmetric antenna patterns that vary with wavelength can create time-ordered data that may be processed into multiple images corresponding to different bands of wavelengths from just a single set of scans. Our goal is to quantify, both statistically and analytically, the ability of these telescopes to perform such a reconstruction given different cases. In the case that the telescope is observing the full sky, we reconstruct our maps via a spherical harmonic basis. In this way, the reconstructed images are described as a set of spherical harmonic coefficients, whose properties can be analyzed and computed relatively easily. In the case that the telescope is only observing part of the sky, we must reconstruct maps with a value assigned to each discretized point in the sky, and thus more computation and analysis is required. In each case, we find eigenvectors in wavelength space that maximize the reconstructed signal-to-noise ratio, and use these to quantify the number of maps that can be reconstructed accurately. This project is inspired by the instrument QUBIC, whose antenna pattern consists of a large central gaussian peak, along with many smaller gaussian peaks that are both asymmetrically distributed and separated by a distance that is dependent on wavelength.

**Author(s):** Solomon Quinn, Emory Bunn, Connor Mooney  
**Institution(s):** University of Richmond

### **363 - Surveys and Large Programs -- Posters** **363.01 - The Breakthrough Listen Search for Intelligent Life: Flux and Polarization Calibration with the Green Bank Telescope(Mark Siebert)**

Polarization is an often overlooked property of electromagnetic radiation that can tell us a great deal about the underlying emission mechanisms of astronomical objects. It is critical for identifying stellar flare or potentially exoplanet radio emission with single dish radio telescopes, as it provides an important discriminant against radio frequency interference (RFI). Polarization information (in the form of the four Stokes parameters) is obtained through linear combinations of raw complex voltages from two orthogonal dipoles; however, Stokes parameters are highly sensitive to instrument error. In order to

obtain accurate polarization information in radio observations, a calibration routine is crucial for identifying and correcting for this error. Currently, generating polarization information is not yet standard practice for Breakthrough Listen observations. Here I present a method for creating calibrated full-Stokes data products of Breakthrough Listen observations on the 100m Robert C. Byrd Green Bank Telescope using noise diode measurements and Mueller Matrix algebra. This method can be employed for any future GBT observations and could lead to a variety of promising astrophysical studies.

**Author(s):** J. Emilio Enriquez, Mark Siebert,  
**Institution(s):** Cornell University, University of California, Berkeley

### **363.02 - The Breakthrough Listen Search for Intelligent Life: Characterization of Pulsars at High Frequencies(Caroline Bamberger)**

The Breakthrough Listen (BL) project conducts searches for signals from Extra-Terrestrial Intelligence across a wide range of frequencies from two of the world's largest telescopes. Pulsars are integral to these BL programs at both the Green Bank Telescope (GBT) and the Parkes Telescope for system integrity checks during every observing session. For the BL-GBT observing program above 8 GHz, there are only a handful of pulsars which have been studied previously in detail, most of which were studied over 2 decades ago. This results in a limited sample and increased overhead during observations. Beyond using them for quality checks, pulsars are interesting objects in their own right and high frequency data can allow for a better understanding of emission mechanisms and pulse evolution. The BL-GBT backend is in a unique position to study pulsars at high frequencies because of its capabilities to record data across a wide bandwidth ( $> 4$  GHz). We have observed over 20 pulsars at X-band (8-12 GHz) and intend to study more at both X and C-band (4-8 GHz). By developing an automated python-based pipeline, we are able to fully calibrate flux and polarization properties of the pulsars. Using the wide-bandwidth, high-sensitivity data from the BL-GBT backend has enabled us to study and calibrate a large number of pulsars never before detectable at such frequencies. This study has more than doubled the number of pulsars useful for the BL-GBT program for its high frequency observations, allowing for more efficient use of telescope time. Overall this data greatly adds to the study of high-frequency radio emissions of pulsar by vastly increasing the number of properly calibrated pulsars studied above 4 GHz.

**Author(s):** Caroline Bamberger,  
**Institution(s):** Cornell University, Berkeley SETI Research Center

### **363.03 - HST/COS Ecliptic-poles Stellar Survey (EclipSS)(Thomas R Ayres)**

Ecliptic-poles Stellar Survey (EclipSS) currently is collecting far-ultraviolet spectra (115-143 nm), using HST's ultra-sensitive Cosmic Origins Spectrograph (COS), of a sample of 49 F2-K2 dwarf stars in the North and South ecliptic polar regions, to further advance studies of magnetic activity among cool Main sequence stars similar to the Sun. The ecliptic poles are favored places for current and up-coming astronomical survey satellites, including TESS (exoplanets and asteroseismology) and eROSITA (coronal X-rays). These instruments scan along lines of ecliptic longitude, and thus accumulate their deepest exposures close to the ecliptic poles. EclipSS targets were selected to be bright enough for eROSITA, not too bright for TESS, and just right for COS. The combined photometric (starspots), asteroseismic, FUV, and X-ray measurements will provide synergistic information concerning rotation periods, radii, masses, metallicities, ages, activity levels, and coronal properties to inform community-wide efforts to explore stellar activity and its underlying magnetic engine, the Dynamo. As of September 2018, about half of the EclipSS sample has been successfully observed by COS.

**Author(s):** Thomas R Ayres

**Institution(s):** University of Colorado

### **363.04 - NASA's Physics of the Cosmos (PCOS), Cosmic Origins (COR), and Exoplanets Exploration (ExE) Programs Manage and Coordinate Strategic Astrophysics Technology Development and Technology Gap Prioritization(Thai Pham)**

The three abiding questions driving astrophysics research are "How did our universe begin and evolve?" "How did galaxies, stars, and planets come to be?" and "Are we alone?" Answering these in ever-increasing detail requires space observatories with ever-increasing capabilities. To drive such capabilities, NASA's PCOS, COR, and ExE Program Offices (POs) manage technology maturation projects funded through the Strategic Astrophysics Technology program, as well as directed funding programs. We present an overview of NASA's Astrophysics Division (APD) strategic technology development activities and current investment portfolio. In 2016, APD established four Science and Technology Definition Teams (STDTs) to study large-mission concepts in preparation for the 2020 Decadal Survey. These are the far-IR Origins Space Telescope (OST), the Large UV/Optical/IR Surveyor (LUVOIR), the Lynx X-ray observatory, and the Habitable Exoplanet Observatory (HabEx). The teams submitted interim reports in 2018 and plan to submit their final reports in 2019. The reports present compelling science cases, design reference architectures, technology development needs, and cost estimates. The teams' technology gap inputs were integrated into our gap prioritization process. Once their final reports are submitted, the gaps they identified will continue to be prioritized, with continuing input from the community and the three Program Analysis Groups (PAGs). As of this year, APD directed the three

POs to coordinate their gap solicitation and prioritization processes, and to reduce the cadence to every other year. We discuss the new process and how the resulting prioritization and investment recommendations will inform the SAT program. The Programs' priorities are driven by strategic direction from APD, which is informed by Decadal Survey reports, the Astrophysics Implementation Plan, and the Astrophysics Roadmap "Enduring Quests, Daring Visions."

**Author(s):** Thai Pham, Opher Ganel, Nicholas Siegler, Brendan P Crill

**Institution(s):** NASA Astrophysics

### **363.05 - Maunakea Spectroscopic Explorer - the premier 10m class spectroscopic survey observatory for the next decade(Kei Szeto)**

Maunakea Spectroscopic Explorer (MSE) is a dedicated 10m class observatory designed for large survey programs. The MSE Observatory is optimized to collect millions of spectra in the optical to near-infrared at low ( $R \sim 3000$ ) to high ( $R \sim 40000$ ) spectral resolution by observing more than 4000 spectra per pointing via a highly multiplexed fiber-fed system. The new Observatory is a transformation of the current Canada-France-Hawaii telescope and facility building on the Maunakea summit. The MSE project has successfully completed its conceptual design phase. The system architecture of the MSE Observatory representing the planned 10m class spectroscopic survey facility is described.

**Author(s):** Kei Szeto,

**Institution(s):** Canada-France-Hawaii Telescope Corp., Maunakea Spectroscopic Explorer Contributing Team(s): The MSE team

### **363.06 - How to observe millions of targets every few weeks with thousands of fibers: the Operations Concept of the Maunakea Spectroscopic Explorer.(Nicolas Flagey)**

The Maunakea Spectroscopic Explorer (MSE) will each year obtain millions of spectra in the optical to near-infrared, at low ( $R \sim 3000$ ) to high ( $R \sim 40000$ ) spectral resolution by observing more than 4000 spectra per pointing via a highly multiplexed fiber-fed system. Key science programs for MSE include black hole reverberation mapping, stellar population analysis of faint galaxies at high redshift, and sub-km/s velocity accuracy for stellar astrophysics. The architecture of MSE is an assembly of subsystems designed to meet the science requirements and describes what MSE will look like. In this presentation, we focus on the operations concept of MSE, which describes how to operate a fiber fed, highly multiplexed, dedicated observatory given its architecture and the science requirements. The operations concept details the phases of operations, from selecting proposals within the science community to distributing back millions of spectra to this community. For each phase, the operations concept describes the tools required

to support the science community in their analyses and the operations staff in their work. It also highlights the specific needs related to the complexity of MSE with millions of targets to observe, thousands of fibers to allocate, and different spectral resolution to use. Finally, the operations concept shows how the science requirements for calibration and observing efficiency can be met.

**Author(s):** Nicolas Flagey

**Institution(s):** Canada-France-Hawaii Telescope Corporation  
**Contributing Team(s):** MSE Project Office

### **363.07 - Repurposing NEOWISE-Reactivation for Astrophysics Beyond the Inner Solar System(Aaron Michael Meisner)**

With its combination of high sensitivity and full-sky coverage at mid-infrared wavelengths, the Wide-field Infrared Survey Explorer (WISE) satellite is a unique and extraordinarily valuable tool for a broad range of scientific applications, from near-Earth asteroids to precision cosmology. Although the NEOWISE-Reactivation (NEOWISER) extension has supplied over 80% of archival 3.4 micron (W1) and 4.6 micron (W2) observations, this asteroid-hunting mission does not provide any coadded data products optimized for science beyond the inner solar system. We are leading a wide-ranging effort to repurpose NEOWISER observations for astrophysics, starting by building deep full-sky coadds from tens of millions of W1/W2 exposures. We present an updated version of our “unWISE coadd” data set, incorporating five full years of 3-5 micron WISE imaging. We thereby push ~0.7 magnitudes deeper than AllWISE with a corresponding factor of 15 time baseline enhancement. Among the important projects enabled by our custom WISE coadds are 1) selection of quasar and luminous red galaxy targets for the Dark Energy Spectroscopic Instrument 2) the deepest ever full-sky WISE-selected catalog, with roughly 2 billion unique objects 3) the Backyard Worlds citizen science project, a crowdsourced motion survey improving our census of the Sun’s closest and coldest neighbors, and 4) the “CatWISE” catalog, measuring solar neighborhood proper motions to new depths at very late spectral types. Our comprehensive WISE archival analyses are both timely and enduring. Among other applications, our data products will reveal exceptionally cold brown dwarfs and extremely distant quasars -- just in time for follow-up with soon-to-retire warm Spitzer and soon-to-launch JWST. Upon WISE’s permanent retirement, our coadds will represent the definitive 3-5 micron full-sky maps for decades to come. Our work will therefore be an essential input and/or complement for virtually all upcoming infrared missions and wide-area surveys, including DESI, Euclid, JWST, LSST and WFIRST.

**Author(s):** Aaron Michael Meisner, Dustin Lang, Edward Schlafly, David Schlegel

**Institution(s):** National Optical Astronomy Observatory, Lawrence Berkeley National Laboratory, Perimeter Institute

### **363.08 - Scheduling the Zwicky Transient Facility Surveys(Eric Bellm)**

The Zwicky Transient Facility (ZTF) is a new wide-field optical time domain survey now in routine operations. It is conducting two public surveys: a 3-day cadence survey of the Northern Hemisphere Sky and a nightly sweep of the Galactic Plane. Additionally it is conducting several private collaboration surveys. The ZTF scheduler employs a novel algorithm based on Integer Linear Programming techniques to schedule an entire night’s observations to maximize transient discovery. I will describe the surveys, the scheduler, and on-sky performance to date.

**Author(s):** Shrinivas Kulkarni, Matthew Graham, Eric Bellm  
**Institution(s):** University of Washington, California Institute of Technology  
**Contributing Team(s):** The Zwicky Transient Facility Collaboration

### **363.09 - The Spitzer Warm Mission Supermosaics and Source List Project(Patrick W. Morris)**

The Spitzer Science Center and NASA Infrared Science Archive (IRSA) will produce and release a set of Enhanced Imaging Products from the Spitzer Warm Mission, employing the InfraRed Array Camera (IRAC) in its 3.6 and 4.5 micron channels. The anticipated products include enhanced mosaics and a source list of photometry for compact sources, created from observations across multiple programs starting with Cycle 7 in August 2010. More than 30,000 high quality mosaics with a large range of exposure depth and angular coverage are anticipated for release by the Winter 2020 AAS meeting, along with the source list whose primary requirement is very high reliability. These products will be complementary to the Spitzer Enhanced Imaging Products created from the cryogenic mission and available in IRSA, providing additional angular coverage, signal depth, and a new resource for investigations of transient phenomena.

**Author(s):** Vandana Desai, Patrick Lowrance, Bernhard Schulz, Schuyler van Dyk, Sean Carey, Patrick W. Morris,  
**Institution(s):** Caltech, SOFIA Science Center, IPAC

### **363.10 - The NEOCam mid-infrared survey(Joseph Masiero)**

The Near-Earth Object Camera (NEOCam), is a proposed mission to survey the Solar System at two simultaneous thermal IR bandpasses. NEOCam would detect and track the majority of potentially hazardous asteroids during its planned 5-year lifetime, and constrain the population of smaller objects that could pose a threat to Earth. NEOCam also would provide a synoptic survey of two-thirds of the thermal infrared sky at 4-5.2 microns and 6-10 microns. We will describe the mission as proposed, and the expected data products.

**Author(s):** Joseph Masiero, Amy Mainzer, Edward L Wright  
**Institution(s):** NASA Jet Propulsion Laboratory, UCLA

Contributing Team(s): NEOCam Science Team

### **363.11 - All-sky rapid transient searches with the Evryscope network(Henry T Corbett)**

The Evryscopes are a North/South pair of all-sky telescopes, each of which hosts an array of up to 27 small telescopes on a common mount, capable of observing the entire sky above airmass  $\sim 2$  at two-minute cadence with a limiting magnitude of  $g' \sim 16$ . The southern site, located in Chile on Cerro Tololo, was deployed in mid-2015 and is currently in production creating multi-year light curves with percent-level precision. The northern instrument has been built and will be deployed to Mount Laguna Observatory (MLO) in California in October 2018. Once the MLO site is online, the instruments will share an overlap region of 4000 sq. degrees centered around the equator. Evryscope's large field of view and rapid cadence enable exploration of a previously inaccessible parameter space of bright and fast transients across the full sky, including gravitational wave counterpart kilonovae, near-field planetary microlensing signals, and stellar flares. The system is also capable of providing pre-discovery and follow-up light curves for longer-lived transients, such as super- and classical novae, enabling better constraints on early evolution and short-timescale behavior. Within the overlap region, the combined system will provide simultaneous imaging in both Sloan- $g'$  and Sloan- $r'$  filters across an 8,500 km baseline, enabling transient candidate vetting and classification based on parallax and color. In this poster, we present the current status of the Evryscope transients program and highlight recent followup campaigns.

**Author(s):** Daniel del Ser, Ward S Howard, Henry T Corbett, Nicholas Law, Carl Ziegler, Octavi Fors, Robert Quimby, Erin Goeke, Amy Glazier, Jeff Ratzloff

**Institution(s):** University of North Carolina at Chapel Hill, Dunlap Institute, University of Toronto, Institut de Ciències del Cosmos, Universitat de Barcelona, San Diego State University

### **363.12 - The Breakthrough Listen Search for Intelligent Life: Characterization and Mitigation of Satellite RFI(Christopher Murphy)**

Differentiating between signals from human technology (RFI) and signals emitted from a distant world is one of the most challenging tasks in radio SETI. We have tried to overcome this issue by placing telescopes in remote, protected areas such as Green Bank, WV. Nevertheless, we are unable to completely escape RFI. The myriad of operational satellites in Earth's orbit all contribute as sources of RFI. Fortunately, the position of a satellite can be accurately predicted thanks to well characterized orbital parameters that are publicly available for most satellites. We found examples of satellites impacting Breakthrough Listen archival data taken using the Green Bank Telescope. Our main objective is to use these examples in order to identify characteristics in the data that coincide with particular satellites and then use this information to mitigate

satellite RFI, and eventually provide labeled examples of RFI for input to machine learning algorithms.

**Author(s):** Christopher Murphy, Dave DeBoer, Ryan Dana, Steve Croft

**Institution(s):** University of the Virgin Islands, University of California, Berkeley  
Contributing Team(s): Breakthrough Listen

### **363.13 - STScI's WFIRST Science Operations(Karoline M Gilbert)**

The Wide Field Instrument (WFI) on WFIRST will be a powerful survey instrument, combining comparable sensitivity and resolution to the Hubble Space Telescope but with a field of view 100 times larger. STScI will be the Science Operations Center (SOC) for the WFIRST Mission, with additional science support provided by IPAC and foreign partners. STScI will schedule and archive all WFIRST observations, calibrate and produce pipeline-reduced data products for imaging with the Wide Field Instrument, support the High Latitude Imaging and Supernova Survey Teams, and support the astronomical community in planning WFI imaging observations and analyzing the data. During the design phase of the WFIRST Mission, STScI is building on detailed concepts for WFIRST operations produced in the formulation phase. These include a data management system that will include a novel, cloud-based framework for high-level data processing. This will provide a common environment accessible to all users (STScI operations, Survey Teams, General Observers, and archival investigators). STScI will also continue development on simulation tools to aid the astronomical community in examining the capabilities of the WFI. These tools, including a point spread function simulator, an exposure time calculator, and an image simulator, are publicly available. We describe their functionalities and give examples of their use.

**Author(s):** Karoline M Gilbert,

**Institution(s):** Space Telescope Science Institute, Johns Hopkins University  
Contributing Team(s): STScI WFIRST Team

### **363.14 - UV-Visible observations with HST in the JWST North Ecliptic Pole Time-Domain Field(Rolf A Jansen)**

We report on a UV-Visible HST imaging survey to  $m_{AB} \sim 28$  mag of the JWST North Ecliptic Pole (NEP) Time-Domain Field (TDF). Using near-CVZ opportunities, we observed 7 of 9 tiles with WFC3/UVIS in F275W and with ACS/WFC in F435W and F606W. Our HST survey will provide near-contiguous 3-filter coverage of the central  $\sim 5''^2$  of this new community field for time-domain science with JWST (Jansen & Windhorst 2018). The JWST NEP TDF is located within JWST's northern Continuous Viewing Zone, will span  $\sim 14''^2$  in diameter, is devoid of sources bright enough to saturate the NIRCam detectors, has low Galactic foreground extinction, and will be roughly circular in shape. JWST GTO program 1176 will initially



sample the NEP TDF during Cycle 1 at four distinct orientations (“spokes”) with JWST/NIRCam, and take NIRISS slitless grism spectroscopy in parallel such that it overlaps the coverage of an alternate NIRCam orientation. This is the only region in the sky where JWST can observe a clean extragalactic deep survey field of this size at arbitrary cadence or at arbitrary orientation. This will crucially enable a wide range of new and exciting time-domain science, including high-*z* transient searches and monitoring (e.g., SNe), variability studies from Active Galactic Nuclei to brown dwarf atmospheres, as well as proper motions of extreme scattered Kuiper Belt Objects and comets beyond the distance of Neptune, and of nearby brown dwarfs, low mass stars, and ultracool white dwarfs. Ancillary data across the electromagnetic spectrum will exist for this field when JWST science operations commence in 2021. This includes deep ( $m_{AB} > 26$  mag) wide-field ( $\sim 23'' \times 25''$ ) Ugriz imaging of the JWST NEP TDF and surrounding area from LBT/LBC, Subaru/HSC, and GTC/HiPERCAM, YJHK to  $m_{AB} \sim 24$  mag from MMT/MMIRS, sub- $1\frac{1}{4}$  Jy JVLA 3GHz and VLBA 5GHz radio observations, and deep (900ks) Chandra/ACIS X-ray images. Observations at long-wave radio (LOFAR) and (sub)mm (IRAM30m, JCMT, SMA) wavelengths, optical narrow-band spectrophotometry (J-PAS), and multi-object spectroscopy (MMT) are in progress, scheduled, or proposed, ensuring a rich legacy of the UV-Visible HST observations.

**Author(s):** Anton Koekemoer, Norman Grogan, Rolf A Jansen, Rogier Windhorst, Walter Briskin, W. Peter Maksym, Bhavin Joshi, Nimish Hathi, Patricia Royle, Cameron William White, Simon Driver, Duho Kim, Teresa Ashcraft, Steve Rodney, Christopher Willmer, Adam Riess, ,

**Institution(s):** oUofSC, ASU, LBO, STScI, ICRAR/UWA, UNottingham, UofA, UTexas, JHU, CfA Contributing Team(s): HST-GO-578 team, Webb Medium Deep Fields IDS GTO team, VLA NEP Deep Field team, Chandra DTDF team

### **363.15 - The Deep Chandra Campaign to Observe the JWST North Ecliptic Pole Time Domain Field(W. Peter Maksym)**

The James Webb Space Telescope North Ecliptic Pole Time Domain Field (JWST-NEP-TDF) is a JWST Guaranteed Time Observer field planned for JWST Cycle 1. Thanks to its location in JWST's continuous viewing zone (CVZ), JWST-NEP-TDF is in an optimal position for time domain astrophysics that can take advantage of JWST's unprecedented infrared sensitivity. And the field's low infrared background and lack of bright foreground objects ensure that deep co-adds from multiple anticipated time domain exposures over the JWST mission will make it the deepest possible JWST field. Although JWST is planned to launch in 2021, observations are already underway to develop JWST-NEP-TDF as a multi-wavelength field suited to take advantage of JWST's unprecedented capabilities. We present early results from the first 300 ks of a 900-ks multi-cycle Chandra campaign, including early time domain analysis. Cross correlation of the deepest object-free Chandra images with those available from JWST will yield IR-X-ray power spectra that provide critical constraints to the sky-SB that may

come from the first black hole accretion disks associated with stars and galaxies in the early universe.

**Author(s):** Anton Koekemoer, W. Peter Maksym, Martin Elvis, Walter Briskin, Norman Grogan, Chelsea L MacLeod, Richard Perley, Seth Cohen, Francesca Maria Civano, Nico Cappelluti, Guenther Hasinger, Matthew L. N. Ashby, James Condon, Giovanni Fazio, Rolf A

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Space Telescope Science Institute, Arizona State University, European Space Agency, University of Miami, Smithsonian Astrophysical Observatory, NRAO

### **363.16 - Preliminary Science with the COSMOS HI Large Extragalactic Survey (CHILES)(Julie Davis)**

An enduring question in galaxy evolution concerns how galaxies obtain cold neutral gas--the fuel for ongoing star formation. To address this, we utilize the COSMOS HI Large Extragalactic Survey (CHILES), a project currently underway on the Jansky Very Large Array (VLA). The CHILES collaboration has been granted 1000 hours of B-array observing time to image neutral hydrogen (HI) and obtain a simultaneous deep continuum image in a  $30' \times 30'$  cone centered on the COSMOS field, covering a redshift range of  $0 < z < 0.45$ . We present here an early science case for both the spectral line and continuum data. From the first 180 hours of data, we have performed a kinematic study on the nearest galaxies ( $z < 0.1$ ) accompanied by complementary optical long slit data, finding mostly regular rotation but at times interesting morphology or kinematics in the neutral or ionized gas. Using the continuum data, we have performed initial experiments in searching for HI absorption through stacking background sources. We expect further interesting results upon completion of data collection in spring 2019.

**Author(s):** Julie Davis, Julia Gross

**Institution(s):** University of Wisconsin Madison, Columbia University Contributing Team(s): The CHILES Collaboration

### **363.17 - Exploring the Eclipsing Binary Yield of the Large Synoptic Survey Telescope(Ava Polzin)**

When the Large Synoptic Survey Telescope (LSST) goes online in the early 2020s, it will provide astrometric and photometric data on more than 10 billion stars, generating more than 30 terabytes of data per night for the duration of its 10-year project run. LSST will be uniquely adept at characterizing eclipsing binaries, due to the breadth of the survey (covering twice the area of the Sloan Digital Sky Survey in six different photometric bands), its short, 3-day cadence, and its long operational duration. Searching through the data for eclipsing binaries will be a feat unto itself for the sheer volume. Herein, we investigate the expected number of eclipsing binaries LSST will observe, detect, and properly characterize, as well as constrain the observing parameters that will maximize the number of eclipsing binaries detected.

**Author(s):** Aaron Geller, Ava Polzin, Katelyn Breivik, Adam Miller,

**Institution(s):** Northwestern University, Canadian Institute for Theoretical Astrophysics, University of Toronto, Adler Planetarium

### **363.18 - Constraining Stellar Parameters for Hotter Stars in the MaStar Library (Dan J Lazarz)**

MaStar is a large, comprehensive library of stellar spectra with wavelength coverage and instrumental resolution identical to that of the MaNGA galaxy survey. Part of the goal in creating MaStar is to produce a library with significantly improved parameter coverage in comparison to past libraries, including coverage of warm and hot stars. Here, we will present results from a stellar parameter determination method specifically designed for warmer stars ( $6,000\text{ K} < T_{\text{eff}} < 12,000\text{ K}$ ) in MaStar. For stars around  $10,000\text{ K}$ , the Balmer lines are not very sensitive to temperature changes, making it difficult to determine the stellar parameters using model fits to the entire stellar spectrum. We make use of the slope of the Balmer discontinuity and the shape of the heavily smoothed spectra, from the flux calibrated MaStar data, to help break the degeneracy between temperature, surface gravity, and extinction. With the latest ATLAS9-based theoretical spectral templates from Bohlin et al. (2015), we derive  $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$ , and extinction using Bayesian inference. We compare the parameters with the results from other methods and Gaia-based luminosity estimates to verify their robustness.

**Author(s):** Ronald Wilhelm, Renbin Yan, Dan J Lazarz

**Institution(s):** University of Kentucky Contributing Team(s): MaStar Team

### **363.19 - TolTEC/LMT Galactic Star Formation Legacy Surveys: A Large-Area Search for Cores and a Survey of B-Fields in Filamentary Clouds (Giles Novak)**

High angular resolution millimeter-wave observations of protostars with ALMA are revolutionizing our understanding of the birth of stars and planets. Star formation is governed by physical processes that operate over a huge range of physical scales, including for example stellar feedback and magnetic effects, and this highlights the need to leverage the ALMA discoveries by adding a holistic view. Such a view will be provided by TolTEC, a revolutionary 7,000-pixel imager for the 50-meter Large Millimeter Telescope. TolTEC captures total and polarized intensities at 1.1, 1.4 and 2.1 mm, all simultaneously. During 2019-2021, TolTEC/LMT will conduct two public Galactic star formation legacy surveys. The Clouds-to-Cores (C2C) Legacy survey will map over a dozen nearby ( $< 1.5\text{ kpc}$ ) giant molecular clouds in their entirety, characterizing the core spatial distribution, properties and core mass function (CMF) down to  $0.1\text{ M}_{\text{sun}}$ , well beyond what has been possible in the past for such a large sky area. C2C will thereby test theories that postulate a causal connection between

CMF and stellar initial mass function (IMF). The Fields-in-Filaments (FIF) Legacy Survey will obtain deep observations of polarized dust emission from five filaments located in five different nearby ( $< 450\text{ pc}$ ) clouds plus two more distant filamentary infrared dark clouds (IRDCs). The resulting 5 arcsec resolution B-field maps will be compared with ALMA observations as well as with MHD simulations to estimate B-field strengths and to study the effects of B-fields on the formation of planet-forming disks. The C2C and FIF surveys will provide important public legacy datasets, informing a wide range of future investigations into the origins of stars and planets. More details on TolTEC can be found on our website: <http://toltec.astro.umass.edu>

**Author(s):** Laura Fissel, Giles Novak, Grant Wilson, Stella Offner, Robert Gutermuth

**Institution(s):** Northwestern University, Uof Massachusetts, NRAO, Uof Texas Contributing Team(s): TolTEC collaboration

### **363.20 - TolTEC/LMT Extragalactic Legacy Surveys: Completing our Census of Dust-Obscured Star Formation (Alexandra Pope)**

Millimeter wavelengths are uniquely suited to measure the dust-obscured star formation in galaxies out to the highest redshifts. While previous millimeter surveys have been limited to the most extreme star forming galaxies, the 50-meter Large Millimeter Telescope can push to much fainter galaxies, measuring the dust-obscured star formation in typical, main-sequence galaxies out to the epoch of reionization. Coupled with TolTEC, a revolutionary new camera for the LMT, allows surveys over large areas of the cosmic web down with a spatial resolution of 5 arcseconds. From 2019-2021, TolTEC/LMT will conduct two public extragalactic legacy surveys simultaneous at three wavelengths; 1.1, 1.4 and 2.1mm. The Ultra-Deep Survey of Star-forming Galaxies (nominally  $\sim 1\text{ sq. deg}$ ) is a confusion-limited survey which links the Luminous Infrared Galaxy (LIRG) population from redshifts 2-10 directly to their optical counterparts to determine how massive galaxies build up dust/metals and stars over cosmic time. The Large Scale Structure Survey (nominally 50-100 sq. deg) probes the relationship between the spatial distribution of dusty star forming galaxies and large scale structure, and provides a detailed view of clusters and their substructure via the Sunyaev-Zeldovich (SZ) effect. More details on TolTEC can be found on our website: <http://toltec.astro.umass.edu>

**Author(s):** Itziar Aretxaga, Alexandra Pope, Grant Wilson, David Hughes, Min Yun

**Institution(s):** University of Massachusetts Amherst, INAOE Contributing Team(s): TolTEC collaboration

### **363.21 - Normal Galaxy Studies with Next-generation X-ray surveys: eROSITA and Athena WFI(Antara Basu-Zych)**

Upcoming future X-ray surveys like eROSITA and Athena WFI will detect 10-100 times more normal (i.e., non-AGN) galaxies than previous X-ray surveys, and therefore, vastly enhance our understanding of X-ray emission from X-ray binaries and hot gas within galaxies. For example, multiple scans of particular objects may reveal transient sources. Additionally, such complete and unbiased surveys of galaxies may lead to discoveries of rare and unique X-ray sources within galaxies. We can also use these wide field surveys to measure and quantify scatter in X-ray scaling relations with physical galaxy properties (e.g., stellar mass, star formation rates, metallicities and star formation histories). Using existing multiwavelength surveys, we predict what we expect to observe in these wide-field X-ray surveys. We present the status of current X-ray surveys and put next-generation X-ray surveys into context in terms of key parameters such as X-ray flux and solid angle surveyed.

**Author(s):** Joern Wilms, Andreas Zezas, Frank Haberl, Neven Vulic, Andrew Ptak, Antara Basu-Zych, Ann Hornschemeier

**Institution(s):** NASA GSFC/UMBC, NASA GSFC/UMCP, NASA Goddard Space Flight Center, Remeis-Observatory/ECAP, Max-Planck-Institute, Center for Astrophysics

### **363.22 - Characterizing OH Sky Spectra Using SDSS BOSS Data(Lina Maria Florez)**

In ground-based spectroscopy of faint sources in the optical/near-infrared, the flux of the emission lines due to the Earth's atmosphere are many times larger than the sources we are concerned with. Longwards of 6000 Angstroms, the night-sky spectrum is dominated by multiple rotational/vibrational transitions of the OH radical from our upper atmosphere. We carried out Principal Component Analysis of flux-calibrated sky spectra from the Sloan Digital Sky Survey Baryon Oscillation Spectroscopic Survey (SDSS BOSS) to explore correlations among these sky emission lines. While the wavelengths of these lines are the same in each sky spectrum, their relative strengths vary considerably as a function of time and position on the sky, but we expect that the strengths of lines from common upper energy levels will be correlated with one another. Essentially, the limiting factor in faint-object spectroscopy is the degree to which systematics in the sky subtraction can be minimized. Our aim is to use these correlations to work towards creating improved sky subtraction algorithms for the Prime Focus Spectrograph (PFS) on the 8.2-meter Subaru Telescope. The better we can model the strengths of the emission lines, the better we can hope to subtract them off. Since PFS will be gathering data on sources as faint as 24th magnitude and fainter, it's of utmost importance to be able to accurately measure and subtract sky spectra from the data that we receive.

**Author(s):** Michael A Strauss, Lina Maria Florez

**Institution(s):** University of Illinois at Urbana-Champaign,

Princeton University

### **363.23 - HI-MaNGA: HI Followup for the MaNGA Survey(Karen Masters)**

Mapping Nearby Galaxies at Apache Point Observatory (MaNGA, part of the fourth incarnation of the Sloan Digital Sky Surveys or SDSS-IV), is obtaining spatially resolved spectral maps for ~10,000 nearby galaxies selected from the SDSS Main Galaxy Sample. These data will unwrap the layers of local galaxies - revealing their stellar and gas dynamics, as well as the ages and chemical make-up of their constituent stars, and locations of current star formation. MaNGA began observations on the Sloan Telescope at APO in July 2014 and is now the largest sample of resolved spectroscopy in the world, with well over 6000 galaxies observed to date. MaNGA will provide an amazing census of the stellar and ionized gas content of galaxies for a representative sample of nearby galaxies. However, complementary information about the cold gas content is crucial for a number of applications, but especially understanding the physical mechanisms that regulate gas accretions and quench galaxy growth. I give an overview of the HI-MaNGA project; a follow-up project for MaNGA focused on collecting total HI content and rotation widths. We have at the time of writing made use of ~1300 hours of filler time on the Robert C. Byrd Green Bank Telescope (in West Virginia) to obtain 21cm HI (neutral hydrogen) global profiles of over 2000 galaxies in the MaNGA sample.

**Author(s):** Karen Masters, David Vincent Stark

**Institution(s):** Haverford College, IPMU, Portsmouth University  
Contributing Team(s): MaNGA Team

## **364 - Stellar Evolution, Stellar Populations -- Posters**

### **364.01 - Spotting Young Stars in the Age of Precision Distance Measurements(Jordyn L Mascarenas-Wells)**

Populations of young stars with bulk properties are inherited from stellar siblings provide key age-calibrated benchmarks in our understanding of time evolving astrophysical phenomena. Identifying such new populations of young stars, or new members of known populations, has been difficult due to the lack of or uncertainty in distance measurements to most stars. The latest data from the Gaia mission offers unprecedented precision on the positions and distances of stars with sub-milliarcsecond parallax measurement uncertainties. With this incredible resource, we are able to determine precise absolute magnitude values and can thereby identify young stars that lie above the main sequence on Hertzsprung-Russell Diagrams. To identify such young stars, we have created a python model that uses Bayes Theorem to predict the age/mass for stars in Gaia DR2 by comparing each data point to a synthetic population of 2 million elements with ages ranging from 1-3,000 million years and masses ranging from 0.1-1 solar masses. In this model, we included an initial mass function (Chabrier 2003), binary probability (Raghavan+ 2010) and model photometry

from PARSEC isochrones (Marigo+ 2017). We then compared the model photometry to each star in Gaia DR2 data. We then tested the model on the region of sky containing the Taurus-Auriga star forming region in order to ensure that the model works as designed. Taurus contains over 400 newly formed stars (<5 Myr old) and is the most well-studied and nearest region of ongoing star formation to the Earth ( $d=145$  pc). From this information, age and mass probability distributions for each star were produced. Comparing the results of our model to specific target stars in Taurus, we found that it produced consistent results with the expected values up until the range of one solar magnitude. Moving forward, we will add metallicity and extinction into the model, increase the mass range, add photometry from infrared wavelengths (2MASS), add estimates for higher order multiples, apply the model to other important data such as TESS and K2, and perform a blind search for new groups of young stars in the full Gaia dataset.

**Author(s):** Aaron C Rizzuto, Jordyn L Mascarenas-Wells,

**Institution(s):** University of Oregon, University of Texas at Austin

### **364.02 - A Search for Intermediate Separation Binaries in the Orion Nebula Cluster(Matthew De Furio)**

We present the results of a binary population study in the Orion Nebula Cluster (ONC) using archival Hubble Space Telescope (HST) data obtained with the Advanced Camera for Surveys (ACS) in B, V, i, and z filters (Treasury Program 10246, PI M. Robberto). Young clusters and associations may hold clues to the origin of the initial mass function as well as the properties of multiple star systems as we continue to develop a predictive theory of star formation. Low mass star-forming regions such as Taurus, reveal an excess of multiples over separation ranges sampled and perhaps unusual companion mass ratio distributions (Kraus et al. 2011; Reggiani & Meyer 2011). The Orion Nebula Cluster is a high mass star-forming region with a binary population that has been studied in the separation ranges of < 10 AU (Kounkel et al. 2016) and > 65 AU (Reipurth et al. 2007). Star clusters like the ONC could be the dominant source of the Galactic field star population and a likely birthplace for our solar system. Intermediate separation binaries might be useful as a tracer of the initial binary population since they are not likely to be destroyed through dynamical interactions (Parker & Meyer 2014). Unfortunately, the gap in our knowledge of the ONC binary population, between 10 - 65 AU, overlaps with the peak binary distribution for M and G dwarfs in the Galactic field (Raghavan et al. 2010; Janson et al. 2012). Including this new analysis, we can i) better assess whether the ONC contributes significantly to the Galactic field star population ii) compare the ONC to low mass star forming regions like Taurus, and iii) search for trends in binary properties as a function of star forming environment. We search for potential binaries by fitting a double point-spread function (PSF) model built from the empirical PSFs of Anderson & King 2006. Our sample of ONC members is representative for masses 0.1 - 1.2  $M_{\odot}$  (MIST 2016)

assuming an age of 1 - 2 Myr and confirmed with radial velocities from Da Rio et al. 2016 based on the APOGEE IN-SYNC survey. Our results will define the binary frequency and the companion mass ratio distribution of the ONC from 20 - 65 AU.

**Author(s):** Matthew De Furio, Alexandra Z Greenbaum, Adam L. Kraus, Trent Dupuy, Michael R. Meyer, Megan Reiter

**Institution(s):** University of Michigan - Ann Arbor, Gemini Observatory, UK Astronomy Technology Centre, University of Texas - Austin

### **364.03 - Lithium Depletion and Stellar Jitter Measurements in Young Open Clusters(Azmain Nisak)**

Open clusters are fantastic laboratories for testing theories of stellar evolution and planet migration because these large, coeval populations have well-determined ages. Here we present new, high dispersion, multi-epoch measurements with CHIRON on the 1.5-m CTIO telescope for Sun-like stars in the young open clusters IC 2602 (44 Myr) and IC 2391 (51 Myr), and the young Moving Group AB Doradus (149 Myr). These new measurements, coupled with Gaia distances and proper motions, allow us to refine membership lists and delineate more accurately their single-star main sequences. In particular, the data provide better constraints on the depletion of lithium at early times. The radial velocity stability of the spectrograph also enables us to investigate the magnitude of stellar jitter as a function of age, and put the first constraints on the presence of short-period giant planets orbiting these adolescent age stars.

**Author(s):** Hodari-Sadiki James, Russel White, Leonardo Paredes, Azmain Nisak, Todd Henry

**Institution(s):** Georgia State University, RECONS Institute

### **364.05 - High-Resolution Abundances of Carbon-Enhanced Metal-Poor Stars(Catherine Kennedy)**

High-resolution spectroscopy and subsequent abundance analysis of ~20 carbon-enhanced metal-poor (CEMP) stars has been performed as the result of observations gathered from Magellan/MIKE. Abundances of CNO, including carbon isotopic ratios, as well as alpha elements, iron-peak elements, and neutron-capture elements (both l/s and h/s) are determined. The metallicities of the sample stars range from  $-4.0 < [Fe/H] < -1.5$ , and hence, the sample includes the full abundances for very metal-poor stars (VMP), extremely metal-poor stars (EMP), and ultra metal-poor stars. Based on this abundance analysis, the sample includes mostly CEMP stars that are enhanced in neutron-capture elements, with 2-3 stars that show no such elevated enhancements, and hence are among the CEMP-no variety. We explore the possible progenitors the stars and the source of their enhancements by comparing their chemical abundances to theoretical abundance yields.

**Author(s):** Catherine Kennedy

**Institution(s):** University of Tampa

**364.06 - Surprises from Dwarf Carbon Stars: A Dispersion in Abundances and Binary Periods(Bruce Margon)**

Dwarf carbon (dC) stars - objects which show prominent C2 bands in their spectra, yet have main sequence luminosities - pose a number of interesting problems in stellar evolution. Information on chemical abundances and binarity of these stars is only now beginning to emerge. There is a published abundance analysis for only one such object, the prototype G77-61, and it is extremely metal-poor. Although all of these objects are presumed to be binaries, receiving the C2 via mass transfer from a now invisible, more highly evolved companion, only a handful of binary periods are known, and all but one are long (of order years). Oddly, the remaining example, SDSS J1250+25, is drastically shorter (2.9 d). Here we report spectroscopy of 15 dC stars, with  $15 < r < 17$ , selected mainly from high proper motion catalogs and the SDSS. The data were obtained with spectral resolution  $R \sim 6,000$ , using the Keck II telescope and the Echellette Spectrograph and Imager (ESI), with the goal of deriving information on both metallicity and (short term) radial velocity variations. Our preliminary analysis show a large star-to-star dispersion in [Fe/H], [Ca/H] and [Mg/H], implying that the extremely metal-poor nature of G77-61 may not be universal. We also see evidence for intraday radial velocity variations in several objects, so the very short period of SDSS J1250+25 may also not be unique. It seems increasingly likely that these odd stars may involve more than one evolutionary path.

**Author(s):** Bruce Margon, Michael Bolte, Sara Lucatello, Puragra Guhathakurta

**Institution(s):** University of California, Santa Cruz, INAF - Osservatorio Astronomico di Padova

**364.07 - Galactic Radius and Chemical Composition of Milky Way Stars(Claire Mechemann)**

In this project, I studied the chemical composition of 270,000 disk stars in relation to where they were located in the Milky Way. These stars span from the Galactic Center to the outer disk. I did this by combining the chemical abundance and parallax data from the APOGEE-2 survey and the GAIA mission. With this information I was able to chart the changing correlations between the stars' distance from the Galactic center and their chemical composition. This enabled me to build an empirical map of the changing gas enrichment history across the disk, as a function of height from the plane.

**Author(s):** Claire Mechemann, Anderson Lauren, Melissa Ness

**Institution(s):** CUNY Lehman, Center for Computational Astrophysics

**364.08 - The Impact of Luminosity Class on the H-alpha Index(Eric G Hintz)**

In Joner & Hintz (2015) they discuss the development of a new H-alpha index designed around a pair of wide and narrow filters, both centered on H-alpha. This is very similar to the older H-beta index that was often used with the Stromgren filter set. The original sample of stars was dominated by main sequence dwarf stars. To examine the impact of luminosity class on the H-alpha system we obtained a sample of stars covering the remaining luminosity classes. This data was obtained using the 1.2-m telescope of the Dominion Astrophysical Observatory, just like the original sample. We will show the slight changes seen in the value of the index for the various luminosity classes.

**Author(s):** Michael D. Joner, Eric G Hintz

**Institution(s):** Brigham Young University

**364.09 - Time-Domain Astronomy with SOFIA: Results from Current Observations with FORCAST and Prospects with the Proposed New Instrument S3(Kathleen Kraemer)**

The most recent Decadal Review identified "time-domain astronomy" as an important frontier for astrophysical investigations. A key advantage to SOFIA in this realm is its 20+ year lifetime which allows long-term scientific studies that are not possible with space-based infrared missions alone. Here, we present two time-domain projects enabled by SOFIA's unique capabilities, one with current instrumentation - FORCAST, and the second with a proposed new instrument - S3. (1) The first project uses the FORCAST grism to obtain 5-37  $\mu\text{m}$  spectra of carbon-rich post-AGB stars. Although most phases of stellar evolution take place on timescales of millions or billions of years, the post-asymptotic giant branch (post-AGB) phase, when a star rapidly transitions from a cool, dust-enshrouded object to a hot white dwarf illuminating a planetary nebula, lasts only  $\sim 1,000$ -10,000 years. Spectra from SOFIA's FORCAST instrument are enabling us to investigate the processes that occur during one of the most fleeting stages in a star's life. We compare these data to the mid-infrared spectra of the same objects obtained at  $\sim 10$ -15 year intervals over the past 35 years with Spitzer, ISO, and IRAS. (2) The second project will use a proposed new instrument, the high sensitivity, high spectral-resolution, heterodyne Submillimeter Spectrometer for SOFIA, S3. S3 is enabled by recent advances in detector technology, including improvements to digital backend spectrometers, low noise amplifiers, local oscillators, and closed cycle refrigerators. We will observe the line profiles of four carefully selected protoplanetary disks with S3 and their changes over the course of  $\sim 3$  years. By repeatedly observing key transitions of ammonia and isotopic water in protoplanetary disks, we will trace the structure and composition of the disk to constrain the disk dynamics and planet formation models for each system we observe. These observations by S3 allow us to use Doppler tomography and

similar techniques to kinematically image, for the first time, the \*inner\* regions of the planet-forming systems.

**Author(s):** Thomas A Kuchar, Catherine Espaillat, Andrew J Gatesman, Jeanne M Hartley, A W Lichtenberger, Christopher J Beaudoin, Kathleen Kraemer, G. C. Sloan, Donald R Mizuno, Thomas M Goyette, Timothy Cook, R M Weikle, Susanna C Finn

**Institution(s):** Boston College, Space Telescope Science Institute, UMass Lowell, Boston University, University of North Carolina, Chapel Hill, University of Virginia  
**Contributing Team(s):** the S3 Science & Instrument Team

### **364.10 - Searching for the Metallicity Limit for Carbon Star Formation in M31(Martha Boyer)**

Carbon stars are known to form easily at low metallicity due to efficient dredge up and a low surface abundance of oxygen, but their behavior at high metallicity is not yet anchored to observations. To calibrate models at high metallicity, we targeted 20 fields across the disk of M31, taking advantage of M31's metallicity gradient and diversity in stellar age. The results show a clear drop in the ratio of carbon stars to M-type stars (C/M) of more than an order of magnitude from the outer to inner disk. This C/M drop occurs with a steeper slope than at lower metallicity throughout the Local Group, hinting that we are approaching a metallicity ceiling in M31 above which carbon stars cannot form.

**Author(s):** Phil Rosenfield, Paola Marigo, Dan Weisz, Puragra Guhathakurta, Knut Olsen, Dylan Gregersen, Bernhard Aringer, Julianne Dalcanton, Leo Girardi, Benjamin F Williams, Karl D Gordon, Martha Boyer, Anil Seth

**Institution(s):** STScI, Osservatorio Astronomico di Padova, University of Washington, University of California, Santa Cruz, University of Utah, National Optical Astronomy Observatory, AURA, Universita degli Studi di Padova, Eureka Scientific, Inc, University of C

### **364.11 - Magnetic hot giants and supergiants: The descendants of magnetic main sequence massive stars(Mary Elizabeth Oksala)**

With the discovery of the first few magnetic hot supergiants within the BRITE spectropolarimetric (BRITEpol) survey, we have developed the Large Impact of magnetic Fields on the Evolution of hot stars (LIFE) project, which aims to detect magnetic fields in bright evolved OBA giants and supergiants to investigate the evolution of these stars from their main sequence (MS) counterparts into their late post-MS stages. We present both the BRITEpol results and current LIFE results of the survey from spectropolarimetric observations using the ESPaDOnS instrument of the Canada-France-Hawaii Telescope. Based on these initial results, we find that the longitudinal surface magnetic field is very weak, but the field configuration resembles the ones of main sequence hot stars. A simple analysis indicates that the decreased field strength can

be understood primarily in the context of magnetic flux conservation as the radius of the star expands with evolution.

**Author(s):** Mary Elizabeth Oksala,

**Institution(s):** California Lutheran University, Paris Observatory

### **364.13 - XMM-Newton observations of the AGB star chi Cyg and post-AGB star U Mon(Rodolfo Montez)**

Surface magnetic fields strengths of 2-10 G have been measured from the evolved stars chi Cyg and U Mon. These measurements lend support to the notion that large-scale magnetic fields may thread the circumstellar environment of asymptotic giant branch (AGB) and post-AGB stars. Magnetic fields might assist in wind driving and asymmetric shaping of mass loss from the AGB to post-AGB phase. Magnetic activity and X-ray emission have been linked through coronal activity in young, main sequence, and giant stars, but evidence for such linkage has not been established for the AGB phase. We present the results of an XMM-Newton search for X-ray emission from the aforementioned evolved stars with well-established surface magnetic field strengths. We detected U Mon in X-rays, but did not detect chi Cyg. This research has been supported by NASA grant NNX17AD78G awarded to the Smithsonian Astrophysical Observatory.

**Author(s):** Rodolfo Montez, Joel H Kastner, Laura Vega, Sofia Ramstedt, Wouter Vlemmings

**Institution(s):** Smithsonian Astrophysical Observatory, Chalmers University of Technology, Rochester Institute of Technology, Vanderbilt University, Uppsala Universitet

### **364.14 - Magnetic Fields in the Core of Magnetic Fields in Stars and their Compact remnants(Luis A Sanchez)**

Stars more massive than about 1.1 solar masses are stirred by vigorous convection in their hydrogen-burning cores. Convection can, in principle, amplify and sustain magnetic fields through a process called "dynamo". In order to estimate the amplitude of dynamo-generated magnetic fields in the convective cores of hydrogen-burning stars, we assumed equipartition of convective kinetic energy density and magnetic energy density. We simulated stars of different masses using the MESA (Modules for Experiments in Stellar Astrophysics) code during the core-hydrogen burning phase (main sequence). After estimating the expected amplitude of core dynamo-generated magnetic fields at the end of the main sequence, we also determined the expected values of magnetic fields in stellar compact remnants, assuming magnetic flux conservation. We compare these predictions to the range of values observed in strongly magnetized white dwarfs (WD) and neutron stars (NS), also known as magnetars. The good agreement between this simple estimate and the observations, shows that an efficient convective-core dynamo during the main sequence can in principle explain the magnetic fields of a subset of stellar compact remnants.

**Author(s):** Luis A Sanchez,  
**Institution(s):** Flatiron Institute CCA, American Museum of Natural History

### **364.15 - The Fate and Long Term Evolution of Massive Stellar Mergers(Samantha Wu)**

We present hydrodynamical simulations of the binary interaction between a mildly-evolved massive primary star and main-sequence massive secondary companion using the FLASH code with adaptive mesh refinement. It has been shown that about 24% of stars born as O-type stars are in binaries and merge with their secondary, less-massive companion. The more massive, evolved primary star was modeled by mapping onto a 3D computational grid a star profile from the Modules for Experiments in Stellar Astrophysics (MESA) stellar evolution code for a 15 solar mass evolved star and the main-sequence secondary companion was treated as a 12 solar mass point mass. We simulate the inspiral and eventual merger of the companion with the core of the primary. From the simulation, we track the energy deposition into the envelope, the mixing profiles of elements, and the mass shedding history during the merger. The timescales for the remnant to regain its thermal equilibrium are vastly longer than the minutes or days needed for dynamical equilibrium to be restored; instead, such timescales are on the order of millions of years. Using the results from this simulation, the merger remnant will be evolved in one dimension using MESA to map its long-term evolution.

**Author(s):** Enrico Ramirez-Ruiz, Samantha Wu, Rosa Wallace Everson

**Institution(s):** University of California, Santa Cruz

### **364.16 - Using Distant Galaxies to Constrain the Ionizing Photon Budget of Massive Stars(Evan Haze Nunez)**

The hydrogen ionizing photon production rate  $Q_H$  of massive stars ( $M > 8 M_\odot$ ) must be known to interpret important observable quantities including galaxy star formation rates, the energy budget for nebular emission and the re-ionization epoch of the universe. Recently it has been shown that Stellar Population Synthesis (SPS) predictions for  $Q_H$  diverge by a factor of  $\sim 2$  in low-metallicity environments. To test these predictions we use SPS to model the spectra of galaxies with different stellar evolution models. We analyze three different input physics models that account for single-star evolution (PARSEC), stellar rotation (MIST) and binary evolution (BPASS). These parameters and models affect  $Q_H$ . We create grids of metallicity, star formation history and dust then plot data onto them to compare our models. We find that stellar rotation and binary interactions both produce significantly more ionizing photons than single-star models. The results suggest that single, non-rotating stars are unable to reproduce the ionizing flux needed to model the bluest and

highly star forming galaxies in our dataset. The primary challenge present in this analysis is accounting for the many parameters that can affect  $Q_H$  so moving forward we must verify galaxy properties on a case by case basis.

**Author(s):** Joel Leja, Charlie Conroy, Evan Haze Nunez,  
**Institution(s):** California State Polytechnic University, Pomona, Harvard-Smithsonian Center for Astrophysics

### **364.17 - Measuring the Massive Star Binary Fraction with Stellar Population Diagnostics(Trevor Dorn-Wallenstein)**

Populations of massive stars are directly reflective of the physics of stellar evolution. Counting subtypes of massive stars and ratios of massive stars in different evolutionary states have been used ubiquitously as diagnostics of age and metallicity effects. While the binary fraction of massive stars is significant, inferences are often based upon models incorporating only single-star evolution. In this work, we utilize custom synthetic stellar populations from the Binary Population and Stellar Synthesis (BPASS) code to determine the effect of stellar binaries on number count ratios of different evolutionary stages in both young massive clusters and galaxies with massive stellar populations. We find that many ratios are degenerate in metallicity, age, and/or binary fraction. We develop diagnostic plots using these stellar count ratios to help break this degeneracy, and use these plots to compare our predictions to observed data in the Milky Way and the Local Group. These data suggest a possible correlation between the massive star binary fraction and metallicity. We also examine the robustness of our predictions in samples with varying levels of completeness. We find including binaries and imposing a completeness limit can both introduce  $\sim 0.1$  dex changes in inferred ages. Our results highlight the impact that binary evolution channels can have on the massive star population.

**Author(s):** Emily Levesque, Trevor Dorn-Wallenstein

**Institution(s):** University of Washington

### **364.18 - Accelerating the evolution of simulated convective atmospheres(Evan H Anders)**

Turbulent astrophysical convection is a classic system with a large timescale separation between flow speeds and the thermal relaxation time. We present a method of fast-forwarding through the long thermal relaxation of convective simulations, and show that this method is valid in a simple system. Flow properties between accelerated evolution (AE) solutions and standard evolution (SE) solutions differ by at most a few percent. In the most turbulent cases studied at which we compare SE and AE, we find that AE solutions require roughly an order of magnitude fewer computing hours to evolve than SE solutions. An eventual extension of this technique is to use AE in stellar structure models. Modern stellar structure codes typically employ parameterized 1-dimensional models of

convection, but a generalized AE technique could be used to self-consistently evolve a star's structure while incorporating information from resolved 2- or 3-dimensional convective simulations.

**Author(s):** Benjamin Brown, Jeffrey S Oishi, Evan H Anders,  
**Institution(s):** University of Colorado -- Boulder, Bates College, Laboratory for Atmospheric and Space Physics (LASP)

### 364.19 - Interpolation Schemes that don't Ruin Stars(Zachary Way)

Stellar evolution codes work by modelling the internal structure of a star as a discrete grid of points. Each point describes the thermodynamic state (pressure, temperature, composition, etc.). Many applications of this grid-based scheme require varying levels of spatial resolution. An example is asteroseismic analysis of solar-like oscillations in RGB stars, where the short wavelengths of gravity modes in the stellar core necessitate a high spatial resolution there. The standard approach is to interpolate, but the nature of a star can sometimes be lost. In this work, we show that commonly adopted interpolation schemes can result in models that fail to conserve mass, and/or are out of hydrostatic equilibrium. We also describe new interpolation schemes that do obey stellar physics and demonstrate their impact on example asteroseismic calculations using the open-source stellar oscillation code GYRE.

**Author(s):** Aaron Lopez, Zachary Way, Richard H. D. Townsend  
**Institution(s):** University of Wisconsin - Madison

### 364.20 - Rotation and Macroturbulence of RR Lyrae and Red Horizontal Branch Stars(Christopher Sneden)

We have derived new upper limits on the axial equatorial rotational velocities of RR Lyrae (RRL) and metal-poor red horizontal branch stars (RHB), using the very large set of Las Campanas du Pont echelle spectra gathered over the last 15 years. We also have determined the variations of macroturbulent velocities in RRL atmospheres during pulsation cycles. During RRab pulsation cycles line widths are dominated by phase-dependent convolutions of axial rotation and macroturbulence (called here  $V_{\text{macrot}}$ ). Variations in  $V_{\text{macrot}}$  are essentially uniform among the RRab stars, but the behavior of  $V_{\text{macrot}}$  among RRC stars varies strongly from star to star. For RRab stars we find  $V_{\text{macrot}} \approx 5$  km/s, while the minima for RRC stars range from 2 to 10 km/s. The  $V_{\text{macrot}}$  minimum for RRab stars provides an upper limit for the rotational velocity  $V_{\text{sini}}$ . The abrupt decline in large  $V_{\text{macrot}}$  values with decreasing effective temperature at the blue edge of the instability strip and the apparently smooth continuous variation among the RRab and RHB stars suggests that HB stars gain/lose surface angular momentum on time scales that are short compared to HB lifetimes. We suggest that surface

angular momentum as measured by  $V_{\text{sini}}$  is not a reliable indicator of total stellar angular momentum anywhere along the HB. This work has been supported in part by NSF grant AST1616040 to C.S. and by the University of Texas Rex G. Baker, Jr. Centennial Research Endowment.

**Author(s):** Christopher Sneden, Merieme Chadid, Stephen A. Shectman, George W. Preston, Ian B. Thompson  
**Institution(s):** University of Texas at Austin, Universite Nice Sophia--Antipolis, Carnegie Observatories

### 364.21 - New Precise Abundance Determinations of the Iron-Peak Elements in a Very Metal-Poor Star(John Cowan)

We report new precise abundance determinations for the iron-peak elements in the metal-poor ( $[\text{Fe}/\text{H}] \sim -2.9$ ) main sequence turnoff star BD+03 740. These abundances were obtained employing new high resolution UV data from HST (STIS) with additional ground-based data from McDonald Observatory and spectra from a variety of online archives. We have employed new atomic lab data (from the Wisconsin group) and examined the abundances of both neutral atoms and ions in our results. In all cases except one, the abundances of neutrals and ions were consistent: in the case of Co there was a significant difference between the two states, with Co I suggesting a higher abundance than Co II. We find a large overabundance of Ti, V and Sc in this low metallicity star, not seen in several others similar stars. Contrary to some older results in the literature, we find no evidence of a large upward trend of Co/Cr at low metallicity. These results place important constraints on how these heavy elements were formed in early Galactic supernovae. This work has been supported by HST STScI Program GO-14232; and NSF grant AST-1616040 to CS; NSF grants AST 1613536 and AST 181540 to IUR; AST-1516182 to JEL and EDH; NASA grant NNX16AE96G to JEL.

**Author(s):** Ann Boesgaard, John Cowan, Jennifer Sobeck, Chris Sneden, James Edward Lawler, Ian Roederer, Elizabeth Den Hartog

**Institution(s):** University of Oklahoma, University of Texas, University of Michigan, University of Hawaii, University of Wisconsin, University of Washington

### 364.22 - What is a Luminous Blue Variable (LBV) / S Doradus Variable?(John Martin)

Over the past several years, the rare class of evolved massive stars called Luminous Blue Variables (LBVs) have become increasingly popular subjects of study. Many objects suggested as LBV candidates are selected based on their estimated temperature and luminosity but have \*not\* shown S Dor variability (the definitive characteristic of LBVs). B[e] supergiants and other stars at the top of the Hertzsprung-Russell Diagram which have spectra similar to quiescent LBVs are often confused with LBVs. We review the defining characteristics of S Doradus variables and provide a list of those



stars which have exhibited LBV/S Doradus variability.

**Author(s):** John Martin, Roberta Humphreys

**Institution(s):** University of Illinois Springfield, University of Minnesota

### **365 - Stellar Atmospheres, Winds -- Posters**

#### **365.01 - Retracing the Histories of Pre Planetary Nebulae(Bruce Balick)**

This poster summarizes the common features of steady-flow hydrodynamic models that emulate the present sizes, structures, kinematics, and estimated ages of pre PNe to within  $\sim 100$  y of the onset of their formations. Various examples of the model outcomes and corresponding HST images are presented. The models are intended to constrain detailed models of collimated mass ejection in mass-exchange binaries involving a post-AGB star and a compact companion.

**Author(s):** Adam Frank, Bruce Balick

**Institution(s):** University of Washington, University of Rochester

#### **365.02 - Modeling Variability in f/i Line Ratios for X-rays from Stellar Winds(Zebedee Damrau)**

Massive stars are sources of X-ray emission with a variety of causes. X-rays can be produced in the colliding winds of massive binaries, or in relation to interaction between a star's wind and magnetosphere. In the case of single stars, X-rays naturally arise from embedded wind shocks owing to the line-driven wind instability. An important X-ray diagnostic is the f/i line ratio from the forbidden and intercombination line fluxes of He-like ions. The ratio is influenced by the UV radiation field of the star, and can serve as a diagnostic for the location of X-ray production in the wind. Hole & Ignace (2012) explored temporal variations that could arise in f/i ratios from stellar pulsations that modify the UV radiation. Here we explore drivers of time variability arising in the wind itself. Illustrative results are presented for the case of variable mass loss, and ramifications of the model for interpreting observations are discussed. The authors gratefully acknowledge funding support for this research with a grant from NASA (GO8-19011F; PI W. Waldron).

**Author(s):** Karen Hole, ZebEDEE Damrau, Richard Ignace

**Institution(s):** East Tennessee State University, Norwich University

#### **365.03 - Improving the Spectral Fit for the Diffuse Soft X-ray Background Using Atomdb CHARGE Exchange Models(German Vazquez Perez)**

The origin of the Diffuse Soft X-ray background has always been ground for many questions and debates. Previous investigations have concluded that this background radiation could be mostly due to charge exchange (CX), caused by the interaction between ions from the solar winds and neutral

hydrogen and helium atoms in the heliosphere. In 2014, simplified CX models were constructed, which successfully fit the high-resolution spectral data from the Diffuse X-ray Spectrometer mission (DXS), flown in 1993 (Smith, 2014). This model has since been deployed to analyze potential CX in a range of other plasmas (Zhang et al., 2017). In 2017, updated CX cross section data was released by the Kronos project, including velocity-dependent cross sections for all ions. In this project, we incorporate the cross section data into the AtomDB Charge Exchange Model (ACX), then compare two versions of the model by re-analyzing the DXS data for the solar wind components. Our results show significant changes in the spectrum for some ions, but an overall improvement in the model fit. Key words: X-ray sources: diffuse background - Solar astronomy: solar wind

**Author(s):** Adam Foster, German Vazquez Perez,

**Institution(s):** University of Puerto Rico, Mayaguez, Smithsonian Astrophysical Observatory

#### **365.04 - The Lines They Are A-Changing: A Spitzer Study of Mid-Infrared Spectral Lines in Mira Variable Atmospheres(Dana K Baylis)**

One of the outstanding questions in astrophysics is how stars enrich their environments as they reach the end of their lives. This enrichment is vital for new star and planet formation, but our understanding of molecule and dust production in circumstellar environments is still rudimentary. Mira variables are highly evolved cool stars with regular pulsations that loft enriched material into their surroundings, making them perfect laboratories for studying molecules and dust in stellar environments. We present analysis of mid-infrared Spitzer spectra of oxygen-rich (M-type) and carbon-rich (C-type) Mira variables. Due to the brightness of this sample, it is straightforward to monitor changes with phase in the infrared spectral features of these regular pulsators. We have spectra of 25 Mira variables, taken with phase, using the Spitzer Infrared Spectrograph (IRS) in the high-resolution mode. Each star has multiple spectra obtained over a one-year period (from 2008-09). We have identified several CO<sub>2</sub> lines in the M-type Miras, and HCN and C<sub>2</sub>H<sub>2</sub> lines in the C-type Miras. Our spectra show CO<sub>2</sub> lines that are not observable with ground based instruments because telluric features dominate at these wavelengths. Additionally, there is a narrow bright feature at 17.6  $\mu$ m that is present in both chemistries; we have preliminarily identified this feature as Fe fluorescence. The CO<sub>2</sub> lines exhibit unique, fluctuating behavior possibly tied to the pulsational phase of the star; for example the fundamental band at 15  $\mu$ m is seen in both emission and absorption. We built a file of ro-vibrational data that we used to model the CO<sub>2</sub> lines with the radiative transfer code RADEX. We present results from these CO<sub>2</sub> models that describe the physical characteristics of the gas such as temperature and density. Using RADEX results from several M-type stars will give us a better understanding of how the CO<sub>2</sub> gas behaves in oxygen rich Mira atmospheres.

**Author(s):** Dana K Baylis, Michelle J. Creech-Eakman, Tina

Güth

**Institution(s):** New Mexico Institute of Mining and Technology

### **365.05 - H-alpha Spectroscopy of Bright Stars(Macon Magno)**

A LHires III spectrograph with a SBIG ST-8XME CCD camera was mounted onto the Celestron C14 telescope at the Harry D. Powell Observatory at East Tennessee State University. We determined the characteristics of the spectrograph, including calibrating the wavelength coverage with grating position along with determining the practical aspects of its use. The spectrograph will primarily be used for H-alpha line monitoring of bright stars to investigate stellar atmospheres and winds. Student projects will be planned in coordination with existing research projects using the Southeastern Association for Research in Astronomy (SARA) observatories. We present here a few reduced spectra of some target stars to demonstrate the capabilities of the spectrograph and to show comparison with SARA Observatory spectra since the instruments have very similar resolutions. We also investigated several software programs for processing astronomical spectra with regard to their use by novice undergraduate students.

**Author(s):** Macon Magno, Benjamin Moretz, Gary Henson, Katelynn Sobota

**Institution(s):** East Tennessee State University, Texas A&M University-Commerce

### **365.06 - M-Giant Mass-Loss Rates and Wind Parameters from UV Emission Line Profiles(Kenneth G Carpenter)**

Strong chromospheric emission lines in the UV spectra of M giants show superposed absorption features created by their photon-scattering winds. These self-reversed emission profiles provide us with an opportunity to assess important parameters of the wind, including flow and turbulent velocities, the optical depth of the wind above the region of photon creation, and the star's mass-loss rate. We use the Sobolev with Exact Integration (SEI) radiative transfer code, along with simple models of the outer atmospheric structure and wind, to determine the wind characteristics of the two M-giant stars Gamma Cru (M3.4) and Mu Gem (M3IIIab). We use this code because it is computationally fast and allows a great number of possible wind models to be examined. The program calculates line profiles for the Mg II (UV1) lines and a range of unblended Fe II lines. These lines represent a wide range of wind opacities, and thus different heights in the atmosphere. The assumed wind properties are iterated, until the predicted profiles match the observations (in this case HST/GHRS UV spectra), over as many lines as possible. We present estimates of the wind parameters for these two M-giant stars, and offer a comparison to wind properties previously-determined for low-gravity K stars using the same technique and similar data.

**Author(s):** Kenneth G Carpenter, Krister E Nielsen, Gioia Rau,

**Institution(s):** NASA's GSFC, Catholic University of America

### **365.07 - Comparison between panchromatic spectra of early- and late-M stars(Dennis Tilipman)**

We have begun computing panchromatic spectra of M dwarfs that are known to host exoplanets. We are particularly interested in ultraviolet radiation that drives photochemical processes in exoplanet atmospheres. Here we present revised results on GJ 832, a relatively quiet M2 V dwarf, and a tentative model for GJ 876, an active M5 V dwarf. The model atmospheres are computed with the SSRPM radiative transfer code developed by Dr. Juan Fontenla. The code solves for the non-LTE statistical equilibrium populations of 18,538 levels of 52 atomic and ion species and computes the radiation from all species (435,986 spectral lines) and about 20,000,000 spectral lines of 20 diatomic species.

**Author(s):** Kevin France, Mariela Vieytes, Dennis Tilipman, Jeffrey L. Linsky

**Institution(s):** University of Colorado, Boulder, Instituto de Astronomia y Física del Espacio (CONICET-UBA)

### **365.08 - Wind Blown Bubbles around Massive Stars Revisited(Vikram Dwarkadas)**

Massive stars ( $> 8$  solar masses) lose mass throughout their evolution. In the post main-sequence phases, these mass-loss rates can reach up to  $10^{-4}$  solar masses/year. Wind velocities can exceed 1000 km/s for main sequence stars, and for the massive Wolf-Rayet (W-R) stars. The mass loss can lead to the formation of very large wind-blown bubbles around these stars, with sizes ranging up to tens of parsecs depending on the properties and duration of the mass-loss. Wind-blown bubbles have been observed and analysed around many W-R stars. The large wind velocities should lead to high post-shock temperatures, such that the bubbles should be distinctly visible as regions of diffuse X-ray emission with temperatures exceeding 107 K. However, if diffuse x-ray emission is seen at all, the temperatures are found to be generally lower, of order a few million Kelvin or lower. Bubbles should also be seen around massive main-sequence stars, which have high wind velocities but lower mass-loss rates. However, wind blown bubbles have been observed only around some massive main-sequence stars, while others do not appear to show signs of bubbles. We have succeeded in formulating a solution that parameterizes the dynamical and kinematic properties of the bubble, such as radius, bubble density and pressure, completely in terms of the evolutionary parameters of the star, including the star's mass, radius, temperature, luminosity, and Eddington parameter. Analysis of the bubble properties in this manner reveals several aspects of wind-blown bubbles that have not been well studied, or at least better appreciated, in the literature, but which affect the evolution of the bubble as well as the X-ray emission. In this

presentation we discuss the evolution of wind-blown bubbles using (semi)-analytic calculations and ionization-gasdynamic simulations. We provide possible answers to the questions raised above, as well as many other vexing questions regarding the evolution, structure, kinematics, and dynamics of wind-blown bubbles around massive stars.

**Author(s):** Vikram Dwarkadas

**Institution(s):** University of Chicago

### **365.09 - Initial Results of the Large Legacy zeta Pup Chandra Campaign (Joy S. Nichols)**

A large, multi-wavelength campaign to study the winds of the massive star zeta Pup (O4 I) has begun with the initial 480 kiloseconds of exposure time using Chandra's High Resolution Transmission Grating (HETG) during the summer of 2018. Zeta Pup is a particularly rewarding target for the HETG because its X-ray emission lines show an interesting and detailed structure indicating both Doppler-broadening and absorption due to its stellar wind. X-ray emission line fitting and short timescale variability are discussed and compared to previous results using XMM and Chandra. In contrast to the earlier Chandra observations in 2000, these observations comprise enough exposure time to make meaningful line shape measurements with the High-Energy Grating of the HETG in addition to the Medium-Energy Grating of the HETG used in previous studies. Variability analyses include a discussion of statistical methods and fitting of emission lines in spectrally-resolved short time slices. Multi-wavelength observations which will be added to this project during the Chandra observations of this star in 2019 will also be discussed.

**Author(s):** Yael Naze, D. Huenemoerder, J. Lauer, N. Miller, Joy S. Nichols, W. Waldron, R. Ignace

**Institution(s):** Harvard-Smithsonian Astrophysical Observatory, Universite de Liege, MIT, University of Wisconsin, Eau Claire, Eureka Scientific, East Tennessee State University  
Contributing Team(s): The zeta Pup Consortium

### **365.10 - High velocity CO Outflows in VHyA (Kenneth Hinkle)**

The carbon-rich AGB star VHyA is a rare example of a star caught in transition between the AGB and planetary nebula stages. Recent high resolution imaging in the mid-IR and radio interferometry spectra suggest the existence of an equatorial dust and molecular disk and high velocity outflows in the polar direction. We present high resolution mid-IR spectra observed with the Phoenix spectrometer. These are taken with the slit at subarcsecond offsets from the central star in the four cardinal directions. We detect high velocity CO outflows and interpret these in the context of the equatorial disk and polar outflow models.

**Author(s):** Jayadev Rajagopal, Kenneth Hinkle, Raghvendra Sahai, Richard Joyce

**Institution(s):** NOAO, JPL

## **366 - Star Formation I -- Posters**

### **366.01 - Origins Space Telescope: Nearby Galaxies, the Milky Way, and the Interstellar Medium (Cara Battersby)**

The Origins Space Telescope (OST) is the Mission Concept for the Far-Infrared Surveyor, one of the four science and technology definition studies of NASA Headquarters for the 2020 Astronomy and Astrophysics Decadal survey. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. This presentation will summarize the science case related to Nearby Galaxies, the Milky Way, and the Interstellar Medium (Interstellar Medium). The Origins Space Telescope will enable a wealth of unprecedented scientific advances in this area, both those we know to expect, and the discovery space that lies unexplored. Origins will enable a comprehensive view of magnetic fields, turbulence, and the multiphase ISM; connecting these physics across scales of galaxies to protostellar cores. With unprecedented sensitivity, Origins will measure and characterize the mechanisms of feedback from star formation and Active Galactic Nuclei, and their interplay, over cosmic time. Origins will unveil the abundance and availability of water for habitable planets by allowing us to trace the trail of water from interstellar clouds to protoplanetary disks, to Earth itself.

**Author(s):** Karin Sandstrom, Cara Battersby

**Institution(s):** University of Connecticut, University of California San Diego  
Contributing Team(s): The Origins Space Telescope Science and Technology Definition Team

### **366.02 - Overview of the MASSES Survey (Ian William Stephens)**

The Mass Assembly of Stellar Systems and their Evolution with the SMA (MASSES) survey mapped molecular lines and continuum about all 74 known protostars within the Perseus Molecular cloud. This SMA interferometric survey allows us to statistically constrain how stars gain their mass, which can be done by analyzing fragmentation, disk and envelope evolution, angular momentum transport, and outflow energetics. In this talk, I will give a brief overview of the survey and highlight some of the key results. The subcompact data are publicly available, and the full dataset will be released soon.

**Author(s):** Riway Pokhrel, Tyler Bourke, Philip Myers, Michael Dunham, Ian William Stephens

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, SKA Organization, SUNY Fredonia, University of Massachusetts  
Contributing Team(s): MASSES Team

### **366.03 - Revisiting the Integrated Star Formation Law(Mithi Alexa Caballes de los Reyes)**

The relationship between gas and star formation rate (SFR) surface densities, known as the star formation law, can provide physical insight into star formation on multiple scales. Here, we revisit the disk-averaged star formation law (often called the Kennicutt-Schmidt law) for non-starbursting spiral and dwarf galaxies. Using UV-based SFRs with individual IR dust corrections, we confirm that "normal" spiral galaxies alone define a tight power law with index  $n \sim 1.4$ . Spiral galaxies also show a near-linear correlation between SFR and molecular gas surface densities, but a very weak correlation between SFR and atomic gas surface densities. However, many dwarf galaxies lie below the star formation law defined by spirals, suggesting a low-density threshold in the star formation law. Our improved measurement precision also allows us to determine that much of the  $\sim 0.3$  dex scatter in the star formation law is intrinsic, and we find that dwarf galaxies in particular exhibit second-order correlations that may explain some of this scatter. Finally, we discuss various systematic uncertainties that should be kept in mind when interpreting any study of the star formation law.

**Author(s):** Mithi Alexa Caballes de los Reyes, Rob C Kennicutt, Jr.,

**Institution(s):** Caltech, Texas A&M University, University of Arizona

### **366.04 - Studying Young Stars in L1688 using Submillimeter, Infrared, and Optical Data(Laura Orr)**

We are looking for new candidate young stellar objects (YSOs) within 10 arcminutes of the heart of the Rho Ophiuchi (L1688) cluster using Herschel Space Telescope far-infrared (FIR) data. The goal of our study is to identify new YSOs as well as measure FIR brightnesses for literature-identified YSOs. This will support the greater understanding of the variety and evolution of young stars. We started with 155 sources identified in the literature combined with long wavelength (70, 100, and/or 160  $\mu$ m) detections in the Herschel PACS Point Source Catalog (PSC). Multiwavelength data were incorporated from PanSTARRS, UKIDSS, Gaia DR2, 2MASS, Spitzer/IRAC & MIPS, WISE, AKARI, and Herschel/PACS & SPIRE. Initial catalog cross-matching was done by position. Available images for each of these sources were inspected to ensure correct matching across bands. Spectral energy distributions (SEDs) were constructed and inspected as well. For the Herschel bands, photometry was obtained for sources that could be seen in the images but did not have corresponding catalog entries in the PACS or SPIRE PSCs. These data were added to the SEDs. We made color-color and color magnitude diagrams to check that the properties of these YSO candidates match those of other known YSOs. We found 3 entirely new YSO candidates, detected solely at Herschel bands. Of the remaining 152 YSOs, we dropped  $\sim 14\%$  as unlikely to be true point sources (despite appearing in the Herschel PACS PSC), and we obtained new Herschel measurements for 87 YSOs in at least one band. This research was made possible through the NASA/IPAC Teacher

Archive Research Program (NITARP) and was funded by the NASA Astrophysics Data Program.

**Author(s):** Emma Daniels, Bobbie Sharpe, Laura Wommack, Skyler Nannenga, Doug Schurman, Nancy Coster, Deborah Morgan, Luisa Rebull, Bracken Jolley, Brianna Coster, Jacie Erickson, Laura Orr

**Institution(s):** Ukiah High School, South Sevier High School, Kankakee Valley High School, Caltech/IPAC, Lakeside Jr-Sr High School, Echo High School

### **366.05 - Unveiling Star Formation and its Demise in Ultra-compact Post-merger Galaxies using Jansky VLA Continuum Measurements(Grayson Petter)**

AGN feedback has emerged as the favored solution to the "overcooling" problem, the deficit of massive galaxies observed when compared to predictions from  $\Lambda$ CDM simulations. A sample of massive and compact galaxies hosting high-velocity gas outflows was found at  $z \sim 0.6$ , estimated to have exceptionally large star formation rate (SFR) surface densities, approaching the proposed "Eddington limit" for radiation pressure on dust grains. This suggests that star formation rather than AGN feedback may be driving the observed outflows. However, these estimates suffer from significant systematic uncertainties due to large extrapolations needed to calculate SFRs with mid-IR observations, and because mid-IR emission may be extinguished in these dense and dusty star forming cores. Therefore, we desired a more direct star formation tracer transparent to dust. In this poster, we present SFR estimates calculated using 1.5 GHz continuum observations taken with the VLA for 21 of these galaxies. For a majority of the sample, we estimate SFRs a factor of  $\sim 2.5$  smaller than those calculated from the IR. We conclude that this shift may stem from the template used to extrapolate mid-IR observations to yield a SFR assuming too cool of dust temperatures. With better estimates of these galaxies' true SFRs, we can more effectively investigate whether star formation feedback is indeed driving these outflows. We can also use this sample as an analog to understand massive galaxy evolution at  $z > 3$ , where extremely compact galaxies were more common.

**Author(s):** Ryan C. Hickox, Amanda Kepley, Paul Sell, Alison Coil, John Moustakas, Christy Tremonti, Jim Geach, Grayson Petter, Aleksandar Diamond-Stanic, Gregory Rudnick

**Institution(s):** University of Kansas, University of Wisconsin - Madison, National Radio Astronomy Observatory, Dartmouth College, Siena College, University of California San Diego, University of Crete, University of Hertfordshire

### **366.06 - Do the Pleiads Spin in the Same Direction?(Kaimi Kahihikolo)**

The formation of star clusters, such as the Pleiades, is widely attributed to the gravitational coalescence of a progenitor star-forming molecular cloud. Rather intuitively, one may expect cluster members to inherit some rotation due to the global motion of the molecular cloud, as reported in a few studies of select star clusters. However, due to the highly turbulent nature of star formation--consequently, cluster formation--many studies report the opposite result. In either case, correlation of spin alignment may lead into insight into the initial conditions of the star-forming cloud and deserves some attention. Here we employ a hierarchical Bayesian analysis on the spin distribution of Pleiades cluster members and evaluate it using exquisite data from the GAIA DR2, 2MASS, and K2 surveys. From this hierarchical analysis, we determined that spin distribution is highly consistent with an isotropic distribution. Hence, we are able to conclude that the Pleiads do not in fact "spin together."

**Author(s):** Kento Masuda, Kaimi Kahihikolo

**Institution(s):** University of Hawaii, at Manoa, Princeton University

### **366.07 - From Gas to Stars: Cluster Virialization Observed by ALMA(Jenny Calahan)**

In this project, we have investigated how the virial velocities of stars originate from the gas inside clusters. Using detailed ALMA-ACA (15") array observations of N<sub>2</sub>H<sup>+</sup> and CO together with large-scale IRAM30m (30") N<sub>2</sub>H<sup>+</sup> and HNC data, we investigated the distribution and kinematics of all dense (N<sub>2</sub>H<sup>+</sup>), diffuse (HNC), and outflow (CO) components in 5 intermediate mass (~200 M<sub>sun</sub>) clusters in the Orion A cloud. Within the same regions, we combined our molecular maps with APOGEE measurements of the radial velocities their internal YSO populations. Comparing the velocities of both the dense plus diffuse gas and the YSOs, we found that in each cluster, the gas has a much smaller spread than the YSOs. When comparing dense gas to diffuse gas, in most of these clumps, the diffuse gas has a broader spread in velocity due to the appearance of multiple velocity components. Also, we find the movements of the gas show continuous wave-like structure in all clusters. This shows that as gas goes from diffuse to dense, the gas motions do not present significant variations but rather a selection of individual components. On the contrary, the change in velocities of gas vs YSOs is much more drastic, and shows a clear change in kinematics from the initial to end stages of star formation. We conclude that, once a YSO is formed, chaos is introduced to its motion and becomes virialized and kinematically warmer as it interacts with the potential of the cluster.

**Author(s):** Alvaro Hacer, Jenny Calahan,

**Institution(s):** University of Michigan, Leiden University

### **366.08 - Calibration of a Mid-Infrared Star-Formation Rate Tracer with 33 GHz Thermal Radio Continuum Emission(Cory Whitcomb)**

We present a mid-infrared star-formation rate tracer based on emission in the [Ne II] 12.8 Åμm line and aromatic emission features from polycyclic aromatic hydrocarbons (PAHs). We calibrate our tracer with the thermal component of the 33 GHz radio continuum emission (Murphy et al. 2018) from 56 extranuclear star-forming regions observed in SINGS (Kennicutt et al. 2003). Relationships using only PAH features show a strong metallicity dependence, reproducing previous trends seen by Calzetti et al. (2007) and others. Regions of higher metallicity show a significant increase in PAH intensity compared to lower metallicity regions. We construct a set of linear combinations of PAH bands, ion emission lines, and their respective ratios to minimize this metallicity trend. We show the parameters that most accurately reproduce the 33 GHz star-formation rates are the 12.8 Åμm [Ne II] line and the 7.7 Åμm PAH feature. We find that the best tracer based solely on PAH emission is made using the features at 6.2 and 7.7 Åμm, but this results in a weaker correlation and a stronger metallicity dependence than the [Ne II]-7.7 Åμm relation. The [NeII] line and the 6.2 and 7.7 Åμm PAH bands will be detected in galaxies by the James Webb Space Telescope out to  $z \sim 1.2$  and 2.5, respectively, and potentially much further by the proposed Origins Space Telescope. Our work also shows that subtracting the local background surrounding a star-forming region decreases the 11.3 Åμm to 7.7 Åμm PAH ratio. This implies PAHs are more ionized in star-forming regions relative to their surroundings.

**Author(s):** Eric Joseph Murphy, Sean Linden, Karin Sandstrom, Cory Whitcomb

**Institution(s):** University of California, San Diego, University of Virginia, National Radio Astronomy Observatory

### **366.09 - A Morphological Study of High-Mass Star Forming Regions from the Red MSX Source Survey(Charles Figura)**

High-mass stars have a profound influence on their host galaxies, regulating star formation, enhancing the elemental composition, injecting vast amounts of energy into the ISM. Despite their significance, their rapid formation keeps the details of their genesis shrouded in a natal cocoon of dust. We aim to investigate the physical properties of the environments of high-mass stars at different stages of their natal evolution, and characterise the effects that outflows and UV radiation may have on the local environments throughout high-mass star formation. We have used the Australia Telescope Compact Array to map the ammonia (1,1) and (2,2) inversion transitions toward a sample of 34 regions identified by the Red MSX Source (RMS) Survey as locations of massive star formation. These data have been complemented by data from the ATLASGAL and GLIMPSE Legacy Surveys in order to allow a more complete estimation of physical parameters of these sources, and to provide an improved understanding of the

conditions surrounding massive star formation. We have identified 44 clumps within these 34 fields, and have used distinctions in morphology between the NH<sub>3</sub> emission and the ATLASGAL thermal dust emission to divide this population into two subsets. We find that two-sample KS tests cannot distinguish between the clump-averaged physical properties in these two groups, which may indicate that formation of the HII region during the later stages of star formation has a more significant impact on the overall structure of the natal clump than on its physical properties. We have incorporated maser observations from the Methanol MultiBeam Survey (MMB) and the H<sub>2</sub>O Southern Galactic Plane Survey (HOPS), and use these to illuminate several examples that are suggestive of triggered star formation.

**Author(s):** Toby Moore, David Eden, James Urquhart, Sam Billington, Charles Figura

**Institution(s):** Wartburg College, Liverpool John Moores University, University of Kent

### **366.10 - The Argus+ Project: A 144-pixel 3mm spectroscopic imaging array for the Green Bank Telescope(Felix Lockman)**

The 16-pixel Argus receiver has now been in routine operation on the Green Bank Telescope (GBT) for more than a year, demonstrating the power of the 100-meter diameter single dish for imaging molecular clouds around star-forming regions at high sensitivity and 8" angular resolution. Argus, designed and built by a consortium led by Sarah Church at Stanford, was intended to be a demonstrator for scalable receiver technologies, as well as a working instrument. We are now taking the next step with Argus+: a large format radio camera system for the GBT that will carry out high-fidelity spectroscopic mapping in the molecule-rich 75-116 GHz frequency band around 3mm wavelength. Argus+ will be a 9-times copy of the 16-pixel Argus receiver with lower noise amplifiers, for an increase of a factor of ten in mapping speed. The Argus+ project includes a dedicated spectrometer and a software data reduction pipeline. With 144 pixels, a footprint of 6', an angular resolution of 6" to 8", and the sensitivity of a filled aperture, Argus+ will map fundamental transitions of important species over hundreds of square arc-min with a spatial dynamic range of 10<sup>4</sup> to 10<sup>5</sup>. The Argus+ project will include a legacy survey of molecules in the nearest star-forming regions of the Gould Belt, carried out by the scientific community and defined through a series of workshops. Argus+ will be operated as an open skies facility of the Green Bank Observatory, with the majority of its use being allocated through the normal proposal review process. An important part of the project is improvements to the GBT metrology systems that will more than double the amount of useful observing time at 3mm. This part of the project has just been funded through an NSF MSIP grant, and should be completed in three years. It is described in a companion poster by A. Seymour. The Green Bank Observatory is a facility of the National Science Foundation operated under a cooperative agreement by Associated Universities, Inc. GBT metrology

improvements are supported under NSF grant 1836009.

**Author(s):** Felix Lockman

**Institution(s):** Green Bank Observatory

### **366.11 - Mapping Star Formation Rates in the Nearby Universe(Frances H Stone)**

A key component of many extragalactic studies is the correlation of a galaxy's overall star formation rate with the incidence or frequency of a particular type of astronomical object, like supernovae, luminous X-ray binaries, or ultraluminous X-ray sources. These correlations have allowed for considerable progress in understanding the nature, formation, and diversity of these objects. However, star formation is not uniform across a galaxy, and a galaxy's overall star formation rate may be dominated by a handful of intense knots of star formation or may be made up rather uniformly over the entire disk. Given this, we have been making maps of local star formation rates to better assess the correlations of star formation rate with certain types of objects, and we present our latest results. We make our star formation rate maps using far ultraviolet (FUV) data from the Galaxy Evolution Explorer Telescope (GALEX) and 24-micron infrared data from the Spitzer Space Telescope. Corrections are made to the FUV and IR images to account for background and correct for differences in angular resolution. Maps of star formation rate per unit area are then generated by a weighted combination of the FUV and IR images in the appropriate units. We then convert these to maps of star formation rate taking into account the distance to the galaxy, which is often poorly known. We also generate companion images of the uncertainty in star formation rate, both statistical and due to uncertainties in distance.

**Author(s):** Frances H Stone, David Pooley

**Institution(s):** Trinity

### **366.12 - High-Mass Star Formation in Protoclusters of W51(Brian Connor McClellan)**

The star-forming region W51 is a powerful laboratory in which to study the mass function of protostars. Recent images of W51 from the Atacama Large Millimetre Array (ALMA) reveal new lower-mass stars not previously detected and not yet cataloged. We present a Python package, dendrocat, which performs automated radio source detection and aperture photometry for radio observations across several frequencies at a time. Using this package, we have measured the spectral energy distributions of protostars in W51, and used the shapes of these distributions to identify both optically thick and thin dust and HII as drivers of radio light emission. These light emission mechanisms (and combinations of them) form a useful characterization of each of the protostars in W51, and have been used to measure at least one high-frequency spectral turnover which indicates the presence of an atypically dense HII region.

**Author(s):** Brian Connor McClellan, Adam Ginsburg

**Institution(s):** University of Florida, National Radio

### **366.13 - Identifying and Characterizing New Spectroscopic Binaries in Orion (Lisa Prato)**

Double-lined, young spectroscopic binaries provide the opportunity for precise measurements of pre-main sequence stellar mass ratios. In conjunction with additional information, such as orbital inclinations based on astrometric photocenter orbits, available in the future from GAIA, very precise stellar component masses may be determined. Mass ratio distributions yield clues to the formation of the closest binaries, a poorly understood problem. Absolute young star masses are important to test and refine the pre-main sequence evolutionary models that are central to the determination of properties such as the initial mass function, secondary star mass function, and star formation history of young clusters. We report on the results of our optical and infrared observations to identify and characterize new spectroscopic binaries in the Orion star forming region. Support for this research was provided in part by NSF award AST-1518081.

**Author(s):** Kyle Lindstrom, Kendall Sullivan, Sean Graham, Lisa Prato,

**Institution(s):** Lowell Observatory, UT Austin, Northern Arizona University

### **366.14 - New Insights into the Physical Conditions and Internal Structure of a Candidate Proto-Globular Cluster (Molly Finn)**

We present ~0.1" resolution (~10 pc) ALMA observations of a molecular cloud identified in the merging Antennae galaxies with the potential to form a globular cluster, nicknamed the ``Firecracker". Since star formation has not yet begun at a detectable level in this region, this cloud provides an example of what the birth environment of a globular cluster may have looked like before stars form and disrupt the natal physical conditions. Using emission from 12CO(2-1), 12CO(3-2), 13CO(2-1), HCN(4-3), and HCO+(4-3) molecular lines, we are able to resolve the cloud's structure and find that it has a maximum radius of 28 pc and a mass of  $(1-9) \times 10^6$  Msun. We demonstrate that since the cloud appears to be bound (based on its bright, compact morphology), an external pressure in excess of  $P/k > 10^8$  K cm<sup>-3</sup> is required. This is consistent with theoretical expectations that cluster formation requires high pressure environments, much higher than typical values found in the Milky Way. The position-velocity diagram of the cloud and its surrounding material suggests that this high pressure may be produced by ram pressure from the collision of filaments. The relative line strengths of HCN and HCO+ in this region also suggest that these molecular lines can be used as a tracer for the evolutionary stage of a cluster.

**Author(s):** Adam Leroy, K. E. Johnson, Christine Wilson, Ashley Bemis, William E. Harris, Remy Indebetouw, Molly Finn, Crystal Brogan, Julia Kamenetzky

**Institution(s):** University of Virginia, McMaster University, National Radio Astronomy Observatory, Westminster College, The Ohio State University

### **366.15 - Disk wind feedback from high-mass protostars (Jan Staff)**

To investigate the impact of outflows driven by disk winds in massive star formation, we have performed a sequence of 3D magnetohydrodynamic (MHD) simulations of a massive protostar forming via collapse of an initial cloud core of 60 Msun. We find that the opening angle of the flow increases with increasing protostellar mass. Once the protostar reaches ~24 Msun the outflow's opening angle is so wide that it has blown away most of the core, thereby nearly ending its own accretion. We thus find an overall star formation efficiency of ~50%, similar to that expected from low-mass protostellar cores. Our simulation results therefore indicate that the MHD disk wind outflow is the dominant feedback mechanism for helping to shape the stellar initial mass function from a given prestellar core mass function.

**Author(s):** Jonathan C. Tan, Kei Tanaka, Jan Staff

**Institution(s):** University of the Virgin Islands, Chile Observatory, NAOJ, Osaka University, University of Virginia, Chalmers University of Technology

## **367 - Star Formation II -- Posters**

### **367.01 - Exploring Star Formation in Five Isolated Cores (Emma Schwartzman)**

We utilize a combination of ALMA, Herschel, Spitzer, 2MASS, and GAIA data to analyze the distribution of the young stellar population and the distribution of the molecular cloud material in five isolated cores with embedded low luminosity objects: DC 3272+18, CB188, L723, IRAM 04191+1522, and DC 2742-04. All of the cores have multiple candidate young stellar objects (YSOs). In general, the YSOs are distributed both within and outside of the current core boundaries as determined from extinction and Herschel long wavelength images. We characterize this spatial relationship for each core and quantify the correlation between the stellar and material distributions. The ALMA data which are single pointings toward red, low luminosity YSOs within the cores, provide a high resolution (typically 0.2") images of these systems to reveal the presence of disks and companions. ALMA 12CO images probe for compact outflow structures associated with the sources.

**Author(s):** Isabelle Joncour, Emma Schwartzman, Michael Dunham, Lee Mundy

**Institution(s):** University of Maryland, SUNY Fredonia

### **367.02 - Investigating the Role of Magnetic Fields in Binary Star Formation(Justin Kang)**

The conditions that lead to single versus binary star systems are debated. The role of magnetic fields, in particular, is uncertain. Data from ALMA observations, which can probe the polarization within star-forming dense cores, suggests that the environments single star systems form in are most similar to those of weakly magnetized simulations. However, no such comparison has yet been conducted for binary star systems. In order to compare the outcomes of these two systems, we post-process a magnetohydrodynamic simulation of a turbulent, star-forming molecular cloud with moderate-strength magnetic fields. We generate synthetic dust polarization observations of protostellar cores in the simulation using the DustPol module of the ARTIST package, an extension of the LIME radiative transfer code. We compare the polarization fractions, polarization angles, and two-point correlation functions between cores forming single and multiple star systems to make predictions for what observable differences may exist. Comparing the synthetic observations with visualizations of the simulation data, we gain insight into the role of magnetic fields in star-forming regions.

**Author(s):** Justin Kang, Stella Offner

**Institution(s):** University of Texas at Austin

### **367.03 - Investigating the Probability of Outflow Interactions with Neighboring Protostellar Cores(Jeremy R Gingrich)**

We present the initial results of an investigation on the probability of outflows interacting with neighboring protostars and protostellar cores using simulations of clusters. Our simple models reveal the number of expected interactions within evolving clusters of various masses. We additionally investigated the probability of outflow triggered star formation given various initial conditions. We discuss the possible effect outflow triggering may have on the overall star formation within embedded clusters. The authors acknowledge support from the Bridgewater College Martin Science Research Institute.

**Author(s):** Jason E. Ybarra, Jeremy R Gingrich

**Institution(s):** Bridgewater College

### **367.04 - Binary Stars and their Planet-Forming Disks(Kyle Lindstrom)**

The majority of stars in our Galaxy reside in binary or higher order multiple systems. This can have profound effects on the evolution of the stars and in particular their circumstellar disks and the planet formation therein. In this poster we address several fundamental questions: how do circumstellar disks in binaries evolve, are these disks stable, and are their properties favorable for planet formation? To address these topics, our team is completing a spectroscopic survey of over 100 binary systems in young, nearby star forming regions, including

Taurus Auriga, using the Keck II and Discovery Channel Telescopes. Our goal is to analyze these spectra to infer the properties of the stars themselves, as well as their constituent disks. To accomplish this, we generate synthetic spectra with a wide range of effective temperatures, surface gravities, rotational velocities, radial velocities, veiling, and magnetic field strengths for comparison with our target spectra. We present some preliminary results and a discussion of their consequences with respect to the evolution of these systems. This research was supported in part by NSF awards AST-1313399 and AST-1518081 and by NASA Keck KPDA funds.

**Author(s):** Kendall Sullivan, Kyle Lindstrom, Lisa Prato, Christopher Johns-Krull, Sean Graham, Larissa Nofi

**Institution(s):** Northern Arizona University, Rice University, Lowell Observatory, UT Austin

### **367.05 - The Green Bank Ammonia Survey: Investigation of the Hierarchical Structures of Nearby Star-Forming Regions(James Lilly)**

We present an analysis of the hierarchical structures of the four star-forming regions (SFRs) included in the first data release (DR1) of the Green Bank Ammonia Survey (GAS). GAS is an ambitious program that has mapped the dense molecular gas in all the major star-forming molecular clouds within 500 pc in ammonia emission with the Green Bank Telescope. In this poster, we detail our methods for optimizing a robust parameter set for the dendrogram technique used to map the hierarchical structures of these DR1 regions. We find that multiples of the median rms value extracted from the integrated intensity map (0th moment) of each region are sufficient baselines for the dendrogram parameters, with respect to only identifying real structures. Finally, we present preliminary findings for each region on: a) minimal correlations between both structure size and aspect ratio & the relative orientations of small and large-scale structures b) the possibility of dendrograms identifying stellar/pre-stellar cores.

**Author(s):** James Lilly, Rachel Friesen

**Institution(s):** University of Arizona, National Radio Astronomy Observatory (NRAO) Contributing Team(s): The Green Bank Ammonia Survey Team

### **367.06 - Jets and Outbursts in the BHR 71 Class o Protostellar Outflows(Tyler Bourke)**

The BHR 71 low-mass protostellar binary system powers two highly collimated outflows, with the outflow from the primary (IRS1) producing shock-induced chemical activity only seen in a handful of other outflows, notably L1157, but also L1448C and IRAS04166 (Bourke+ 1997, Garay+ 1998, Bourke 2001, Parise+ 2006). This may represent a very short phase in the outflow process that we don't yet understand. The shocks are likely caused by jets with velocities  $> 50$  km/s impacting on the ambient material, but unlike in the other outflows mentioned above, no such jet has yet been identified in BHR 71, although



hints are found in Spitzer 4.5 micron images, and Herschel low-resolution water, high-J CO, and [OI] spectra (Yildiz+ 2013, Mottram+ 2014, Benedettini+ 2017). We present ALMA observations that reveal the jets for the first time, and also reveal past and ongoing episodic outflow ejections and precession.

**Author(s):** Yichen Zhang, Tyler Bourke, Michael Dunham, Hector Arce, Mario Tafalla, John Tobin, Antoine Gusdorf

**Institution(s):** SKA Organisation, SUNY, NRAO, OAN, CNRS, LERMA, RIKEN, Yale

### **367.07 - Using Formaldehyde to Reveal the Temperature Structure of Protostellar Cores in the Perseus Molecular Cloud(Alexander R. MacLeod)**

To investigate how the physical properties of cores affect the development of stars nested within them, we study 6 transitions of formaldehyde (H<sub>2</sub>CO) across 13 protostellar cores in the Perseus molecular cloud. We target a representative sample of dense cores that include a mix of Class 0/I systems as well as cores with single or multiple stars. We use the radiative transfer codes RADEX and XCLASS to measure the physical properties across each core. We produce maps of temperature, H<sub>2</sub>CO column density, H<sub>2</sub> density and ortho-to-para ratio for all cores. We find an anticorrelation between temperature and ortho-to-para ratio, which is expected from previous studies, but we find no correlation between temperature and the number of stars or with the evolutionary stage. We see potential evidence that cores with higher H<sub>2</sub>CO column densities tend to have higher masses or multiple embedded objects, but we require a larger sample to confirm this.. This study suggests that some physical properties of cores may be determined by the initial condition of the system, whereas others could be affected by feedback from the stars.

**Author(s):** Joseph Mottram, Dmitry Semenov, Sarah Sadavoy, Alexander R. MacLeod,

**Institution(s):** University of Massachusetts Lowell, MPIA, Harvard-Smithsonian Center for Astrophysics

### **367.08 - Smooth Inner Emission in the Herbig Ae Disks HD 163296 and HD 190073(Benjamin Setterholm)**

The processes occurring within the inner few astronomical units of proto-planetary disks regulate accretion and planet migration while also affecting the outer planet-forming regions via shadowing. Combining new measurements from CHARA with archival VLTI and Keck data, we confirm previous results suggesting that significant near-infrared emission originates from within the supposed dust destruction radius of this class of object. Our geometrical model fits indicate that the inner-disks of both of these objects exhibit a remarkably smooth, nearly Gaussian emission profile, with no significant sign of a sharp edge expected from a sublimation front. We further find that the H- and K-band sizes of these disks are the same within

( $3\pm 3$ ) % for HD 163296 and ( $6\pm 10$ ) % for HD 190073, indicating a common origin of emission. The origin of this "inner emission" remains a mystery that we hope to solve with the next generation of imaging combiners at CHARA, MIRC-X and MYSTIC.

**Author(s):** Fabien Baron, Stefan Kraus, John Monnier, Claire Davies, Benjamin Setterholm, Alexander Kreplin

**Institution(s):** University of Michigan, Georgia State University, University of Exeter Contributing Team(s): CHARA team

### **367.09 - Using Far-Infrared Spectroscopy to Study Stellar Populations(Elizabeth Post)**

In order to understand star formation over cosmic time, we use far-infrared fine-structure lines to probe the ISM and stellar populations within galaxies. FIR lines require much less energy to ionize than optical lines and are also not obscured by dust. This allows us to observe physical properties of stellar populations and AGN's within galaxies, even in very dusty environments. From the Herschel Space Observatory and Spitzer Space Telescope archives, we have data mined approximately 150 nearby star-forming galaxies. Using the [O III], [N II], and [N III] FIR fine-structure lines we calculate the density of the HII regions, as well as provide an estimated age for the stellar population. We combine these lines with [Ne II] and [Ne III] mid-infrared lines to determine the hardness of the ambient UV radiation field, using the [Ne V] line to correct for AGN contribution. Here we present the initial results of this study, finding the stellar population age of our dataset to be up to four million years old and demonstrate that the N/O abundance ratio of Arp 299 is half solar.

**Author(s):** Elizabeth Post

**Institution(s):** Mount Holyoke College

### **367.10 - Revisiting the Protostellar Phase Lifetime with SESNA, the Spitzer Extended Solar Neighborhood Archive(Robert Gutermuth)**

Spitzer-based surveys of star-forming clouds were a revolutionary step forward in their simultaneous extremely wide coverage and excellent mass completeness to dusty young stellar objects (YSOs). However, many of these surveys were analyzed by independent groups that emphasized differing primary science goals, thus even trivial analyses demonstrate clear discrepancies when compared. These issues can usually be traced back to qualitative differences in data treatment trade-offs, but progress beyond that is stymied without a more complete solution. Our solution is SESNA, a collection of uniformly produced Spitzer mosaics, source catalogs, and YSO identifications, all backed by complementary completeness mapping products, for most of the star-forming clouds within the nearest 1.5 kpc surveyed during the Spitzer cryogen mission. The collection includes most of the clouds closer than 500 pc in Gould's Belt, Cygnus-X at 1.4 kpc, and many other clouds at

distances between those extremes. The full archive spans 92 sq. deg. (plus another 16 sq. deg. of extragalactic fields to explore residual contamination rates), and the catalog contains over ten million sources with tens of thousands of YSOs identified consistently across all surveys. Here we introduce SESNA and demonstrate its utility as a more precise and more powerful means to perform fundamental characterizations in star formation by way of the nominally simple example of constraining the protostellar phase lifetime. Specifically, we utilize the SESNA catalog and completeness maps to extract an extremely uniformly observed subset of YSOs, and then further constrain the sample based on relative surface densities of stars and gas at parsec scales to limit evolutionary differences across regions. The final subsample enables greater statistical leverage than has been achieved to date for constraining the protostellar phase lifetime. This research is supported by NASA ADAP NNX17AF24G.

**Author(s):** Stella Offner, Michael Dunham, Robert Gutermuth  
**Institution(s):** University of Massachusetts Amherst, University of Texas Austin, SUNY Fredonia

### 368 - Starburst Galaxies -- Posters

#### 368.01 - Probing the Environments of Extreme Star-Forming Galaxies (Samantha W Brunker)

We present environmental analyses for several extreme star-forming galaxies similar to Green Pea galaxies. These galaxies were discovered via their strong [O III] emission in the redshift range  $0.3 < z < 0.42$ , and they are undergoing a major burst of star formation. These Green-Pea-like galaxies are compact and have very low metallicities, with many appearing to have metal abundances more than a factor of ten lower than what is observed in nearby galaxies with the same luminosities. These star-forming galaxies appear to be more extreme versions of Green Pea and Luminous Compact Blue galaxies and are possible analogs to the Lyman Break galaxies observed at  $z \sim 2-3$ . Using the Hydra multi-fiber spectrograph on the WIYN 3.5-m telescope, we mapped out the galaxy distribution around each of the star-forming galaxies (out to  $\sim 12$  Mpc at the redshifts of the targets). A primary goal of this study is to understand what role the environment plays in driving the current star-formation activity. By studying the environments around these extreme star-forming galaxies, we can learn more about what triggers their star-formation processes and how they fit into the narrative of galaxy evolution.

**Author(s):** Samantha W Brunker, Brooke Kimsey-Miller, John Salzer, Bryce Cousins

**Institution(s):** Indiana University

#### 368.02 - Examining the Gas Outflow for a Typical Dusty, Star-Forming Galaxy at $z=2$ (Aimee Lee Schechter)

Gas outflows are thought to be ubiquitous as a way of expelling metals from the interstellar medium and enriching the intergalactic and circumgalactic medium. For high-redshift

dusty galaxies, it is rare to have direct constraints on gas outflows as measured in the rest-frame ultraviolet, due to significant levels of dust attenuation obscuring the stellar continuum. This project aims to use features from the observed optical and near infrared spectra of an unlensed, typical dusty star-forming galaxy (DSFG), 450.06, to directly calculate a gas outflow velocity. The galaxy is massive and extreme, with a stellar mass of  $1.1 \times 10^{11} M_{\odot}$ , and  $SFR = 724 M_{\odot} \text{ yr}^{-1}$  at  $z = 2.085$ . We analyze the blueshifted iron lines in the rest-frame UV relative to the galaxy's systemic redshift as measured via  $H\beta$  emission, a tracer of star formation.  $H\beta$  emission indicates a precise systemic redshift of  $2.085 \pm 0.001$ . Three Iron absorption lines (at rest-frame wavelengths  $\lambda_{\text{rest}} = 2344 \text{ \AA}$ ,  $\lambda_{\text{rest}} = 2383 \text{ \AA}$ , and  $\lambda_{\text{rest}} = 2600 \text{ \AA}$ ) were blueshifted with respect to their expected observed wavelength; we co-added the spectra in velocity space relative to this systemic redshift solution to boost the signal-to-noise of the resulting absorption feature. We measure a blueshifted outflow velocity of  $-190 \pm 50 \text{ km s}^{-1}$  for this galaxy, which agrees with outflow rates for galaxies with similar star formation rates in the literature.

**Author(s):** Aimee Lee Schechter

**Institution(s):** The University of Texas at Austin

#### 368.03 - Measurement of Hot Gas Mass Outflow Rates from Starburst Galaxies (Ryan Tanner)

Starburst driven winds provide metal rich gas to the galactic halo. While absorption spectra from neutral or low ionized gas can measure the velocity and mass outflow rate of cold and warm gas in the wind, it does not accurately reflect the velocity of the hot gas. Using synthetic absorption lines generated from 3D hydrodynamical simulations we have previously showed that the velocity of the cold and warm gas in a galactic wind depends on the star formation rate (SFR), while the velocity of the hot gas is independent of the SFR. We present results from further simulations where we measure the mass outflow rate of the hot gas and show how it correlates with the mass loading from the nuclear starburst. Our simulations show how the mass outflow rate of the hot gas is further increased by evaporation from cold gas entrained in the wind. We measure this evaporation and determine that it contributes significantly to the hot gas mass outflow rate.

**Author(s):** Kendra Sands, Ryan Tanner

**Institution(s):** Augusta University

#### 368.04 - Assessing the Feasibility of X-ray Emission in Determining the Star Formation Rates of LIRGs (Cecilia Noemi Molina)

Luminous infrared galaxies (LIRGs) are the most energetic starburst galaxies in the local Universe. They are the sites of gas-rich galaxy mergers and interactions; the interactions drive star-forming molecular gas into the nuclear regions, fueling an intense starburst. However, heavy obscuration from dust in these compact regions complicates the use of optical

wavelength diagnostics in determining physical quantities such as their star formation rate. In the present study, we compare the X-ray and radio properties of LIRGs. The hard X-ray emission emanates from accretion disks associated with active galactic nuclei and stellar X-ray binaries. The radio emission is an optically thin tracer of star formation and emanates from both HII regions (thermal) and supernovae (non-thermal). We correlate the Chandra hard X-ray luminosities (2-10 keV) with the EVLA radio luminosities of a sample of 20 starburst-dominated galaxies in the Great Observatories All-Sky LIRG Survey (GOALS) to examine whether hard X-ray emission is a reliable diagnostic of star formation activity in LIRGs.

**Author(s):** Sean Linden, Cecilia Noemi Molina, Aaron Evans

**Institution(s):** San Francisco State University, University of Virginia, National Radio Astronomy Observatory Contributing Team(s): GOALS

### **368.05 - Evidence for Shocks and Turbulence in the Taffy Galaxy System from ALMA CO Mapping and VIRUS-P IFU Spectroscopy(Philip Noel Appleton)**

We present multiple lines of evidence that gas in the Taffy galaxy system (UGC 12914/5) is in a highly disturbed state as a result of a recent head-on collision between these two gas-rich galaxies. Building on evidence of large quantities of warm molecular hydrogen in the Taffy bridge, and evidence of boosted [CII] emission from Herschel, we observed the Taffy system with ALMA in the CO 2-1 and 3-2 lines, and with the McDonald Observatory VIRUS-P IFU system in the visible light. Strong emission lines were detected from the galaxies and in the bridge with VIRUS-P, showing two dominant velocity components over much of the bridge and parts of both galaxies. We made a detailed analysis of the excitation properties of the ionized gas, finding that a significant amount of the high-velocity component of the bridge gas was consistent with shocks with velocities of 200-300 km/s. Two distinct filaments of ionized gas were found between the galaxies. Our ALMA observations also showed that the dense molecular gas is also highly disturbed. The most remarkable aspect of the ALMA observations is the discovery of a tangled web of molecular filaments in the bridge. The individual filaments are typically 1 kpc in length, are almost unresolved at 60 pc resolution in the other dimension. They also contain clumps that have broad line widths of 80-150 km/s. Although some of the filaments are associated with a prominent extragalactic star formation region located in the bridge, most of the filaments show little obvious sign of star formation despite their apparently high molecular surface densities. Given their high surface densities, it is not clear why the filaments are not forming stars, unless they are magnetically supported. One possibility is that they represent transient density enhancements in a supersonic turbulent multi-phase fluid created in the aftermath of the high-speed collision.

**Author(s):** Edith Falgarone, Bhavin Joshi, George Helou, Guillermo Blanc, Bernd Vollmer, Philip Noel Appleton, Pierre Guillard, Bjorn Emonts, Curtis Struck, Brad Peterson, Jeff Rich, Patrick Ogle, Emily Freeland, Laurant Lanzo, Jonathan

Braine, Katherine Alatalo, Ut

**Institution(s):** Universidad de Granada, Dartmouth College, STScI, Hastings College, Iowa State university, Carnegie Observatories, Observatoire Astronomique, Caltech, Arizona State University, Caltech, Universite of Bordeaux, OAN, University of Chile, Sorbonne

### **368.06 - X-rays from Nearby Ly $\alpha$ emitters: Massive Stars or Compact Objects?(Benjamin Dittenber)**

Lyman  $\hat{\pm}$  emission (Ly $\alpha$ ) is a standard tracer of highly star forming galaxies at high redshift. However, some nearby Ly $\alpha$  emitters (LAEs) appear to be X-ray sources. X-ray emission can be diffuse emission from shock heating by supernovae, or compact X-ray binaries (XRBs), both of which are associated with massive star formation. However, if a significant number of LAEs are ionized by low luminosity active galactic nuclei (LLAGN), then this would call into question the assumption that LAEs are all ionized by massive star formation. We searched the archived Chandra X-ray Observatory and XMM Newton data for known resolved nearby LAEs to set constraints on whether their X-ray sources are LLAGN or XRBs. We found a sample of 7 Lyman Alpha Reference Sample (LARS) galaxies and 4 other known LAEs with X-ray data. Within this sample there are 12 Ly $\alpha$  regions that are also X-ray sources. We identify compact objects by calculating the full width at half maximum of each source. We use the luminosity to further constrain whether unresolved sources are LLAGN. We find that 7 of the 12 are point-like sources with luminosities above 1040 erg/s, and all but 1 of the sources are nuclear.

**Author(s):** Benjamin Dittenber, M. Oey, Edmund Hodges-Kluck, Elena Gallo

**Institution(s):** University of Michigan, NASA Goddard Space Flight Center

### **368.07 - The Old, the Red, and the Dusty(Oscar Alberto Cantua)**

Herschel submillimeter surveys have uncovered a group of galaxies at high redshifts that were previously invisible at optical wavelengths. These submillimeter galaxies appear to have a high rate of star formation ranging in the 100s-1000s of solar masses per year and contain high amounts of dust, for which they are called dusty, star-forming galaxies (DSFGs). The size and abundance of this dust allows it to absorb most of the UV light emitted by the hot, young stars and emit infrared light. Redshifting allows us to observe this light in submillimeter ranges, but it is the phenomenon of negative k-correction that allows us to observe these galaxies. As the thermal dust peak is redshifted, the flux at these wavelengths remains constant as the dimming due to distance is cancelled by the peak of the curve moving. Previous surveys focused on the search of  $z \approx 3$  galaxies by looking at this curve in the form of increasing flux densities from 250  $\mu$ m to 500  $\mu$ m. The Spectral Energy Distributions (SEDs) of these galaxies from Herschel surveys

have been used previously to find the photometric redshift of these galaxies. AzTEC data at 1.1 mm was used in conjunction to corresponding Herschel data to further constrain the redshifts of these galaxies and, using the smaller AzTEC beam size, to find whether previous catalogues of these 500  $\mu$ m risers contained multiple sources that made them appear to have the desired qualities. The results of these calculations were then used to estimate the redshift distribution of these galaxies and their contribution to the Cosmic Star Formation Rate Density models.

**Author(s):** Jorge Zavala, Oscar Alberto Cantua,

**Institution(s):** The University of Texas at San Antonio, The University of Texas at Austin

### **368.08 - Radio Morphologies of Dust Obscured Starbursts in the SuperCLASS Field(Sinclair Manning)**

The SuperCLASS (Super-CLuster Assisted Shear Survey) is a deep, wide-area ( $\sim 2$  square degrees) extragalactic field with high resolution ( $0''.1$ ) radio continuum coverage from e-MERLIN (the upgraded Multi-Element Radio Linked Interferometer Network.) The combination of sensitivity and spatial resolution makes e-MERLIN an ideal tool to trace spatially resolved star-formation in heavily obscured, dusty star-forming galaxies (DSFGs). Additionally, thanks to the tight relationship between radio continuum and far-IR observations, we have an observationally inexpensive and accurate method of mapping star formation density in distant galaxies. We present a case study of radio bright DSFGs in the SuperCLASS field, their photometric redshifts, and comparison of radio and optical morphologies. We aim to conduct the first large sample morphological analysis of  $z \sim 1-3$  obscured galaxies and plan to address two important questions: 1) Are most obscured  $SFR > 50 M_{\odot}/yr$  galaxies driven by major collisions? and 2) do luminous active galactic nuclei (AGN) play a crucial role in the quenching of highly obscured star-formation?

**Author(s):** Chao-Ling Hung, Christopher Hales, Neal Jackson, Richard Battye, Sinclair Manning, Michael Brown, Tom Muxlow, Caitlin M Casey, Ian Harrison, Filipe Abdalla, Robert Watson, Chris Riseley, Scott Chapman, Robert Beswick, Ian Smail

**Institution(s):** University of Texas at Austin, University of Manchester, Manhattan College, University College London, Durham University, Newcastle University, Dalhousie University, CSIRO Astronomy and Space Science

### **368.09 - Green Peas: Local Analogs of Reionization Galaxies(Sangeeta Malhotra)**

We show that low-redshift, compact, extreme line emitting galaxies, known as Green Peas, are excellent analogs of high-redshift Lyman-alpha galaxies. Moreover, they afford excellent opportunities to measure prominent optical emission lines and other properties unavailable for their high-redshift

counterparts. This allows us to study their physical properties in detail. The Green Peas are compact, low metallicity, dust-poor, and very young starbursts. A substantial fraction are suspected of being low luminosity AGN. After deriving correlations of Lyman-alpha escape fraction with kinematics and extinction, we can predict their Lyman-alpha fluxes to 0.3 dex. With JWST, we will have similar information for Lyman-alpha emitters at redshift  $z > 7$ , and thus will be able to derive the Lyman-alpha escape fraction. Thus we can derive the transmission of Lyman alpha through the intergalactic medium for individual galaxies, dramatically increasing their power as diagnostics of reionization.

**Author(s):** James Rhoads, Huan Yang, Tianxing Jiang, Sangeeta Malhotra

**Institution(s):** Goddard Space Flight Center, Arizona State University, Carnegie Observatories

### **368.10 - The Neutral Hydrogen Content of Haro 11(Sarah Taft)**

We present the results of deep HI spectral line observations of the nearby dwarf galaxy Haro 11 (ESO 350-IG038), obtained using the Karl G. Jansky Very Large Array (VLA). Haro 11 is one of a small number of nearby dwarf galaxies that are known to be both Lyman alpha and Lyman continuum emitters. While it harbors strong ongoing star formation, the neutral hydrogen gas in the system has been notoriously difficult to detect. Previous interferometric observations have resulted in non-detections, while a deep GBT spectrum reveals a weak spectral line. Using 24 hours of observing time from program VLA/17B-287, we perform a vigorous search for HI in emission. We confirm the previous detection of HI in absorption, including the velocity offset compared to the optical emission lines. Haro 11 is a highly enigmatic galaxy whose neutral hydrogen content is much less than would be expected given its aggressive star formation rate.

**Author(s):** John M. Cannon, G  ran   stlin, Nils Bergvall, Sarah Taft, Johannes Puschig, Matthew Hayes, Th  ger Rivera-Thorsen, Stephen Parry

**Institution(s):** Macalester College, Stockholm University, University of Wisconsin, University of Oslo, Uppsala University

### **368.11 - High Resolution HI Kinematics and Imaging of Starburst Galaxy eLARS01(Nick Velikonja)**

We present new HI spectral line imaging from the Karl G. Jansky Very Large Array (VLA) of the active galaxy NGC 6090, henceforth eLARS01. eLARS01 is a major merger system with a high star formation rate. It is an important probe of galaxy evolution due to its violent gas kinematics and to the significant resonant scattering of Lyman Alpha photons that has been observed within the system. Here, we present the first detailed HI study of the eLARS01 system using data from the A, B, C, and D configurations of the VLA. The neutral hydrogen in the

source spans a remarkable distance of  $\sim 150$  kpc. Our new HI images show details on kpc scales, enabling a direct comparison of HI and HST images of the galaxy in the UV continuum, Balmer Alpha, and Lyman Alpha emission lines. Such comparisons allow us to draw the first conclusions about the role that neutral hydrogen gas morphology and kinematics play in the resonant scattering of Lyman Alpha photons.

**Author(s):** John M. Cannon, G  ran   stlin, Jens Melinder, Nick Velikonja, Matthew Hayes

**Institution(s):** Macalester College, Stockholm University  
Contributing Team(s): LARS Team

### **368.12 - Deep HI Imaging of the Metal-Poor Starburst Galaxy SBS 0335-052(Benjamin Koenigs)**

We present new HI spectral line images of the nearby metal-poor galaxy pair SBS 0335-052E and SBS 0335-052W, acquired with the Karl G. Jansky Very Large Array (VLA). Located at a distance of 54 Mpc, both galaxies are strongly star-forming systems that host some of the lowest metallicity regions known. The extreme physical conditions of the SBS 0335-052 interacting system make it an important proxy for the star-forming galaxies that were present in the early universe. Prior VLA imaging has resolved the neutral hydrogen gas in each of the primary star-forming regions. The new HI images presented here offer an unprecedented view of the neutral interstellar medium at high angular resolution. Our observations confirm the existence of gaseous structures to the northeast of SBS 0335-052E, as well as the bridge of HI that connects each of the galaxies together. To first order, our results match the predictions of Herenz et al. (2017) in that we identify a lack of HI in the locations of some of the recently discovered ionized gas tails. This supports the interpretation that the ionized gas tails act as escape channels for Lyman continuum radiation.

**Author(s):** John M. Cannon, G  ran   stlin, Polychronis Papaderos, Christian Herenz, Johannes Puschnig, Matthew Hayes, Jens Melinder, Benjamin Koenigs, Arjan Bik

**Institution(s):** Macalester College, University of Porto, Stockholm University

## **369 - Black Holes -- Posters**

### **369.01 - Searching for Intermediate-Mass Black Holes in the Optical Time Domain(Caeley Pittman)**

Determining the occupation fraction of intermediate-mass black holes (IMBHs) in dwarf galaxies is essential for understanding how supermassive black holes (SMBHs) originally formed. We investigate the potential of observing dwarf galaxies in the optical time domain as a useful method for detecting and weighing these IMBHs. Reines et al. (2013) presented 151 IMBH candidates from dwarf AGN detected in a spectroscopic survey of 44,594 dwarf galaxies ( $M_{\text{star}} \approx 3 \times 10^9 M_{\odot}$ ). We extracted light curves for 128/151 of these candidates with aperture photometry from the Catalina Real-time Transient Survey (CRTS) and searched for stochastic

optical variability indicative of black hole accretion. Using the reduced  $\chi^2$  and intrinsic RMS scatter ( $\sigma_{\text{int}}$ ) statistics of the light curves of a control sample of dwarf galaxies, we have determined that a light curve indicating intrinsic variability should have values  $\chi^2 \approx 1.52$  and  $\sigma_{\text{int}} \approx 0.06$ . Light curves of eight dwarf galaxies from the Reines sample pass these variability criteria, suggesting that optical time domain observations can be used to detect dwarf AGN and select candidate nuclear IMBHs independently of spectroscopy. We then use a structure function analysis to search for a characteristic "turn over" timescale of the variability that can test these dwarf AGN as bona fide nuclear IMBHs. However, given the shorter timescales we expect from accretion onto an IMBH (10 days or less), we require higher cadence observations, soon to be available from the Zwicky Transient Facility Northern Sky Survey. This project was supported in part by the NSF REU grant AST-1757321 and by the Nantucket Maria Mitchell Association.

**Author(s):** Suvi Gezari, Caeley Pittman,

**Institution(s):** William Jewell College, University of Maryland, Maria Mitchell Observatory  
Contributing Team(s): Reines et al(03)

### **369.02 - The Astrometric Microlensing of OB150211(Jose Nijaid Arredondo)**

Definitive detection of the population of isolated black holes in our own Galaxy has yet to be successful, making it difficult to constrain the mass function and the relation between initial and final mass. Astrometric microlensing has been proposed as a method to find and measure the mass of black holes and neutron stars by tracking the image of a luminous background star as a remnant passes in front of it, lensing its starlight and allowing for an estimate of its mass. With the precision of the adaptive optics on the W. M. Keck II 10-meter telescope, we attempt to measure the source proper motion and astrometric shift and combine them with the properties derived from the OGLE photometric light curve, allowing us to break degeneracies in photometry-only microlensing models. We observed the microlensing event OGLE-2015-BLG-0211 (OB150211) for 13 epochs from 2015 to 2018. Its 132 day-long Einstein crossing time makes it a good candidate black hole for astrometric follow-up to the OGLE survey's photometry of the event. While our point-source-point-lens model yields a lens mass of  $5.01 - 99.32$  solar masses within a 99.7% confidence level, further fit to binary models and combined astrometry from the Spitzer survey are in progress.

**Author(s):** Fatima Abdurrahman, Jessica Lu, Evan Sinukoff, Szymon Kozlowski, Jose Nijaid Arredondo, Andrzej Udalski, Eran Ofek

**Institution(s):** UC Berkeley, Weizmann Institute of Science, Insitute of Astronomy, Warsaw University Observatory

### **369.03 - Origin of the Spin-Orbit Misalignment in the Microquasar V4641 Sgr(Supavit Pokawanvit)**

V4641 Sgr is a microquasar with the largest misalignment angle observed so far. This misalignment angle is measured between the binary orbital axis and jet axis which we assume to point along the black hole spin axis. The origin of small misalignment angles in other microquasars has been previously explained by an asymmetric supernova progenitor that gives the black hole a natal linear momentum kick. This model, however, favors a small misalignment angle because large kick velocities tend to unbind the binary system. We apply this model to V4641 Sgr to see if it can explain the large misalignment angle of 55 degrees. Using the observed system parameters for V4641 Sgr and population synthesis models, we constrain the pre-supernova orbital velocity to be 414-524 km/s. Using the current systemic velocity to track the Galactic trajectory of the system into the past, we constrain the post-supernova peculiar velocity to be 72-136 km/s. Incorporating these constraints into the linear momentum kick model, we find it is impossible for V4641 Sgr to have a misalignment angle greater than 55 degrees as observed. This result implies that the supernova progenitor imparted angular momentum to the black hole in V4641 Sgr.

**Author(s):** Omer Blaes, Supavit Pokawanvit, Greg Salvesen

**Institution(s):** University of California, Santa Barbara

### **369.04 - Pairing of Supermassive Black Holes in the Aftermath of Galaxy Mergers(Temitope Olatinwo)**

Dynamical friction is a physical mechanism thought to be responsible for pairing of supermassive black holes (SMBHs) in the aftermath of galactic mergers. It arises when a massive perturber traveling through a background medium (either gas or stars) creates in it a density wake. The wake, which trails the perturber on its trajectory, causes it to slow down by gravitational interaction. Despite an important role played by this process in theoretical models, its impact still remains to be tested through observations, and will require detection of SMBH pairs with orbital separations  $<1\text{kpc}$ . We model orbital evolution of a pair of SMBHs at these separations under the influence of gaseous dynamical friction for a range of physically motivated scenarios, encountered in merging galaxies. Based on it we calculate the probability of discovering a SMBH pair as a function of pair separation and make predictions for observations, which can be used to verify the impact of dynamical friction.

**Author(s):** Temitope Olatinwo, Kunyang Li, Yoko Sarah Nakama, Tamara Bogdanovic

**Institution(s):** Spelman College, Georgia Institute of Technology

### **369.05 - LISA OBSERVATIONS OF INSPIRALING MASSIVE BINARY BLACK HOLES(Samantha J.H. Berry)**

In the 2030s LISA will be the first space-based gravitational wave detector, observing a new portion of the gravitational wave frequency spectrum. In this project, we found the approximate number of detectable massive binary black holes that do not evolve past the inspiraling phase during the time LISA is observing. My poster describes the process we used to create the systems of massive binary black holes and the calculation of the LISA detectability based on the signal-to-noise ratio. We used Illustris, a cosmological simulation, to model the population of massive binary black hole systems. Then we used the Monte Carlo method to create 8000 statistical copies, which allow us to model the expected possible range of MBH catalogs that LISA might detect. In this study, we considered 4 possible LISA configurations: the current "Proposed LISA" configuration observing for 4 and 10 years and Classic LISA configuration observing for 4 and 10 years. This study allows us to understand the possible astrophysical populations of massive black hole binaries, and how our design of LISA will allow us to probe and understand those populations.

**Author(s):** Michael L. Katz, Fani Dosopoulou, Samantha J.H. Berry, Luke Zoltan Kelley, Shane L. Larson

**Institution(s):** Harry STruman College, Northwestern University

### **369.06 - Variable Accretion Disk Winds in GRS 1915+105 with NuSTAR(Pablo Aramburu Sanchez)**

The black hole binary GRS 1915+105 is well known for its accretion and ejection processes, particularly its strong variability. We report on two observations of GRS 1915+105 made by the X-ray telescope NuSTAR in June and August 2017. The lightcurve of the first observation is steady, while the second shows high-amplitude limit cycles characteristic of the source. We analyzed the time averaged spectra as well as time resolved spectra, dividing our observation into intervals with high and low count rates. We report a disk temperature of  $1.73\text{-}0.002\text{+}0.003\text{ keV}$  and  $2.04\text{-}0.01\text{+}0.07\text{ keV}$  for the first and second observations respectively, with generally weak disk emission at low flux. We find that the variability apparent in our second observation can be primarily attributed to changes in the disk flux and spectrum; for instance the disk temperature is  $2.198\text{-}0.001\text{+}0.005\text{ keV}$  at high flux, but  $1.769\text{-}0.007\text{+}0.006\text{ keV}$  at low flux. We also report a significant iron absorption line ( $E\sim 7.05\text{keV}$ ) from an accretion disk wind in both spectra. Surprisingly, the wind appears to be stronger at lower flux: The equivalent width of the iron absorption line is 8.7 eV for the high flux in the first observation and 10.5 eV at low flux; for the second observation we found an equivalent width of 27 eV at high flux, and 32.8 eV at the bottom of the light curve. We discuss these results in the context of mechanisms for wind variability and lags with respect to the continuum. We compare our results to typical behavior of GRS 1915+105.

**Author(s):** Pablo Aramburu Sanchez, Joseph Neilsen  
**Institution(s):** Villanova University

### **369.07 - Searching for Offset Black Holes at the Center of Galaxies(Dalton Grady)**

Science: Observational evidences in the local Universe show that the center of every galaxy lies a black hole. When two galaxies merge together so do their black holes, and as a result, strong gravitational waves are emitted. If these physic conditions are such that the gravitational waves are asymmetric, the newly formed black hole may be ejected out from its galaxy center. This has been observed in a few objects, including CID-42. GOAL: We are looking to discover more offset black holes by performing detailed analysis of galaxy profiles and measure the separation between the galaxy center and the position of their black hole. Method: We have performed 2D fitting of ~25000 galaxies in the COSMOS field, using the code Galfit applied to Hubble data. A Sersic profile is used for the modeling.Future: We plan to include a point source component to each fit to model the black hole emission and discover other possible occurrences of offset black holes.

**Author(s):** Dalton Grady, Francesca Maria Civano  
**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Massachusetts - Lowell

### **369.08 - Black Hole Imaging with Space-Based Telescopes(Maura Shea)**

The Event Horizon Telescope (EHT) is a millimeter-wavelength array using very long baseline interferometry (VLBI) to image the supermassive black holes at the center of galaxies. The EHT has enough angular resolution to image the shadow of the supermassive black hole in the center of our galaxy as well as in the nearby giant elliptical galaxy M87. With baselines approaching an Earth diameter, the EHT is near the limit of the resolution achievable from ground-based VLBI. This poster explores the potential benefits of adding telescopes in extended orbits to the EHT, allowing for higher-fidelity imaging of current target sources as well as the addition of new target sources with smaller shadows. To test the effectiveness of orbital patterns, we first generate models of sources with various black hole shadow sizes, then create model telescope arrays that include telescopes in different orbits. We then reconstruct model images using simulated data from these telescope arrays. We determine that, by including a geostationary Earth orbiting satellite and a high-inclination medium Earth orbiting satellite, we can successfully reconstruct high-fidelity images of the next tier of shadow sources down to a shadow diameter of ~3 microarcseconds. This would allow the array to image the shadow of the black hole in the Sombrero Galaxy, among others, and would allow the EHT to study the fine structure of jet launch and collimation in M87 and other active galactic nuclei. This work is made possible by funding from the National Science Foundation (AST-1659420, AST-

1614868, and AST-1440254).

**Author(s):** Kazunori Akiyama, Maura Shea, Vincent Fish  
**Institution(s):** Wellesley College, MIT Haystack Observatory

### **369.09 - Looking for Variability in Cygnus X1(Bailey Conrad)**

We present observations of HDE 226868, the companion to Cygnus X-1. Low resolution ( $R=4.3 \text{ \AA} \dots$  per pixel) spectra of the visible region,  $6500 \text{ \AA} \dots$  to  $3000 \text{ \AA} \dots$ , made with Maryland Space Grant Consortium's 0.5-meter telescope at John Hopkins University over the summer. This region includes emissions from hydrogen and helium which are shown to be time variable by Gies et al. (2003). We examined these spectra for variability. References: D. R. Gies et al. "Wind Accretion and State Transitions in Cygnus X-1" in The Astrophysical Journal, 583 (2003)

**Author(s):** Bailey Conrad, Alex Storrs  
**Institution(s):** Towson University

### **369.10 - A New Evolutionary Channel Towards the Merger of Two Stellar Origin Black Holes(Amy Hariett Knight)**

The discovery of gravitational radiation from mergers of binary black holes and neutron stars has made it necessary to explore the physical processes that bring stellar remnants close enough together to merge within a Hubble time. Here we present a new evolutionary channel towards the merger of two stellar mass black holes, by combining homogeneous evolution of a massive, tightly bound stellar binary with mass transfer from a third star. The inner black hole binary and the third star form a hierarchical triple, in which the outer star transfers mass to the inner binary through processes such as stellar winds. We derive the consequences of mass flowing toward the inner binary. These include equalizing the masses of the inner binary black holes and changing the time to merger. The development of gravitational merger progenitor scenarios provides important insight into how the black holes can become close enough to merge within a Hubble time. It also predicts possible detectable signatures of these systems as they evolve.

**Author(s):** Amy Hariett Knight, Rosanne di Stefano  
**Institution(s):** University of Southampton, Harvard Center for Astrophysics

### **369.12 - Detection of a radio bubble around the Ultraluminous X-ray Source Holmberg IX X-1(Ciprian Berghea)**

We present C and X-band radio observations of the famous Ultraluminous X-ray source (ULX) Holmberg IX X-1, previously found to be associated with an optical emission line nebula several hundred pc in extent. Our recent infrared study of the ULX suggested that a jet could be responsible for the infrared

excess detected at the ULX position. The new radio observations, performed using the Karl G. Jansky Very Large Array in B-configuration, reveal the presence of a radio counterpart to the nebula with a spectral slope of 0.41 similar to another well-known ULX, Ho II X-1. Importantly, we find no evidence for an unresolved radio source associated with the ULX itself, and we set an upper limit on any 5 GHz radio core emission of  $\sim 5\text{ }\mu\text{Jy}$ . If a jet exists it is thus faint and its core component is unlikely to be responsible for the infrared excess. We discuss different possible interpretations of the radio/optical bubble.

**Author(s):** Ciprian Berghea

**Institution(s):** USNO Contributing Team(s): Megan Johnson, Nathan Secrest, Rachel Dudik, Greg Hennessy

### **369.13 - Probing the Mass Spectrum of Massive Black Holes with LISA(Shane L Larson)**

LISA is sensitive to low-frequency gravitational waves from roughly 10 microHertz to 0.1 Hertz. In the parameter space of binary systems, this corresponds roughly to orbital periods from roughly 2 days to tens of seconds. This part of the gravitational wave spectrum is rich in sources, but one of the most compelling is the merger of massive black holes. Across its band, LISA will be sensitive to stellar origin black hole binaries early in their inspirals, limited only by distance. Similarly, intermediate mass black hole binaries will also be detectable by LISA, but over a much larger volume of the Universe. At masses of 100,000 solar masses or more, black hole binaries inspiral and merge at frequencies to which LISA is most sensitive. The detectability of heaviest black hole binaries, in excess of 10 million solar masses or more, is a strong function of LISA's low frequency performance. In this study, we consider how the shape of the LISA sensitivity affects how deeply into the high mass end of the black hole mass spectrum we can probe with low-frequency gravitational wave observations. We introduce a publicly available tool package, BOWIE, suitable for visualizing the different capabilities of different gravitational wave detector configurations.

**Author(s):** Shane L Larson, Michael Katz

**Institution(s):** Northwestern University

### **369.14 - Exploring the Evolution of Supermassive Black Holes in Different Environments(Alexander Turner)**

Observational studies suggest that every galaxy has a supermassive black hole (BH) at its center. These studies have revealed correlations between the BH mass, and various galactic properties, such as the stellar bulge mass and dark matter halo mass. However, little is known about how the environment surrounding the host galaxy affects BH growth. We evaluate the ratio of BH mass-to-halo mass, and the ratio of BH mass-to-stellar bulge mass, for a broad collection of field, group, and cluster galaxies. We obtain the halo mass by using

Chandra and XMM-Newton measurements of the hot X-ray gas in elliptical galaxies. This is used alongside measurements from the MASSIVE survey, which provides the stellar masses and BH masses of the galaxies. Combining these data will allow us to explore how BH evolution differs in galaxies with different environments, and how feedback processes regulate the growth of BHs.

**Author(s):** Alexander Turner, Akos Bogdan

**Institution(s):** University of Southampton, Harvard-Smithsonian Center for Astrophysics

### **369.15 - Nonlinear memory effect on gravitational wave amplitude from merging binary black holes(Ashok Choudhary)**

The nonlinear memory effect is slowly growing non oscillatory contribution to the gravitational wave amplitude. It originates from gravitational wave that are sourced by previously emitted gravitational waves. Gravitational wave with memory causes a permanent displacement of test masses after it has passed through the detector. Detection of nonlinear memory provides an important test for general relativity in strong field regime. A detector like LISA, whose proof-masses are truly freely floating could maintain a permanent displacement and in principle could detect this memory effect. We study this memory effect on gravitational wave amplitude for different initial parameters, in particular the effect of initial spins of individual black holes. We use publicly available SXS psi4 data to compute the nonlinear memory contribution for a range of parameters.

**Author(s):** Sean McWilliams, Ashok Choudhary

**Institution(s):** West Virginia University

### **369.16 - Searching for Intermediate Mass Black Holes in Ultraluminous X-ray Binaries(Hannah Fritze)**

We are beginning to understand the frequency of black hole mergers thanks to recent observations by LIGO. However, these observations do not tell us anything directly about Intermediate Mass Black Holes (IMBHs), and the merger products do not suggest that the mergers are a viable formation mechanism of "true" IMBHs. We still don't know how rapidly IMBHs grow, how frequently they merge, and whether they represent a step in the evolution of supermassive black holes, although that seems increasingly unlikely. We conduct a volume-limited archival survey of all Chandra X-ray Observatory sources in galaxies within 15 Mpc of the Earth that aims to locate and analyze IMBHs. Here, an IMBH is defined as any black hole whose mass exceeds the threshold where it is likely to form from a single progenitor star. We perform a multiwavelength analysis of the highest-count sources in this sample, in the hope of discovering an intermediate mass black hole. We identify an IMBH candidate in NGC 4631, as well as four candidate super-Eddington neutron stars in other nearby galaxies, and examine the optical environments around these sources in the hopes of further characterizing their nature.



**Author(s):** Hannah Fritze, Roy Kilgard  
**Institution(s):** Wesleyan University

### **369.17 - AGNs Reveal How Black Holes Embedded In Gas Become Full of Themselves(Andrea Mejia)**

The masses of the black holes LIGO detected and the rate at which they merge are larger than expected. Active Galactic Nuclei (AGN) disks are a promising environment to boost the masses and rates of merger of black holes. I ran hydrodynamic simulations of a uniform gas disk to study how embedded bodies interact with the gas. My goal is to establish how effective AGN disks are at bringing orbiting black holes together.

**Author(s):** Amy Secunda, K.E. Saavik Ford, Mordecai-Mark Mac Low, Andrea Mejia, Jillian Bellovary, Betsy Hernandez, Barry McKernan, Marguerite Epstein-Martin, Wladimir Lyra, Jose Adorno

**Institution(s):** CUNY - Hunter College, California State University, American Museum of Natural History, Queens College, Princeton University

### **369.18 - Migration of Embedded Black Holes in Active Galactic Nucleus Disk Simulations(Betsy Hernandez)**

The Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) is used to detect gravitational waves created by stellar mass black hole (BH) mergers. The progenitor masses of the first BH merger detected by aLIGO were more massive than the stellar mass BHs observed in our own Galaxy ( $5-14 M_{\odot}$ ), and the rate of BH mergers in the Universe inferred by aLIGO is higher than previously projected. It has been proposed that BHs can grow and form pairs that then merge in Active Galactic Nucleus (AGN) disks, which can explain aLIGO's BH merger observations. We simulated the prograde and retrograde motions of intermediate mass BHs of order  $10^4 M_{\odot}$  in AGN disks, using a hydrodynamic grid code, the Pencil Code. We find prograde orbiters produce larger density perturbations than retrograde orbiters, so the torques on prograde orbiters significantly exceed the torques on retrograde orbiters. We also examine the torques produced by multiple interacting orbiters. The calculated torques will be useful for models of formation and merger of BH binaries.

**Author(s):** Mordecai-Mark Mac Low, Betsy Hernandez, Wladimir Lyra, K.E. Saavik Ford, Barry McKernan,

**Institution(s):** American Museum of Natural History, California State University, Northridge, Princeton University, Borough of Manhattan Community College - CUN

## **370 - The Sun -- iPosters**

### **370.01 - Sustaining a Solar-like Near-Surface Shear Layer and its Applicability to Other Stars(Maria Ann Weber)**

Helioseismology has revealed that the solar differential rotation profile exhibits an outward decrease in angular velocity at all latitudes across the upper 5% of the Sun by radius. This near-surface shear layer (NSSL) is thought to play a significant role in defining the nature of large-scale convective patterns that drive the Sun's magnetism. Previous work has been done to study the mechanisms that establish the solar NSSL, but in large part these processes remain elusive. It is expected that NSSLs also exist on other low mass stars, but observing such layers directly is currently beyond our capabilities and little work has been done to explore them theoretically. To address this, we have performed simulations of compressible convective motions in the thin, near surface layers of cool stars using the Compressible Spherical Segment (CSS) Code. Results from these models indicate that the influence of rotation on smaller-scale convection, quantified by the Rossby number, has an influence on the flow patterns that are sustained in the thin NSSL. As the star is spun faster or the convective driving is reduced (i.e. smaller Rossby number), the shear across the layer is also reduced. In the most extreme cases with the lowest Rossby numbers, Jupiter-like alternating bands of zonal flows are found. Counterparts to these behaviors have been found previously in simulations of deep stellar convection, where the redistribution of angular momentum via the Reynolds stresses and meridional circulation act to establish the unique differential rotation profile. Additionally, our simulations of near-surface convection representative of the Sun overestimate the radial shear observed across the NSSL. One possible explanation is that the shear in the solar NSSL is not self-sustained, but rather driven by the inflow of convective plumes and the imprint of rotational torques from deeper layers into the shallower NSSL.

**Author(s):** Matthew Browning, Kyle Augustson, Maria Ann Weber,

**Institution(s):** University of Chicago, University of Exeter, Adler Planetarium, CEA-Saclay

### **370.02 - The Citizen CATE Experiment: Coronal Evolution from High Resolution Video of the 2017 Solar Eclipse(Logan Jensen)**

The Citizen Continental-America Telescopic Eclipse Experiment (CATE) deployed 68 identical telescope/detector systems across the path of totality for the August 2017 solar eclipse. The sites were located from Oregon to South Carolina, and while at any one site the solar corona was observed for just 2 minutes, the combined data set reveals evolution of the corona for 93 minutes of time. We present a high-definition video of the combined data. Polar plumes are observed to the edge of the field above both north and south polar coronal holes. Slow evolution of low-lying coronal loops is seen, and large-scale motions are visible in a coronal streamer on the

south-east solar limb. An ejection event is observed in the southern coronal hole, and numerous smaller, low contrast events are evident in the CATE video as well. CATE was funded with a collaboration of federal, corporate and private groups. CATE training was funded by NASA, and CATE equipment was funded by Daystar, Mathworks, Celestron, colorMaker, NSF and a dozen smaller donors.

**Author(s):** Michael J Pierce, Logan Jensen

**Institution(s):** Arizona State University, University of Wyoming Contributing Team(s): Citizen CATE Team

### **370.03 - Testing the Utility of a Swarm of Spacecraft to Study Magnetized Turbulence(Kristopher Gregory Klein)**

Turbulence is fundamentally a multiscale phenomena, with the transport of energy, mass, and momentum across both spatial and temporal scales. In a magnetized, collisionless plasma, such as stellar winds, black hole accretion disks, and the interstellar medium, there are a number of outstanding problems concerning both turbulent transport as well as how the energy is extracted from the cascade and dissipated as plasma heat. In situ observations of the near-Earth solar wind have provided significant insight into these processes, but to date have been limited to single point or single scale measurements. To characterize the multiscale nature of turbulence, a constellation of spacecraft with inter-spacecraft spacing spanning scales associated with the inertial and dissipation scales is needed. In this study, we sample a turbulent numerical simulation using a synthetic swarm configuration of spacecraft. Using this configuration, we test the robustness of established four-spacecraft techniques, and extend them to larger numbers of spacecraft to demonstrate what scales and quantities can be measured with such a constellation.

**Author(s):** Kristopher Gregory Klein, Jason TenBarge, Harlan Spence

**Institution(s):** University of Arizona, University of New Hampshire, Princeton University Contributing Team(s): The Helioswarm Mission Team

## **371 - Stellar Evolution, Stellar Populations -- iPosters**

### **371.01 - Automated Classification of a Mysterious Population of Weak CN Stars in the Andromeda Galaxy(Alexandra Masegian)**

Stellar evolution has been researched for decades, yet certain phases of the stellar life cycle remain poorly studied. Recent analyses of spectroscopic and photometric data of stars in the Andromeda Galaxy (M31) from the Spectroscopic Landscape of Andromeda's Stellar Halo (SPLASH) and the Panchromatic Hubble Andromeda Treasury (PHAT) surveys have revealed an unusual population of "weak CN" stars in the galaxy's disk that may represent one such poorly studied phase. Based on their positions in color-magnitude space, members of this previously unknown population appear to be associated with the He-

burning phase of relatively massive stars. Their defining feature is a weak double-peaked spectral absorption line at around 8000Å... indicating the presence of the CN molecule. This same double-peaked feature appears more strongly in the spectra of carbon stars, leading us to hypothesize that an association exists between the two populations. Using data from SPLASH and PHAT, we sought to investigate this probable association by developing an algorithm capable of objectively classifying stars as "carbon," "weak CN," or "other" based on spectral features. The algorithm employed a multi-metric comparison performed against a training set of visually classified stars to make automated classifications. Stars the algorithm classified as "weak CN" were subsequently plotted in color-magnitude diagrams (CMDs) to photometrically compare the training set with the algorithm's spectroscopically-oriented classifications. Results obtained from this algorithm and the CMDs have been instrumental in confirming the significance of weak CN stars as a relatively well-defined stage of stellar evolution and will ultimately contribute to a greater understanding of the physical properties of both carbon and weak CN stars. This research was funded in part by the National Science Foundation and National Aeronautics and Space Administration/Space Telescope Science Institute. High school students Alexandra Masegian and Arya Maheshwari participated in this research under the auspices of the Science Internship Program at the University of California Santa Cruz.

**Author(s):** Rachel Raikar, Arya Maheshwari, Alexandra Masegian, Puragra Guhathakurta

**Institution(s):** Branham High School, University of California, Santa Cruz, The Harker School

### **371.02 - OB and Oe/Be v sin i distributions in the SMC(Kevin Paggeot)**

Stellar rotation, parameterized by a star's projected rotational velocity  $v \sin i$ , is a fundamental parameter linked to star formation, evolution, and dynamical interaction. These are still poorly understood for OB stars, which typically rotate faster than their lower-mass counterparts. We determine  $v \sin i$  for 210 field OB stars in the Small Magellanic Cloud, 39 of which are classical Oe/Be stars due to the low-metallicity environment of the SMC. We use spectroscopic data from the RIOTS4 survey, employing Fourier analysis to derive  $v \sin i$  from the rotational broadening of spectral lines, primarily He I and He II. We confirm that Be stars are typically much faster rotators than normal B stars, and their  $v \sin i$  distribution is a single symmetric peak with a mean of 180 km / s and standard deviation of 50 km / s. We therefore suggest that stars linked to the Be phenomenon may correspond to the high-velocity peak of the well-known bimodal  $v \sin i$  distribution of B stars. We will also correlate rotation with other stellar parameters, such as proper motion, galactic environment, degree of isolation, and radial velocity to probe physical properties of OB stars.

**Author(s):** Sergio Simão-D'Áz, M. Oey, Kevin Paggeot, John Dorigo Jones, Norberto Castro

**Institution(s):** University of Michigan, Instituto de

## 372 - Stellar Atmospheres, Winds -- iPosters

### 372.01 - Is the Effective Temperature of ROB 162 Really 51,000 K?(William Van Dyke Dixon)

The UV-bright star ROB 162 in the globular cluster NGC 6397 is a post-AGB star with a mass between 0.55 and 0.6  $M_{\odot}$ . Model fits to its optical spectrum yield an effective temperature  $T_{\text{eff}} = 51,000 \pm 2,000$  K. A recent analysis of the UV-bright star Y453 in M4 (NGC 6121) found that, while its optical spectrum yields a similar temperature,  $T_{\text{eff}} \sim 56,000$  K, its FUV spectrum reveals the star to be much hotter, with  $T_{\text{eff}} \sim 72,000$  K. Could the temperature of ROB 162 be similarly underestimated? To find out, we analyze archival FUSE and STIS spectra of the star. By fitting the absorption features of multiple ionization stages of nitrogen and oxygen, we derive an effective temperature of  $\sim 48,000$  K, consistent with the optically-derived value. Why do the optical and FUV spectra yield consistent values for ROB 162, but not for Y453? In a word, metallicity. The metallicity of M4 ( $[\text{Fe}/\text{H}] = -1.16$ ) is nearly an order of magnitude greater than that of NGC 6397 ( $[\text{Fe}/\text{H}] = -2.02$ ). Furthermore, Y453 is overabundant (relative to M4) in the iron-peak elements Ti, Cr, and Ni. These metal enhancements alter the structure of the photosphere, and thus the shape of the Balmer lines, leading us to underestimate the effective temperature when fitting those lines with H-He stellar-atmosphere models. The lower metallicity of ROB 162 makes it less susceptible to these effects.

**Author(s):** William Van Dyke Dixon, Pierre Chayer

**Institution(s):** Space Telescope Science Institute

## 373 - Variable Stars -- iPosters

### 373.01 - ZTF Observations of the Disk Formation and Dissipation Process in the Eruptive Be Star HO Puppis(Chien-De Chandler Lee)

The hot circumstellar gas in the line-emitting region of Be stars were mainly supplied by the eruptive stellar activity like matter outburst, known as decretion disk. During the outburst events, because of the obscuration along the line of sight from popped up materials, such Be stars will display dips or fading on their light curves, together with the spectroscopic brightening in Balmer lines. However, a well-covered spectroscopic follow up observations was rarely achieved, because most of the fading events last more than hundreds days. In this work, we report the finding of fading events for HO Pup, a Be star known as Gamma Cassiopeia type variable, based on a few months commissioning data from the Zwicky Transient Facility (ZTF). The g and r band light curves from ZTF clearly displayed the fading events up to 2.5 magnitudes. We supplemented the ZTF data with light curve data from ASAS-SN survey, the combined light curves clearly display eruptive variability in the past 4 years. Together with the proposed spectroscopic observations, we may witness the entire disk decretion process including formation and dissipation for HO Pup.

**Author(s):** C.-C. Ngeow, P.-C. Yu, J.-Y. Ou, Chien-De

Chandler Lee

**Institution(s):** Institute of Astronomy, National Central University

### 373.02 - Multiwavelength Gaia DR2 Calibration of the RR Lyrae Period-Luminosity-Metallicity Relation(Jillian Neeley)

RR Lyrae stars are popular standard candles and are known to obey period-luminosity relations at infrared wavelengths. However, the effect of metallicity on this relation has remained uncertain. Now, however, with the second data release from the Gaia mission (DR2) we are better equipped than ever before to investigate this issue. We present multiwavelength (optical UBVRcIc and Gaia G, BP, RP; near-infrared JHKs; mid-infrared [3.6], [4.5]) period-luminosity (PL), luminosity-metallicity (LZ), and period-luminosity-metallicity (PLZ) relations. These relations were determined using our calibrating sample of 55 Galactic field RR Lyrae stars, and includes photometry obtained from The Carnegie RR Lyrae Program and parallaxes from Gaia DR2. The metallicity slope, which has long been predicted by theoretical relations, can now be measured in all bandpasses. The scatter in the PLZ relations is on the order of 0.2 mag, still dominated by uncertainties in the parallaxes. As a consistency check of our PLZ relations, we also measure the distance modulus to the globular cluster M4, the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC), and our results are in excellent agreement with estimates from previous studies.

**Author(s):** Ata Sarajedini, Massimo Marengo, Jillian Neeley, Barry F. Madore, Rachael Lynn Beaton, Mark Seibert, Dylan Hatt, Taylor Hoyt, Wendy Freedman, Victoria Scowcroft, Jeffrey Rich

**Institution(s):** Florida Atlantic University, Carnegie Observatories, Iowa State University, University of Bath, University of Chicago Contributing Team(s): CRRP team

### 373.03 - Where's the Flux now?(Tabetha Boyajian)

Beginning in 2017 May, a sequence of six small (few percent) dips in KIC 8462852 were detected from ground based observations. This collection of events continues until 2018 March and is known as the "Elsie" family of dips. Here we present the analysis of the 2018 dips, "Caral-Supe" and "Evangeline", the two largest detected since the NASA Kepler mission. Our analysis uses data from the Las Cumbres Observatory 0.4m telescope network taken in multiple filters to study the wavelength dependence in each of the dips. We discuss the evolution of the chromaticity throughout the "Elsie" family, and constraints these newest data put on possible working scenarios to explain the variability.

**Author(s):** Tabetha Boyajian, Tyler Ellis, Jason T Wright, Eva Bodman, Geoffrey C Clayton

**Institution(s):** Louisiana State University, ASU Contributing Team(s): Boyajian's Star Obs Squad, The Most Mysterious Star

in the Galaxy Kickstarter

### **373.04 - A Memoirs of the Most Mysterious Star in the Galaxy(Alejandro Wilcox)**

We present new photometric data of KIC 8462852 ("Tabby's Star") in the 2018 calendar year. In addition to our continued monitoring, we outline the improvements to our data reduction pipeline to account for fringing and flat field gradients which boost our photometric accuracy and precision. We use the new data to recalibrate the normalization of the 5 photometric bands (g', r', i', z', and V) we continue to monitor the star in, further improving our understanding of the various observed dips. Our new results also give us more confidence in the nature of the star's obscuring material and lay a more solid foundation for our continued monitoring of this intriguing star.

**Author(s):** Tabetha Boyajian, Jon Swift, Alejandro Wilcox

**Institution(s):** Thacher School, Louisiana State University

### **374 - Evolved Stars, Cataclysmic Variables and Friends iPosters**

#### **374.01 - Evolution of Low-Mass AGB Stars: An Analytical Approach to Mass-loss Formulas(Henry Alexander Prager)**

In the final stages of their evolution, intermediate mass stars (between 0.7 and 2.0 solar masses) ascend the Asymptotic Giant Branch (AGB). During their last few hundred thousand years on the AGB, in what we will call the high mass loss phase (HML-AGB), these stars experience a steep increase in mass-loss rate and quickly lose their envelopes. Most of the mass is lost near the star's "death line", at a critical mass loss rate defined as the ratio of the initial AGB mass of the star to its characteristic evolution time  $L/(dL/dt)$ . Most of the stars we observe to be rapidly losing mass appear in the death zone defined to be between 0.1 and 10 times the critical mass loss rate. The "width" of this death zone is inversely proportional to a parameter  $b$  defined as the rate of change of the mass loss rate with stellar luminosity, in logarithmic units. This is exact in power-law formulations as we have used in this work, but can be found for any mass-loss rate formula near the death line. We show that by combining this with the initial-final mass relation and the core mass-luminosity relation, we can test for  $b$  with three observables - the duration of passage through the death zone  $\Delta L/(dL/dt)$ , the amplitude of mass loss variations (when  $L$  varies on an observable time scale such as a shell flash), and the distributions with luminosity ( $N(L)$ ) and pulsation period ( $N(P)$ ). By applying the initial mass function and star formation rate of an observed region, we can determine  $b$  directly from observed distributions. For this project, we have fixed the death line, varied the exponent  $b$ , and approximated the behavior near the death line as a power law. This allowed us to build sample data sets for several values of  $b$ , ranging from 2 to 20. The results of this study support a rapid increase in mass loss on the HML-AGB, with a value of  $b=5$  being the minimum to replicate observable properties, and a

value of  $b=10$  with weak pre-AGB mass loss being most consistent with observation. This tells us that mass loss evolution on the AGB is much faster than classically considered, and the overwhelming majority of mass loss occurs at the end of stellar evolution.

**Author(s):** Lee Anne Willson, Massimo Marengo, Michelle J. Creech-Eakman, Henry Alexander Prager,

**Institution(s):** New Mexico Tech, Iowa State University

#### **374.02 - Short-cadence K2 observations of an accretion-state transition in Tau 4, the first polar observed by Kepler(Colin Littlefield)**

We present the 81-day, short-cadence K2 light curve of Tau 4 (RX J0502.8+1624), the first AM Herculis cataclysmic variable star to be observed by the Kepler spacecraft. The light curve covers a serendipitous jump from a low-accretion state into a high state, and the one-minute cadence of the observations provides exquisite insight into the evolution of the orbital light curve throughout this transition. During the first 71 days of the K2 campaign, the light curve consisted primarily of a 0.2-mag, double-peaked orbital waveform that lacked any sign of significant mass transfer, and we consider the possibility that this modulation was the result of localized hotspots on the WD from a previous episode of accretion. However, in the final 10 days, unmistakable signs of enhanced accretion began to emerge, with a very strong (1.7 mag) cyclotron-beaming component appearing for 70% of the 1.59-hour binary orbit. Before the onset of the high state, the system gradually increased in brightness by 0.1 mag over the course of ~20 days with no concomitant changes to the orbital waveform. We compare these observations with theories about the nature of low states in cataclysmic variable stars.

**Author(s):** Gavin Ramsay, Peter Garnavich, Steve Howell, Colin Littlefield, Paula Szkody, Mark Kennedy

**Institution(s):** University of Notre Dame, NASA Ames Research Center, Armagh Observatory & Planetarium, University of Manchester, University of Washington

### **375 - Star Formation -- iPosters**

#### **375.01 - Dissecting Massive Protostars: Testing Theoretical Models with Flux Density Profiles(Yara Yousef)**

We present an analysis of infrared images of massive protostars, selected from the SOFIA Massive (SOMA) Star Formation survey, to characterize their flux density profiles. We focus on SOFIA-FORCAST images at 31 and 37 microns that probe deep into the protostellar cores. We first measure flux density profiles along outflow axes of the sources, as previously determined from molecular line observations. Generally the near-facing outflow cavity appears brighter than the far-facing cavity, because of extinction in the core envelope. We then compare these observational results to predictions of theoretical models and radiative transfer simulations of the massive protostars forming in the context of the Turbulent Core

Accretion model (McKee & Tan 2003; Zhang & Tan 2018). This analysis determines the validity of the model, and furthermore examines how the extra information available from flux density profiles can improve constraints that are derived solely from spectral energy distribution fitting.

**Author(s):** Yichen Zhang, Kei Tanaka, Jonathan C. Tan,

Viviana Rosero, Yara Yousef, James De Buizer, Mengyao Liu

**Institution(s):** University of Virginia, RIKEN, Chalmers University of Technology, Osaka University, National Radio Astronomy Observatory, SOFIA-USRA, NASA Ames Research Center

### **375.02 - PDR Astrochemical Models of Massive Star Formation(Robin Leichnetam)**

We present astrochemical models of a massive protostar forming from a 60 solar mass core in the context of the Turbulent Core Model (McKee & Tan 2003). An evolutionary sequence is studied via snapshots of the core, including infall envelope, disk, outflow cavity and protostellar properties for protostellar masses of 1, 2, 4, 8, 12, 16 and 24 solar masses, taken from the Zhang & Tan (2018) model grid. We utilize the DALI code (Bruderer et al. 2012) to calculate radiative transfer of UV photons, especially in the FUV regime that create Photodissociation Regions (PDRs). A gas-grain chemical network is calculated, responding to the radiation field and calculated gas temperature. We examine the abundances of various species, especially containing C and O, at various locations in the core and discuss observable signatures for various components, such as infall envelope, disk and outflow.

**Author(s):** Yichen Zhang, Kei Tanaka, Jonathan C. Tan, Robin Leichnetam, Christian Eistrup, Simon Bruderer, Davide Fedele

**Institution(s):** University of Virginia, Max-Planck-Institute for Extraterrestrial Physics, Chalmers University of Technology, Star and Planet Formation Laboratory, Osaka University, Leiden University, INAF-Osservatorio Astrofisico di Arcetri

### **375.03 - Modeling the Disk-Envelope Boundary around the Protostar L1527(Susan Terebey)**

ALMA probes continuum and spectral line emission from protostars that comes from both the envelope and circumstellar disk. For the protostar L1527 there is also spectral line emission that appears to trace the disk-envelope boundary. We present models of what ALMA should detect that incorporate a self-consistent collapse solution, radiative transfer, and chemical abundance calculations. Results for the outer disk show that there can be significant differences from standard assumptions due to the effect of CO freeze out, shocks, and non-Keplerian dynamics.

**Author(s):** Lixandra Flores Rivera, Karen Willacy, Susan Terebey, Neal Turner

**Institution(s):** California State University, Los Angeles, Jet Propulsion Laboratory, California Institute of Technology

## **376 - Large Scale Structure, Cosmic Distance Scale -- iPosters**

### **376.01 - Deep and Wide: Mass Mapping of E & B Modes in Four Cosmic Shear Surveys(Andrew Kenneth Bradshaw)**

We explore the weak lens mass mapping of E- and B-mode shear signals using publicly available data from a variety of deep galaxy surveys (DES, KiDS, DLS, CFHTLS) and N-body simulations. Using measurements of galaxy shear and photometric redshift, we generate multi-scale 3-dimensional mass maps of the foreground overdensities by optimally filtering the tangential shear that they induce on background galaxies. We develop and test a flexible method to approximate the foreground structure as a superposition of NFW-like halos by locating these overdensities and estimating their mass and redshift, thereby modeling the background correlated shear field as a sum of lensings induced by the foreground clusters. We demonstrate that the E & B-mode maps, as well as their shear correlation functions, are related to the estimated cluster masses and locations. Using this approximation method, we can identify several known origins of weak lensing B-modes including leakage and edge effects, source clustering, and multiple lensing, as well as speculate on other high S/N detections of B-modes which can be observed in these deep cosmic shear surveys.

**Author(s):** Andrew Kenneth Bradshaw

**Institution(s):** University of California at Davis

### **376.02 - A Hybrid Polarized Imaging and Calibration Scheme for HERA using CASA(Tashalee Billings)**

We describe a calibration and synthesis imaging method for the Hydrogen Epoch of Reionization Array (HERA) using the Common Astronomy Software Application (CASA) package combined with custom software for simulation of interferometric visibilities. HERA is a purpose-built interferometer for studying the Epoch of Reionization and Cosmic Dawn which will eventually be 350 14-m dishes in a transit array, operating from 50 - 250 MHz. For this study we use commissioning data from the first season of operation with 19 antennas operating from 100 - 200 MHz. Our approach uses detailed electromagnetic simulations of the primary beam combined with the unpolarized Global Sky Model to make high fidelity simulations of the Galactic Center to serve as a primary calibrator for the bandpass amplitudes and phases. We perform consistency checks on the calibration by examining the autocorrelation amplitudes, the visibility and power spectrum noise, and the amplitude and spectrum of point sources from the GLEAM catalog away from the Galactic Center. Since CASA does not allow for a full Mueller matrix deconvolution, the simulation serves as a model of Stokes I to Q, U, V leakage, and this is compared against the data at the visibility level, making this a hybrid scheme. This approach allows us to understand the polarization properties of HERA and particularly the scale of polarized leakage.

**Author(s):** Tashalee Billings, Zachary Martinot, James

Aguirre

**Institution(s):** University Of Pennsylvania Contributing Team(s): HERA Collaboration

### **377 - Intergalactic Medium, QSO Absorption Line Systems -- iPosters**

#### **377.01 - Absorption Characteristics of Ions in the Circumgalactic Medium(Colin Hamill)**

We extend the results of a study of 44 low redshift quasars ( $0.06 < z < 0.85$ ) observed by the Cosmic Origins Spectrograph on the Hubble Space Telescope that lie within the Sloan Digital Sky Survey. We have used galaxy photometric data from SDSS Data Release 12, along with the known anticorrelation between Lyman alpha absorption equivalent width and galaxy impact parameter for absorber-galaxy pairs, to identify the most probable galaxy matches to absorbers in the spectroscopic dataset. We compare our results to confirmed galaxy absorbers from the published literature and to the equivalent width - impact relationships for a variety of ions in the circumgalactic medium. We explore modifications to our matching algorithm to improve its accuracy.

**Author(s):** Colin Hamill

**Institution(s):** Towson University

#### **377.02 - Searching for Diffuse Ly $\alpha$ Emission in the Local IGM/CGM with HST/COS(Steven Victor Penton)**

The Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) has observed thousands of Lyman-alpha (Ly $\alpha$ ) forest absorbers with both the G130M grating ( $0 < z < 0.19$ ) and the G160M grating ( $0.14 < z < 0.48$ ). In this research, we use the two-dimensional nature of the COS FUV detector to constrain the Ly $\alpha$  EMISSION associated with both Ly $\alpha$  absorbers, AND regions of the IGM not associated with Ly $\alpha$  absorbers. We will divide our Ly $\alpha$  absorber sample based upon proximity to the closest known galaxy to differentiate emission between intergalactic (IGM) and circumgalactic (CGM) regions. We will discuss the limits of these constraints/detections in terms of both cosmological implications and from a technological standpoint (If we were to design a Ly $\alpha$  emission detection/mapping mission, what have we learned from HST+COS?).

**Author(s):** Steven Victor Penton, James Green

**Institution(s):** University of Colorado, Laboratory for Atmospheric and Space Physics Contributing Team(s): STScI HST/COS Team

### **378 - Extrasolar Planets: Characterization & Theory -- iPosters**

#### **378.01 - Inside-Out Planet Formation - Tests of Predicted Planetary Properties(Genesis Brockett)**

Systems with Tightly-Packed Inner Planets (STIPs) could be the most common type of planetary system in the universe, but

their formation mechanism is much debated. One theory, involving in situ formation, is Inside-Out Planet Formation (IOPF, Chatterjee & Tan 2014), which anticipates these systems forming sequentially from the inside out, with the first "Vulcan" planet located at the dead zone inner boundary where disk midplane temperatures rise to 1200K and its mass set by shallow gap opening leading to isolation from further pebble accretion. The extent of dead zone retreat sets locations of subsequent planets, but their masses are also set by this gap opening process. Thus IOPF makes predictions for inner planet orbital radii, masses and mass scaling with orbital radii within given systems. Here we test these predictions against latest exoplanet data, especially using an improved sub-sample of STIPs planets with dynamical mass measurements, and examine potential dependencies with mass of the host star, which further constrain the theoretical models. We confirm earlier results of increasing Vulcan radius and mass with orbital radius, with our fiducial scaling being  $M_p, r \propto r^{0.472}$  compared to the IOPF prediction of  $M_p, r \propto r^{1.2}$ . For the in-system dependence of planet mass versus orbital radius, we find  $M_p \propto r^{0.435}$  compared to the IOPF prediction of  $M_p \propto r^{0.125}$ . We discuss the implications of our results.

**Author(s):** Jonathan C. Tan, Sourav Chatterjee, Genesis Brockett

**Institution(s):** University of Virginia, Tata Institute of Fundamental Research, Chalmers University of Technology

#### **378.02 - Precise Dynamical Masses of Directly Imaged Companions from Hipparcos-Gaia DR2 Accelerations and Radial Velocities(Trent Dupuy)**

Previous work on dynamical masses for substellar objects has necessarily focused on binary systems with sufficiently short periods for full orbit determinations. In contrast, directly imaged companions on much wider orbits have very long orbital periods that are generally not amenable to orbit monitoring on human timescales. We present a joint analysis of radial velocities with Hipparcos and Gaia DR2 astrometry that directly measures the three-dimensional acceleration induced by a directly imaged companion on its host star. We show that such measurements combined with contemporaneous astrometry of companions relative to their host stars results in precise companion masses, independent of any assumptions about the host star's mass. Our analysis method is validated by companions with previously published orbits and mass determinations, and we greatly improve the mass precision for the coldest brown dwarf with a dynamical mass.

**Author(s):** Timothy Brandt, Trent Dupuy, Brendan Bowler  
**Institution(s):** Gemini Observatory, UT Austin, UCSB

### **378.03 - Investigation of HD as a Tracer of Protoplanetary Disk Mass(Yuan Chen)**

To investigate the utility of HD as a promising alternative probe of disk mass, we use a thermo-chemical and radiative-transfer code RAC2D to compute a grid of models that sample different stellar masses (spectral types), dust-to-gas ratios, dust distributions and so on. From this grid we generate predictions for line fluxes and spectral profiles of HD (1-0) and (2-1), and pay attention to the sensitivity dependence on each parameter in the meantime. We also explore how to use ALMA observations of carbon monoxide as complement tracer with HD to extract unknown gas mass in protoplanetary disks.

**Author(s):** Edwin Bergin, Yuan Chen, Ke Zhang

**Institution(s):** University of Michigan, Ann Arbor, Peking University

### **379 - Catalog -- iPosters**

#### **379.01 - Chandra Source Catalog Release 2.0 - The State of the Art Serendipitous X-ray Source Catalog(Ian N Evans)**

By combining Chandra's sub-arcsecond on-axis spatial resolution and low instrumental background with consistent data processing, the Chandra Source Catalog (CSC) delivers a wide variety of uniformly calibrated properties and science ready data products for detected sources over four dex of fluxes. The second major release of the catalog, CSC 2.0, roughly triples the size of the previous catalog to more than 315,000 unique X-ray sources on the sky, allowing statistical investigations of large samples of objects using the catalog, as well as individual source studies. The sensitivity limit for compact sources in CSC 2.0 is significantly improved by using a two-stage approach that involves co-adding multiple observations of the same field prior to source detection, and then using an optimized source detection method. This combination yields a point source detection threshold of ~5 net counts on-axis for exposures shorter than ~15 ks. The implemented Bayesian aperture photometry code produces robust photometric probability density functions (PDFs) in crowded fields, even for low count detections. CSC 2.0 also adds a Bayesian Blocks analysis of the multi-band aperture photometry PDFs to identify multiple observations of the same source that have similar photometric properties, and therefore can be analyzed simultaneously to improve S/N. We discuss these and other updates that significantly enhance the scientific utility of CSC 2.0 when compared to the previous catalog, briefly discuss the catalog statistical characterization, and consider further enhancements to be included in future catalog releases. This work has been supported by NASA under contract NAS 8-03060 to the Smithsonian Astrophysical Observatory for operation of the Chandra X-ray Center.

**Author(s):** Nicholas P Lee, Raffaele D'Abrusco, Douglas L Morgan, Francis Anthony Primini, Kenny J Glotfelty, Diane M Hall, Arnold H Rots, Francesca Maria Civano, Dan T Nguyen, Craig S Anderson, Panagoula Zografou, Michael Nowak, Rafael Mart  nez-Galarza, David W Van

**Institution(s):** Harvard-Smithsonian Center for Astrophysics,

Washington University in StLouis, Northrop Grumman Mission Systems

### **380 - Surveys and Large Programs -- iPosters**

#### **380.01 - Uncovering Infrared Transients with Palomar Gattini-IR(Matthew Hankins)**

Palomar Gattini-IR is a new survey designed to undertake a ground-based wide-field search for infrared transients. Our 30 cm telescope operates with a J-band Camera that achieves a 25 square degree FOV. We recently began full survey operations and are covering 15,000 square degrees in J-band from Mount Palomar to a depth of 16.0 mag (AB) every night. Gattini-IR science goals include discovering dusty classical novae, uncovering low-mass stellar mergers within the Galaxy and high-mass mergers in nearby galaxies, revealing obscured supernovae, and determining the rates and origins of new classes of near-IR transients. We plan to present preliminary results from the first few months of survey data focusing on high-amplitude transients. We will also discuss plans for follow up studies of Gattini-IR transients and our work on a pipeline to provide real time transient alerts.

**Author(s):** Jill Burnham, Matthew Hankins, Jamie Soon, Mansi Kasliwal, Alex Delacroix, Michael Ashley, Tony Truong, Ryan Lau, Kishalay De, Roger Smith, David Hale, Timothee Greffe, Anna Moore, Scott Adams, Dan McKenna

**Institution(s):** Caltech, Australian National University, JAXA, University of New South Wales

#### **380.02 - The Evryscopes: monitoring the entire sky every two minutes(Nicholas Law)**

The Evryscopes are array telescopes which monitor the entire accessible sky in each exposure. The systems, each with 700 MPix covering an 8,000-square-degree instantaneous field of view, are building many-year-length, high-cadence light curves for every accessible object brighter than ~16th magnitude. Every night, we add 9 billion object detections to our databases, enabling searches for exoplanet transits, microlensing events, nearby extragalactic transients, and a wide range of other short timescale events. Simultaneous observations of the entire TESS field during nighttime provide multi-color light curves with an order-of-magnitude higher cadence than TESS observations alone. I will present our science plans, the status of our current Evryscope systems in Chile and California, the big-data analysis required to explore the petabyte-scale dataset we are collecting over the next few years, and the first results from the telescopes, including superflares from nearby stars, transients, and large-scale transit and eclipse searches.

**Author(s):** Octavi Fors, Henry T Corbett, Nicholas Law, Ward S Howard, Robert Quimby, Jeff Ratzloff

**Institution(s):** UNC Chapel Hill, San Diego State University

### **380.03 - Overview of the DESI Legacy Imaging Surveys(David Schlegel)**

The DESI imaging Legacy Surveys ([www.legacysurvey.org](http://www.legacysurvey.org)) are a combination of three public projects (the Dark Energy Camera Legacy Survey, the Beijing-Arizona Sky Survey, and the Mayall z-band Legacy Survey) that are jointly imaging 14,000 square degrees of the extragalactic sky visible from the northern hemisphere in three optical bands (g, r, and z) using telescopes at the Kitt Peak National Observatory and the Cerro Tololo Inter-American Observatory. The optical imaging is conducted using an innovative dynamic observing strategy that results in a survey of nearly uniform depth. In addition to calibrated images, the project is delivering an inference-based catalog (using the “Tractor” code) which includes photometry from the grz optical bands and from four mid-infrared bands (at 3.4, 4.6, 12 and 22 microns) observed by the Wide-field Infrared Survey Explorer (WISE) satellite during its full operational lifetime. The Legacy Surveys will enable the selection of 40 million spectroscopic targets for the Dark Energy Spectroscopic Instrument (DESI), a next-generation redshift survey slated to begin its five year mission in early 2020. These DESI targets include luminous red galaxies to redshift 1, emission line galaxies to redshift 1.6, quasars to redshift 3.5, a dense sample of bright galaxies in the local Universe, and 10 million Milky Way stars. More broadly, the Legacy Surveys provide a much deeper multi-purpose successor to the Sloan Digital Sky Survey imaging catalog over a similar footprint, with science applications ranging from faint dwarf galaxies to the most distant known quasars. The most recent northern and equatorial public data releases (DR6 and DR7, respectively), combine to include 1.2 billion unique sources and achieve depths of 24.7, 23.9 and 23.0 in g, r, and z.

**Author(s):** Aaron Michael Meisner, Christophe Yèche, Benjamin A. Weaver, Martin Landriau, John Moustakas, Arjun Dey, Stephanie Juneau, Frank Valdes, Edward Schlafly, Jacqueline Beechert, Joseph Findlay, Dustin Lang, David Schlegel, Jinyi Yang, Adam D Myers, David H

**Institution(s):** Lawrence Berkeley National Lab, National Optical Astronomy Observatory, University of California Berkeley, Perimeter Institute, University of Wyoming, University of Arizona, Siena College, CEA, Université Paris-Saclay Contributing Team(s): Dark Energy C

### **381 - Computation, Data Science, and Image Analysis -- iPosters**

#### **381.01 - Explorations on White Dwarf Merger Simulations with Castro(Maria Barrios Sazo)**

The progenitor of Type Ia supernovae (SNe Ia) remains an open question with ongoing research. Type Ia supernovae are the result of a thermonuclear explosion consuming degenerate carbon and oxygen, which indicates the presence of at least one white dwarf (WD). Observations have shown diversity in SNe Ia, opening room for different models as possible progenitors for these events. A proposed scenario is the double degenerate model, in which two WDs are in a binary system. In the white

dwarf merger model, the less massive WD is tidally disrupted by the primary WD forming a disk. The primary WD then accretes carbon and oxygen generating the conditions for thermonuclear ignition. Hydrodynamic simulations are key to understand the dynamics of the merger process and consequent evolution of the system. We perform 3D hydrodynamic simulations using the adaptive mesh refinement (AMR) code Castro. Some of Castro’s capabilities include self-gravity, general equation of state and nuclear reactions, and radiation. Castro is built on the AMReX library and supports a hybrid parallelization approach with MPI+X, where X is OpenMP for CPUs and CUDA for GPUs. We will present results obtained towards validation of numerical methodology along with a simulation solving the Poisson equation for self gravity of a 0.6  $M_{\odot} + 0.9 M_{\odot}$  WD merger system. We will also show further studies on the feasibility of detonation conditions with emphasis on analyzing various WD initial models, different mass combinations, and self consistent initial conditions of the system.

**Author(s):** Michael Zingale, Maria Barrios Sazo, Maximilian Katz

**Institution(s):** Stony Brook University, NVIDIA Corp

#### **381.02 - DCR-matched templates for image differencing.(Ian Sullivan)**

Image differencing is a powerful tool for detecting variable and moving objects, but there can be large residuals if the observing conditions of the template and science images are not closely matched. For large surveys such as LSST, images will be taken at a wide range of airmasses, and variations in Differential Chromatic Refraction (DCR) between observations need to be addressed. We present a new technique for constructing template images that are matched to the observing conditions of the science image, and demonstrate that it achieves a significant reduction in the number of false detections for a survey covering a wide range of airmasses. Additionally, we show how the spectral information derived while constructing the template provides a new way of identifying quasars.

**Author(s):** Ian Sullivan

**Institution(s):** University of Washington

#### **381.03 - ASTROstream: Automated claSsification of Transient astRonomical phenOmena in the streaming mode(V. Zach Golkhou)**

We present a real-time light curve classification system for the Zwicky Transient Facility (and the upcoming Large Synoptic Survey Telescope) alert streams based-on a Lambda Architecture (LA) and using Apache Kafka and Apache Spark. LA is a scalable and fault-tolerant data processing architecture that is designed to handle both real-time and historically aggregated batched data in an integrated fashion. Spark is a cluster computing framework which is widely used as an industry tool for processing and analyzing large data sets. We



demonstrate how batches of data can be ingested and cross-matched against data from the PS1, SDSS, and other catalogs, and how the light curves from these data can be rapidly characterized by scaling existing Python applications to large data volumes. We produce a catalog of the transient sky, including a large and diverse range of phenomena: variable events, periodic, explosive, and eruptive transients. LA also enables a continuous processing of real-time observation via speed layer. This layer ingests streaming alert packet as it is generated in the Apache Avro format, and distributed using Apache Kafka, and analyzes data in real-time to get insight immediately and provides potential targets for follow up to space/ground based telescopes.

**Author(s):** Andrew Connolly, Magdalena Balazinska, V. Zach Golkhou

**Institution(s):** University of Washington

### **381.04 - Correcting Offsets in Stellar Spectra(Arnab S Krishnamoorthi)**

The spectrum of a star, the flux energy density received from the star as a function of wavelength, contains important information about its line-of-sight velocity component and surface chemical composition as encoded in the position (i.e., wavelength) and strength of the spectral absorption lines, respectively. Therefore, it is important to identify and correct errors in stellar spectra in order to measure the physical properties of stars. Three factors can cause the wavelengths of stellar absorption lines measured using a slit spectrograph to be offset from their corresponding laboratory (rest) wavelengths: (1) imperfect wavelength calibration, (2) mis-centering of the star within the slit in the width direction (dispersion axis), and (3) the star's radial velocity. We present an analysis of wavelength calibration errors in a few thousand 1D stellar spectra obtained with the DEIMOS multi-slit spectrograph on the Keck 10-m telescope as part of the HALO7D survey, one of the deepest stellar/galactic spectroscopic surveys to date. Specifically, we examined the observed wavelengths of telluric (atmospheric skyglow) emission lines in the "sky" spectrum associated with each star's "science" spectrum. The wavelengths of sky emission lines provide a direct assessment of wavelength calibration errors because they are obviously independent of the slit mis-centering and the radial velocity of the target star. We use our code to measure the wavelength calibration residuals and thereby test the performance of the spec2d data reduction pipeline. Our goal is to develop a procedure that corrects deep slit-based stellar spectra for all three effects listed above. This research was funded in part by NSF and NASA/STScI. High school students PB, IC, and AK conducted this research under the auspices of the Science Internship Program at UC Santa Cruz.

**Author(s):** Ishani Cheshire, Puragra Guhathakurta, Kevin McKinnon, Emily Youkyung, Praneet Bhoj, Arnab S Krishnamoorthi

**Institution(s):** James C Enochs High School, The Harker School, Monta Vista High School, University of California

Santa Cruz

### **381.05 - Understanding and using the Fermitools(Joseph Asercion)**

The Fermi Science Support Center (FSSC) provides information, documentation, and tools for the analysis of Fermi science data, including both the Large-Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM). The data analysis tools (named Fermitools) can be installed via the conda package manager on both Linux and MacOS systems. An overview document, the Cicerone, provides details of the Fermi mission, the science instruments and their response functions, the science data preparation and analysis process, and interpretation of the results. Analysis Threads provide the user with step-by-step instructions for many different types of data analysis: point source analysis - generating maps, spectra, and light curves, pulsar timing analysis, source identification, and the use of python for scripting customized analysis chains. The reference manual gives details of the options available for each tool. We present an overview of the structure of the Fermitools and documentation, and how to acquire them. We also provide information on the software and distribution system changes that are included in the most recent Fall 2018 release of the Fermitools

**Author(s):** Joseph Asercion

**Institution(s):** NASA/GSFC Contributing Team(s): Fermi Science Support Center

### **381.06 - The Fermi Science Support Center Data Servers and Archive(Alexander Reustle)**

The Fermi Science Support Center (FSSC) provides the scientific community with access to Fermi data and other products. The Gamma-Ray Burst Monitor (GBM) data is stored at NASA's High Energy Astrophysics Science Archive Research Center (HEASARC) and is accessible through their searchable Browse web interface. The Large Area Telescope (LAT) data is distributed through a custom FSSC interface where users can request all photons detected from a region on the sky over a specified time and energy range. Through its website the FSSC also provides planning and scheduling products, such as long and short term observing timelines, spacecraft position and attitude histories, and exposure maps. We present an overview of the different data products provided by the FSSC, how they can be accessed, and statistics on the archive usage since launch.

**Author(s):** Alexander Reustle

**Institution(s):** NASA Goddard Space Flight Center

### **381.07 - Polarization Calibration Post-Pipeline in CASA: Pilot Implementation(Indu N. Korambath)**

In this poster we present the pilot implementation of the scripted polarization calibration pipeline in the Common Astronomy Software Application (CASA). As implemented it is a stand-alone script for polarization calibration complementing the current CASA VLA (Very Large Array) pipeline. This pilot implementation currently takes the output of that CASA VLA pipeline in the form of calibration tables and applies calibrations for polarization. We begin by applying a broadband polarization model of the known polarization calibrators in the dataset and use it to derive the cross hand delay, polarization leakage, and the polarization position angle using the calibration tasks in CASA. Our pilot implementation was tested on the L and S Band datasets of the project VLA 18A-161 to produce a wide-band calibrated dataset from the standard pipeline output. The wide fractional bandwidths at cm wavelengths make the VLA an ideal instrument for studying cosmic magnetic fields through wide-band polarimetry and rotation measure synthesis. Our pilot implementation of the polarization calibration pipeline removes the excess time radio astronomers will spend on calibrating their data.

**Author(s):** Indu N. Korambath, Neeraj Gupta, Preshanth Jagannathan

**Institution(s):** Carnegie Mellon University (CMU), Inter-University Centre for Astronomy and Astrophysics (IUCAA), National Radio Astronomy Observatory (NRAO)

### **381.08 - Transitioning from ADS Classic to the new ADS search platform(Alberto Accomazzi)**

The NASA Astrophysics Data System is phasing out support for its legacy interface ("ADS Classic") in favor of a more modern, featureful system ("the new ADS"). Given the significant impact of such a transition to its user base, the ADS team has been very deliberate in this process, allowing plenty of time for individual users and curators to get acquainted with the new system and to provide feedback on its functionality and usability. The new system consists of a state-of-the-art Application Programming Interface (API) providing access to the ADS bibliographic data, upon which a modern web-based interface has been developed. In addition to having achieved feature parity with ADS classic, the new interface provides additional functionality including visualizations such as co-author and co-citation networks to help identify connections between people and topics, article analytics to help identify impact of papers, and full integration with the ORCID initiative. This poster highlights the functionality of the new system and discusses the upcoming milestones in the transition.

**Author(s):** Michael J Kurtz, Carolyn S Grant, Timothy Hostetler, Golnaz Shapurian, Kelly Lockhart, Stephen McDonald, Matthew Templeton, Alberto Accomazzi, Sergi Blanco-Cuaresma, Edwin Henneken, Roman Chyla, Donna M Thompson

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

### **382 - Laboratory Astrophysics -- iPosters** **382.01 - Uncertainties in atomic data and their use in astrophysical diagnostics(Stuart Loch)**

Interpreting astrophysical spectra relies not only on incorporating the correct bulk plasma properties in the model of the system, but also on the underlying data at the atomic level which gives rise to emission and absorption lines. The ratios of a range of emission lines are commonly used as diagnostics for plasma quantities such as the electron density, electron temperature or the over- or under- ionization of the plasma. Unfortunately, the atomic data on which these diagnostic line ratios are not always well known. Many of the quantities are hard or even impossible to measure in a laboratory, and often calculations of the same value do not agree with each other. Therefore while line ratio diagnostics are presented as absolute values with all errors attributed to measurement uncertainty in the astrophysical spectrum, there is often a significant possible systematic uncertainty in the underlying atomic data which is overlooked. Quantifying the accuracy and reliability of these line diagnostics, including identifying which diagnostics are fundamentally unreliable, would greatly benefit the entire astrophysical community, with potential effects on the significance of physics results from future missions. We present an overview and initial results of a project to both assign meaningful uncertainties on atomic data and to carry these uncertainties through to coefficients that are used in diagnostic and modeling codes. We present recent results showing uncertainties on dielectronic recombination rate coefficients using a Bayesian analysis approach. We also describe how the uncertainty data will be used, focusing on correlation effects on the uncertainties on the fundamental atomic data and correlation effects caused by the collisional-radiative modeling. The project is a collaboration between the Center for Astrophysics at Harvard and Auburn University and involves researchers in astrophysics, physics, and mathematics.

**Author(s):** Kyle Stewart, Stuart Loch, Hans Werner Van Wyk, Adam Foster

**Institution(s):** Auburn University, Center for Astrophysics at Harvard

### **382.02 - A Neon Photoionized Plasma Experiment to Test Photoionized Plasma Models(Daniel C Mayes)**

We discuss an experimental effort to create and study astrophysically relevant photoionized plasmas in the laboratory. Conditions relevant to the extreme environments in x-ray binaries, accretion disks around black holes, and active galactic nuclei have long been experimentally inaccessible. The interpretation of complex datasets from such objects is dependent upon the photoionization models that astronomers use, yet we are only beginning to be able to probe this regime experimentally with devices such as the Z-Machine at Sandia National Laboratories. Our experiment employs the intense x-ray flux emitted at the collapse of a Z-pinch to heat and backlight a neon photoionized plasma contained within a cm-scale gas cell. The broadband x-ray flux at the gas cell is of order

1012 W/cm<sup>2</sup> with atom number densities in the range 10<sup>17</sup> to 10<sup>18</sup> cm<sup>-3</sup>. Thus the platform affords an order of magnitude range in ionization parameter (about 5 to 80 erg\*cm/s) characterizing the photoionized plasma at the peak of the x-ray drive. This allows the study of trends in ionization distribution as a function of ionization parameter. The resulting plasma conditions are determined using K-shell line absorption spectroscopy from a spectrometer capable of capturing both time-integrated and time-gated transmission spectra. Analysis of these spectra yields ion areal densities and charge state distributions, which can be compared with simulation results from atomic kinetics codes. In addition, the electron temperature is extracted from level population ratios of nearby energy levels in Li- and Be-like ions, which can be used to test heating models of photoionized plasmas.

**Author(s):** Guillaume P Loisel, Gregory A Rochau, James E Bailey, Roberto C Mancini, Daniel C Mayes

**Institution(s):** University of Nevada, Reno, Sandia National Laboratories

### 383 - Cosmology -- iPosters

#### 383.01 - J-PAS: The Javalambre-Physics of the Accelerating Universe Astrophysical Survey(Renato A Dupke)

The Javalambre-Physics of the Accelerated Universe Astrophysical Survey (J-PAS) is a narrow band, very wide field Cosmological Survey to be carried out from the Javalambre Astrophysical Observatory in Spain with a purpose-built, dedicated 2.5m telescope and a 5 sq.deg. camera with 1.2Gpix. Starting in 2019, J-PAS plans to observe >8000sq.deg. of Northern Sky and measure  $\sigma_z \sim 0.003(1+z)$  photo-z for up to 9E7 LRG and ELG galaxies plus several million QSOs, sampling an effective volume of  $\sim 14 \text{ Gpc}^3$  up to  $z \sim 1.3$  reaching Stage IV radial BAO experiment. J-PAS is expected to detect  $\sim 7E5$  galaxy clusters and groups, setting constraints on Dark Energy which rival those obtained from its BAO measurements. Thanks to the superb characteristics of the site (seeing  $\sim 0.7$  arcsec), J-PAS is expected to obtain a deep, sub-arcsec multi-band image of the Northern sky, which combined with its unique photo-z precision will have an immense legacy value for almost all astrophysical areas. J-PAS unprecedented spectral time domain information will enable a self-contained SN survey that, without the need for external spectroscopic follow-up, will detect, classify and measure  $\sigma_z \sim 0.5\%$  redshifts for  $\sim 4000$  SNe Ia and  $\sim 1000$  SNecc. The key to the J-PAS potential is its innovative approach: a contiguous system of 54 filters with 145Å width, placed 100Å apart over a multi-degree FoV is a powerful "redshift machine", with the survey speed of a 4000 multiplexing low resolution spectrograph. Its commissioning camera, PathFinder, has been running and collecting data since the beginning of 2018 with all J-PAS filters of a variety of targets and fields, in particular of the AEGIS field (mini-JPAS) as a proof of concept for photo-z depth. Here I will present the status of J-PAS and some preliminary results from mini-JPAS.

**Author(s):** Renato A Dupke, Javier Cenarro, Jose Vilchez, Jimmy Irwin, Raul Abramo, Silvia Bonoli

**Institution(s):** Univof Alabama, National Observatory, UnivMich, Eureka Scientific, The University of Sao Paulo, Centro de Estudios de Física del Cosmos de Aragón, Instituto de Astrofísica de Andalucía Contributing Team(s): renato dupke

#### 383.02 - A New SED Model for Type Ia Supernova(Mi Dai)

Type Ia supernovae (SNe Ia) are used as standardizable candles to measure cosmological distances and survey the accelerating Universe. While the physics of the supernova explosion is still being explored, SNe Ia light curves are conventionally fitted with empirical models to obtain their standardized magnitudes before they are used in the cosmological analyses. We describe a new SN Ia SED model that includes various effects accounting for intrinsic SN variation, host-galaxy and Milky Way dust, and host-galaxy properties, based on a large data sample covering a wide range of redshifts and rest-frame wavelengths. Our modular framework also allows for adding new effects or choosing different models for existing effects. We anticipate applying this approach to SN cosmology with new facilities and surveys such as LSST and WFIRST.

**Author(s):** Saurabh Jha, Mi Dai

**Institution(s):** Rutgers, The State University of New Jersey

#### 383.03 - WFIRST: Science from Deep Field Surveys(Anton Koekemoer)

WFIRST will enable deep field imaging across much larger areas than those previously obtained with Hubble, opening up completely new areas of parameter space for extragalactic deep fields including cosmology, supernova and galaxy evolution science. The instantaneous field of view of the Wide Field Instrument (WFI) is about 0.3 square degrees, which would for example yield an Ultra Deep Field (UDF) reaching similar depths at visible and near-infrared wavelengths to that obtained with Hubble, over an area about 100-200 times larger, for a comparable investment in time. Moreover, wider fields on scales of 10-20 square degrees could achieve depths comparable to large HST surveys at medium depths such as GOODS and CANDELS, and would enable multi-epoch supernova science that could be matched in area to LSST Deep Drilling fields or other large survey areas. Such fields may benefit from being placed on locations in the sky that have ancillary multi-band imaging or spectroscopy from other facilities, from the ground or in space. The WFIRST Deep Fields Working Group has been examining the science considerations for various types of deep fields that may be obtained with WFIRST, and present here a summary of the various properties of different locations in the sky that may be considered for future deep fields with WFIRST.

**Author(s):** Anton Koekemoer, Ryan Foley

**Institution(s):** Space Telescope Science Institute, University of California, Santa Cruz Contributing Team(s): WFIRST Deep

### **383.04 - Near Field Cosmology: Characterizing the Properties Leading to Radiation Leakage in Local Low- and Intermediate-Mass Galaxies(Andrew Pilon)**

The escape of radiation from galaxies is a frontier cosmology problem with wide-ranging implications for reionization, galaxy evolution and detection strategies for high-redshift systems. Low- and intermediate-mass galaxies may have played a crucial role in reionization at early times, and by studying their analogues in the local universe, we can test models of radiation escape in galaxies that are more observationally accessible. We present here our cross-sectional analyses of the characteristics of low-redshift galaxies from surveys including KISSR, LARS, and two Green Pea galaxy samples through various computational and visualization techniques. Local systems with measured high ( $> 0.1$ ) Lyman-alpha escape fractions tend to have high equivalent widths in H-alpha (EWHA) and low Lyman-alpha red-peak velocity. The KISSR systems contain a population, in appearance resembling "purple peas", with potentially steep UV slopes and high EWHA (please see accompanying poster by Olivieri Villalvazo et al. at this meeting). These might represent a population of local star-forming galaxies that are more common than, e.g., Green Pea galaxies, that also have potentially high Lyman-alpha, and likely Lyman-continuum, escape. These galaxies could potentially test theoretical models and advance studies of the "first-light" galaxies anticipated from the James Webb Space Telescope through characterizing the underlying physical properties that contribute to radiation leakage. This work was supported by the University of San Francisco (USF) Faculty Development Fund, the USF Student Travel Fund, and by the Undergraduate ALFALFA Team through NSF grant AST-1637339.

**Author(s):** John M. Cannon, Mario Arturo Olivieri Villalvazo, John Salzer, Aparna Venkatesan, Max Gronke, Andrew Pilon, Steven Janowiecki, Jessica Rosenberg

**Institution(s):** University of San Francisco, Indiana University, George Mason University, Macalester College, UC Santa Barbara, University of Texas Austin

### **383.05 - Near Field Cosmology: Translating Galaxy Properties to Lyman-alpha and Lyman-continuum escape fractions(Mario Arturo Olivieri Villalvazo)**

We present our analyses of 39 selected star-forming low- to intermediate-mass low-redshift galaxies from the KISSR survey. These galaxies were selected as being representative in the local volume of the kinds of early galaxies that might have hosted the first stars, and span a range of galaxy properties (EWHA, reddening, metallicity, stellar mass). The KISSR systems contain a population, in appearance resembling "purple peas", with potentially steep UV slopes and high equivalent widths in H-alpha. Using archival GALEX data and

theoretical models of radiation transport in dusty galaxies with clumpy gas media, we translate measurements of the UV slopes of these low-mass low- $z$  KISSR galaxies to their escape fractions in Ly-alpha (LyA) and Ly-continuum (LyC) radiation, confirming a relationship between a galaxy's steep UV spectral slope and a significant ( $> 0.1$ ) LyA escape fraction. This relationship is seen in existing data of low- to intermediate-mass galaxies in the local volume (please see accompanying poster by Pilon et al. at this meeting). We also translate measured LyA escape fractions in the literature for 14 LARS galaxies and a few dozen green pea galaxies to their LyC escape fractions using similar modeling. This work was supported by the University of San Francisco (USF) Faculty Development Fund, the USF Student Travel Fund, and by the Undergraduate ALFALFA Team through NSF grant AST-1637339.

**Author(s):** John M. Cannon, Mario Arturo Olivieri Villalvazo, John Salzer, Aparna Venkatesan, Max Gronke, Andrew Pilon, Steven Janowiecki, Jessica Rosenberg

**Institution(s):** University of San Francisco, UC Santa Barbara, George Mason University, Macalester College, Indiana University, University of Texas Austin

### **383.06 - Canadian Hydrogen Intensity Mapping Experiment (CHIME) Update(Gary Hinshaw)**

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a new radio transit interferometer located at the Dominion Radio Astrophysical Observatory (DRAO) near Penticton, BC Canada. CHIME is designed to measure 21 cm emission from neutral hydrogen at redshift  $0.8 < z < 2.5$  to map baryon acoustic oscillations to constrain the dark energy equation of state. The telescope consists of four 100 m x 20 m parabolic cylinders. The dominant foreground is synchrotron emission from the Milky Way. We are developing techniques for removing this foreground emission and will also use it to construct an all-northern sky survey of polarized emission from the magnetized interstellar medium at 400-800 MHz. We will present an update on the CHIME instrument and early scientific observations.

**Author(s):** Gary Hinshaw

**Institution(s):** University of British Columbia Contributing Team(s): CHIME Collaboration

## **400 - Plenary Lecture: The Era of Surveys and the Fifth Paradigm of Science, Alexander Szalay**

### **(Johns Hopkins University)**

#### **400.01 - The Era of Surveys and the Fifth Paradigm of Science(Alexander Szalay)**

Starting with the SDSS and the Hubble Deep Field, astronomy has entered the Era of Surveys. Today we have covered a large fraction of the sky in multiple wavelengths. Much of this data is now available on-line, as an easy-to-use virtual telescope. The datasets are interoperable and it is easy to cross-correlate

between surveys. Astronomers became proficient in databases, and they use these not as tools but rather like musical instruments. Over the centuries science has gone through several paradigms, starting with the “empirical”, followed by “theoretical” and “computational” approaches to science. Today, the large surveys have led us to the so-called Fourth Paradigm of Science, where discoveries are “data-driven”. Astronomers were early adopters, as we can only observe the sky, but cannot undertake experiments which change the behavior of celestial objects. This data-intensive approach to astronomy has resulted in disruptive changes, both technological and sociological. This talk will discuss the journey over the last 20 years, and where these changes have led us, and what may lie ahead. The Large Synoptic Survey Telescope, LSST, will open up the time domain and will produce the largest dataset astronomers will encounter. Such data sets will bring new challenges, as systematic errors will increasingly dominate over statistical noise. We already see how machine learning is turning new detections into discoveries. But the most interesting changes are still ahead: just as in self-driving cars, algorithms are making the decisions, and soon we will see AI tools setting adaptive choices about survey strategies, like target selection. This may be the beginning of the Fifth Paradigm of Science, where computers decide objectively which experiments will yield the biggest gain in our knowledge. Finally, I will also discuss structural and organizational changes that should happen, to make sure that legacy data sets, which have cost hundreds of millions to acquire, can be safely preserved and analyzed throughout their useful lifetime. This will require a fresh look at long term data curation - how to be FAIR (Findable, Accessible, Interoperable, Reusable) and how to be open, free and sustainable, all at the same time.

**Author(s):** Alexander Szalay  
**Institution(s):** Johns Hopkins University

## 401 - The Sun and Solar System

### 401.01 - Calibration of full-disk He I 10830 Å... filtergrams of the Chromospheric Telescope(Zili Shen)

The Chromospheric Telescope (ChroTel) is a small 10-cm robotic telescope at Observatorio del Teide on Tenerife (Spain), which observes the entire solar disk in H $\alpha$ , Ca II K, and He I 10830 Å.... We present a new calibration method that includes limb-darkening correction, removal of non-uniform filter transmission, and determination of He I Doppler velocities. Chromospheric full-disk filtergrams are often obtained with Lyot filters, which may display non-uniform transmission causing large-scale intensity variations across the solar disk. After the removal of a 2D symmetric limb-darkening function from full-disk images, transmission artifacts remain and are even more distinct. Zernike polynomials with a Noll index up to  $j = 36$  are well-suited to reconstruct the large-scale intensity variations of the background. Zernike coefficients show a distinct temporal evolution for ChroTel data, which is likely related to the telescope’s alt-azimuth mount that introduces image rotation. The intensity variations in the He I filtergrams could be removed resulting in flat full-disk data. In addition, applying this calibration to sets of seven filtergrams that cover

the He I triplet facilitates determining chromospheric Doppler velocities. To validate the method, we use three data sets with varying levels of solar activity. The Doppler velocities are benchmarked with respect to co-temporal high-resolution spectroscopic data of the GREGOR Infrared Spectrograph (GRIS). ChroTel Doppler velocities derived from line-wing difference images and from spectral line fitting match those of GRIS Dopplergrams. From this comparison, it was possible to derive a velocity analog and full-disk Dopplergrams of ChroTel. Furthermore, the Zernike technique can be applied to ChroTel H $\alpha$  and Ca II K data. The calibration method for ChroTel filtergrams can be easily adapted to other full-disk data exhibiting unwanted large-scale variations and provide valuable context data for near-infrared spectropolarimetry.

**Author(s):** Zili Shen, Andrea Diercke, Carsten Denker  
**Institution(s):** University of Texas at Austin, Universität  
 Potsdam, Leibniz-Institut für Astrophysik Potsdam

### 401.02 - Scattering Objects as a Probe of the Distant Solar System(Nathan Kaib)

Among the trans-Neptunian Objects actively scattering off the known giant planets, a significant fraction are observed with orbital inclinations well above those typically attributed to the observable Kuiper belt. In particular, ~10% of the scattering objects detected by the Outer Solar System Origins Survey (OSSOS), the Canada-France Ecliptic Plane Survey (CFEPS) and its high latitude extension (HiLat), and the Alexandersen et al. (2016) survey have inclinations over 40 degrees. Here we use numerical models of the formation and evolution of the Kuiper belt and Oort cloud to probe the relationship between these high-inclination scatterers and the Oort cloud as well as a putative distant planet. We show that our dynamical models combined with a simulator of the aforementioned surveys can provide new constraints on the Oort cloud and the viability of an undiscovered planet in the distant solar system.

**Author(s):** Samantha Lawler, Rosemary Pike, Nathan Kaib  
**Institution(s):** University of Oklahoma, Institute of Astronomy and Astrophysics, Academia Sinica, NRC-Herzberg Astronomy and Astrophysics

### 401.04 - The NuSol Detector: Design of a Space-Based Neutrino Detector to Study the Sun.(Robert McTaggart)

Neutrinos produced by fusion processes in the Sun exit almost immediately, offering a unique insight into how the interior of the Sun works. A space-based detector inside the orbit of Mercury offers several benefits for neutrino detection. First, it would increase the neutrino flux due to the inverse square law. Second, it would allow for a different perspective of the solar dynamo because the detector would not be confined to the plane of the ecliptic. However, one has to show that an appropriate signal-to-noise ratio for neutrino detection is feasible, because neutrinos do not interact very often. Because

such a detector must be much smaller than terrestrial neutrino detectors, neutrino interactions may be selected by a double-pulsing technique with the addition of a Gallium dopant without the light attenuation that may occur in a large volume. Noise will be reduced through the use of radiation shielding and a veto detector made of scintillating fiber. Results from the simulation of galactic cosmic ray protons and the diffuse gamma ray background using the Geant4 simulation toolkit will be presented, as well as the simulated response of neutrino signals in a liquid scintillator detector read out by photomultiplier tubes.

**Author(s):** Mark Christl, Nickolas Solomey, Caleb Gimar, Austin Nelsen, Holger Meyer, Robert McTaggart

**Institution(s):** South Dakota State University, NASA Marshall Space Flight Center, Wichita State University

#### **401.05 - Evidence for super-catastrophic asteroid disruption in the near-Sun meteoroid environment?(Paul Wiegert)**

Granvik et al. (2016) proposed that asteroids passing near the Sun super-catastrophically disrupt when their perihelia drop below roughly 16 solar radii ( $q < 0.075$  au). This would explain an absence of asteroids with small perihelia, however, the mechanism of their disruption remains an open question. We use meteor observations from the Canadian Meteor Orbit Radar (CMOR) to examine whether there is a population of meteoroids from a few hundred microns to millimeters in diameter with perihelia near the Sun, which might shed some light on the disruption mechanism. In particular, the ability of meteor radars to observe during the day allows particles coming from the near-Sun region to be easily observed. Our preliminary result is that there is an excess of meteoroids with perihelia near the Sun that might be the debris of super-catastrophically disrupted asteroids, but the picture is complicated by the effect of Poynting-Robertson drag (which causes particles at these sizes to spiral inwards) and, the presence of cometary meteoroid streams (which contaminate the sample), and the radiation pressure (which can blow smaller meteoroids out of the Solar System).

**Author(s):** Petr Pokorny, Paul Wiegert, Cole Gregg, Quan-Zhi Ye, Zbigniew Krzeminski, Peter Brown, Karina Lenartowicz

**Institution(s):** UWestern Ontario, California Institute of Technology, The Catholic University of America

#### **401.06 - Evidence for Shock Source of Solar Sustained Gamma-ray Emission: Fermi, Wind, and SOHO Observations(N. Gopalswamy)**

Fermi Large Area Telescope (Fermi/LAT) observations have shown that sustained gamma-ray emission (SGRE) from the Sun is rather common. Such events are now called sustained gamma ray emission (SGRE) events. Some SGRE events last for almost a day. SGRE is thought to be pion continuum resulting from the impact of  $>300$  MeV protons impacting the solar

chromosphere. Two sources of the high-energy protons have been discussed in the literature: (i) continued acceleration/trapping of protons in large-scale magnetic structures in the associated solar eruption and (ii) precipitation of sunward propagating protons accelerated in CME-driven shocks. One of the best observational signatures of CME shocks is the interplanetary type II radio emission due to nonthermal electrons accelerated in the shock front. Shocks start accelerating particles very close to the Sun and often continue to do so far into the IP medium resulting in kilohertz radio emission. We examined the type II burst properties such as the duration and ending frequencies and compared them with the SGRE durations. The SGRE duration has a significant linear relationship with the duration and ending frequency of type II bursts. This result strongly supports the idea that protons accelerated at the shock front travel back to the Sun to precipitate and produce SGRE. The protons must be traveling along field lines threading the shock front and lying at the periphery of the CME flux rope. Initial estimates show that the shocks at a distance of several tens of solar radii when the SGRE and type II bursts end. The required  $>300$  MeV proton events are not observed at Earth in most of the events. This can be explained by the fact that SEP events need magnetic connectivity to the observer, whereas type II bursts and SGRE are electromagnetic emissions and hence do not have the connectivity requirement.

**Author(s):** Hong Xie, Sachiko Akiyama, Alejandro Lara Sanchez, Seiji Yashiro, Pertti Mäkelä, Robert J MacDowall, N. Gopalswamy,

**Institution(s):** NASA Goddard Space Flight Center, The Catholic University of America

#### **401.07 - The Source of Venus's Zodiacal Dust Ring(Marc J Kuchner)**

Photometry from the Helios satellites and images from the STEREO spacecraft reveal regions of enhanced sky surface-brightness suggesting a narrow circumsolar ring of zodiacal dust associated with Venus's orbit. We modeled this phenomenon by integrating the orbits of  $>100,000$  dust grains subject to gravitational and non-gravitational forces, and experimented with seven different possible sources for the dust. We found that only a narrow class of models can produce enough signal in a narrow ring to match the observations, changing our picture of the dynamics of the inner solar system.

**Author(s):** Petr Pokorny, Marc J Kuchner

**Institution(s):** NASA Goddard Space Flight Center, The Catholic University of America

#### **401.08 - Evidence for a New Component of Solar Gamma-Ray Emission(Tim Linden)**

The Fermi-LAT has detected a bright solar gamma-ray flux produced by the efficient redirection of incoming cosmic-rays by solar magnetic fields. I will show new observations, including the first resolved imaging of this gamma-ray signal across the solar surface, that find three surprising results. First, the gamma-ray emission extends to energies exceeding 200 GeV, implying that Solar magnetic fields can redirect TeV protons. Second, the morphology and spectrum of gamma-ray emission varies significantly over the solar cycle. Third, a significant “spectral-dip” appears between energies of 30-50 GeV. These observations are in significant tension with all current models of solar gamma-ray production. I will conclude by focusing on possible theoretical interpretations of these results, and their implications for our understanding of our nearest stellar neighbor.

**Author(s):** Qingwen Tang, Tim Linden, John Beacom, Bei Zhou, Annika Peter, Kenny Ng

**Institution(s):** The Ohio State University, Nanchang University, Weizmann Institute of Science

#### **401.03D - A Novel Approach to Determining the Acceleration Mechanism of Coronal Jets(Samaiyah I Farid)**

Coronal jets are thought to be the result of magnetic reconnection, often when bipolar magnetic fields emerge into the open, ambient corona. Jet parameters vary widely, making the ability to understand the acceleration mechanism difficult. This is further complicated by the wide range of jet topologies, local environments, and magnetic field configurations. In this work we approach this problem twofold. First we calculate the plasma parameters of several active region jets, including the plane of sky velocity, Doppler velocity (when data is available), the differential emission measure (DEM), and underlying magnetic flux. We calculate the velocity as a function of temperature and estimate the emission measure weighted temperature during the evolution of the jet. In some jets, we find evidence of a temperature-dependent velocity-characteristic of chromospheric evaporation, commonly observed in active region flares. We also use the Coronal Modeling System (CMS), a Non-Linear Force Free (NLFF) model, to examine the topology of selected jets before and during their eruption. In cases where a filament is observed in EUV, we employ the filament insertion method. We find that in several jets, the NLFF model matches the EUV observations of the jet spire well, allowing us to identify the height of the null point (region) and the upper limits of the toroidal, and poloidal flux. In other cases, we find that the direction of the spire is distorted by nearby features (large filaments, coronal holes, etc.). Finally, we estimate the thermal flux during the jet eruption and determine if we should expect explosive or gentle reconnection. All of these observations combined give unique insight in the acceleration mechanism(s) of coronal jets.

**Author(s):** Antonia Savcheva, Katharine Reeves, Samaiyah I

Farid,

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, Vanderbilt University  
**Contributing Team(s):** Natalia Soto Rodriguez, University of Puerto Rico, Harvard-Smithsonian Center for Astrophysics REU Student

#### **402 - Extrasolar Planets: Detection - Space-Based Direct Imaging**

##### **402.01 - Preparing for JWST Coronagraphy, a roadmap(Julien H Girard)**

Coronagraphs onboard JWST NIRCams and MIRI will enable imaging of faint and dusty objects around a central host with an unprecedented combination of sensitivity and angular resolution at wavelengths from 2 to 23  $\mu\text{m}$ . JWST coronagraphy is well suited for the characterization of giant exoplanets at large separations (0.5-10 arcsec projected radius), the panchromatic study of circumstellar disks but also to reveal extended structures in the vicinity of dying stars, active galactic nuclei, quasars and more. The Coronagraphs Working Group at the Space Telescope Science Institute along with the Instruments Teams and internal/external partners works diligently to provide the community with the best possible preparation tools, documentation, pipelines. In this contribution, we expose our roadmap and end-to-end strategy to generate and analyze realistic coronagraphic datasets for various science use cases. Our aim is to maximize the science return of JWST coronagraphs from day 1.

**Author(s):** Marshall Perrin, Bryan Hilbert, Alicia Canipe, Christopher Stark, Keira Brooks, Dean Hines, John Stansberry, Julien H Girard, Laurent Pueyo, Bryony Nickson, Adric R. Riedel, Brian York

**Institution(s):** Space Telescope Science Institute  
**Contributing Team(s):** The JWST Coronagraphy Working Group, The pipeline and ETC development teams, the MIRI and NIRCams Instrument Development Teams (IDTs)

##### **402.02 - The Feasibility of Directly Imaging Cold Planets with MIRI/JWST(Jonathan Brande)**

The 2021 planned launch of the James Webb Space Telescope will push the boundaries of observational astronomy further than ever, and this is particularly true for exoplanets. Until now, the majority of exoplanets have been discovered through transit photometry or radial velocity surveys. However, JWST's high contrast coronagraphic imaging modes will enable the discovery of many new directly imaged exoplanets. These planets will also be detectable at distances and planet-star separations as yet unseen by existing ground- and space-based observatories: within a few parsecs from Earth and a few AU from their host stars. Microlensing and radial velocity surveys indicate that these planets do exist around M-dwarfs, and JWST's coronagraphic imaging capability will be able to expand this population. To guide such observations in the future, we present a study investigating the feasibility of using JWST's Mid-Infrared Instrument's coronagraphic imaging modes to

detect Saturn and Jupiter sized planets around the closest M-dwarfs. Our exposure simulations show that for optimal planetary parameters, JWST would be able to produce the first directly imaged exoplanet detections in our desired planetary population.

**Author(s):** Eric D. Lopez, Thomas Barclay, Jonathan Brande, Elisa Quintana

**Institution(s):** University of Maryland, College Park, NASA Goddard Space Flight Center, University of Maryland, Baltimore County

#### **402.03 - The WFIRST Coronagraph Instrument (CGI): An Update(N. Jeremy Kasdin)**

The Wide Field Infrared Survey Telescope (WFIRST), now in Phase B development, is NASA's next large space observatory, scheduled for launch in 2025. It contains two primary science instruments: A Wide Field Instrument (WFI) to carry out surveys of galaxies in the near infrared; explore the properties of dark energy and dark matter; and carry out a microlensing survey to complete the census of exoplanets, and a Coronagraph Instrument (CGI) to demonstrate high-contrast technology for exoplanet imaging and spectroscopy. Understanding how to implement the technology for CGI is a critical step toward future, larger missions targeted at direct imaging of Earthlike planets in the habitable zone of nearby stars. If successful, CGI will also carry out a participating science program targeted at large Jupiter size planets and disks. This talk will present an overview of the instrument, its key enabling technologies, and its operational plans, including its science program. Also presented will be the Phase B status of the instrument and plans moving forward.

**Author(s):** Jason Rhodes, Vanessa Bailey, N. Jeremy Kasdin, Margaret Turnbull, Bruce Macintosh, John Terry Trauger, Bertrand Mennesson, Margaret A. Frerking

**Institution(s):** Princeton University, SETI Institute, Stanford University, Jet Propulsion Laboratory Contributing Team(s): The WFIRST Coronagraph Instrument and Science Investigation Teams

#### **402.04 - Simulating Known Exoplanet Orbits for WFIRST CGI Imaging(Dmitry Savransky)**

The coronagraphic instrument (CGI) on the Wide Field Infrared Survey Telescope (WFIRST) will likely provide our earliest opportunity to directly image and spectrally characterize the reflected light from sub-Jovian, extrasolar planets. The CGI will serve as an important technology demonstrator for future space coronagraphs, and is likely to produce highly valuable science products in its own right, so it is extremely important to develop an observing program to fully demonstrate its capabilities. One approach to maximizing the probability of imaging exoplanets with the CGI is to preferentially target systems with known exoplanets that were discovered by indirect means from the ground or other space missions. Unfortunately,

of the nearly 4000 confirmed exoplanets, fewer than 100 are likely to be observable by the WFIRST CGI, due to the inherently opposing biases on planet period between indirect methods and imaging. Furthermore, the orbits of these known planets are only partially constrained, and their photometric characteristics are typically entirely unknown. Here, we describe methods for selecting the most likely known target systems for CGI imaging and for estimating the probabilities of planet detection in each case. We couple the partially constrained orbital solutions from the literature with statistical models of unknown orbital parameters and photometric model grids to evaluate distributions of potential planet angular separations and relative fluxes at varying observing times. Finally, we present and discuss the top current known planet candidates for CGI imaging and how this list is likely to evolve with new discoveries.

**Author(s):** Dean Keithly, Natasha E Batalha, Vanessa Bailey, Dmitry Savransky, Nikole K Lewis, Bruce Macintosh, Mark Marley, Daniel Garrett

**Institution(s):** Cornell University, UC Santa Cruz, JPL/CalTech, Stanford University, NASA Ames Research Center

#### **402.05 - The ExoEarth Yield Landscape for Future Direct Imaging Space Telescopes(Christopher Stark)**

The expected yield of potentially Earth-like planets is a useful metric for designing future exoplanet-imaging missions. Recent yield studies of direct imaging missions have focused primarily on yield methods and trade studies using "toy" models of missions. Here we increase the fidelity of these calculations substantially. We adopt a continuous, measured exoplanet occurrence rate distribution as input. We define standardized inputs for instrument simulations and use these standards to directly compare the performance of realistic coronagraph designs, including, for the first time, the sensitivity of coronagraph contrast to stellar diameter. We also adopt engineering-based throughputs and detector parameters. We apply these new high-fidelity yield models to study two critical telescope design trades: monolithic vs segmented primary mirrors and on-axis vs off-axis secondary mirrors. We show that as long as the gap size between segments is sufficiently small, there is no yield penalty for segmentation if the primary mirror is off-axis and unobscured, assuming that the requisite engineering constraints imposed by the coronagraph can be met in both scenarios. We also show that there is currently a yield penalty for on-axis telescopes compared to off-axis telescopes, and note that there is room for improvement in coronagraph designs for on-axis telescopes.

**Author(s):** Christopher Stark, A J Eldorado Riggs, Remi Soummer, Dan Sirbu, Garreth Ruane, Neil Zimmerman, Rus Belikov, Bernard Rauscher, Kathryn St. Laurent, Matthew Bolcar, Laurent Pueyo, John Krist, Bijan Nemati, Brendan Crill, Tyler Groff

**Institution(s):** Space Telescope Science Institute, Jet Propulsion Laboratory, NASA Ames Research Center, University of Alabama in Huntsville, NASA Goddard Space



Flight Center, California Institute of Technology

#### **402.06 - Coronagraph Simulations with LUVOIR and HabEx: The New Era of Exoplanet Direct Imaging and Characterization(Amber Vanessa Britt)**

As we move into the next era for exoplanet studies, space based missions like HabEx and LUVOIR are at the forefront of direct exoplanet imaging and characterization. Pertinent to direct imaging, is the question of how much observing time will be needed to obtain planet spectra with sufficient signal-to-noise to permit atmosphere studies? And what observing strategy will optimize science return given the time constraints associated with the mission duration? Here we present a project to address these questions with a coronagraph modeling tool adapted from Robinson et al. 2016. The coronagraph model produces simulated spectra that include the effects of instrument noise (dark current, read noise), as well as astrophysical nuisance signals (zodiacal light, exo-zodiacal light, etc.). Additional tunable parameters of the model include basic instrument design parameters such as telescope aperture, spectral resolution, throughput, distance to target, coronagraph inner and outer working angles, etc., as well as target-star parameters such as distance. This work is aimed at developing a Design Reference Mission (DRM) tool that can be used to calculate the integration times for any particular target. Here we present results for two example stars in the HabEx target list (tau-Ceti and 82 Eridani) along with nominal analogs for the LUVOIR target list. This project aims to contribute to the development of optimal observing strategies for direct imaging missions of exoplanets. Robinson, T. D., Stapelfeldt, K. R., & Marley, M. S. (2016). Characterizing Rocky and Gaseous Exoplanets with 2 m Class Space-based Coronagraphs. Publications of the Astronomical Society of the Pacific, 128(960), 025003.  
**Author(s):** Giada Arney, Shawn David Domagal-Goldman, Amber Vanessa Britt, Keivan G Stassun  
**Institution(s):** Vanderbilt University, Goddard Space Flight Center

#### **402.07 - Determining orbits of directly imaged exoplanets within the habitable zone(Claire Marie Guimond)**

Future space-based direct imaging missions (HabEx, LUVOIR) would observe reflected light off rocky exoplanets in the habitable zones of Sun-like stars. The ultimate goal of these concept missions is to characterize the planets we detect, but the spectroscopic measurements required for that are quite costly. Therefore, to vet the best spectroscopy targets, one should leverage all the information available a priori. There are two ways in which knowing an exoplanet's orbit would help: (i) the orbit's semi-major axis informs whether the planet might possibly harbour liquid surface water, making it a peak-curiosity target; and (ii) predicting the planet's future location would tell us where and when to look. The science yields of

HabEx and LUVOIR should therefore depend on the number, cadence, and precision of observations required to establish the orbit of a planet within its star's habitable zone. We quantify these statistically: using Markov chain Monte Carlo methods, we fit the six Keplerian orbital parameters to mock direct imaging data for hundreds of simulated planets, and retrieve the parameters' average precisions as functions of cadence, number of epochs, distance to target, and astrometric error. Because each image returns two data (the x and y positions), at most three epochs should be required to fit all six parameters. However, we find that less than three epochs could place an Earth twin planet within the habitable zone at 1-sigma confidence.

**Author(s):** Claire Marie Guimond, Nicolas Cowan

**Institution(s):** McGill University

#### **404 - Extrasolar Planets: Characterization & Theory Track 1: XIII. Exomoons and Comparative Planetology**

##### **404.01 - Using Radio Emission from Planetary-Mass Objects to Understand Planetary Magnetism(Melodie Kao)**

Magnetic fields play a pervasive role in stellar and planetary systems, impacting interior structure, atmospheric evolution, and habitability. Empirical studies of fully convective dynamos are particularly important for characterizing the magnetic fields of planetary systems and cool substellar objects. Such dynamos are ubiquitous in low mass stars, brown dwarfs, gas giant planets, and even small rocky planets. Until we can measure fields on exoplanets, the best tests of exoplanetary convective dynamos are young planetary-mass objects, of brown dwarf spectral types. Observations of coherent radio pulses at GHz frequencies provide the only direct measurements of magnetic fields on L and later type brown dwarfs and planetary-mass objects. We present the first radio detection of a free-floating young, planetary-mass object, review the state of the art for measurements of radio emission from other young planetary-mass objects, highlight implications for models of substellar magnetism, and discuss implications for searches of radio emission from extrasolar planets and how next generation VLA capabilities can push our understanding of brown dwarf and extrasolar planetary magnetism.

**Author(s):** David Stevenson, Evgenya L. Shkolnik, Melodie Kao, J. Sebastian Pineda, Adam Burgasser, Gregg Hallinan

**Institution(s):** Arizona State University, CU Boulder, Caltech, UC San Diego

##### **404.03 - On the Exomoon Candidate Kepler-1625b-i(Alex Teachey)**

Observations performed with the Hubble Space Telescope in October 2017 yielded evidence for a large exomoon orbiting Kepler-1625b. While other explanations remain plausible, the exomoon hypothesis provides a single mechanism for producing the measured transit timing effects as well as the

apparent reduction in the star's brightness towards the end of the 40 hour observation. In this talk I will discuss our analysis of the available data, plans for follow-up, and the outlook for the exomoon search going forward.

**Author(s):** David M Kipping, Alex Teachey

**Institution(s):** Columbia University

#### **404.04 - Exploring Giant Planets And Their Potential Moons In The Habitable Zone.(Michelle Hill)**

While the search for exoplanets has been focused primarily on trying to find Earth like planets, or planets of a similar size, distance from its star and composition as Earth, there have been discoveries of many different worlds that have caused us to revise our ideas as to what could be a potentially habitable world. Interestingly there has been a significant number of giant exoplanets (>3 earth radii) discovered in the habitable zone of their star, the region around a star where water can exist in a liquid state on the surface of a planet with sufficient atmospheric pressure. These giant planets are likely gas giants and thus are not considered habitable on their own, but they each could potentially be host to large rocky exomoons which would also exist in the habitable zone. These moons, should they exist, will offer new ways to understand the formation and evolution of planetary systems, and widen the search for signs of life out in the universe. The occurrence rates of these moons are related directly to the occurrence rates of giant planets in the habitable zone of their star, thus we estimate the frequency with which we expect giant planets to occur in the habitable zones. These results will be presented, along with calculations of potential exomoon properties of habitable zone giant planets that will help aid in the detection of moons in the future.

**Author(s):** Eduardo Seperuelo Duarte, Dawn Gelino, Rob Wittenmyer, Ravi Kopparapu, Stephen Kane, Michelle Hill,

**Institution(s):** University of California, Riverside, Instituto Federal do Rio de Janeiro, University of Southern Queensland, NASA Exoplanet Science Institute, NASA Goddard Space Flight Center Contributing Team(s): Michelle Hill

#### **404.06 - Comparative Terrestrial Exoplanetology in an Era of Space-Based Infrared Spectroscopy(Caroline Morley)**

An exciting and imminent frontier of exoplanet science is the characterization of Earth-sized planets. The most amenable planets for characterization in the coming decades are transiting planets orbiting the smallest stars. During the past two years, ten planets close to Earth in radius have been discovered around nearby M dwarfs cooler than 3300 K. These planets include the 7 planets in the TRAPPIST-1 system and two planets discovered by the MEarth survey, GJ 1132b, LHS 1140b, and LHS 1140c. A number of other such planets are expected to be found by the TESS mission and ground-based surveys like MEarth and SPECULOOS. Some of these planets orbit at distances potentially amenable to surface liquid water, though

the surface temperatures will depend strongly on the albedo of the planet and the thickness and composition of its atmosphere. The stars they orbit also vary in activity levels, from quiet M dwarfs like LHS 1140 to more active stars like TRAPPIST-1.

This set of planets will form the testbed for our first studies of the diversity of atmospheres around Earth-sized planets. Here, we present model spectra of the ten currently-known temperate terrestrial worlds amenable to atmosphere characterization. We also present model spectra of a set of simulated planets from the Barclay et al. 2018 catalog, which represent the types of planets that TESS will find. We show the distributions of planet radii, orbital periods, temperatures, host star temperatures, and distances for the predicted sample of TESS terrestrial planets that provide the best opportunities for characterization. We vary composition and surface pressure of the atmosphere, basing our elemental compositions on outcomes of planetary atmosphere evolution in our own solar system. We present both thermal emission spectra and transmission spectra for each of these objects, and we provide predictions for the observability of these spectra with JWST and with two different versions of the Origins Space Telescope mission concept. We show which big questions in terrestrial planet science are likely to be studied with JWST and which can be studied in the future.

**Author(s):** Michael R. Line, Robert Thomas Zellem, Tiffany Kataria, Caroline Morley, Jonathan Fortney, Kevin Stevenson, Luke Tremblay

**Institution(s):** University of Texas at Austin, UC Santa Cruz, JPL, ASU, STSci

#### **404.07 - A Panchromatic Comparative View of Exoplanet Atmospheres(David K. Sing)**

Hubble has played the definitive role in the characterisation of exoplanets and from the first planets available, we have learned that their atmospheres are incredibly diverse. With HST, JWST, and TESS a new era of atmospheric studies is opening up, where wide scale comparative planetology is now possible which can provide insight into the underlying physical process through comparative studies. Hubble's full spectroscopic capabilities are now being used to produce the first large-scale, simultaneous UVOIR comparative study of 20 exoplanets ranging from super-Earth to Neptune and Jupiter sizes. With full UV to infrared wavelength coverage, an entire planet's atmosphere can be probed simultaneously and with sufficient numbers of planets, it will be possible to statistically compare their features with physical parameters. The panchromatic treasury program aims at build a lasting HST legacy, providing the UV and blue-optical exoplanet spectra which will be unavailable to JWST, providing key insights into clouds and mass loss. Early highlights of the program include atmospheric water resolved in emission and new absorption features seen in transmission. I will present the latest findings from the ongoing Hubble Treasury program and discuss synergies with JWST.

**Author(s):** Mercedes Lopez-Morales, David K. Sing

**Institution(s):** Johns Hopkins University, CfA Contributing

Team(s): the Hubble PanCET collaboration

#### **404.02D - Flying Exomoons around Jumping Jupiters(Yu-Cian Hong)**

Planet-planet scattering is the leading mechanism to explain the broad eccentricity distribution of observed giant exoplanets. Here we study the orbital stability of primordial giant planet moons in this scenario. We use N-body simulations including planet oblateness to ensure that moons don't experience unrealistic orbital instabilities due to slowed nodal precession (Hong et al. 2015). Planets in planet-planet scattering develop high obliquities and inclinations, so the N-body integrator also evolve spin for the giant planets using a non-secular equation of motion, to address relevant dynamics for moons. In the end, we find that the vast majority ( $\sim 80\text{-}90\%$  across all our simulations) of orbital parameter space for moons is destabilized. There is a strong radial dependence, as moons past  $0.1$  Hill radii are systematically removed. Closer-in moons on Galilean-moon-like orbits ( $< 0.04$  Hill radii) have good chances of survival ( $\sim 20\text{-}40\%$ ). Destabilized moons may undergo a collision with the star or a planet, be ejected from the system, be captured by another planet, be ejected but still orbiting its free-floating host planet, or survive on heliocentric orbits as "planets." The survival rate of moons increases with the host planet mass but is independent of the planet's final (post-scattering) orbits. Based on our simulations we predict the existence of an abundant galactic population of free-floating (former) moons.

**Author(s):** Yu-Cian Hong, Sean N. Raymond, Jonathan I. Lunine, Philip D Nicholson

**Institution(s):** Astronomy Department, Cornell University, Carl Sagan Institute, Cornell University, Laboratoire d'astrophysique de Bordeaux, Université de Bordeaux

#### **404.05D - Characterizing the Atmospheres of Exoplanet Populations: From Sub-Jovian to Ultra-hot Jupiter Exoplanets(Joshua Lothringer)**

With thousands of exoplanets now discovered and the diversity of worlds beyond our solar system being unveiled, we are now beginning to characterize individual worlds to understand exoplanet populations in detail. The most direct way that we can characterize an exoplanet is by studying its atmosphere. Using transit spectroscopy with HST/STIS, we observed the atmospheres of several sub-Jovian exoplanets, including the JWST GTO target GJ 436b. We find intriguing similarities and differences in their full transmission spectra, indicating a diversity among sub-Jovian exoplanets. While sub-Jovian exoplanets are on the frontier of characterization, ultra-hot Jupiters are some of the most ideal targets for observation due to their high temperature, inflated radii, and short periods. Using the self-consistent PHOENIX atmosphere model, we show that the atmospheres of ultra-hot Jupiters exhibit some unique properties, including thermal dissociation and intense

temperature inversions, even in the absence of TiO or VO. Since ultra-hot Jupiters are amongst the most highly irradiated objects, we explore the role that the host star irradiation spectrum plays in the planet's temperature structure and composition, finding that ultra-hot Jupiters around hotter host stars will have more intense temperature inversions. Lastly, we present some novel techniques to analyze exoplanet atmospheres using PETRA, a new retrieval algorithm we have built around PHOENIX.

**Author(s):** Travis Barman, Joshua Lothringer

**Institution(s):** University of Arizona

#### **405 - Kepler and K2's 500,000 High-precision Light Curves: Prospects for Future Discoveries**

##### **405.01 - Kepler and K2's 500,000 lightcurves(Jessie Dotson)**

The Kepler space telescope was launched in 2009 and spent over 9 years taking high-precision, high-cadence, uninterrupted light curves of over 500,000 astrophysical targets, including nearby Solar System targets, nearly every type of star, and a large sample of galaxies. Light curves obtained during the Kepler mission have up to a 4 year duration while those obtained during K2 have 60-80 day durations. I will provide an overview of the Kepler/K2 dataset of light curves and highlight some as yet underutilized data.

**Author(s):** Jessie Dotson

**Institution(s):** NASA Ames Research Center

##### **405.02 - Are there any more planets in the Kepler / K2 data?(Christina L Hedges)**

The Kepler/K2 mission has been exceptionally successful at detecting transiting exoplanets. The Kepler mission has detected more than 2300 confirmed exoplanets to date, with K2 detecting more than 300 additional confirmed exoplanets. Kepler/K2 is able to identify some of the smallest exoplanets around solar-like stars, owing to its extreme photometric precision and long baseline. Several of these planets have become vital components in our modeling of planet formation and composition, as well as targets for atmospheric characterization. However, there is a wealth of data that is currently under-utilized. In particular, several K2 campaigns have provided fewer exoplanets, due to difficult instrument systematics and crowding complicating data analysis. For example, campaigns 9 and 11 are extremely crowded, causing contamination and diluting exoplanet transits. These campaigns require precise extraction techniques to rebuild subtle exoplanet transits, such as PSF photometry. With the new TESS photometry likely to require more complex extraction techniques, now is the ideal time to revisit Kepler/K2 data and find the planets that remain in this huge dataset. Additionally, there are several campaigns in from the K2 mission that have been underutilized purely because of the sheer volume of data, including the recent campaigns 16, 17 and

18. In this talk I will highlight some of the Kepler/K2 datasets where valuable, undiscovered planets may still be hiding.

**Author(s):** Geert Barentsen, Michael A. Gully-Santiago, Nicholas Saunders, Jessie Dotson, Ann Marie Cody, Christina L. Hedges,

**Institution(s):** NASA Ames, Bay Area Environmental Research Institute

#### **405.03 - What is left to learn about Kepler/K2 planet host stars?(Daniel Huber)**

The Kepler & K2 missions have revolutionized our understanding of exoplanet demographics. However, for most Kepler/K2 discoveries our knowledge of planet radii has been limited by the uncertainties in the radii of the host stars. Additionally, radius uncertainties for the full sample of ~500,000+ targets have been a dominant source of systematic errors for measuring planet occurrence rates. The release of Gaia DR2 parallaxes in April 2018 has spectacularly solved this bottleneck by allowing a precise radius determination for nearly every Kepler/K2 target. In this talk I will review the latest results on Kepler/K2 exoplanet radius demographics based on Gaia DR2 parallaxes, including an investigation of the intriguing radius gap for close-in super-Earths and a revised catalog of small, habitable-zone exoplanets. I will also discuss the remaining challenges for characterizing exoplanet host stars in the Gaia era, including strategies towards accurate effective temperature and radius scales for solar-type stars through the combination of constraints from interferometry, asteroseismology and astrometry.

**Author(s):** Daniel Huber

**Institution(s):** University of Hawaii

#### **405.04 - What will Kepler/K2 teach us about our Galaxy?(James Davenport)**

While the Kepler and K2 missions were designed to search for Earth-like exoplanets, their impact has reached far beyond the statistics of planet occurrence. Over the past decade, the Kepler/K2 platform has generated the most precise light curves ever produced for nearly a half million stars. With these data we are discovering new astrophysics of stars, and in turn revealing clues about the formation history of our own Galaxy. Here I will highlight a few key discoveries and mysteries about stellar populations within our Galaxy that Kepler/K2 have found, and point to a bright future for this field with upcoming missions like TESS.

**Author(s):** James Davenport

**Institution(s):** University of Washington, Seattle

#### **405.05 - How can new data analysis methods get more out of Kepler/K2 data?(Daniel Foreman-Mackey)**

In this talk, I will describe how the Kepler and K2 data have driven (and continue to drive) the development of new algorithms for time series analysis. I will discuss some of the important lessons that the wide range of methods for de-trending, filtering, and transit search have taught us. These lessons continue to improve our methods for analyzing current and future photometric time series datasets. I will also describe some ways that recent software developments in astronomy and other fields might be harnessed to continue to extract exciting results from the Kepler and K2 datasets.

**Author(s):** Daniel Foreman-Mackey

**Institution(s):** Flatiron Institute

#### **405.06 - What Will Kepler/K2 Tell us About Other Galaxies?(Krista Lynne Smith)**

The even cadence, dense sampling, long baselines and unprecedented photometric precision required to allow Kepler to detect exoplanet transits also made it an ideal instrument for studying high energy phenomena in many contexts, even beyond the Milky Way. In particular, Kepler has enabled a new optical timing window into accretion onto supermassive black holes by way of quasar and AGN light curves, and into the physics of relativistic jets through blazar monitoring. Kepler has also provided us with a new way to search for AGN that is complementary to traditional methods, and may even locate some of the elusive lightest supermassive black holes. Kepler has also provided early-time light curves of supernovae in faraway galaxies, providing new insights into shock breakout models and progenitor populations for these powerful explosions.

**Author(s):** Krista Lynne Smith

**Institution(s):** Stanford University

#### **405.07 - How can machine learning contribute to mining Kepler data?(Megan Ansdell)**

Machine learning has been successfully used to rapidly classify transit signals (e.g., as planet candidates or false positives) in light curves from the Kepler mission using deep convolutional neural networks. However, these machine learning models depend on traditional exoplanet detection pipelines (e.g., the Kepler Science Processing Pipeline) to first identify the transit signals with brute-force methods, such as Box Least Squares periodogram searches across all possible periods on significantly pre-processed data (i.e., after light curve extraction and flattening). Moreover, the currently available training set for Kepler data is limited to only ~15,000 labeled examples, whereas successful supervised machine learning applications typically have at least an order of magnitude more; additionally, these labeled examples are mostly false positives (e.g. eclipsing binaries, instrumental artifacts) or planet candidates with high SNR (e.g., close-in giant planets), making it difficult to train

models that can reliably identify low SNR transits that correspond to interesting cases such as rocky planets in the habitable zone. Advances in using machine learning to mine the Kepler data will therefore depend on the construction of much larger and more balanced training datasets, such as via innovative data augmentation techniques or more realistic injected light curves. The biggest breakthroughs will be in developing methods for using machine learning to detect (rather than just classify) exoplanet transits, not just in the light curves but also in the less processed target pixel files.

**Author(s):** Megan Ansdell

**Institution(s):** University of California, Berkeley

#### **405.08 - A Uniformly Vetted Catalog of K2 Transit Signals with DAVE(Susan E Mullally)**

We have adapted the algorithmic tools developed during the Kepler mission to vet the quality of transit-like signals for use on the K2 mission data. We packaged them into an open-source, fully-automated vetting package called DAVE (Discovery and Vetting of Exoplanets). Using four of the publically available K2 lightcurves (K2SC (Aigrain et al. 2015), EVEREST (Luger et al. 2017), K2SFF (Vanderberg et al. 2014), and PDC (Smith et al. 2012)) we produced a uniformly-vetted catalog of the reported, candidate transit signals from the K2 data which are publicly available at the NASA Exoplanet Archive. Our analysis identifies more than 80 new false positives, effectively doubling the overall number of reported astrophysical signals mimicking planetary transits in K2 data. Most of the targets listed as false positives in our catalog show prominent secondary eclipses, transit depths suggesting a stellar companion instead of a planet, or significant photo-center shifts during transit. We will describe the tests performed by the DAVE pipeline and how to access the public code. This research is based on data collected by the K2 mission. Funding for the K2 mission is provided by the NASA Science Mission Directorate. This work was made possible because of funding by K2 Guest Observer Grants (NNX16AE74G). We thank the NASA Exoplanet Archive for hosting the K2 candidates and false positives, and the Mikulski Archive for Space Telescopes for hosting the K2 data products and K2 high-level science light curves.

**Author(s):** Joshua Schlieder, Susan E Mullally, Thomas Barclay, Knicole Colon, Fergal Mullally, Veselin Kostov, Elisa Quintana, Christopher Burke, Jeffrey Coughlin

**Institution(s):** Space Telescope Science Institute, NASA Goddard, SETI Institute, MIT

#### **406 - A Hubble Space Telescope for the 2020s: Capabilities and Opportunities**

##### **406.01 - Hubble Will Shine Well into the 2020s(Thomas Michael Brown)**

Nearly 10 years after its last servicing mission, the Hubble Space Telescope is near its peak performance and scientific productivity. The oversubscription pressure remains as high as

ever, and the publication rate of peer-reviewed papers based upon Hubble data continues to climb, with over 900 such papers in 2017, over half of which were based upon archival research. The graceful aging of its science instruments and subsystems is mitigated through both operational and data processing innovations. Updates to the annual call for proposals provoke exciting new avenues of exploration, including the UV initiative, the JWST preparatory program, and the fundamental physics program, while the additional opportunities provided by the mid-cycle calls and Director's Discretionary time enable rapid response to discoveries. For the foreseeable future, Hubble will remain the only facility providing continuous unfettered access from the far-UV through the near-IR, with stable high-resolution imaging, spectroscopy, astrometry, and coronagraphy. For these reasons, Hubble will continue to play a vital synergistic role with other facilities on the ground and in space during the next decade - an era of all-sky transient and multi-messenger astronomy.

**Author(s):** Thomas Michael Brown

**Institution(s):** Space Telescope Science Institute

##### **406.02 - Exoplanet Characterization with HST - Unique role of HST in the era of JWST and ground-based exoplanet characterization(Mercedes Lopez-Morales)**

The past decade has seen a revolution in the study of exoplanetary atmospheres. In just a few years we have gone from detecting atmospheric spectral features in hot Jupiters to observing much smaller planets. In the next few years we will be studying super-Earths and hot Neptunes around nearby bright stars, while learning about the physics of these worlds as a stepping-stone towards future observations of terrestrial planets in the habitable zone. The depth, quantity, and quality of exoplanet atmospheric studies is set to increase even more dramatically in upcoming years, after the Transiting Exoplanet Survey Satellite (TESS) mission finds hundreds of nearby planets. In this presentation I will highlight the unique ways we expect HST will contribute to exoplanet atmospheres studies in the upcoming decade.

**Author(s):** Mercedes Lopez-Morales

**Institution(s):** Harvard-Smithsonian CfA

##### **406.03 - The Unique Nature of UV Astrophysics with the Hubble Space Telescope(Sanchayeeta Borthakur)**

Next decade brings in the promise of more powerful telescopes that will transform our understanding of the universe. With JWST and large optical telescopes coming online, HST will be our unique window to the ultraviolet wavelengths. This regime will be critical for low- and intermediate-redshifts as it is our only hope of capturing the rest-frame far-UV and extreme-UV frequencies. Hubble will still have the edge in terms of spatial and spectral resolution and will be the perfect complement to

the upcoming large observatories. I'll discuss specifically how Hubble can contribute to the various aspect of extragalactic astronomy in the upcoming decade.

**Author(s):** Sanchayeeta Borthakur

**Institution(s):** Arizona State University

#### **406.04 - The Role of HST in Surveys of Moderate Size(Julianne Dalcanton)**

In this talk I will consider the role that HST might play in the era of JWST, WFIRST, and ever-larger ground-based telescopes. Even within this expanding landscape, HST will still offer scientifically compelling ways to navigate the scientific terrain. I will focus on the scientific potential of modest surveys that take advantage of HST's depth, spatial resolution, stability, broad wavelength coverage, and/or spectroscopic capabilities, operating either independently or in tandem with other facilities.

**Author(s):** Julianne Dalcanton

**Institution(s):** University of Washington

#### **406.05 - Transient Science - HST's capability to respond to transients(Raffaella Margutti)**

I will present a brief overview of key science opportunities for HST in the era of time-domain astronomy.

**Author(s):** Raffaella Margutti

**Institution(s):** Northwestern University

#### **Panel Discussion w/input from the community**

**Author(s):**

**Institution(s):**

#### **407 - Galaxy Formation and Evolution VIII**

##### **407.01 - Studying Extra-Planar, Diffuse Ionized Gas in Stacked MaNGA Galaxies(Amy Michelle Jones)**

Gas in the outskirts of galaxies can greatly influence the evolution of their host galaxies and additionally can help clarify the missing baryons problem. Warm ionized gas is faint and diffuse and hence difficult to study. Only a handful of nearby galaxies have been studied in detail and many questions remain about the ionization source(s) and amount of gas present in the outskirts of galaxies along the disk-halo boundary. By stacking multiple similar, highly inclined, SDSS IV MaNGA galaxies, we can clearly detect this extra-planar gas out to several kpc, between four and nine kpc depending on the sample. MaNGA is an IFU survey that covers the entire optical range, so we have detections of emission lines, including [OII], [OIII], H $\beta$ , [OI], [NII] H $\beta$ , [SII], as a function of scale height. Currently there are about 5000 galaxies observed, and 1100 are suitable for this

study. This increases our previous sample by over a factor of ten! We split this sample into many subsamples to see how the gas properties, e.g. temperature, density, ionization state, depend on the host galaxy properties, e.g. morphological type, star formation rate, stellar mass. Some of the gas properties show a strong dependence on the host galaxy properties.

**Author(s):** Preethi Nair, Amy Michelle Jones

**Institution(s):** University of Alabama   Contributing Team(s): MaNGA team

##### **407.05 - Quantifying the Role of Galaxy Mergers Among Starburst Galaxies in COSMOS and CANDELS(Jeyhan S. Kartaltepe)**

Galaxy mergers and interactions are thought to play a key role in the evolution of galaxies. These collisions can affect many important galaxy properties, such as their physical structure, their star formation rates, and the growth of their central black holes. However, the details of this role, and how it has changed over the age of the Universe, is still a matter of much debate. Both theoretical models and some recent observations have suggested that mergers do not play a dominant role in the early Universe, but that instead much of the mass growth of galaxies can be attributed to secular processes such as disk instabilities. I will present the results of a detailed, multiwavelength analysis of galaxies selected to have very high star formation rates in the early Universe, at the key epoch when the majority of stars in the Universe formed. By studying the structure and morphology of these objects, we can place constraints on their merger histories and quantify how such an event influences the overall rate of star formation.

**Author(s):** Kevin C. Cooke, Dale Mercado, Jeyhan S.

Kartaltepe, Krystal Tyler

**Institution(s):** Rochester Institute of Technology

Contributing Team(s): COSMOS Collaboration, CANDELS Collaboration

##### **407.06 - Tracing Black Hole Fueling and Feedback with Adaptive Optics(Anne M Medling)**

We present KOALA: the Keck OSIRIS AO LIRG Analysis, an adaptive optics-assisted near-infrared integral field spectroscopy campaign of 30+ nearby gas-rich galaxy merger nuclei. Our dataset traces stellar and gas kinematics and properties at few 10s of pc resolution, providing an excellent laboratory for studying the fueling and feedback associated with the central supermassive black holes and nuclear starbursts. These data have shown that 50-500 pc nuclear disks are a nearly ubiquitous mechanism for funneling gas to the black holes. High central dynamical masses suggest that black holes may 'claim their mass' early in a merger, but that that material takes much of the merger timescale to find its way through the accretion process. High ratios of shock-excited molecular gas (H $\beta$  2.12 micron emission) compared to ionized hydrogen (Br $\gamma$  emission) reveal star formation- and AGN-driven nuclear

outflows that in some cases can be traced out to several kpc scales. For more information on the survey and access to our data, visit [koala-goals.github.io](https://github.com/koala-goals).

**Author(s):** Vivian U, Anne M Medling,

**Institution(s):** University of Toledo, University of California - Irvine, Australian National University

#### **407.02D - Characterizing bursty star formation and ionizing photon production in dwarf galaxies through cosmic time(Najmeh Emami)**

We investigate the related physical properties of "bursty" star formation and ionizing photon production in local dwarf galaxies and in lensed dwarf galaxies at  $z \sim 2$ . In our first investigation, we focus on characterizing the time scale and amplitude of these bursts by modeling them as exponential functions, and fitting the observed distributions of  $\text{LH}\alpha/\text{LUV}$  vs. displacement from the average  $\text{LH}\alpha$  in bins of stellar mass. We find that, in local dwarf galaxies, the time scale of the bursts are long ( $>300$  Myrs) in galaxies with stellar masses above  $108.5 M_\odot$ , and short ( $<30$  Myrs) in galaxies with stellar masses below  $107.5 M_\odot$ . In our next investigation, we analyze the ionizing photon production efficiency,  $\text{f}_{\text{ion}}$ , of lensed, dwarf star-forming galaxies at  $z \sim 2$ , by measuring the  $\text{LH}\alpha/\text{LUV}$  ratio. We find that dwarf galaxies at high redshift have significantly higher  $\text{f}_{\text{ion}}$  than local dwarf galaxies of similar mass. We also find that there is not much difference between galaxies of different masses ( $108-1010$ ) at  $z \sim 2$ . This suggests that the primary driver of  $\text{f}_{\text{ion}}$  evolution with time is the iron abundance, and that the star formation histories of galaxies up to  $z \sim 2$  is insufficiently different to drive large Fe/H variations between low and high mass galaxies. Finally, we characterize bursty star-formation at high redshift, across four orders of magnitude, to compare the amplitudes and timescales to dwarf galaxies at low redshift.

**Author(s):** Anahita Alavi, Timothy Gburek, Najmeh Emami, Weisz Daniel, benjamin johnson, Brian Siana

**Institution(s):** UC Riverside, Harvard-Smithsonian Center for Astrophysics, UC Berkeley, California Institute of Technology

#### **407.03D - Studying AGN Feedback in the Epoch of Peak Cosmic Star Formation(Cody James Lamarche)**

A correlation is known to exist between the mass of supermassive black holes, which power active galactic nuclei (AGN), and the mass of the stellar bulges surrounding them, suggesting that the two co-evolve. Similarly, simulations which exclude the effects of AGN feedback tend to miss the quenching of star formation in the most massive galaxies, suggesting that AGN regulate star formation in these systems. The best way to study this interplay is by examining the effects of AGN feedback on star formation within galaxies during the epoch of both peak cosmic star formation and AGN accretion rate density ( $z \sim 1-3$ ). In this dissertation talk I will focus on one aspect of my

thesis, describing a panchromatic study of 3C 368, an FR-II type radio galaxy at  $z = 1.131$ . This peculiar galaxy exhibits a star formation rate of  $\sim 350 M_\odot/\text{yr}$ , headed by stars of type O8, as determined by mid- and far-infrared fine-structure line analysis, and yet is undetected in CO(2-1), a tracer of star-forming molecular gas, down to a level  $\sim 12x$  below that expected in star-forming galaxies. Intriguingly, the 6.5 Myr age of the young stellar population makes the most recent star-forming event roughly concurrent with the most recent episode of AGN flaring, as estimated by the propagation of the radio lobes, suggesting that the two events are linked. We propose that the star-forming molecular clouds within the interstellar medium (ISM) of 3C 368 are highly fractionated by momentum injected by the AGN, reducing the CO column, which requires dust shielding to survive the intense radiation fields, while leaving the star-forming molecular hydrogen, which is self-shielding, mostly intact.

**Author(s):** Thomas Nikola, Gordon Stacey, Amit Vishwas, Drew Brisbin, Dominik A Riechers, Cody James Lamarche, Steven Hailey-Dunsheath, Carl Ferkinhoff, Matthias Tecza, James Higdon, Sarah Higdon, Aprajita Verma, Henrik Spoon, Chelsea Sharon

**Institution(s):** Cornell University, Universidad Diego Portales, Winona State University, McMaster University, California Institute of Technology, University of Oxford, Georgia Southern University

#### **407.04D - The Role of Tidal Interactions and Mergers on the Evolution of Intermediate Redshift Galaxies(Sinan Deger)**

Interactions between galaxies, be it a tidal interaction or a merger, are processes that are capable of altering both the morphologies and the star formation properties of galaxies. They therefore are prime candidates for explaining observations in galaxy evolution, as observational evidence suggests a link between transformations in galaxy morphology and star formation. In a recent paper, we have identified the subsample that are undergoing tidal interactions and mergers (TIM) within the EDisCS sample, where we analyzed 11 clusters, 7 groups, and accompanying field galaxies at  $0.4 < z < 0.8$ . Our identification uses a combination of visual detection of TIM signatures on morphology, and the G-M20 method, both performed on deep HST images. The results of our first paper indicate that the fraction of TIM events show a mild enhancement in intermediate density environments such as groups, and the outer regions of clusters. Albeit tentative, this enhancement we find is suggestive, as such environments are conducive for galaxy interactions due to their relatively higher densities and lower velocity dispersions. When we separate our galaxies into passive and star-forming using their U-V and V-J colors, we find that our TIM galaxies preferentially lie in the star-forming region. We also analyze the deep rest-frame optical spectra of our sources to determine the stellar populations of galaxies of different morphological types. We find that our TIM galaxies preferentially have higher Balmer absorption and lower D4000 indices, indicating the existence of

younger stellar populations and recent star formation. Our undisturbed galaxies on the other hand predominantly have low Balmer absorption and high D4000, signs of older stellar populations. We are currently measuring the recent star formation history of our galaxies from our spectra, and a merger timescale using G-M20 values of simulated galaxies. Using these two measures, and by combining our morphological classification and stellar population studies we will constrain the relative importance of TIM events in shaping the morphological and star forming properties of galaxies.

**Author(s):** Sinan Deger, Gregory Rudnick

**Institution(s):** University of Kansas

## **408 - Extrasolar Planets: Detection - Radial Velocity and Astrometry Searches and Detections**

### **408.01 - Radial velocities from the N2K Project: 6 new cold gas giant planets orbiting HD 55696, HD 98736, HD 148164, HD 203473, and HD 211810(Kristo Ment)**

The N2K planet search program was designed to exploit the planet-metallicity correlation by searching for gas giant planets orbiting metal-rich stars. Here, we present the radial velocity measurements for 378 N2K target stars that were observed with the HIRES spectrograph at Keck Observatory between 2004 and 2017. With this data set, we announce the discovery of six new gas giant exoplanets: a double-planet system orbiting HD 148164 ( $M \sin i$  of 1.23 and 5.16 MJup) and single planet detections around HD 55696 ( $M \sin i = 3.87$  MJup), HD 98736 ( $M \sin i = 2.33$  MJup), HD 203473 ( $M \sin i = 7.8$  MJup), and HD 211810 ( $M \sin i = 0.67$  MJup). These gas giant companions have orbital semi-major axes between 1.0 and 6.2 AU and eccentricities ranging from 0.13 to 0.71. We also report evidence for three gravitationally bound companions with  $M \sin i$  between 20 to 30 MJup, placing them in the mass range of brown dwarfs, around HD 148284, HD 214823, and HD 217850, and four low-mass stellar companions orbiting HD 3404, HD 24505, HD 98630, and HD 103459. In addition, we present updated orbital parameters for 42 previously announced planets. We also report a nondetection of the putative companion HD 73256 b. Finally, we highlight the most promising candidates for direct imaging and astrometric detection, and find that many hot Jupiters from our sample could be detectable by state-of-the-art telescopes such as Gaia.

**Author(s):** Gaspar Bakos, Debra Fischer, Andrew Howard, Howard Isaacson, Kristo Ment

**Institution(s):** Harvard University, Princeton University, Yale University, University of California, Berkeley, California Institute of Technology

### **408.02 - “Retired” A Stars and their Companions: Prospects for Catching Long-Period RV Planets in Transit with TESS(Jacob Luhn)**

On the main sequence, stars of mass  $\sim 1.3$  Msun and higher prove difficult to obtain precise radial velocities. However, once they become subgiants, these stars become suitable for radial velocities as they become cooler and spin more slowly. These “retired” A stars serve as useful probes of planet demographics for both higher mass and more evolved stars. We examine the sample of “retired” A stars with Keck velocities described in Johnson (2006), including several new planet companions that increase the number of planets around subgiants by 15%. Most of these are Jupiter-sized planets at 1-2 au, where discovery via transit is unlikely. However, some may have observable transits from TESS that would allow further characterization (e.g. transmission spectroscopy) and would therefore be a unique addition to the sample of known transiting planets. With this in mind, we provide updated orbital parameters as well as predicted transit probabilities, times, and durations for known radial velocity planets with subgiant hosts.

**Author(s):** Jacob Luhn, Fabienne Bastien, Jason T Wright, John Johnson, Andrew Howard, Howard Isaacson

**Institution(s):** Pennsylvania State University, California Institute of Technology, Harvard-Smithsonian Center for Astrophysics, University of California, Berkeley

### **408.03 - The NEID Doppler spectrometer at WIYN(Christian Schwab)**

The US exoplanet science community urgently requires a radial velocity instrument with the sensitivity to observe rocky planets in the habitable zone, and follow-up the most promising TESS candidates. To address this need, we are building NEID, the new NN-Explore extreme precision Doppler spectrometer for the WIYN telescope at Kitt Peak Observatory. The guiding metric for the complete design was the instrument's performance for its primary science goal, the Doppler observation of Earth-like exoplanets. It is based on a high optical performance Echelle spectrograph built around a classical white pupil relay with large beam size, and is fed by a high-scrambling fiber train. NEID covers the wavelength range from 380 - 930nm in a single frame with a resolution of  $\sim 100,000$ . The optics bench is housed in a vacuum chamber for environmental control, reaching sub-millikelvin temperature stability. Together with a sophisticated front end to provide excellent atmospheric dispersion correction and guiding stability, this forms a system with predicted Doppler precision of  $< 25$  cm/s. In this talk, we will present the optical and optomechanical designs, and discuss the interplay of technical design choices and science demands.

**Author(s):** Frederick Hearty, Lawrence Ramsey, Andrew Monson, Sam Halverson, Michael McElwain, Gudmundur Kari Stefansson, Emily Hunting, Christian Schwab, Shubham Kanodia, Sarah E. Logsdon, Paul Robertson, Arpita Roy, Suvrath Mahadevan, Qian Gong, Emily Lubar, Ming L

**Institution(s):** OCarleton College, Macquarie University,



NASA GSFC, NOAO, University of Pennsylvania, Steward Observatory, Pennsylvania State University, MIT, Caltech, UC Irvine Contributing Team(s): the NEID team

#### **408.04 - MINERVA-Red: An Observatory Dedicated to the Discovery of Planets Orbiting the Nearest Low-Mass Stars(David H Sliski)**

The discoveries of the Earth-sized exoplanets orbiting Proxima Centauri and Trappist-1 lend further support to the theory that terrestrial planets may be common around low-mass stars. Since low-mass stars are intrinsically faint at optical wavelengths, obtaining the meter-per-second Doppler precision necessary to detect their Earth-sized planetary companions remain a challenge for instruments designed to observe Sun-like stars. To study these “redder” stars, new spectrometers must be developed. We describe the MINERVA-Red spectrometer and a novel, ultra-high-cadence observing approach aimed at detecting and characterizing planets orbiting the closest low-mass stars to the Sun. In order to characterize the impact of astrophysical noise on our radial velocity measurements, we will gather simultaneous photometry (ugriz, H $\alpha$ , H $\beta$ , Calcium H&K), which will provide a substantial dataset for studying the short-term line and continuum photometric variability in cool stars. We will present photometric results from this robotic observatory and the current status of the spectrograph.

**Author(s):** Sam Halverson, Rob Wittenmyer, John Johnson, Jason Eastman, David H Sliski, Ashley Baker, Cullen Blake

**Institution(s):** University of Pennsylvania, Sagan Fellow, Massachusetts Institute of Technology, University of Southern Queensland, Harvard-Smithsonian Center for Astrophysics

#### **408.05 - EarthFinder: A Probe-Class Mission Precise for a Radial Velocity Survey of our Nearest Stellar Neighbors to detect and characterize Earth-Mass Habitable Zone Analogs Using High-Resolution UV-Vis-NIR Echelle Spectroscopy(Peter Plavchan)**

We present the science case for a 1.45 meter space telescope to survey the closest, brightest FGKM main sequence stars to search for Habitable Zone (HZ) Earth analogs using the precise radial velocity (PRV) technique at a precision of 1-10 cm/s. Our baseline instrument concept uses three diffraction-limited spectrographs operating in the 0.3-0.4, 0.4-0.9, and 0.9-2.4 microns spectral regions each with a spectral resolution of R=150,000~200,000. Because the instrument utilizes a diffraction-limited input beam, each spectrograph arm will be extremely compact, less than 50 cm on a side, and illumination can be stabilized with the coupling of starlight into single mode fibers. With two octaves of wavelength coverage and a cadence unimpeded by any diurnal, atmospheric and most seasonal effects, EarthFinder will offer a unique platform for recovering stellar activity signals from starspots, plages, granulation, etc. to detect exoplanets at velocity semi-amplitudes currently not

obtainable from the ground. Variable telluric absorption and emission lines may potentially preclude achieving PRV measurements at or below 10 cm/s in the visible and <50 cm/s in the near-infrared from the ground. Placed in an Earth-trailing (e.g. Spitzer, Kepler) or Lagrange orbit, the space-based cadence of observations of a star can be year-round at the ecliptic poles, with two 90-day “seasons” every 6 months in the ecliptic plane. This cadence and wavelength coverage will provide a distinct advantage compared to an annual ~3-6 month observing season from the ground for mitigating stellar activity and detecting the orbital periods of HZ Earth-mass analogs (e.g. ~6-months to ~2 years). Finally, we have compiled a list of ancillary science cases for the observatory, ranging from asteroseismology to the direct measurement of the expansion of the Universe.

**Author(s):** Peter Plavchan

**Institution(s):** George Mason University Contributing Team(s): EarthFinder Team

#### **408.06 - High Precision Radial Velocities in the Near-Infrared: First results from the Habitable Zone Planet Finder on the Hobby-Eberly Telescope(Suvrath Mahadevan)**

The Habitable Zone Planet Finder (HPF) is a stabilized cryogenically cooled fiber fed spectrometer designed to enable high precision radial velocities in the near-infrared to enable the detection and characterization of planets around M dwarfs. We will discuss the commissioning results of the HPF on the 10m Hobby-Eberly Telescope, and the instrumental, calibration, and data analysis challenges in achieving RV precision approaching 1m/s in the NIR. We will also discuss the first results from the HPF, showing early science results as well as RV precision of ~1.53m/s on Barnard’s Star over three months.

**Author(s):** Suvrath Mahadevan

**Institution(s):** The Pennsylvania State University Contributing Team(s): The HPF Team

#### **408.08 - Ground-based Astrometric Detection of Exoplanets with CAPSCam: Current Status(Alan P. Boss)**

We began using the Carnegie Astrometric Planet Search Camera (CAPSCam) in 2007 on the 2.5-m du Pont telescope at the Las Campanas Observatory, Chile. Our targets are 100 nearby (within 20 pc) late M, L, and T dwarfs. Nearby, low mass stars maximize the possibility of discovering exoplanets by ground-based astrometry. Being intrinsically more suited to detecting long-period exoplanets than Doppler spectroscopy or transits, astrometry has the potential to join microlensing and direct imaging in determining long-period exoplanet demographics, a key constraint on theoretical models of gas giant planet formation. With an observing allocation of about five nights every two months over the last twelve years, CAPSCam has the potential to make the first astrometric

discovery of a gas giant exoplanet orbiting a single star. CAPSCam was anticipated to have an astrometric accuracy of 0.25 milliarcsecond (mas), allowing the detection of a Jupiter-mass exoplanet orbiting at 5 AU around a 0.4-solar-mass star with a signal-to-noise ratio of four. With 18 epochs, CAPSCam determined the parallax of GJ 317 to within 0.15 mas (Anglada-Escude et al. 2012). Our determination of the parallax of the TRAPPIST-1 star of 80.09 +/- 1.17 mas (Boss et al. 2017) agrees with the 80.45 +/- 0.12 mas of Gaia DR2 and placed limits on the presence of any long-period gas giants in that system. One of us (TLA) has developed a new data reduction pipeline. The primary goal is to correct for atmospheric distortion and optical distortion of the telescope and instrument. A model using polynomials for the optical distortions and atmospheric differential chromatic refraction has been developed using the combined Gaia DR2 (for positions) and NOMAD (for colors) catalogs. The data processed with the new pipeline can then be fit with a 5-parameter astrometric model (positions, proper motions, and parallax) or a 12-parameter model that includes an orbital solution (5 astrometric parameters, 6 orbital elements, and a mass ratio). By comparing the probabilities of these two models for all of our targets, it is implied that roughly half of our targets show no evidence for companions.

**Author(s):** Alycia J Weinberger, Tri L Astraatmadja, Alan P. Boss,

**Institution(s):** Carnegie

#### **408.07D - Hundreds of New Planet Candidates from K2(Ethan Kruse)**

The K2 mission uses the Kepler spacecraft to survey different regions of the ecliptic for 80 day campaigns. Each campaign produces light curves for tens of thousands of stars that can then be searched for transiting exoplanets. Due to the spacecraft's lack of fine pointing that ended the original Kepler mission, these light curves have increased noise and instrumental variability, making planet detection especially challenging. The short campaigns also mean many planets transit three or fewer times. I have extended the Carter & Agol (2013) Quasiperiodic Automated Transit Search (QATS) into a general purpose planet search with the goal of being able to detect planets often overlooked in other pipelines, e.g. planets with transit timing variations or very few transits. Using K2 light curves processed by EVEREST (Luger et al. 2016) to remove systematics, I searched K2 campaigns 0-8 with my improved QATS pipeline. Here I present the results of my K2 Co-8 planet search, showing that we find hundreds of new planet candidates missed by other groups. I briefly discuss the reasons behind our improved sensitivity, and I show how my pipeline will extend to TESS and improve its planet yields. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant DGE 1256082. This research is part of the Blue Waters sustained-petascale computing project (Graduate Research Fellowship), which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-

Champaign and its National Center for Supercomputing Applications. This research was supported by an appointment to the NASA Postdoctoral Program at the NASA Goddard Space Flight Center, administered by Universities Space Research Association under contract with NASA.

**Author(s):** Eric Agol, Ethan Kruse, Rodrigo Luger, Daniel Foreman-Mackey

**Institution(s):** NASA Goddard Space Flight Center, Center for Computational Astrophysics, University of Washington

#### **409 - Large Scale Structure and Cosmology I 409.01 - Mean Distances for Galaxies with Redshift-Independent Estimates in NED(Ian Steer)**

Redshift-independent distance estimates were used by Edwin Hubble to establish the extragalactic distance scale and the rate of universal expansion (Hubble 1926, 1929). Today, such estimates (hereafter simply distances) are available for more than 147,000 galaxies, as tabulated in the NASA/IPAC Extragalactic Database (NED), and updates are released on a regular basis. Most galaxies with distances have only a single estimate available. Around 11,000 of the nearest well studied galaxies however, have multiple estimates and in some cases dozens. Further, published estimates are not all based on the same extragalactic distance scale. Around 20% of the estimates published assume either a different Hubble constant or a different distance scale zero point than the canonical values. Currently, the NED user interface presents simple summary statistics along with the individual, raw, un-scaled estimates. Clearly many science applications will benefit greatly from a single, scale-adjusted mean distance for galaxies with multiple estimates. Here, we present preliminary results of testing six different methods to derive mean estimate distances. Those include the most common practice followed, which involves best estimate distances derived by selecting individual estimates per indicator with the smallest uncertainties. The intent is to generate these derived mean estimates by an algorithm in the database as new distances are entered. This research and NED are funded by and operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

**Author(s):** Ian Steer, Joseph Mazzarella, Marion Schmitz, Barry F. Madore, Michael Randall

**Institution(s):** NED, Caltech/IPAC

#### **409.05 - The Role of Environment on Star Formation Activity to $z \sim 5$ (Nima Chartab Soltani)**

One of the key questions in galaxy formation and evolution is understanding the role of environment on star formation activity. To address this question, we need large samples of galaxies with deep, multi-wavelength photometric data to accurately measure the physical parameters in galaxies (e.g. stellar mass and star formation rates). The sample should also cover large comoving volumes to probe different environments

spanning a wide range in redshift. In this talk, I present recent results using the latest CANDELS data covering 5 separate fields and consisting of > 150,000 galaxies to investigate the role of environment on star formation activity. I will present a unique method to assess density measurements which combines a weighted Gaussian kernel density estimator taking into account boundary effects. We find that not taking boundary/edge effects into account can result in significant underestimation of the density measurement. With our new approach, we make accurate density catalogs. We then use these to explore the star formation rate-density relation at high redshifts, especially at the peak of cosmic star formation activity ( $z \sim 2$ ). We find strong correlations between these two physical properties for both star-forming and quiescent galaxies. I will conclude my talk with a discussion regarding the implications of these results in regard to the environmental quenching of star-forming galaxies and its efficiency in halting star formation at different epochs.

**Author(s):** Nima Chartab Soltani, Bahram Mobasher  
**Institution(s):** University of California, Riverside

#### **409.06 - What can gravitational waves tell us about the assembly of supermassive black holes?(Cole Miller)**

One of the most important frontiers in astronomy over the next two decades will be an understanding of the assembly of structure in the high-redshift universe. The tight correlations between the properties of galaxies and their massive central black holes, at least at low redshifts, suggests that a critical component of that understanding will involve the detection of coalescences between the central black holes of merging galaxies. For this task, it is likely that gravitational waves will provide the only reliable probe. I will discuss the prospects for what can be learned by future space-based detectors such as LISA, which will explore rest masses in the  $\sim 10^4$ - $10^6$  Msun range, and proposed ground-based detectors such as the Einstein Telescope and Cosmic Explorer, which will explore lower rest masses in the  $\sim 10^2$ - $10^4$  Msun range. In particular, I will emphasize the information carried by spin magnitudes and alignment as well as masses and rates.

**Author(s):** Cole Miller

**Institution(s):** University of Maryland

#### **409.02D - Better Input, Better Output: Improving Photometric Redshifts by enhancing training data and optimizing observations(John Bryce Kalmbach)**

Photometric redshift methods are widely used in astronomy to estimate the distances to galaxies from broadband photometry. Accurate photometric redshifts are necessary for high precision cosmological measurements in surveys such as DES and LSST. This work presents three different approaches, based upon probabilistic techniques, to enhance existing photometric estimation techniques. The first method uses Information Gain and Entropy to calculate the effectiveness of filter sets in terms

of their photometric redshift accuracy. Using code written to implement this technique we construct an optimal filter set of 6 filters designed for photometric redshifts and evaluate how the properties of these filters impact their photometric redshift performance. We further determine how to create a single complementary filter to the LSST filters that would most improve photometric redshift performance. The second method uses Gaussian Processes and Principal Component Analysis to map simulated Spectral Energy Distributions to the observed colors of galaxies. We show that this approach can reduce the bias and uncertainties in current photometric redshift estimators. Finally, we once again use Gaussian Processes but this time augment existing training data to improve redshift estimation. In this talk I will explain each new method in detail and show results demonstrating that the new techniques can complement and improve currently existing photometric redshift algorithms.

**Author(s):** John Bryce Kalmbach

**Institution(s):** University of Washington

#### **409.03D - Galaxy clustering with DECaLS photo-z's(Rongpu Zhou)**

Large photometric galaxy surveys such as the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST) rely on photometric redshifts (photo-z's)-redshifts derived from broad-band photometry-as the distance measurement, and accurate photo-z estimation and its optimal utilization are crucial for precision cosmology. In this talk, I will present a new method of measuring and modeling galaxy clustering using photo-z's. We select a sample of luminous red galaxies (LRGs) from DECaLS-part of the imaging surveys for the Dark Energy Spectroscopic Instrument (DESI)-and obtain accurate photo-z's using DECaLS grz, WISE W1W2 and galaxy morphology. Rather than measuring the angular correlation function  $w(\theta)$  in bins of photometric redshift, we measure the projected correlation function  $w_p(r_p)$  between objects in a particular photo-z bin and the entire sample, with a sufficiently large window in the redshift direction to include most physical pairs even in the presence of photometric redshift errors. We model the measured correlation functions in the halo occupation distribution framework with the photo-z error estimates properly incorporated into the analysis. This method maximizes the signal-to-noise in the correlation function measurement and simplifies interpretation compared to a  $w(\theta)$  analysis. The results can be used to optimize DESI target selection and create accurate mocks, as well as for studying the formation of massive galaxies.

**Author(s):** Andrew Zentner, Rongpu Zhou, Jeffrey Newman,

**Institution(s):** University of Pittsburgh, PITT-PACC  
 Contributing Team(s): DECaLS Collaboration; DESI Collaboration

#### **409.04D - Jumping to Conclusions: Correcting**

## **Interloper Bias in Emission Line Surveys(Henry Gebhardt)**

The galaxy catalogs generated from low-resolution emission line surveys often contain interlopers due to line misidentification which leads to interloper bias in the measurement of cosmological parameters. In this paper, we present a novel method for correcting the interloper bias by using the cross-correlation between the survey galaxies and interlopers. This method uses the fact that the cross-correlation between galaxies at widely separated redshifts is much smaller than their auto-correlation; the cross-correlation exceeding the predicted value, therefore, must indicate the interloper fraction. With the estimated interloper fraction we can remove the interloper bias in the cosmological parameter estimation. As our main example, we study the case for the HETDEX (Hobby-Eberly Telescope Dark Energy eXperiment) survey, where low-redshift ( $z < 0.5$ ) Oxygen line ([O II]  $\lambda 3727\text{\AA}$ ...) emitters contaminate high-redshift ( $1.9 < z < 3.5$ ) Lyman- $\alpha$  ( $1216\text{\AA}$ ...) emitters. We show that the cross-correlation method leads to a high signal-to-noise measurement of the interloper fraction while only marginally increasing the uncertainties of the cosmological parameters. We also show the same is true for the WFIRST survey where contamination happens between the Balmer (H $\beta$ ) line emitters at lower redshifts ( $1.1 < z < 1.9$ ) and Oxygen ([O III]  $\lambda 5007\text{\AA}$ ...) line emitters at higher redshifts ( $1.7 < z < 2.8$ ).

**Author(s):** Donghui Jeong, Henry Gebhardt

**Institution(s):** The Pennsylvania State University

## **410 - Supernovae V**

### **410.01 - Self-similar, Weak Shock Propagation in Failed Supernovae(Eric Robert Coughlin)**

Shocks are ubiquitous in the Universe, and understanding how they propagate and affect their environments can reveal useful information about many seemingly-distant astrophysical phenomena. I will describe a new regime of self-similar shock propagation that, in contrast to the well-known, Sedov-Taylor blastwave, is valid when the shock is only marginally supersonic, accounts for the gravitational field of a central object, and results in accretion onto that central object. I will compare the predictions of this self-similar solution to numerical simulations of failed supernovae, wherein a weak shock is generated within and propagates through the hydrogen envelope of a massive star.

**Author(s):** Eliot Quataert, Eric Robert Coughlin, Stephen Ro

**Institution(s):** Columbia University, University of California, Berkeley  
**Contributing Team(s):** Eric Robert Coughlin

### **410.03 - Amplification of magnetic field downstream of inward shocks in supernova remnant Cassiopeia A(Mohira Russell)**

X-Ray observations of the supernova remnant Cassiopeia A have shown a rapid and strong variation (up to 50%) in the

non-thermal flux over 15 years of multi-epoch observations that alone cannot be explained by shock compression of the magnetic field. Combined Chandra and NuSTAR observations investigated six distinct inward shocks in the central/west regions of Cas A that were possibly created when the forward shock collided with a molecular cloud in the interstellar medium. We use an analytic model based on MHD jump conditions at rippled shocks and synchrotron theory to give the first quantitative explanation for the X-ray variability at two of such shocks, W2-W4. The predicted flux is based on the assumption that the speed of the inward shocks was constant across all times and only the downstream magnetic amplification governs the flux increase. We found a scale of the clumps that cause the amplification to be  $10^{18}$  cm, consistent with the shock W3, previously determined with the same method. We have found that the amplification is relatively modest across W2-W4, consistent with low Mach number.

**Author(s):** Federico Fraschetti, Mohira Russell

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Arizona

### **410.05 - Signs of Circumstellar Interaction in Type IIL Supernovae(K. Azalee Bostroem)**

Single, hydrogen-rich, core collapse supernovae typically divided into three classes: IIP, with a 100 day plateau following maximum light, IIL, showing a linearly declining light curve following maximum light, and IIn which show narrow emission lines in their spectra. These classifications are indicative of the characteristics of the late stage evolution of the hydrogen envelope of the progenitor star. In general, interaction with circumstellar material is only considered for type IIn supernovae. However, recent hydrodynamic modeling of IIP and IIL supernovae with conventional red supergiant progenitors, has been unable to reproduce their early (~30 days post explosion) light curves without the introduction of circumstellar material. In this scenario, IIL supernovae experience large amounts of mass loss before exploding and are the ideal candidates for understanding whether IIP and IIL supernovae experience interaction with a stellar wind. We test this hypothesis on ASASSN-15oz, a type IIL supernova and the closest type II supernova in 2015. With extensive follow-up in the X-ray, UV, optical, IR, and radio we present our search for signs of interaction, and the mass-loss history indicated by their detection.

**Author(s):** Assaf Horesh, Stefano Valenti, David Sand, Anders Jerkstrand, Paul Kuin, Samuel Wyatt, Viktoriya Giryanskaya (Morozova), K. Azalee Bostroem

**Institution(s):** University of California, Davis, Princeton University, Hebrew University of Jerusalem, University of Arizona, Mullard Space Science Laboratory - University College London, Max-Planck Institut Für Astrophysik

#### **410.06 - Delayed Circumstellar Interaction for Type Ia SN 2015cp Revealed by an HST Ultraviolet Imaging Survey(Melissa Lynn Graham)**

The nature and role of the binary companion of carbon-oxygen white dwarf stars that explode as Type Ia supernovae (SNeIa) are not yet fully understood. Past detections of circumstellar material (CSM) that contain hydrogen for a small number of SNIa progenitor systems suggest that at least some have a nondegenerate companion. In order to constrain the prevalence, location, and quantity of CSM in SNIa systems, we performed a near-ultraviolet (NUV) survey of 70 nearby SNeIa with the Hubble Space Telescope (HST) in Cycle 24, and obtained single-epoch NUV imaging at 1-3 years after their light curve peaks. Our survey revealed that SN2015cp, a SN1991T-like overluminous SNIa, was experiencing late-onset interaction between its ejecta and surrounding CSM at 664 days after its light-curve peak. Our ground- and space-based follow-up observations of SN2015cp revealed optical emission lines of hydrogen and calcium, typical signatures of ejecta-CSM interaction, making SN2015cp the second case in which an unambiguously classified SNIa was observed to interact with a distant shell of CSM that contains hydrogen (i.e., after PTF11kx). The remainder of our HST NUV images of SNeIa were nondetections that we use to statistically constrain the occurrence rate of observable late-onset CSM interaction. We apply theoretical models for the emission from ejecta-CSM interaction to our NUV nondetections, and place upper limits on the mass and radial extent of CSM in SNIa progenitor systems.

**Author(s):** Melissa Lynn Graham, Kate Maguire, Chelsea Harris, Peter Nugent, Mark Sullivan, Ken Shen, Curtis McCullyo, Stefano Valenti, Ori Fox, Alexei Filippenko, Thomas Brink, Patrick Kelly, Matthew Smith, Ariel Goobar

**Institution(s):** oLas Cumbres Observatory, University of Washington, Lawrence Berkeley National Laboratory, University of California - Berkeley, University of Southampton, Queen's University, Stockholm University, University of California - Davis, University of Minn

#### **410.07 - Light Echos of Supernovae in the LMC(Sтивен Margheim)**

Light echos provide a unique opportunity in astronomy to study the spectra of light from supernovae explosions whose light first reached Earth hundreds to thousands of years ago. These observations can allow us to tie together the explosion physics with modern observations of the remnant systems. In this work, we present light echo spectra of two supernovae in the Large Magellanic Cloud. These spectra are correlated to dust-scattered, time-integrated SNe templates to classify the SNe. We will place these results into the context of LMC SNe and other light-echo detected SNe.

**Author(s):** Steven Margheim, Armin Rest, Thomas Matheson  
**Institution(s):** Gemini Observatory, NOAO, Space Telescope Science Institute

#### **410.04D - Hunting Magnetar Central Engines in Superluminous Supernovae(Kornpob Bhirombhakdi)**

A magnetar central engine is the best candidate for explaining the very energetic nature behind most superluminous supernovae (SLSNe), which are 10--100 times brighter at their optical peaks compared to typical SNe, by releasing its rotational energy, or spinning down. A magnetar spin-down model fits well to UV, optical, and infrared (UVOIR) data of SLSNe during the early times around their peaks, but predicts brighter emission than what is observed at later times in the nebular phase. Non-thermal emissions by radio synchrotron, X-rays from inverse Compton scattering, or gamma-rays from pair annihilation are suggested to explain the discrepancy. The searches for these non-thermal signals have shown non-detections in most SLSNe, which are consistent with predictions, and still cannot confirm the existence of a central engine. Here, we present two SLSNe which are candidates for magnetar spin-down powering. SN 2008es is a hydrogen-rich event which fit well to both the magnetar spin-down and circumstellar interaction (CSI) models at early times, and required later-time data for better constraints. Our late-time observations in the optical and near-infrared with both photometry and spectroscopy support the event being powered by CSI. However, this does not rule out the existence of a magnetar inside the massive circumstellar envelope. SN 2015bn is a hydrogen-poor event in which the magnetar spin-down is the best candidate explanation, but still requires a smoking gun to confirm. X-ray ionization breakout is predicted as a direct signal from the magnetar activity, and should be detected on a timescale of years. A deep observation with XMM-Newton at an age of more than 2 years still resulted in a non-detection. We constrain various X-ray emission scenarios with the non-detection, and identify a missing energy problem.

**Author(s):** Kornpob Bhirombhakdi

**Institution(s):** Astrophysical Institute, Department of Physics and Astronomy, Ohio University

#### **411 - ISM & Related Topics IV**

##### **411.01 - HAWC+/SOFIA Observations of OMC-1(David Chuss)**

HAWC+/SOFIA has made polarimetric and photometric observations of the massive star formation region, OMC-1, at 53, 89, 154, and 214 microns. The inferred magnetic field direction at the longer wavelengths is globally in agreement with previous measurements supporting the idea that the cloud is undergoing magnetically-regulated star formation. In the 53 and 89 micron bands, the polarization around the BN object differs from that of the longer two wavelengths and displays a similar bipolar symmetry as the BN/KL explosion indicating that the magnetic field energy density is less than the kinetic energy density of the explosion near the center of this region. We also find a correlation between the degree of polarization and the local dispersion in polarization angle that lends evidence that depolarization with increasing unpolarized intensity is likely due to magnetic field geometry as opposed to

variations in grain alignment efficiency.

**Author(s):** David Chuss

**Institution(s):** Villanova University Contributing Team(s):  
HAWC+ Science Team

#### **411.02 - Probing Irradiated Molecular Gas in the Planetary Nebulae NGC 7027 and NGC 7293 (the Helix)(Joel H Kastner)**

Planetary nebulae (PNe) represent the near endpoints of evolution for stars of initial mass  $\sim 1-8 M_{\odot}$ , wherein the envelope of an asymptotic giant branch (AGB) star is photodissociated and ionized by high-energy radiation from a newly emerging white dwarf that was the progenitor star's core. Though best known as  $\sim 10^4$  K optical emission line sources, a subset of PNe retain significant masses of cold, dense molecular gas that is irradiated from within by UV from PN central stars (CSPNe) --- and, in certain nebulae, by X-rays from the CSPN or wind-collision-generated shocks. This makes PNe fertile ground for studies of radiation-driven molecular gas heating and chemistry, with the results potentially applicable to a diverse range of astrophysical environments. We report on IRAM/NOEMA radio interferometric observations of the well-studied, young PN NGC 7027 as well as an IRAM 30 m spectral line survey of selected regions within the molecule-rich, globule-studded Helix Nebula (NGC 7293). Our NOEMA CO+ map of NGC 7027 is among only a handful obtained for any astrophysical object --- and the first map of a planetary nebula -- obtained in this key tracer of molecular ionization. Although X-ray-driven chemistry is typically invoked to explain CO+ abundance enhancements in molecular gas, preliminary analysis indicates that UV may dominate the production of CO+ in NGC 7027. Our 30 m spectra of the Helix Nebula have yielded first-time detections of numerous species, including HCN, HNC, and HCO+, within individual globules. We use these data to investigate the utility of the HNC/HCN abundance ratio as diagnostic of UV-driven heating of molecular gas.

**Author(s):** Pierre Hily-Blant, Rodolfo Montez, Jesse Bublitz, David Wilner, Young Sam Yu, Joel H Kastner, Valentin Bujarrabal, Thierry Forveille, Javier Alcolea, Miguel Santander-Garcia, Isabel Aleman

**Institution(s):** Rochester Institute of Technology, OAN, IPAG, SAO, Leiden Observatory, KASI

#### **411.03 - The Origin of [CII] $158\mu\text{m}$ Emission toward the HII Region Complex S235(Loren Anderson)**

Although the  $2P_{3/2} - 2P_{1/2}$  transition of [CII]  $158\mu\text{m}$  (1.9 THz) is known to be an excellent tracer of active star formation, we still do not have a complete understanding of where within star formation regions the emission originates. Here, we use SOFIA upGREAT observations of [CII] emission toward the HII region complex Sh2-235 (S235) in order to better understand in detail the origin of [CII] emission. We find that about half of the total [CII] emission associated with S235 is spatially coincident

with the ionized hydrogen gas. Accounting for possible front- and back-side photo-dissociation regions (PDRs), we find no evidence that there is [CII] emission from the ionized hydrogen volume. The strength of velocity-integrated [CII] emission is strongly correlated with WISE  $12\mu\text{m}$  intensity across the entire complex, indicating that both trace ultra-violet radiation fields that ionize carbon and cause polycyclic aromatic hydrocarbons to fluoresce at  $12\mu\text{m}$ . The  $22\mu\text{m}$  and radio continuum intensities are only correlated with [CII] intensity in the ionized hydrogen portion of the S235 region and the correlations between the [CII] and molecular gas tracers are poor across the region. We find similar results for emission averaged over a sample of external galaxies, although the strength of the correlations is weaker. Therefore, although many tracers are correlated with the strength of [CII] emission, only WISE  $12\mu\text{m}$  emission is correlated on small-scales of the individual HII region S235 and also large-scales of entire galaxies. Future studies of a larger sample of Galactic HII regions would help to determine whether these results are truly representative.

**Author(s):** Loren Anderson

**Institution(s):** West Virginia University

#### **411.04 - Alumina Polymorphism in the Dust from Asymptotic Giant Branch Stars(Benjamin Sargent)**

AGB stars are low- to intermediate-mass evolved stars that eject their outer layers in outflows of dust and gas in the penultimate stages of their lives. Since dust plays a major role in mass loss from Asymptotic Giant Branch (AGB) stars, it is important to understand the properties of AGB dust. AGB mass loss rates are determined by radiative transfer modeling of their spectral energy distributions (SEDs; plots of flux versus wavelength). Such modeling requires knowledge of the properties of these stars' circumstellar dust. Unfortunately, not all solid-state features in the infrared spectra of AGB stars have been identified. I present models of infrared emission from circumstellar dust around AGB stars that match features observed at 11, 20, 28, and 32 microns wavelength in spectra from the Short Wavelength Spectrometer (SWS) on the Infrared Space Observatory (ISO) and the Infrared Spectrograph (IRS) on the Spitzer Space Telescope. This quartet of emission features is well-matched in dust emission model spectra by including opacities corresponding to mixtures of various alumina polymorphs. I present models of ISO-SWS and Spitzer-IRS spectra showing this quartet of features and discuss the implications of the presence of the alumina polymorphs. One implication, in particular, is that the 13 micron feature in infrared spectra of AGB stars is related in some way to the presence of corundum, the alpha polymorph of alumina. I acknowledge funding from NASA ADAP grant 80NSSC17K0057.

**Author(s):** Benjamin Sargent

**Institution(s):** Space Telescope Science Institute

#### **411.06 - Mixed Aromatic Aliphatic Organic Nanoparticles (MAON) as Carriers of Unidentified Infrared Emission Bands(Sun Kwok)**

The unidentified infrared emission (UIE) phenomenon consists of a family of emission bands, broad emission plateaus, all superimposed on an underlying continuum. While the emission bands are almost certainly due to the stretching and bending modes of aromatic and aliphatic groups, the exact vibrational modes of these bands and the chemical structure of the carrier are not known. We report results of quantum chemistry calculations of large (>100 carbon atoms) molecules with mixed aromatic/aliphatic structures with the goal of identifying the origin of the UIE bands and explore various possibilities of the chemical nature of the UIE carrier.

**Author(s):** Seyedabdolreza Sadjadi, Sun Kwok, Yong Zhang

**Institution(s):** University of British Columbia, Sun Yat Sen University, University of Hong Kong

#### **411.07 - Physical Conditions in the Interstellar Medium from a Survey of O I and Si II Fine-Structure Excitations(Adam Ritchey)**

In theoretical models of the interstellar medium, thermal instability plays a major role in segregating the neutral gas into two distinct phases in pressure equilibrium: a warm neutral medium and a cold neutral medium. Temperatures intermediate between the warm and cold phases are forbidden because at constant thermal pressure, gas at such temperatures would be thermally unstable. While interstellar turbulence can drive the gas into the thermally unstable regime, a two-phase description of the neutral ISM is still approximately valid as long as the gas cooling time is much shorter than the characteristic time between shocks in a turbulent medium. We have recently developed a technique that allows us to determine simultaneously the densities and temperatures in interstellar clouds through an analysis of O I and Si II fine-structure excitations. Here, we present preliminary results of our survey, which utilizes high-resolution HST/STIS spectra of 29 sight lines where the population ratios among the three O I fine-structure levels may be reliably measured. Total proton densities, electron densities, and kinetic temperatures are derived at 350 discrete velocities along the 29 lines of sight. This information is used to construct a phase diagram for the interstellar medium, which is interpreted in the context of theoretical models of a two-phase medium. We will discuss the implications of these results for modeling efforts that seek to characterize the structure and dynamics of the neutral ISM.

**Author(s):** Steven Federman, Adam Ritchey, Edward Jenkins

**Institution(s):** Eureka Scientific Inc., University of Toledo, Princeton University Observatory

#### **411.08 - New Tools in X-ray Dust Tomography(Sebastian Heinz)**

The study of X-ray dust echoes from transient X-ray sources in the Galaxy provides a rich, new field of study: It can constrain distances to X-ray source, map the dust distribution in the galactic plane to high accuracy, and probe dust grain size distribution and composition. The analysis of dust echoes requires the development of new tools. This poster presents a suite of methods and tools that can be used in the analysis of future dust echoes, including cross section calculations and new deconvolution algorithms.

**Author(s):** Lia Corrales, Randall Smith, Sebastian Heinz

**Institution(s):** UW Madison, University of Michigan, High Energy Astrophysics, Smithsonian Astrophysical Observatory

#### **411.05D - AzTEC Survey of the Central Molecular Zone: Modeling Dust SEDs and N-PDF with Hierarchical Bayesian Analysis(Yuping Tang)**

We present the AzTEC/LMT survey of dust continuum at 1.1mm on the central 200pc (CMZ) of our Galaxy. A joint SED analysis is performed, from 160μm to 1.1mm. Our analysis follows a MCMC sampling strategy incorporating the knowledge of PSFs in different maps, this, together, with a high spatial resolution at 1.1mm achieved by the AzTEC, provide unprecedented information on the spatial distribution of dust emissions across the CMZ. There is a remarkable trend of increasing dust spectral index, from 2.0 to 2.5, towards dense peaks in the CMZ, which could indicate a lack of large grains in the CMZ. The column density ranges from  $\text{Log}_{10}(\text{NH}_2[\text{cm}^{-2}]) = 22.0$  to  $23.5$ . When temperature variation and self-shielding of dust along the line of sight are modeled, the dense clumps in the CMZ typically show no significant sign of buried star formation. We also show that, if a non-single power-law dust absorption curve is present, as opposed to the favored hypothesis in traditional models, the dust temperature could be underestimated by more than 30%. The dust absorption curve could be better described with a broken power-law. We further apply a hierarchical Bayesian analysis to infer the column density probability distribution function (N-PDF), while simultaneously removing the Galactic foreground and background emission. The N-PDF at high densities shows a steep power-law profile with  $\hat{\Gamma} \pm 3$ , suggesting that formation of dense structures is suppressed.

**Author(s):** Mark Heyer, Robert Gutermuth, Yuping Tang, Grant Wilson, Daniel Wang

**Institution(s):** University of Massachusetts

## **412 - AGN Gas & Obscuration**

### **412.01 - Photoionization modeling of the broad-line region in M81(Nicholas Devereux)**

High angular resolution spectroscopic observations of the low-luminosity AGN in M81 obtained recently with the Space Telescope Imaging Spectrograph aboard the Hubble Space Telescope (HST) has revealed a UV-visible spectrum rich in emission lines. The broad  $H\beta$  emissionline profile exhibits a "flat-top" that has been noted in prior HST observations, although there is no sign of the "double-peak" observed with HST in 1995. However,  $H\beta/H\gamma \sim 5$ , as reported previously. The photoionization code Xstar is employed together with reddening-insensitive emission line diagnostics to constrain a physical model for the broad-line region consisting of an H+ region photoionized by the central UV-X-ray source. Modelling the shape of the broad  $H\beta$  emission in terms of an azimuthally symmetric ballistic inflow constrains the size of the H+ region to be  $\sim 0.7$  pc in radius with a gas density  $\sim 10^4$  cm $^{-3}$ . The [O III] 5007/ $H\beta$  ratio constrains the metallicity of the H+ region to be  $\sim 0.02$  Z/ $Z_{\odot}$ . Interpreting the broad  $H\beta$  emission line in terms of a steady-state spherically symmetric inflow leads to a mass inflow rate of  $0.03 M_{\odot}/\text{yr}$ ; about one order of magnitude higher than required to explain the observed X-ray emission in terms of an advection-dominated accretion flow.

**Author(s):** Nicholas Devereux

**Institution(s):** Embry-Riddle Aeronautical University

### **412.02 - Resolving the Truth: The role of local environment in star formation and low-level nuclear activity in nearby galaxies(Mallory Molina)**

Nuclear activity and star formation exhibit different properties with observed spatial scale. To fully understand them, we must consider the local environment's impact on measured global properties. My dissertation focuses on the spatially resolved excitation mechanisms that power observed emission, and the dust that obscures it. Low ionization nuclear emission regions (LINERs) are a common occurrence in nearby galaxies, and are often explained by low-level nuclear activity. But this energy source is not sufficient to power the observed emission lines that define LINERs on 100 pc scales. Using HST/STIS, we resolved the nuclear regions of three nearby LINERs on scales of  $\sim 9$  pc to track the dominant power source with distance from the nucleus. The resulting physical model involved photoionization from the central engine within the central 20 pc, and shock excitation at larger distances. We conclude that integrated LINER-like emission can be explained by a combination of AGN photoionization and shocks on different spatial scales. Star formation is the most prevalent energy source across all galaxies, making its advancement and cessation in galaxies vital for galaxy evolution. However, our current understanding of star formation is highly dependent on dust attenuation, which itself depends on the spatial scales and properties on which it is observed. We studied the attenuation law of kpc-size star forming regions in  $\sim 30$  nearby galaxies using Swift NUV photometry and SDSS-IV/MaNGA optical IFU

spectroscopy. We compared the resulting attenuation relation with that of the parent galaxy, connecting the local properties to the integrated galaxy light. Through spatially resolved studies of the processes that create and obscure observable emission, my dissertation work provides context for the physical processes that dictate the integrated properties in star forming galaxies and LINERs, and of their place in galaxy evolution.

**Author(s):** Mallory Molina

**Institution(s):** Pennsylvania State University

### **412.03 - Imaging Spectroscopy of Ionized Gaseous Nebulae around Optically Faint AGN at Redshift $z \sim 2$ (David R Law)**

We will discuss recent Keck/OSIRIS laser guide-star assisted adaptive optics (LGSAO) integral field spectroscopy of [O III] 5007 Angstrom nebular emission from twelve galaxies hosting optically faint active galactic nuclei (AGN) at redshift  $z \sim 2 - 3$ . In combination with HST imaging, Keck/MOSFIRE rest-optical spectroscopy, and Keck/KCWI rest-UV integral field spectroscopy we demonstrate that both the continuum and emission-line structure of these sources exhibit a wide range of morphologies from compact isolated point sources to double-AGN merging systems with extensive  $\sim 50$  kpc tidal tails. We do not find widespread evidence of star formation in the host galaxies surrounding these AGN and the sample is most consistent with a population of AGN that radiate at approximately their Eddington limit and photoionize extended [O III] nebulae whose characteristic sizes scale approximately as the square root of the AGN luminosity.

**Author(s):** Charles C Steidel, Ryan Trainor, Gwen C Rudie, Yuguang Chen, Allison L Strom, David R Law

**Institution(s):** STScI, Carnegie Observatories, Caltech, Franklin & Marshall College

### **412.05 - A deep look at nearby heavily obscured AGN with NuSTAR and XMM-Newton(Xiurui Zhao)**

The cosmic X-ray background (CXB), the diffuse X-ray emission observed between 0.5 keV and 300 keV, is thought to be mainly produced by obscured and unobscured active galactic nuclei (AGN). Compton-thick (CT-) AGNs (with absorbing column density  $N_H > 10^{24}$  cm $^{-2}$ ) are responsible for  $\sim 30\%$  of the CXB at its peak and expected to be numerous. However, as of today CT-AGNs have never been detected in large numbers, their observed fraction in the local universe being  $\sim 5-10\%$ , significantly below the predictions of different CXB models ( $\sim 20\%-30\%$ ). I will present a deep observation of two candidate CT-AGNs, selected using an effective technique reported by our group two years ago, using the unprecedented-quality data from NuSTAR and XMM-Newton, which allows us to have a better understanding of the physics of the obscuration process in AGNs.

**Author(s):** Stefano Marchesi, Giancarlo Cusumano, Xiurui Zhao, Cristian Vignali, Valentina La Parola, Marco Ajello, Lea



Marcotulli

**Institution(s):** Clemson university, INAF-OABO, INAF-IAFSC, Università di Bologna

#### **412.06 - AGN/Star Formation Mixing Fractions for RESOLVE and ECO Galaxies using Bayesian Inference(Mugdha Polimera)**

We apply a Bayesian classification scheme using all available optical spectroscopy to predict the percentage of Active Galactic Nuclei (AGN) vs. Star Formation emission in galaxies from the RESOLVE and ECO surveys. Diagnostic plot classification using BPT diagrams with Strong Emission Lines (SELs) leaves some galaxies ambiguously classified as AGN or Star Forming, suggesting the potential importance of mixed cases. Furthermore, the recently introduced diagnostic plot of [HeII/H-beta] vs. [NII/H-alpha] reveals additional AGN that are missed by a binary BPT classification. These observations motivate the need to use all available spectroscopic information simultaneously in a single Bayesian modeling framework. We also use new grids that self-consistently model different mixing fractions of AGN + Star Formation emission, correctly treating the combined radiation field, unlike older grids that have linearly combined pure AGN and pure Star Forming models to approximate mixed cases. This Bayesian classification gives insight into emission processes for galaxies that are ambiguously and inconsistently classified using traditional diagnostic plots by providing a single multi-dimensional posterior distribution for the AGN - Star Formation mixing fraction based on all available lines. We find that this approach is especially important for the low metallicity dwarfs that dominate our volume-limited local universe surveys.

**Author(s):** Chris Richardson, Amanda J Moffett, Mugdha Polimera, Sheila Kannappan

**Institution(s):** University of North Carolina at Chapel Hill, Elon University, Vanderbilt University  
**Contributing Team(s):** RESOLVE Team

#### **412.08 - The impact of inaccurate collisional excitation rates on radio recombination line observations(Francisco Guzman Fulgencio)**

Radio recombination lines (RRL) are an important tool in astronomy. They are used to determine the temperature, density and metallicity, and probe the structure of H II regions, active galactic nuclei (AGN), photo-dissociation regions (PDR) and molecular clouds. It is important that the underlying atomic physics theory is accurate in order to correctly interpret the observations. Currently, there are four datasets of collisional excitation rate coefficients based in several levels of theoretical approximation and semi-empirical formulas. However, these available datasets disagree by several order of magnitude at all temperatures. Collisional excitation brings the high Rydberg levels to local thermodynamic equilibrium (LTE), and is the driving mechanism for the distribution of the

population in highly excited levels. We will show that these different atomic datasets produce critical disagreements in the predictions of RRL and optical depths in our models for the broad line regions (BLR) of NGC 5548, and the Orion blister nebula. We will also present a method to observationally discriminate between different collisional theories. Finally, we will show that the number of levels chosen to represent the atom is critical for the correct prediction of RRLs.

**Author(s):** Otho Ulrich, Marios Chatzikos, Francisco Guzman Fulgencio, Peter van Hoof, Dana Balser, Maryam Dehghanian, Gary Ferland

**Institution(s):** University of Kentucky, Royal Observatory of Belgium, NRAO

#### **413 - 21 cm Cosmology**

##### **413.01 - Mitigating the Effects of Antenna-to-Antenna Variation on Redundant-Baseline Calibration for 21 cm Cosmology(Joshua S Dillon)**

The separation of cosmological signal from astrophysical foregrounds is a fundamental challenge for any effort to probe the evolution of neutral hydrogen during the Cosmic Dawn and epoch of reionization (EoR) using the 21 cm hyperfine transition. Foreground separation is made possible by their intrinsic spectral smoothness, making them distinguishable from spectrally complex cosmological signal even though they are ~5 orders of magnitude brighter. Precisely calibrated radio interferometers are essential to maintaining the smoothness and thus separability of the foregrounds. One powerful calibration strategy is to use redundant measurements between pairs of antennas with the same physical separation in order to solve for each antenna's spectral response without reference to a sky model. This strategy is being employed by the Hydrogen Epoch of Reionization Array (HERA), a large radio telescope in South Africa that is now observing while being built out to 350 14-m dishes. However, the deviations from perfect redundancy inherent in any real radio telescope complicate the calibration problem. Using simulations of HERA, we show how calibration with antenna-to-antenna variations in dish construction and placement generally lead to spectral structure in otherwise smooth foregrounds that significantly reduces the number of cosmological modes available to a 21 cm measurement. However, we also show that this effect can be largely eliminated by a modified redundant-baseline calibration strategy that relies predominantly on short baselines.

**Author(s):** Aaron Parsons, Nithyanandan Thyagarajan, Joshua S Dillon, Aaron Ewall-Wice, Naomi Orosz

**Institution(s):** University of California, Berkeley, National Radio Astronomical Observatory, NASA Jet Propulsion Laboratory  
**Contributing Team(s):** The Hydrogen Epoch of Reionization Array (HERA)

##### **413.03 - A reanalysis of PAPER-64 epoch of reionization observations at redshifts 7 to 11.(Daniel Jacobs)**

The redshifted 21 cm hydrogen line is a unique probe of the early universe. Challenges include human generated interference, calibration of instrument chromaticity, and foregrounds which are 10000x brighter than the background. All impose large additional covariance. The Precision Array for Probing the Epoch of Reionization (PAPER) was an experimental array built to tackle these issues with the goal of measuring the power spectrum during the redshift range 6 to 12. Previous analyses of PAPER data have attempted to mitigate systematic covariance by down-weighting covariance determined empirically from the same data. A followup analysis of this pipeline has shown that this is difficult to do correctly and can produce highly biased estimates. In this study an alternate analysis eliminates foreground subtraction and down-weighting steps and uses noise and foreground simulations to validate pipeline outputs in relevant power regimes. This "simpleDS" pipeline is used to analyze the power spectrum in the previously studied 100 day observation by the PAPER 64-antenna array across redshift windows ranging from 7 to 11. Though some measurements are consistent with noise, others are not. Among those that are not, bootstrapped error bars also suggest that variation within the data set is also not consistent with noise. Jackknives across local sidereal time and other null tests are used to explore these variations.

**Author(s):** Matthew Kolopanis, Daniel Jacobs, Carina Cheng

**Institution(s):** Arizona State University, UC Berkeley  
Contributing Team(s): PAPER Team

#### **413.04 - Fast Radio Imaging with the Long Wavelength Array(Adam Beardsley)**

Direct imaging backends for large-N radio telescopes are a promising solution to the huge computational and storage requirements to enable the next generation cosmology and transient arrays. The E-field Parallel Imaging Correlator (EPIC) is one implementation which combines optimal mapmaking using a spatial fast Fourier transform on gridded antenna voltage samples in the aperture plane to yield real-time radio images at extremely high time resolution, allowing for non-regular arrays, and scaling only as  $N \log(N)$ . I will briefly outline the concept behind EPIC and present the results from our first deployment of a GPU implementation of the algorithm on the Long Wavelength Array Sevilleta station, including the serendipitous detection of lightning and several meteors entering the atmosphere.

**Author(s):** Nithyanandan Thyagarajan, Greg B Taylor, James Kent, Jayce Dowell, Judd Bowman, Adam Beardsley

**Institution(s):** Arizona State University, NRAO, University of Cambridge, University of New Mexico

#### **413.06 - The Radio Astronomy Software Group: Foundational Tools for 21 cm Cosmology and Beyond(Jonathan Pober)**

In this talk, I will highlight the projects led by the newly established Radio Astronomy Software Group: pyuvdata and pyuvsim. The goal of these projects is to support radio astronomers, particularly those in the field of 21 cm cosmology, as they work to vet their analysis pipelines. pyuvdata provides seamless support for a number of common radio astronomy data formats, with work underway to enable similar functionality for beam and telescope models, calibration solutions, and radio source catalogs. pyuvsim is a massively parallelized "brute force" interferometric simulation suite, aimed at providing robust, high fidelity simulations for end-to-end testing of analysis pipelines. Taken together, these software advances can provide a new level of reliability and reproducibility for the field of 21 cm cosmology and other radio astronomy experiments facing stringent calibration and analysis challenges.

**Author(s):** Jonathan Pober

**Institution(s):** Brown University Contributing Team(s): The Radio Astronomy Software Group

#### **413.07 - Measuring the kSZ-kSZ-21cm Bispectrum from the Epoch of Reionization(Paul La Plante)**

Next-generation radio interferometers, such as the Hydrogen Epoch of Reionization Array (HERA) and the Square Kilometre Array (SKA) are expected to measure the 21 cm power spectrum from the Epoch of Reionization (EoR) with exquisite accuracy. The information contained in the power spectrum will offer a unique insight into the broad brush strokes of the history of the EoR, such as when the midpoint and duration of reionization occurred. However, due to the non-Gaussian nature of the 21 cm field during the EoR, there is significant information present in the fields that in principle can be probed by higher-order statistics, such as the bispectrum. The bispectrum can be computed for the 21 cm field alone, or can be used in cross-correlations with other observational probes of the EoR. One such probe is the kinetic Sunyaev-Zel'dovich effect (kSZ) of the cosmic microwave background (CMB), which arises due to CMB photons passing through the ionized IGM and inverse Compton scattering off of electrons with significant velocity relative to the CMB rest frame. Because the kSZ and 21 cm signals are both generated by the same physical sources, in principle their signals should be correlated to a certain degree. Measuring this correlation can serve as an important validation of the two-point statistics measured by HERA and SKA alone, and complement any inferences of reionization derived from their measurements. We present results of a theoretical measurement of the kSZ-kSZ-21cm bispectrum from semi-numeric simulations of reionization. These predictions will serve as an important motivation for cross-correlating real-world measurements of the 21cm and kSZ signals, such as those between HERA and the upcoming Simons Observatory. We show that there are several key features present in the

bispectrum as a function of redshift that can serve as indicators of the reionization history. We also examine the effect that the noise levels of the different instruments has on the potential to make a detection.

**Author(s):** Adam Lidz, James Aguirre, Paul La Plante

**Institution(s):** University of Pennsylvania

#### **413.02D - 21cm Power Spectrum Analysis Lessons(Carina Cheng)**

The Epoch of Reionization (EoR) represents an era in our Universe's history during which the first stars and galaxies ionized the neutral hydrogen in the intergalactic medium. Several experiments, including the Donald C. Backer Precision Array for Probing the Epoch of Reionization (PAPER) and the Hydrogen Epoch of Reionization Array (HERA), are investigating the EoR by tracing the 21cm line from neutral hydrogen. Because this signal is very faint compared to bright foregrounds and systematics, 21cm power spectrum analyses employ clever techniques in order to place increasingly stringent limits on the EoR. In this dissertation talk, I will tell the story of how my graduate work led to the unexpected discovery of errors in previously published results from PAPER. I will summarize the main reasons for our originally underestimated limit and highlight subtle traps in a power spectrum analysis that have shaped a revised PAPER analysis. I will focus especially on issues related to cosmological signal loss and describe the trade-offs associated with different analysis techniques. Along the way, I hope to motivate our updated analysis pipeline for PAPER and HERA and share that the best science is not always a traditional success story.

**Author(s):** Aaron Parsons, James Aguirre, Saul Kohn, Daniel Jacobs, Matthew Kolopanis, Jonathan Pober, Adrian Liu, Carina Cheng

**Institution(s):** University of California, Berkeley, University of Pennsylvania, Arizona State University, Brown University  
Contributing Team(s): PAPER Collaboration

#### **413.05D - Recovering 21cm Power Spectra in Simulated Delay Spectrum Pipelines(Adam Lanman)**

Cutting-edge 21cm experiments like Hydrogen Epoch of Reionization Array (HERA) and the Phase II deployment of the Murchison Widefield Array (MWA) promise to measure the power spectrum of redshifted 21cm absorption from the Cosmic Dawn. These arrays feature highly-redundant, compact layouts that improve power spectrum sensitivity and calibratability by producing multiple samples of the each Fourier mode, with high frequency resolution. While these designs greatly reduce thermal noise and foreground contamination, they do so at the expense of sample variance, as they only sample a handful of angular Fourier modes within the survey volume. Here, I directly measure the sample variance of simulated measurements, using a simple delay spectrum estimator like that which will be used by HERA. I compare this variance to the

variance due to thermal noise, and estimate the number of baselines required for sample variance to fall below the noise level. I will also discuss the challenges of producing realistic instrument simulations and recent efforts to develop a robust and verified simulation pipeline.

**Author(s):** Adam Lanman

**Institution(s):** Brown University  
Contributing Team(s): Radio Astronomy Software Group (RASG), Hydrogen Epoch of Reionization Array (HERA), Murchison Widefield Array (MWA)

#### **414 - Accreting BlackHoles & WDs, and Their Environments**

##### **414.01 - Finding Cataclysmic Variables in the Zwicky Transient Facility(Paula Szkody)**

The Zwicky Transient Facility began its 3 year time-domain survey in March 2018, using its camera with a 47 square degree field on the Palomar 48 inch Schmidt telescope. The observing cadence of the entire visible sky in g and r every 3 nights and the visible galactic plane in g and r every night is ideal for finding variable objects. Among this group are cataclysmic variables, which have disk instability outbursts causing increases of brightness by 2-8 magnitudes within 1-2 days. A summary of the CV results on over 200 candidates and previously known objects since the start of the survey are presented. Alert filtering and follow-up coordination was done by the GROWTH marshal funded by NSF PIRE grant 1545949. PS acknowledges support from NSF grant AST 1514737.

**Author(s):** Paula Szkody, Thomas Kupfer, Lynne Hillenbrand, Anna Ho

**Institution(s):** University of Washington, UCSB, Caltech  
Contributing Team(s): ZTF Variable Star Collaboration

##### **414.02 - Five-out-of-Six Classical Novae Have Their Orbital Periods Decreasing Across Eruptions; So the Hibernation Mechanism is Dead(Bradley E. Schaefer)**

The evolution of cataclysmic variables (CVs) is the largest mystery for the zoo of CV classes, required for any understanding of the big picture. Since the 1980s, the leading model has been called Hibernation, where CVs cycle between high-accretion states that produce novae and low accretion states where the system is largely disconnected. The fundamental mechanism that drives Hibernation is that the mass loss from the nova eruption makes the orbital period increase, causing the disconnection that lowers the accretion rate. A direct test of this required mechanism is possible by getting an accurate orbital period before the nova and then after. This can only be done by pulling out pre-eruption magnitudes from archival sky photographs to trace the periodic variations (like eclipses) that track the orbital period. Previously (Schaefer & Patterson 1981), this was done for one nova (BT Mon) that had its period increase by +40 ppm.

However, recently (Salazar et al. 2017), my group has measured the pre-eruption orbital period of V1017 Sgr, only to find that the period \*decreased\* by  $-273 \pm 61$  ppm. Now, I can report the results of four more measures of the pre-eruption orbital periods of later classical novae, as taken from photometry on the archival plates at Harvard, Sonneberg, Vatican, and Asiago. DQ Her has a pre-eruption eclipse period of  $0.19362180 \pm 0.0000005$  days, for a period change, (Ppost-Ppre)/Ppost, of  $-4.8 \pm 0.2$  ppm. QZ Aur has a pre-eruption eclipse period of  $0.3575991 \pm 0.0000006$  days, changed by  $-284 \pm 2$  ppm. RR Pic has a pre-eruption period of  $0.14509097 \pm 0.0000006$  days, changed by  $-448 \pm 4$  ppm. HR Del has a pre-eruption period of  $0.2142115 \pm 0.0000010$  days, changed by  $-204 \pm 5$  ppm. All four new cases have the orbital period \*decreasing\*. So the required Hibernation mechanism is \*not\* working (actually, it must be dominated by some mechanism with a greatly larger opposite effect) for five-out-of-six ordinary classical novae, which is to say that Hibernation does not in fact operate for most of the nova population. With a less nuanced statement; "Hibernation is dead".

**Author(s):** Bradley E. Schaefer

**Institution(s):** Louisiana State University

#### **414.03 - Long-Lived Prominences on the Cool Secondary Star in the White Dwarf Pulsar AR Scorpii(Peter Garnavich)**

The white dwarf in AR Scorpii is converting its rotational energy into electromagnetic emission, making it the first white dwarf pulsar. However, the mechanism driving the strong emission pulses seen at the beat and spin frequencies of the system remains uncertain. With Keck, we obtained high temporal resolution spectroscopy of AR Sco covering nearly an orbit. The  $H\beta$  emission shows a complex line structure consistent with long-lived prominences originating on the red dwarf. Tomograms of the emission indicate that these are "slingshot" prominences that extend more than 3 stellar radii from the secondary and this requires surface magnetic fields between 100 and 500 G. The secondary's magnetic field is comparable to the WD magnetic field near the cool star's surface and we suggest that the excess energy generated in AR Sco may result from the direct interaction between the two magnetic fields. Our time-resolved spectra also show emission fluxes, line equivalent widths, and continuum color varying over the orbit and the beat/spin periods of the system. During much of the orbit, the optical spectral variations are consistent with synchrotron emission with the highest energy electrons cooling between pulses. On the time-scale of the beat/spin period we detect red and blue-shifted  $H\beta$  emission flashes that reach velocities of 700 km/s. Red-shifted Balmer emission flashes are correlated with the bright phases of the continuum beat pulses while blue-shifted flashes appear near the time of minimum in the beat light curve.

**Author(s):** Mark Kennedy, Colin Littlefield, Peter Garnavich, Stella Kafka

**Institution(s):** University of Notre Dame, University of

Manchester, AAVSO

#### **414.04 - Dwarf Carbon Stars: Chandra Constraints on Activity Induced by Mass Transfer(Paul J Green)**

Scads of main sequence stars in our galaxy have a secret history of inheriting mass from a currently-invisible companion, but among these, the dwarf carbon (dC) stars show the most obvious spectral signatures- broad molecular bands of C2 and CN. The well-studied CH, Ba II and CEMP-s giants have all likely evolved from dC stars. The nature of the dCs is now being actively probed by experiments in radial velocity variability, and by new constraints on their basic characteristics afforded e.g., by Gaia. How much mass and angular momentum did dC stars accrete from their former AGB companions? Does that accretion result in renewed activity, as seen in young stars with rapid rotation rates? We probe this question with a pilot Chandra X-ray study of 6 dC stars.

**Author(s):** Rodolfo Montez, Paul J Green, Joseph Filippazzo, Fernando Mazzoni

**Institution(s):** Smithsonian Astrophysical Observatory

#### **414.05 - Hierarchical Triples: Dynamical Roche Lobes and the Effects of Mass Transfer(Rosanne Di Stefano)**

Many important high-energy and gravitational wave phenomena occur because of binary interactions. A significant fraction of interacting binaries spend portions of their lives in hierarchical triples or in other types of high-order multiples. During recent years, three-body dynamical interactions that influence binary evolution have begun to be well studied. Here we report on new work focused on mass transfer from the star in the outer orbit to the inner close binary. We have found that the Roche lobe can assume a dynamical role in influencing mass loss by the outer star. Whether the donor loses mass through the L1 point or through winds, the fates of the components of the inner binaries, their masses, and their times-to-merger are altered by infalling mass.

**Author(s):** Rosanne Di Stefano

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

#### **414.06 - Young black hole and neutron star systems in the nearby star-forming galaxy M33: the NuSTAR view(Jun Yang)**

We can learn a lot about the formation of compact objects, such as neutron stars and black holes, by studying the X-ray emission from accreting systems in nearby star-forming galaxies. The harder ( $E > 10$  keV) X-ray emission in particular allows strong discrimination among the accretion states and compact object types. A NuSTAR survey of M33 was conducted to study the distribution of X-ray binary (XRB) accretion states in an actively star-forming environment. The 6 NuSTAR observations of M33 allow us to construct diagnostic diagrams,

which is used to infer XRB accretion states. We have characterized XRB accretion states for  $\sim 32$  sources. The detailed classification of XRBs by their compact object types will be discussed using NuSTAR color-intensity and color-color diagrams. We further characterize the black holes by their accretion states (soft, intermediate, and hard) and the neutron stars by their weak or strong (accreting pulsar) magnetic field. In contrast to a similar NuSTAR survey of M31 (with a low-mass XRB-dominant population), the source population is dominated by high-mass XRBs, allowing the study of a very different population with similar sensitivity. These results provide a significant improvement in our knowledge of high-mass XRB accretion states that proves valuable for theoretical XRB population synthesis studies.

**Author(s):** Andreas Zezas, Benjamin F Williams, Daniel Wik, Dominic Walton, Lacey West, Thomas J. Maccarone, Neven Vulic, Andrew Ptak, Vassilios Antoniou, Jun Yang, Mihoko Yukita, Paul Plucinsky, Kristen Garofali, Frank Haberl, Ann Hornschemeier, Bret Lehmer

**Institution(s):** The Johns Hopkins University, University of Cambridge, The University of Utah, Harvard-Smithsonian Center for Astrophysics, University of Arkansas, University of Maryland, NASA Goddard Space Flight Center, University of Washington, Texas Tech University

#### **414.07 - Beyond Blue Stragglers: Rotational Identification of Mass-Transfer and Collision Products on the M67 Main-Sequence from K2 and WYIN Observations (Robert Mathieu)**

At an age of 4 Gyr, typical solar-type stars in M67 have rotation rates of 20-30 days. Using K2 Campaign 5 and 16 light curves and the spectral archive of the WYIN Open Cluster Study, we identify eleven three-dimensional kinematic members of M67 with anomalously fast rotation periods of 2-8 days, implying ages of less than 1 Gyr. We have shown that post-interaction stars like blue stragglers have similarly rapid rotation rates soon after formation and spin down as they age much as standard main-sequence stars do. We therefore hypothesize that these anomalously fast rotators have been spun up by mass transfer, mergers, or stellar collisions during dynamical encounters within the last Gyr, and thus represent lower-luminosity counterparts to the blue straggler stars. These 11 candidate post-interaction stellar systems have much in common with the blue stragglers including a high binary fraction (73%), a number of long-period, low-eccentricity binary systems, and in at least one case a UV excess consistent with the presence of a hot white dwarf companion. The identification of these 11 systems provides the first picture of the low-luminosity end of the blue straggler distribution, providing new constraints for detailed binary evolution models and cluster population studies. This result also clearly demonstrates the need to properly account for the impact of binaries on stellar evolution, as significant numbers of post-interaction binaries likely exist on cluster main sequences and in the field. These stars are not always easy to identify, but make up 10% or more of the spectroscopic binary population among the solar-type stars in

M67. With support from NSF AST-1714506 and AST-1801937 and NASA NNX15AW69G

**Author(s):** Andrew Vanderburg, Emily Leiner, Robert Mathieu

**Institution(s):** University of Wisconsin - Madison, University of Texas at Austin, Northwestern University

#### **414.08 - Outliers in globular clusters: the case of 47 Tucanae (Fabiola Campos)**

We constructed multicolor photometric color-magnitude diagrams of the globular cluster 47 Tucanae using photometry obtained with the Hubble Space Telescope. We identify 24 previously-unremarked objects that are outliers from the single-star model tracks in the color-magnitude diagram. Based on their proper motions, all the objects are members of the cluster with high probability. We show that the majority of the sources are likely to be binary systems. Since only two of those objects are possible counterparts to X-ray sources, we conclude that most of the binaries consist of a white dwarf and a main-sequence star. While three may be double-degenerate binaries. This is the first time multicolor photometry is employed to search for binaries in clusters. Extension of this work can help shed light in late stages of binary stellar evolution in different environments.

**Author(s):** Andrea Bellini, Fabiola Campos, Domenico Nardiello, Aaron Dotter, Don Winget, Giampaolo Piotto, Edward L. Robinson, Michael Houston Montgomery, Alina Istrate, Kepler Oliveira, Ingrid Pelisoli, Stefan Dreizler, Sebastian Kamann, Tim-Oliver Hushe

**Institution(s):** Harvard-Smithsonian Center for Astrophysics, University of Texas at Austin, Institute for Physics and Astronomy, University of Potsdam, Universidade Federal do Rio Grande do Sul, Astrophysics Research Institute, Liverpool John Moores University, Institut

#### **415 - Cosmology: Galaxy/Structure Evolution II**

##### **415.01 - Optimally Mapping the Large-Scale Structure with Luminous Sources (Yun-Ting Cheng)**

Intensity mapping has emerged as a promising tool to probe the three-dimensional structure of the Universe. The traditional galaxy surveys probe the large-scale structure based on individual galaxy detection, whereas intensity mapping uses the integrated emission from all sources in a 3D pixel (or voxel) to trace the underlying density field. In this work, we develop a formalism to quantify the performance of both approaches when measuring large-scale structures. We compute the Fisher information of an arbitrary observable, derive the optimal estimator, and use it to determine the best strategy for tracing large-scale density field for any given survey. In this talk, I will first give an overview of intensity mapping method, and then introduce the formalism and application of this technique.

**Author(s):** Yun-Ting Cheng, Olivier Dore, Tzu-Ching Chang, Roland de Putter

**Institution(s):** Caltech, ASIAA, JPL

**415.02 - Small scale structure of the IGM: A Dark Matter Tale(Vid Irsic)**

The intergalactic medium (IGM) plays a unique role in constraining the (small scale) matter clustering in the Universe, since the low-density, high redshift IGM filaments are particularly sensitive to the small scale properties of dark matter. The main observable manifestation of the IGM, the Lyman-alpha forest, has provided important constraints on the linear matter power spectrum, especially when combined with cosmic microwave background data. This includes, most notably, the tightest constraints on warm dark matter (WDM) and fuzzy dark matter (FDM) models, that I will present in this talk. I will also present some recent constraints on general non-CDM models, using the same data.

**Author(s):** Vid Irsic

**Institution(s):** University of Washington  
**Contributing Team(s):** XQ-00 Legacy Survey Team

**415.03 - Simulating the High-Redshift Cosmic Web with Massive Neutrinos and Dark Radiation(Graziano Rossi)**

We present a novel suite of state-of-the-art hydrodynamical simulations that incorporate warm and cold dark matter, baryons, massive neutrinos, and dark radiation, targeted for the study of the high-redshift cosmic web. Alongside, we carry out a detailed study of the impact of massive neutrinos and dark radiation on the main Lyman-Alpha forest observables, and accurately measure the tomographic evolution of the shape and amplitude of the small-scale flux and matter power spectra across cosmic times, searching for unique signatures and preferred scales where a neutrino mass detection may be feasible; improving the theoretical modeling and the understanding of the effects of neutrinos and dark radiation on structure formation at small scales are necessary, to obtain robust cosmological bounds free from systematic biases. Our results indicate that the intergalactic medium at redshift  $\sim 3$  provides the best sensitivity to active and sterile neutrinos. Our novel suite will be particularly relevant for interpreting upcoming high-quality data from surveys such as the Extended Baryon Oscillation Spectroscopic Survey (eBOSS), or the Dark Energy Spectroscopic Instrument (DESI).

**Author(s):** Graziano Rossi

**Institution(s):** Sejong University

**415.04 - Deep Learning, Sky Calibration, and Foreground Subtraction for HERA 21cm Epoch of Reionization Studies(Joshua Kerrigan)**

The Hydrogen Epoch of Reionization Array (HERA) is a next generation radio interferometer with the goal of detecting the cosmological 21cm Epoch of Reionization (EoR) signal. Unfortunately, this signal is incredibly weak, which when compared to galactic and extragalactic foregrounds is  $\sim 5$  orders of magnitude smaller; even before handling the issue of bright foregrounds, we have to contend with precision calibration of the array and anthropogenic radio frequency interference (RFI). Current attempts to identify RFI have issues, such as poor scaling, large time complexities, and lack robustness. I present a machine learning approach using a Deep Fully Convolutional Neural Network (D-FCN) to combat these issues. To extract all possible time-frequency context surrounding RFI from interferometric visibilities, the D-FCN is designed with a dual channel input to predict jointly on both amplitude and phase components. This more robust RFI identification strategy leads to improved calibration and imaging. Calibration, which is exceptionally important for 21cm EoR studies, requires an unprecedented level of knowledge of both the instrument and sky. HERA is designed to take advantage of redundant calibration, but this method cannot determine amplitude or phase scaling important for connecting the instrument to physical observation. I approach a sky-dependent absolute calibration with the use of the Fast Holographic Deconvolution (FHD) interferometric software package. I demonstrate that by supplying an extragalactic point source catalog, I am able to calibrate HERA observations leaving no degeneracies, therefore improving both imaging and power spectra compared to more traditional absolute calibration techniques. Finally, I show that after proper removal of RFI using my deep learning technique and sky-based calibration, extragalactic foregrounds can be properly subtracted from HERA observations. The combined results of these improvements will lead to more sensitive measurements in both imaging and power spectrum pipelines allowing for the tightest constraints on the EoR signal at the largest k-modes accessible to HERA.

**Author(s):** Joshua Kerrigan

**Institution(s):** Brown University  
**Contributing Team(s):** HERA Collaboration

**415.05 - Measuring Higher-order 21 cm One-point Statistics from the Epoch of Reionization(Piyanat Kittiwisit)**

Upcoming radio interferometers, such as the Hydrogen Epoch of Reionization Array (HERA) and the Murchison Widefield Array (MWA) Phase II, are expected to measure 21 cm power spectrum from the Epoch of Reionization (EoR) with high sensitivity. These measurements will provide an overall look into the reionization process during the EoR. However, due to the non-Gaussian nature of the 21 cm intensity field, significant information is contained in the higher-order statistical domains. One-point statistics and related moments (variance,

skewness and kurtosis) are the simplest forms of higher-order statistics that can be measured. I will present a sensitivity analysis of 21 cm one-point statistics measurements for HERA, based on mock observations that account for sky curvature, instrument configuration, thermal noise, sample variance and foreground contamination in a foreground avoidance regime. Based on this study and an exploratory analysis of legacy data from the first season data of the MWA Phase I, I will establish expectation values and observational strategies for these statistics in the upcoming surveys.

**Author(s):** Piyanat Kittiwisit

**Institution(s):** Arizona State University

#### **415.06 - Bubbles in LAGER(James Rhoads)**

The central stage of reionization is inhomogeneous in most models. From our survey of Lyman alpha galaxies at redshift  $z=7$ , the Lyman Alpha Galaxies Epoch of Reionization (LAGER) Survey, we show that the distribution of Lyman-alpha galaxies is patchy, indicating inhomogeneous reionization. The UV luminosity of the detected galaxies is sufficient to drive the ionization in some of these bubbles.

**Author(s):** Alistair Walker, Weida Hu, Leopoldo Infante, Junxian Wang, Sangeeta Malhotra, James Rhoads, Zhenya Zheng

**Institution(s):** NASA GSFC, University of Science and Technology of China, Shanghai Astronomical Observatory, Las Campanas Observatory, Cerro Tololo Interamerican Observatory Contributing Team(s): the LAGER Team

#### **415.07 - A cosmology-optimized dust reddening map(Douglas Finkbeiner)**

I will describe our efforts to produce a dust reddening map optimized for cosmological applications. The most widely used maps are based on far infra-red emission from dust (measured by e.g. Planck or DIRBE and IRAS). These maps are contaminated with emission from dust in unresolved galaxies throughout the universe, commonly known as the "cosmic infra-red background anisotropy" (CIBA). It is also possible to make reddening maps from stellar reddenings, as our group has done in recent years (Schlafly et al. 2014, Green et al. 2015, 2018). These maps all also contaminated, mainly by quasars included in the star sample. While this leakage is preferable to the CIBA contamination, it will lead to unsatisfactory results in the LSST era. We present a map based on a more careful selection of stars, using an approach that trades spatial resolution for precision, and assess the (small!) correlation with large-scale structure over a wide range of redshifts.

**Author(s):** Gregory Maurice Green, Catherine Zucker, Joshua Speagle, Douglas Finkbeiner, Edward Schlafly

**Institution(s):** Harvard, UC Berkeley, KIPAC

### **416 - Dwarf & Irregular Galaxies III: Ultra Diffuse Galaxies and Kinematics of the Magellanic Clouds**

#### **416.01 - Ultra-diffuse galaxies in Coma and Virgo clusters(Sungsoo Lim)**

Ultra-Diffuse Galaxies (UDGs) are unusual galaxies having luminosities comparable to classical dwarf galaxies but sizes more typical to the Milky Way. These faint stellar systems have been found mainly in galaxy clusters, although some have now been identified in lower density environments. Some UDGs are known to have sizeable globular cluster (GC) populations, which is unexpected in galaxies of such low stellar density and low stellar mass. In this talk, I present a comprehensive study of GCs belonging to UDGs in the Coma and Virgo clusters, based on data from HST and the Next Generation Virgo cluster survey (NGVS). Our data show a diversity among UDGs, with some galaxies having substantial GC populations and others have no GCs at all. The GC specific frequency of Coma UDGs is observed to vary dramatically, with a mean GC specific frequency being relatively higher than that of classical dwarfs in the cluster; in addition, the GC specific frequency of Coma UDGs shows a clear environmental dependence. In Virgo, we use the NGVS to introduce a quantitative method for identifying UDGs, and provide a complete census of UDGs in the cluster. I discuss how UDGs are distinguishable from other galaxies and describe the implications of our observations for models of UDG formation.

**Author(s):** Laura Ferrarese, Patrick C  t  , Eric W. Peng, Sungsoo Lim

**Institution(s):** Herzberg Astronomy & Astrophysics Research Centre, National Research Council of Canada, Kavli Institute for Astronomy and Astrophysics, Peking University, Department of Astronomy, Peking University Contributing Team(s): NGVS Team

#### **416.02 - Globular Clusters and Distances of Diffuse Galaxies in the Hyper Suprime-Cam Survey(Johnny Greco)**

New generation optical imaging surveys are uncovering vast numbers of diffuse galaxies for which obtaining spectroscopic redshifts will be extremely difficult if not impossible. We investigate the use of globular cluster populations as a distance indicator for our new sample of very low surface brightness galaxies discovered with the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP). The depth of HSC-SSP makes it sensitive to the peak of the globular cluster luminosity function (GCLF) out to distances of  $\sim 80$  Mpc. Hence, using HSC-SSP imaging data alone, the GCLF should provide distance constraints for many of these galaxies, as well as insight into their formation histories and perhaps their dark matter halos. Our catalog of low surface brightness galaxies will ultimately grow to thousands of objects, which span galaxy morphologies, gas fractions, and halo environments. We will characterize the globular cluster populations for hundreds of these systems, using spectroscopic follow-up for a subset of objects to shed

light on the utility of the GCLF as a distance indicator for diffuse galaxies in the LSST era.

**Author(s):** Johnny Greco, Scott Carlsten, Jenny Greene, Christopher Garling, Rachael Lynn Beaton

**Institution(s):** The Ohio State University, Princeton

University Contributing Team(s): The HSC-SSP Collaboration

#### **416.04 - Nature Versus Nurture: Unraveling the Mystery of Ultra Diffuse Galaxy Formation with the RomulusC Galaxy Cluster Simulation(Michael Josef Tremmel)**

Current cosmological simulations have so far been limited to studying the formation of ultra diffuse galaxies (UDGs) in isolation, or with environmental effects applied artificially. Here I present the first self consistent prediction for the formation of UDGs in a galaxy cluster. With unprecedented resolution, the RomulusC cosmological simulation of a  $10^{14} M_{\odot}$  galaxy cluster is uniquely able to resolve cluster member galaxies down to stellar masses of  $10^7 M_{\odot}$  in halos as small as  $3 \times 10^9 M_{\odot}$ , resulting in 77 resolved UDGs within  $1.5 R_{200}$  at  $z = 0$ . I examine the relative influences of ram pressure stripping and tidal effects due to the environment on the formation of cluster UDGs, giving new insight into different UDG formation channels and their observable consequences.

**Author(s):** Thomas Quinn, Daisuke Nagai, Andrew Pontzen, Michael Josef Tremmel, Anna Wright, Alyson Brooks, Ferah Munshi

**Institution(s):** Yale University, University of Oklahoma, Rutgers University, University College London, University of Washington

#### **416.06 - SMASHing the LMC: A Tidally-induced Warp in the Outer LMC and a Large Scale Reddening Map(Yumi Choi)**

We present a study of the three-dimensional (3D) structure of the Large Magellanic Cloud (LMC) using  $\sim 2.2$  million red clump (RC) stars selected from the Survey of the Magellanic Stellar History (SMASH). To correct for line-of-sight dust extinction, the intrinsic RC color and magnitude and their radial dependence are carefully measured by using internal nearly dust-free regions. These are then used to construct an accurate 2D reddening map ( $165 \text{ deg}^2$  area with  $\sim 10$  arcminute resolution) of the LMC disk and the 3D spatial distribution of RC stars. An inclined disk model is fit to the 2D distance map yielding a best-fit inclination angle  $i = 25.86(^{+0.73}_{-1.39})$  degrees with random errors of  $\pm 0.19$  deg, line-of-nodes position angle  $\hat{l}_* = 149.23(^{+6.43}_{-8.35})$  degrees with random errors of  $\pm 0.49$  deg. These angles vary with galactic radius, indicating that the LMC disk is warped and twisted likely due to the repeated tidal interactions with the Small Magellanic Cloud (SMC). For the first time, our data reveal a significant warp in the southwest of the outer disk starting at  $\hat{l} \sim 7$  deg, that departs from the defined LMC plane up to  $\sim 4$  kpc towards the

SMC, suggesting that it originated from a strong interaction with the SMC. In addition, the inner disk encompassing the off-centered bar appears to be tilted up to  $5\text{--}15$  deg, relative to the rest of the LMC disk. These findings on the outer warp and the tilted bar are consistent with the predictions from the Besla et al. (2012) simulation of a recent direct collision with the SMC.

**Author(s):** Yumi Choi, Knut Olsen, Dennis Zaritsky, David Nidever, Gurtina Besla, Robert Blum

**Institution(s):** Montana State University, NOAO, University of Arizona Contributing Team(s): SMASH team

#### **416.03D - Properties of Tidally-Heated Ultra-Diffuse Galaxies(Timothy Carleton)**

Since the identification of a large population of Ultra-Diffuse dwarf Galaxies (UDGs) in the Coma cluster, there has been a renewed interest as to the role that the cluster environments play in the evolution of dwarf galaxies. Evidence from the morphologies, radial alignment, and abundance of UDGs suggests that cluster environments play an important role in the evolution of these unique systems. In this talk, I will present a model for the formation of cluster UDGs through tidal stripping and heating of dwarf galaxies as they orbit within the cluster. This model is able to reproduce many aspects of the observed UDG population, including the size distribution and the dependence of UDG abundance with cluster mass, assuming that UDGs fall into the cluster living in cored dark matter halos. Given this model for UDG formation, I will also discuss the expected stellar and globular cluster populations, both for the whole galaxy and the presence of possible population gradients within UDGs. Notably, as large UDGs occupy a particular region in orbital parameter space, they offer a unique testbed for our understanding of the role that the cluster environment has in quenching star-formation within dwarfs.

**Author(s):** Timothy Carleton, Manoj Kaplinghat, Raphael Errani, Michael C. Cooper, Jorge Penarrubia

**Institution(s):** UC Irvine, University of Edinburgh, University of Missouri

#### **416.05D - KHAPOW SMC WHAM: Kinematic H-Alpha Phase Observations of the WIM: A Survey of the Magellanic Clouds with the Wisconsin H-Alpha Mapper(Brianna Marie Smart)**

We present the results of KHAPOW SMC WHAM, Kinematic H-Alpha Observations of the WIM: A Survey of the Magellanic Cloud System with the Wisconsin H-Alpha Mapper. Studies in HI have given us insight into the tumultuous history of the Magellanic Clouds. From the Leading Arms, to the Stream, the Magellanic System spans over 200 degrees across the sky in HI. With the Wisconsin H-Alpha Mapper (WHAM), we now have begun to uncover the extended diffuse ionized gas structures that are counterparts to the HI. Our survey has covered the Small Magellanic Cloud, the Large Magellanic Cloud, and the Magellanic Stream. Previous surveys of the SMC and LMC have



focused on the bright H II regions (supernovae remnants/ HII bubbles, etc) centered around the stellar component of the galaxy. These surveys were not sensitive to the fainter Diffuse Ionized Gas (DIG) within and surrounding the galaxies. With WHAM, we detect a halo of diffuse H I± emission extending to radii well beyond the bright H II regions and comparable to extents of observed HI. Using WHAM's unprecedented sensitivity to trace diffuse emission (~ tens of mR) with a velocity resolution of 12 km/s, we have compiled the first comprehensive spatial and kinematic map of the extended H I± emission of the Magellanic System. With these new data in hand, we are able to delineate the considerable warm ionized component associated with the SMC, leading to better calculations of its present-day mass and providing new constraints for dynamical evolution simulations of the Magellanic System. The Magellanic Stream has previously only been examined in H-Alpha via pointed observations, and the Stream portion of the survey has mapped out a 120 by 40 degree region to investigate the full extent of the ionized gas counterpart to the Stream. With the Small and Large Magellanic survey complete and early results for Magellanic Stream, we present an early look at the full extended ionized gas content of the Magellanic System, along with mass estimates for the SMC and LMC.

**Author(s):** Brianna Marie Smart, L. Matthew Haffner, Alex S Hill, Kat Barger, Greg Madsen

**Institution(s):** University of Wisconsin, Texas Christian University, Embry-Riddle Aeronautical University, Institute of Astronomy, University of British Columbia

## **417 - Astronomy Education Research In and Out of the Classroom**

### **417.01 - Motivation vs Engagement in an Astronomy MOOC(Martin Formanek)**

In this talk we present results of an experiment studying motivation of learners in Massive Open Online Courses (MOOCs) which we conducted in our MOOC: "Astronomy: Exploring Time and Space" offered through the Coursera platform. As a first assignment of the course we administered a modified Science Motivation Questionnaire II and collected the survey data from December 2016 till March 2018. More than 2,500 responses from our learners were acquired and this data was analyzed to determine the relationship between course performance and motivation of the learners. We define four course engagement indicators; finishing the course, use of video lectures, participation in the discussion forums and peer-graded assignments. We identify self-determination as the main motivational factor together with grade motivation, and self-efficacy. Surprisingly, the learners showing high career, grade and social motivation engaged less with the video material than the survey average and score on the social motivation didn't affect the forum usage.

**Author(s):** Matthew Wenger, Martin Formanek, Sanlyn Buxner, Chris David Impey

**Institution(s):** University of Arizona

### **417.02 - Astrophysical Fluency Project Part I: Unpacking Your Activities(Rica Sirbaugh French)**

To elevate students' levels of understanding, instructors often actively engage learners with multiple tasks that have been carefully designed and sequenced to build upon their existing knowledge and intuitions. When different intellectual tasks are connected to pedagogically appropriate representations, learners can successfully unpack complex concepts and develop more robust and expert-like understandings. In Part I of the Astrophysical Fluency Project (AFP) we developed a framework to catalog and characterize hundreds of faculty-produced multiple-choice questions. This framework includes coding schemas to characterize the representations and intellectual tasks used, while a Question Complexity Rubric ranks the level of intellectual engagement necessary to unpack and explain the reasoning behind the correct answer to the question. Using this framework, we identified the underutilized variables in hundreds of Think-Pair-Share (TPS) questions on various topics. By applying this framework to other learning materials (in these and other disciplines) instructors can both "inventory" the information contained within those materials and subsequently design more pedagogically interesting and powerful opportunities that feature a greater variety of representations and tasks for learners to engage with as they work towards discipline fluency. This talk, AFP Part I, covers the development of the framework and its use to describe the information contained within a database of TPS questions while AFP Part II will cover the application of the framework to generate "fluency-inspiring" questions and opportunities.

**Author(s):** Rica Sirbaugh French, Edward Prather

**Institution(s):** MiraCosta College & Center for Astronomy Education, University of Arizona & Center for Astronomy Education

### **417.03 - Astrophysical Fluency Project Part II: Generating Fluency-Inspiring Opportunities(Edward Prather)**

Part I of the Astrophysical Fluency Project (AFP) involved creating a framework to characterize and catalog a database of faculty-generated TPS questions in terms of the representations used, intellectual tasks required, and complexity levels reached. Through this work, we have systematically identified the variables missing from the questions on particular topics. In this talk I will discuss Part II of the AFP, which involves applying our framework to generate "fluency-inspiring" questions. These questions not only fill the gaps identified in Part I of this work, they also make use of multiple representations and intellectual tasks that require the learner to develop one or more complex lines of reasoning and, if necessary, integrate them together to answer the question. Additionally, the framework developed through the AFP can generate new ways of thinking about how to move learners toward greater discipline fluency and is applicable to a wide variety of instructional materials and disciplines. Classrooms where learners engage with fluency-

inspiring questions and activities offer richer opportunities for learners to practice critical discernment, unpack their reasoning, and be more reflective about their learning.

**Author(s):** Rica Sirbaugh French, Edward Prather

**Institution(s):** University of Arizona - CAE, MiraCosta College - CAE

#### **417.04 - The Quantitative Reasoning for College Science (QuaRCS) Assessment: Emerging Themes from 5 Years of Data(Katherine Follette)**

The Quantitative Reasoning for College Science (QuaRCS) Assessment is a validated assessment instrument that was designed to measure changes in students' quantitative reasoning skills, attitudes toward mathematics, and ability to accurately assess their own quantitative abilities. It has been administered to more than 5,000 students at a variety of institutions at the start and end of a semester of general education college science instruction. I will begin by briefly summarizing our published work surrounding validation of the instrument and identification of underlying attitudinal factors (composite variables identified via factor analysis) that predict 50% of the variation in students' scores on the assessment. I will then discuss more recent unpublished work, including: (1) Development and validation of an abbreviated version of the assessment (The QuaRCS Light), which results in marked improvements in students' ability to maintain a high effort level throughout the assessment and has broad implications for QR assessments in general, and (2) Our efforts to revise the attitudinal portion of the assessment to better assess math anxiety level, another key factor in student performance on numerical assessments.

**Author(s):** Erin Dokter, Katherine Follette, Sanlyn Buxner

**Institution(s):** Amherst College, University of Arizona

#### **417.05 - Inspiring Lifelong Science Engagement in Non-STEM Majors through Citizen Science(Laura Trouille)**

Through this talk I will present a model for engaging non-STEM majors in introductory science courses in citizen science. The context will be Zooniverse's classroom.zooniverse.org effort, but the framing and questions will be broader - what short and long-term opportunities does citizen science provide for non-STEM majors, what lessons have we learned, and what open questions remain? Working with a national collaboration of astronomy educators and researchers at a range of institution types (R1, SLAC, Community College) with funding from the NSF-IUSE program, we have developed a suite of active learning curricular materials incorporating a citizen science based research experience into Astro 101. The in-class activities and group research experience engage the students in citizen science through Zooniverse and employ custom extensions to Google sheets to provide a student-friendly interface for data analysis and interpretation, all while addressing core Astro 101

topics (see classroom.zooniverse.org). In the next phase of this effort, we will enhance the Astro 101 experience (by extending beyond Galaxy Zoo to provide research opportunities in exoplanets, stars, and planetary science) as well as develop parallel curricular materials for introductory Geoscience and Biology courses, providing Zooniverse-based research opportunities in climate change and biodiversity. The goal is to examine the impact of having a critical mass of non-STEM majors on a given campus sharing a common language, exposure to, and understanding of citizen science. How does membership in a citizen science aware (and potentially engaged) college campus community impact students' attitudes towards science and scientists, the role of society in science, and their own science (and citizen scientist) identity development and potential for lifelong engagement and advocacy?

**Author(s):** Thomas Nelson, Alison Haupt, Laura Trouille, Dave Meyer

**Institution(s):** The Adler Planetarium, Zooniverse, & Northwestern University, Cal State Monterey Bay, University of Pittsburgh, Northwestern University Contributing Team(s): The Zooniverse, Galaxy Zoo

#### **417.06 - ThinkSpace Labs: Teaching Seasons and Moon Phases with WorldWide Telescope(Patricia Udomprasert)**

WorldWide Telescope (WWT) is a powerful visualization program that allows users to connect Earth-based and space-based views of the Sun-Earth-Moon system. With funding from the National Science Foundation, our team has developed an 8-session Seasons curriculum and a 3-session Moon Phases and Eclipses curriculum designed for middle school students, called ThinkSpace Labs. The labs blend WWT's virtual models with hands-on physical activities, allowing students to better visualize these spatially complex topics. The team is also researching how model-based study of spatially rich topics like Seasons and Moon Phases can help to support students' spatial reasoning, a skill that has been shown to be improvable through practice, and which is critical for success in many STEM fields. We will present student learning and spatial thinking outcomes from the ThinkSpace curricula for 900 middle school students in the Greater Boston area and share how you can access these curriculum materials.

**Author(s):** Patricia Udomprasert, Helen Zhang, Susan Sunbury, Erin Johnson, Abha Vaishampayan, Julia Plummer, Kyungjin Cho, Erika A Wright, Alyssa Ann Goodman, Harry Houghton, Philip Sadler

**Institution(s):** Harvard University, Pennsylvania State University, Smithsonian Astrophysical Observatory, Boston College, Harvard University

#### **417.07 - Sonifying the Universe: Electroacoustic Ensembles with Life 2.0(D. Perkins)**

"The universe isn't silent. It has a sound track" that is played on space itself, because space can wobble like a drum; it can ring out a kind of recording throughout the universe of some of the most dramatic events as they unfold. We are adding to our glorious light understanding of the universe, a sonic composition." Jana LevinGround and space-based gravitational wave observatories are listening to the universe for the ringing wobble of gravitational waves in space as it squeezes and stretches from colliding black holes; researchers are sonifying the data. The use of radio waves translated into sound are being used both by research astrophysics in the quest to detect new distant planetary orbits, and atmospheric compositions with Kepler Space Telescope data, as well as at the convening of cosmos and culture. Cosmologists are in quest of possible other universes seeking gravitational distortions in radio waves at the very edges of the perceivable universe. A software program is allowing blind astronomers to study data, as well as to assist sighted astronomers to discern patterns more readily accessible to the ear than by sight. Astrophysicists and astrobiologists, working with composers have developed "Acoustic Astronomy" translating astronomical data, particularly from radio sources into compositions to both inform and inspire. Astronomers are sonifying the data from the cosmic microwave background, pulsars and black hole mergers to better understand the rhythmic and harmonic principles of our universe; while ALMA radio observatory, in Chile has developed a public archived data soundbank. If we are living in an ocean of sound from cosmic processes, what might this imply about the nature and significance of each and every life expression on our planet, each unique bio-organism and ecosystem? What might this imply regarding Earth's harmonics with potential life and universal dynamics in space and on other worlds? This presentation will explore possible implications of our resonant immersion in life's symphonics, and co-creativity in concert with cosmos.

**Author(s):** D. Perkins,

**Institution(s):** GTU/ InfinitiEd, Sofia University

#### **418 - Variable Stars and Their Remnants in Surveys**

##### **418.01 - Nearby Galaxy Surveys in the 2020's and Beyond: The Post Chandra and XMM-Newton Era(Neven Vulic)**

We present prospects for studying black hole and neutron star populations in nearby galaxies, focusing on science topics that need to be addressed by next generation X-ray telescopes. Important questions that can be answered by next generation X-ray telescopes include: how many of the rare (and potential gravitational-wave progenitor) Wolf-Rayet X-ray binaries exist? What are the population characteristics (e.g., accretion mechanism, age dependence, spin period distribution) of X-ray pulsars and the newly discovered ultraluminous X-ray pulsars? What is the role of supernova kicks in the dynamical evolution of X-ray binaries in different environments? Capabilities such

as a large field of view, improved angular resolution, increased sensitivity/effective area, and timing capabilities are required to answer such questions and expand our understanding of X-ray binaries in the Local Universe. We will summarize the prospects for answering these questions based on our current knowledge and simulations of Athena Wide Field Imager observations of galaxies. Athena is an ESA mission planned for launch in ~2031 and the Wide Field Imager is an example of a next generation instrument that will be excellent for studies of black holes and neutron stars in nearby galaxies.

**Author(s):** Joern Wilms, Andreas Zezas, Neven Vulic, Thomas J. Maccarone, Andrew Ptak, Mihoko Yukita, Antara Basu-Zych, Ann Hornschemeier,

**Institution(s):** NASA GSFC, John Hopkins University, University of Maryland College Park, Harvard-Smithsonian Center for Astrophysics, University of Crete, Texas Tech University, University of Erlangen - Nuremberg, University of Maryland Baltimore County

##### **418.02 - Large Surveys Find Extreme Objects: A Case Study from the ATLAS Variable Star Catalog(Aren Nathaniel Heinze)**

The current proliferation of astronomical surveys presents the opportunity to discover rare classes of objects, including small subsets of known categories that exhibit their defining characteristics in an extreme form. These extreme objects may offer the best opportunity to resolve astrophysical mysteries connected with their respective classes. We present a potential example of such a case. Among the 142 million stars probed for the Asteroid Terrestrial-impact Last Alert System (ATLAS) variable star data release 1, we identify about 100 periodic variable stars with a particular, distinctive lightcurve shape not easy to identify with any known type. Gemini/GMOS observations of three of these stars show remarkably similar spectra. They are all early A dwarfs with enormously enhanced heavy-element abundances: that is, they are Ap stars. Ap stars with rotational variability constitute a well-known class (the  $1\pm 2$  CVn variables) and their variability is believed to result from inhomogeneous enhancement of elemental abundances in different parts of the photosphere. The astrophysical mechanism that produces or maintains this inhomogeneity is believed to be magnetic but is not understood in detail. We suggest the ATLAS stars, whose photometric amplitudes are significantly larger than is typical for  $1\pm 2$  CVn variables, offer the best targets for studying the mechanisms of elemental segregation in Ap stars, through high-resolution spectroscopic monitoring.

**Author(s):** John Tonry, Aren Nathaniel Heinze, Heather Flewelling, Larry Denneau

**Institution(s):** University of Hawaii

#### **418.03 - The SUPERWIDE Catalog of Wide Binaries and an Initial Look at the Higher Order Multiplicity of K and M dwarf Wide Binaries(Zachary Hartman)**

We present the SUPERWIDE catalog of wide binaries that were identified through a Bayesian analysis of high proper motions stars ( $m > 40$  mas/yr) from the Gaia DR2 catalog. Initially identified through an earlier search of the SUPERBLINK high proper motion catalog, these binaries were found by their proximity on the sky, common proper motion and similar distances. Taking those pairs with a probability of being a “true” binary (i.e. gravitationally bound system) greater than 99%, we identify  $\sim 22,000$  wide binaries with projected physical separations between  $\sim 100$  AU to  $\sim 1$  pc. We present initial results of an ongoing speckle survey of these wide binaries devoted to the identification of higher order multiples. Using data collected through the POKEMON M-dwarf multiplicity survey, we have examined  $\sim 15$  wide binaries to see if they are in fact triple or quadruple systems. With this information and more to come, we intend to determine the higher order multiplicity fraction for K and M dwarf wide binaries as a function of their physical separation in order to provide constraints for the possible formation mechanisms of these wide systems.

**Author(s):** Gerard van Belle, Sebastien Lepine, Zachary Hartman, Catherine Clark,

**Institution(s):** Georgia State University, Northern Arizona University, Lowell Observatory

#### **418.04 - K2 & K1 Precision asteroseismology of hot horizontal branch (subdwarf B) stars(Michael Reed)**

During the K2 mission, our collaboration has received data on over 170 hot horizontal branch (subdwarf B) stars. These data have resulted in the discovery of over 50 new pulsators and the first space-based data on several known pulsators. These long continuous data sets, combined with the multi-year K1 mission data, allow precision asteroseismology which provides mode identifications and reveals internal structure. I will review some of our more interesting discoveries and their interpretations.

**Author(s):** J. Crooke, A. Slayton, C. S. Jeffery, L. Ketzner, J. H. Telting, A. S. Baran, R. H. Åstensen, Michael Reed, M. Yeager

**Institution(s):** Missouri State University, Nordic Optical Telescope, Pedagogical University, Cracow, Armagh Observatory and Planetarium

#### **418.05 - Short-period Ultra-compact Binaries Identified by the Zwicky Transient Facility (ZTF)(Thomas Prince)**

We will describe searches by ZTF for short-period binary systems ( $P < 30$  min), both in the Galactic Plane and also at higher Galactic latitudes. A new 7-minute orbital period binary will be discussed including spectroscopic using the Keck Observatory as well as high-speed photometric observations of the system using instruments at Palomar Observatory and Kitt

Peak. We will also discuss a 20-minute orbital period system identified earlier using the Palomar Transient Factory, the forerunner of ZTF. The gravitational wave emission from both of these objects will be detectable by the Laser Interferometer Space Mission with the 7-minute system being the strongest LISA detectable source currently known.

**Author(s):** Jan van Roestel, Kevin Burdge, Thomas Prince, Thomas Kupfer, David Kaplan, Eric Bellm, Michael Coughlin

**Institution(s):** California Institute of Technology, University of Wisconsin at Milwaukee, University of Washington, University of California at Santa Barbara Contributing Team(s): Zwicky Transient Facility Partnership

#### **418.06 - Fundamental Properties of Eclipsing Binaries from a Combined APOGEE/Kepler/Gaia Analysis(Joni Marie Clark Cunningham)**

Double-lined, spectroscopic eclipsing binaries (SB2 EBs) fill an important niche in astrophysics as a laboratory for testing stellar evolution models. In particular, the two eclipsing stars can be used to test whether stellar evolution models correctly reproduce the observed properties at one common age (i.e., that the models pass a coevality test). Such tests are most useful when the stars in the binaries span a range of masses, radii, and temperatures, so as to more fully assess the performance of the stellar models over parameter space. However, it is challenging to observe binaries in which the secondary star is much cooler/fainter than the primary. Combining data at visible and infrared wavelengths can help to separate the two stellar components, and the addition of an independent distance to the system can further constrain the system properties. In this work, we complete a detailed analysis for seven SB2 EBs for which both visible-light Kepler light curves and near-infrared APOGEE (Apache Point Observatory Galactic Evolution Experiment) spectra are available. The APOGEE observations have been performed at multiple epochs, permitting us to fully constrain the orbital parameters. These SB2 EBs give a unique opportunity to combine spectra with light curves to directly measure fundamental stellar parameters. We extract radial velocities from the APOGEE spectra via a broadening function analysis. We use the Keblat photometric modeling code to solve for each star’s mass and radius. Five of these systems were also observed by Gaia, whose distances we use to estimate temperatures. Together with Keblat parameters, we use these temperatures to construct H-R diagrams with isochrones from the Dartmouth Stellar Evolutionary Database. We report the results of a coevality test with these SB2 EBs as applied to the Dartmouth models.

**Author(s):** Joni Marie Clark Cunningham, Aleezah Ali, Meredith L. Rawls, Eric Agol, Jason Jackiewicz, Keivan G. Stassun, Diana Windemuth

**Institution(s):** Vanderbilt University, DIRAC Institute, University of Washington, New Mexico State University

#### **418.07 - KELT Discovery of a Fully Convective M Dwarf Eclipsing a Late-B/Early-A Star(Daniel J Stevens)**

Results from surveys looking for low-mass stellar companions to intermediate-mass stars (spectral types B and A) suggest that binaries with companion-to-primary mass ratios of  $q < 0.1$  are relatively uncommon. However, these extreme-mass-ratio binaries are difficult to observe directly due to the relative dimness of the companion, and are difficult to detect via radial velocities (RVs) due to the substantial rotational line broadening of the primary stellar spectra, and the paucity of primary spectral lines. Exoplanet transit surveys that are sensitive to giant planets around hot and bright stars, such as KELT, are comparatively well-suited to identifying such very low-mass companions around hot stars. We present an eclipsing binary composed of a late-B/early-A primary and a late-M secondary in a  $\sim 3.6$ -day orbit, which was discovered by the KELT survey. By jointly analyzing the light curve, RV, SED, and Doppler Tomography data, we find that the M dwarf's mass is consistent with a fully convective interior, making it one of the smallest stars known to eclipse an intermediate-mass star. Given the primary star's large projected rotation velocity,  $v \sin i^* \sim 200 \text{ km/s}$ , we will also show how the choice to apply rotating or non-rotating stellar models affects the inferred system properties, implying the need for model-independent measurements of the properties of binaries with rapidly rotating primaries that can be used to test stellar models.

**Author(s):** Thomas Beatty, Robert Siverd, David James, Jonathan Labadie-Bartz, Joseph Rodriguez, Michael B Lund, Marshall C. Johnson, Daniel J Stevens, Joshua Pepper, B. Scott Gaudi, George Zhou, Keivan G Stassun,

**Institution(s):** The Ohio State University, Harvard-Smithsonian Center for Astrophysics, The Pennsylvania State University, Vanderbilt University, University of Delaware, Fisk University, Lehigh University, University of Arizona  
Contributing Team(s): KELT Collaboration

#### **418.08 - Fermi LAT Observations of Two Be-Pulsar Binary Systems at GeV Energies(Kent S. Wood)**

A small, but growing, number of binary systems comprising a compact object (neutron star or black hole) orbiting a massive Be or O type star are seen to emit phase-varying, non-thermal radiation from radio waves up to TeV gamma rays. The nature of the compact object is only definitively known in two systems, both comprising a young, rotation-powered pulsar and a Be star. The PSR B1259-63 system has an orbital period of 3.4 years and Fermi has observed 3 periastron passages. Enhanced GeV emission appears after periastron, with the most-recent event, in Autumn of 2017, displaying rapid variability on a timescale of minutes. The only observed periastron in the 50-year-period PSR J2032+4127 system occurred in November of 2017. We will describe GeV observations of both periastron passages. Comparisons will be made with a third well-studied Be star binary system, A0538-66, where the neutron star member has a similarly short spin period known from a

transient accretion episode, and with ULX accreting pulsars. Fermi work at NRL is supported by NASA.

**Author(s):** Matthew Kerr, Kent S. Wood, Chi C. (Teddy) Cheung, Masha Chernyakova, Tyrel Johnson, Paul S Ray

**Institution(s):** Praxis, Inc (resident at NRL), GMU, DCU, NRL  
Contributing Team(s): on behalf of the Fermi LAT Collaboration

#### **418.09 - Science with SCORPIO on Gemini in the 2020s(Alexander J. Van Der Horst)**

SCORPIO is envisioned as a workhorse instrument for the Gemini Observatory, capable of wide-band medium-resolution spectroscopy and multi-band imaging covering a broad spectral range, combined with high time resolution. These capabilities are very well suited for efficiently characterizing a large variety of transient and static sources detected by large-scale surveys, in particular by the Large Synoptic Survey Telescope (LSST). Spectral coverage from the optical to the near-infrared, in imaging and spectroscopy, is crucial for a wide range of science, from primitive solar system bodies, to stellar explosions, to accreting compact objects, to high-redshift sources. The high time resolution allows for studying fast changing phenomena, something that has been largely unexplored at Gemini sensitivities. This talk will discuss the broad range of scientific applications of SCORPIO, focusing on those where the new instrument will potentially have the largest impact.

**Author(s):** Alexander J. Van Der Horst, Massimo Robberto,

**Institution(s):** The George Washington University, Johns Hopkins University, Space Telescope Science Institute  
Contributing Team(s): SCORPIO Science Team

#### **419 - Clusters of Galaxies I**

##### **419.01 - Off-Axis Mergers, Gas Sloshing Spirals, and Cool Core Disruption in Galaxy Clusters(Edmund Douglass)**

Spiral-shaped regions of enhanced X-ray surface brightness are found in some of the most relaxed galaxy clusters in the Universe (e.g. A2029). The formation of such spirals is attributed to the sloshing of a dense cool core (CC) about the bottom of the cluster's gravitational potential well. The process is initiated by an off-axis encounter with a subcluster and is generally found to leave the CC fairly intact. The recent identification of cluster-wide spirals in systems lacking strong-CCs (A1763, A2142), however, suggests that more violent off-axis mergers may be capable of inducing core sloshing to the point of CC destruction. To further investigate this phenomenon we have analyzed a sample of systems with intermediate-to-high core entropy ( $K_{500} > 30 \text{ keV cm}^2$ ) which do not appear to be undergoing major head-on mergers. We find numerous systems displaying spiral excesses with ICM cores in various states of disruption, challenging the notion that low angular momentum mergers are required for non-cool core (NCC) formation. Such findings expand our understanding of the dynamical conditions capable of CC destruction and suggest

that off-axis mergers play a greater role in establishing the NCC cluster population than previously assumed.

**Author(s):** Edmund Douglass,

**Institution(s):** SUNY - Farmingdale State Col., American Museum of Natural History  
Contributing Team(s): Edmund M Douglass

#### **419.03 - Tales of radio tails behind Jellyfish galaxies in the Coma cluster(Hao Chen)**

Ram pressure stripping is an important process to study galaxy evolution. The stripped tails have been shown to be multi-phase and forming stars. As energy transfer in multi-phase medium is an outstanding question in astrophysics, important for e.g., galaxy formation and AGN feedback, the stripped tails provide great examples to address the significant questions in multi-phase medium. We present continuum and HI results from new JVLA L-band observations of two fields in the Coma clusters. Our new data, in the B configuration, are much deeper than the previous ones. Over 2000 radio continuum sources are detected and the source density in the central 6.4' radius is 4.6 - 8.0 times the previous one from Miller et al. (2009). For the first time, radio continuum emission is detected in stripped tails, unambiguously revealing the existence of magnetic field in the tails. The radio spectra generally steepen away from the galaxy. We also present HI detections in two Jellyfish galaxies. The implications of our new radio results on stripped tails will also be discussed.

**Author(s):** Craig Sarazin, Michitoshi Yoshida, Giuseppe Gavazzi, Elias Brinks, Ming Sun, Matteo Fossati, O. Jeffrey Kenney, Hao Chen, Elke Roediger, Paul Nulsen, Jeremy Sanders, Masafumi Yagi, Françoise Combes, Pavel Jachym, Hector Bravo-Alfaro, Suresh Sivanandam

**Institution(s):** Academy of Sciences of the Czech Republic, Max-Planck-Institut für Extraterrestrische Physik, Università degli Studi di Milano-Bicocca, Hiroshima University, University of Hull, Harvard-Smithsonian Center for Astrophysics, University of Virginia, Un

#### **419.04 - Observing the Cosmic Web at the cluster boundary: a multi-wavelength campaign to detect cosmic filaments(Thomas Connor)**

For years, detection of cosmic filaments has been an elusive target for observers. While the filamentary nature of the Universe has been observed in the distribution of galaxies for decades, and while simulations predict large gaseous filaments, very few statistically significant measurements of the diffuse web have been made. However, in very deep (2.4 Msec) observations with Chandra around Abell 133, we detected filamentary structures extending out to and beyond the virial radius in X-rays. Following this, we engaged in an intensive campaign of follow-up spectroscopy to map out the kinematic state of the cluster and look for patterns in the galaxy distribution correlating with the X-ray emission. From these

observations, we found a statistically significant link between the galaxy population and the observed filaments, implying that these observed filaments may be real. Here, we discuss these results, as well as the followup work to further extend spectroscopic coverage to tie the observed filaments to the large-scale structure of the Cosmic Web and to measure the properties of these filaments with UV absorption spectroscopy.

**Author(s):** Thomas Connor, Alexey Vikhlinin, John Mulchaey, Daniel D. Kelson

**Institution(s):** Carnegie

#### **419.05 - FRONTIER FIELDS CLUSTERS: A VIEW OF THE POST-MERGING CLUSTER A370(Lorenzo Lovisari)**

In 2013, an ambitious HST program was begun to obtain the deepest views yet of the high redshift Universe by using massive clusters as cosmic lenses. These clusters were chosen because they are extremely massive systems making them exceptional gravitational lenses. While most of these clusters are undergoing very complex mergers, A370 shows a relatively regular ICM morphology although the surface brightness is slightly elongated in the N-S direction. We will present the results from XMM-Newton and Chandra observations of the cluster, aimed to detect and characterize the thermodynamical (e.g. density, temperature, entropy, and pressure) distributions in the ICM. Mapping the thermodynamical properties will allow us to discuss the merger history of the cluster, the mixing of heavy elements in the ICM, and the distribution of the thermal energy.

**Author(s):** Christine Jones, Lorenzo Lovisari, William Forman

**Institution(s):** SAO

#### **419.06 - Protocluster of LAEs at $z=6.5$ : Observations, Analysis, and Confirmation(Krittapas Chanchaiworawit)**

We present the results of our discovery of the protocluster of starburst galaxies (Lyman- $\alpha$  Emitters or LAEs) near the end of the Epoch of Reionization. We conducted the first phase of observations by using OSIRIS in its imaging mode at the 10.4-meter Gran Telescopio Canarias (GTC) in La Palma, Spain. Focusing on two spatially close massive LAEs at the redshift of 6.5 selected from SXDS field, we have carried out a photometric observation with three medium band filters (F883W35, F913W25, and F941W33). The photometric survey covers  $7.0'' \times 8.5''$  sq-arcmin (or  $\sim 1/430,000$  cubic-cMpc at  $z=6.5$ ) and spans over 34 hours. We identified 45 fainter LAE candidates. We have conducted a spectroscopic follow-up of 16 LAE candidates. There were 10 LAEs confirmed. The spectroscopic redshift measurements of these newly confirmed LAEs have led to our derived true survey volume of  $\sim 1/49000$  cubic-cMpc and high overdensity level, parametrized by the density contrast of  $\delta = 3.18 + 3.47/-1.99$ . The two phases of observations and careful

statistical analysis have confirmed the existence of the densely populated region of LAEs in this field. Furthermore, based on our simulation of linearly collapse systems, we predict that the final mass of this structure at the present day would be in the order of  $10^{15}$  solar masses, similar to that of Coma cluster.

**Author(s):** Krittapas Chanchaiworawit, Rafael Guzman

**Institution(s):** University of Florida, National Astronomical Research Institute of Thailand Contributing Team(s): ALBA

#### **419.07 - Molecular Gas and Dust in the Brightest Cluster Galaxy of MACS 1931.8-2635(Kevin Fogarty)**

We present the results of band 3, 6, and 7 ALMA observations obtained of the brightest cluster galaxy (BCG) in MACS 1931.8-2635 over the course of Cycles 4 and 5. MACS 1931 is a massive ( $M_{500} = 1.45 \times 10^{14} M_{\odot}$ ) cool-core galaxy cluster in the Cluster Lensing and Supernova survey with Hubble (CLASH) with the most actively star-forming BCG in the sample, at  $1.4250 M_{\odot} \text{ yr}^{-1}$ . Our observations of the CO (1-0), (3-2) and (4-3) lines reveal a reservoir of molecular gas with a mass of about  $2 \times 10^{10} M_{\odot}$ , on par with the Phoenix cluster, and with a complex dynamical structure. Continuum emission bands 6 and 7 also traces the morphology of cold dust in the BCG. Both the molecular gas and dust morphologies trace ultraviolet knots in the BCG core, along with an  $\text{H I} \pm$ -bright tail extending several tens of kpc away to the northwest. We investigate the multiphase nature of material in this system by comparing our observations of CO and dust with measurements of ultraviolet and  $\text{H I} \pm$  fluxes previously obtained with CLASH photometry, and discuss the correlations between molecular gas and dust morphologies, and features observed in both radio and X-ray data. We examine possible formation scenarios for dust in the BCG, as well as the implications of the velocity structure, CO line ratios, and limits on the molecular gas velocity dispersion for the mechanism of condensation of the multiphase gas in this system.

**Author(s):** Anton Koekemoer, Brenda Frye, Bodo Ziegler, Helmut Dannerbauer, Haoyu Baobab Liu, Marc Postman, Italo Balestra, Keiichi Umetsu, Megan Donahue, Kevin Fogarty, Yuan Li

**Institution(s):** University of Vienna, Space Telescope Science Institute, Michigan State University, California Institute of Technology, ESO, University of California, Berkeley, University Observatory Munich, Instituto Astrofísica de Canarias, Instituto de Astrofísica

#### **419.08 - ALMA Measurements of the molecular mass in the NGC5044 cooling flow group(Gerrit Schellenberger)**

The fate of cooling gas in the centers of galaxy clusters and groups is still not well understood, as is also the case for the complex processes of triggering star formation in central dominant galaxies (CDG) and the re-heating of gas by AGN. Observations of molecular gas in CDG can advance

understanding of heating and cooling mechanisms. We present ALMA observations of the early type galaxy NGC 5044, which resides at the center of an X-ray bright group with a moderate cooling flow. For our analysis we combine CO 2-1 data from three observations with the 12m array with data from the 7m antennas of the Atacama Compact Array. We demonstrate using the 7m array data that we can recover the total flux inferred from IRAM 30m single dish observations, which corresponds to a total molecular mass of about  $6 \times 10^7 M_{\odot}$ . We find more than 25 concentrations (which we identify with giant molecular associations) of molecular gas out to a radius of 10 arcsec (1.5 kpc). The total molecular gas mass is more centrally concentrated than the X-ray emitting gas, and we compare the spatial extent to the  $\text{H I} \pm$  emission: The CO emission overlays the very bright  $\text{H I} \pm$  region in the center, while we do not detect CO emission in the fainter  $\text{H I} \pm$  regions. Furthermore, we see two absorption features spatially located at the center of the galaxy, within 5 pc projected distance to the AGN, infalling at 256 and 264 km/s relative to the AGN. This indicates that the two giant molecular clouds seen in absorption are most likely within the accretion radius of the black hole.

**Author(s):** Gerrit Schellenberger, Jan Vrtilek, Laurence David, Ewan O'Sullivan

**Institution(s):** Smithsonian Astrophysical Observatory

#### **419.02D - The High-z Clusters Occupied by Bent Radio AGN (COBRA) Survey(Emmet Golden-Marx)**

Galaxy clusters are the largest gravitationally-bound systems in the universe. Although there are many known spectroscopically confirmed low-redshift clusters, few high-redshift clusters have been found. To probe the earliest eras of cluster formation and better understand galaxy cluster evolution, observations of high-z clusters with a variety of morphological states and masses are needed. One known tracer of high-z clusters is radio loud active galactic nuclei (RLAGN). Particularly, bent, double-lobed radio sources are an excellent tracer of galaxy clusters. These bent radio AGN have a distinct "c" shape indicative of ram pressure caused by a gaseous medium; specifically, the AGN lobes are bent due to the relative motion of the host galaxy with respect to the intracluster medium. I will present results from the Clusters Occupied by Bent Radio AGN (COBRA) Survey, which consists of 646 bent, double-lobed radio sources from the VLA FIRST Survey and has observations in the infrared from Spitzer and optical from the 4.3m Discovery Channel Telescope. The COBRA survey spans the redshift range  $0.5 < z < 3.0$  and includes candidates with a wide range of masses and dynamical states. Using IR and optical data, we have measured galaxy overdensities, located red sequence galaxies, and determined photometric redshifts. As bent radio AGN are not necessarily found in brightest cluster galaxies, we used local galaxy surface density measurements to analyze the spatial offset between our bent radio AGN and newly-determined cluster centers, which are estimated using the overdensity of red galaxies. We also use these new centers to better identify cluster candidates and probe the infall angle of our target AGN within the cluster. We measured the surface

density of all galaxies and red galaxies to better trace large-scale cluster morphologies and dynamical states to determine if our bent radio AGN are found in merging or relaxed galaxy clusters. We have found that at least 30% of our high-*z* bent radio sources are in cluster environments and that these cluster environments appear to be in a variety of morphological states.  
**Author(s):** Matthew L. N. Ashby, Emmet Golden-Marx, Elizabeth Blanton, Mark Brodwin, Rachel Paterno-Mahler  
**Institution(s):** Boston University, West Los Angeles College, Harvard-Smithsonian Center for Astrophysics, University of Missouri-Kansas City

## **420 - Stars: Stellar Properties II**

### **420.01 - Expanding our Understanding of M Dwarfs in the Kepler Field(Ellianna Schwab)**

M dwarfs have much longer main sequence lifetimes than the Sun and provide stable habitable zones for tens of billions of years, perhaps making M dwarf planets some of the most habitable in the galaxy. Additionally, the smaller radii of M dwarfs allow us to more easily detect transiting Earth-analog planets, due to the higher planet/star radius ratio of the system than of FGK stars. We seek to better understand the M dwarfs (known and new) in the Kepler field, using the wealth of information provided by the Kepler. We confirm a sample of M dwarfs using the crossmatch between the initial Kepler dataset and the second Gaia data release. We calculate the spectral energy distributions (SEDs) of these objects, using distances from Gaia and available archival photometry (e.g., AllWISE, 2MASS, SDSS, and PANSTARRS). We use the SEDs to measure updated luminosities, temperatures, masses and radii using empirically based calculations for these stars, rejecting those that don't qualify as M dwarfs. Using Kepler light curves, we calculate rotation rates of these stars and compile,  $H\beta$ , UV, X Ray and flare rate information from archival surveys. We show that white light (Kepler bandpass,  $K_p$ ) flare strength is highly correlated with rotation rate for M dwarfs and that M dwarfs with fast rotation rates and higher flare strengths in the initial Kepler dataset do not have any confirmed exoplanet detections. While the majority of the stars that we investigate have no confirmed exoplanet detections, a small part of this subsample are known to host transiting exoplanets. We measure updated planetary radii and equilibrium temperatures for these transiting exoplanets. Comparing stellar populations with and without confirmed planets will allow us to examine how M dwarf magnetic strength and activity impact planetary occurrence.

**Author(s):** Jacqueline K Faherty, Courtney Dressing, Ruth Angus, James Davenport, Ellianna Schwab,  
**Institution(s):** American Museum of Natural History, Columbia University, University of California at Berkeley, University of Washington, Seattle

### **420.03 - Constraints on Pollution of M Dwarfs with White Dwarf Companions(Julie Skinner)**

Measuring ages of M dwarfs remains a particularly difficult task despite recent progress in age-dating techniques (e.g. magnetic activity, gyrochronology, chemo-kinematics). M dwarfs with white dwarf (WD) companions hold promise for determining individual M dwarf ages. Assuming the two stars are coeval, the white dwarf can be used as a chronometer to determine the age of the M dwarf. However, it has been shown that the properties (e.g. magnetic activity) of M dwarfs with white dwarf companions are likely affected by binary stellar evolution and that this may depend on the separation of the two stars. To fully capitalize on white dwarf-M dwarf binaries as age-dated benchmark systems, the degree of interaction between the M dwarfs and the WD progenitor needs to be quantified. We present the first steps to quantify the degree of pollution of M dwarfs with a close WD companion due to interaction with the WD progenitor. We show moderate resolution spectroscopy obtained with SpeX on NASA's IRTF for 30 M dwarfs with white dwarf companions, where we find a number of objects that appear very metal-rich ( $[Fe/H] > +0.3$ ) based on calibrated metallicity tracers. We also show follow-up high-resolution near-infrared spectroscopy for the most metal-rich objects obtained with IGRINS ( $R=45,000$ ) at the Discovery Channel Telescope.

**Author(s):** Julie Skinner, Mark Veyette  
**Institution(s):** Smith College, Boston University

### **420.05 - M Subdwarfs May Be Smaller Than You Would Think(Aurora Y Kesseli)**

M subdwarfs are low-metallicity M dwarfs that dominate the halo populations of the Galaxy. Metallicity controls the opacity of stellar atmospheres; in metal poor stars, hydrostatic equilibrium is reached at a smaller radius, leading to smaller radii for a given effective temperature. We compiled a large sample of subdwarf stars that spans spectral classes K7 to M6 and includes stars with metallicity classes from solar-metallicity dwarf stars to the lowest metallicity ultra-subdwarfs to test how metallicity changes the radius. We fit models to optical spectra to derive effective temperatures ( $T_{\text{eff}}$ ) and we measured bolometric luminosities ( $L_{\text{bol}}$ ) by combining broad wavelength coverage photometry with Gaia parallaxes. Radii were then computed by combining the  $T_{\text{eff}}$  and  $L_{\text{bol}}$  using the Stefan-Boltzman law. We find that for a given temperature, ultra-subdwarfs can be as much as five times smaller than their solar-metallicity counterparts. We present color-radius and color-surface brightness relations that extend down to metallicities of -2.0 dex, in order to aid the radius determination of M subdwarfs, which will be especially important for the WFIRST exoplanetary microlensing survey.

**Author(s):** J. Davy Kirkpatrick, Matthew Penny, Aurora Y Kesseli, Patricia Boeshaar, B. Scott Gaudi  
**Institution(s):** Boston University, Caltech/IPAC, University of California, Davis, Ohio State University



#### **420.06 - Radius Inflation in the Hyades Cluster(Karl Jaehnig)**

Radius inflation continues to be explored as a peculiar occurrence within magnetically active, low-mass stars. It has been found to be present within the young open cluster M45 (Pleiades Cluster) (Somers 2017). Moreover, it is found to be correlated to the rotation rate these low-mass stars. Within this work we extend the work of (Somers 2017) by considering radius inflation within a sample of 68 stars of the older open cluster Melotte-25 (Hyades Cluster). We employ spectral energy distribution fitting to derive bolometric flux. With spectroscopically defined  $T_{\text{eff}}$ , and Gaia DR2 distances we calculate stellar radii using the Stefan-Boltzmann equation. We find that there is significant (3-4%) radius inflation present within the Hyades cluster, using the derived stellar radii and radii from isochrones. We compare these results to that of the Pleiades (M45) cluster and consider radius inflation as a function of open cluster evolution. We find that most radii inflated stars cluster around a Rossby number of 0.1-0.2, in spite of the different stellar ages and the spin-down that occurs as the star cluster ages. Our main results imply that magnetic activity within the convective layers of low-mass stars preferentially drives radius inflation.

**Author(s):** Karl Jaehnig, Keivan G Stassun, Garrett Somers

**Institution(s):** Vanderbilt University

#### **420.07 - Isotopic Abundances in Dwarf Stars(Ian Crossfield)**

Late-type stars represent the single most common outcome of star formation and so these objects are popular in studies of stellar and planetary properties. However, the derivation of precise ages and elemental abundances for these stars remains a challenge. A new generation of high-dispersion, infrared echelle spectrographs sheds new light on these dim stars. In particular, these instruments enable new, precise studies of isotopic, not just elemental, abundances. Galactic isotopic ratios are predicted to evolve with time and Galactocentric radius, so measuring these abundances may enable an "isotopic clock" that measures the ages and natal environments of individual stars. I will report on our first measurements with IRTF/iSHELL at  $R=70,000$  (4 km/s) of multiple isotopic ratios in nearby dwarf stars. Such data will also enable a broad diversity of ancillary stellar science and prepare the way for future, similar studies of brown dwarfs and [eventually] giant extrasolar planets.

**Author(s):** Elisabeth Mills, Ian Crossfield, Jessica Valverde, Joshua Lothringer, Andrew J Skemer, Xueying Guo, Richard Freedman, Becky Flores, Brittany Miles

**Institution(s):** MIT, CSUN, LPL, SETI, Brandeis, UCSC

#### **420.04D - Sizing Up Red Dwarfs in the Solar Neighborhood(Michele L. Silverstein)**

Although pinpointing the ages of individual field stars is extremely challenging, sizing up the relative ages of stellar populations is possible for a statistically significant sample of stars and the appropriate set of parameters. We present the results from the Systematic Investigation of Radii and Environments of Nearby Stars (SIRENS) Project: the characterization of the radii of 1662 red dwarf primaries within 25 parsecs that can be used to tease out the different age populations in the solar neighborhood. Our sample spans the entire range of red dwarfs, from spectral type M0V to the understudied late-type M dwarfs that have rarely been resolved with optical or infrared long-baseline interferometers. We utilize VRI, JHK, and WISE W1W2W3 photometry to derive radii, including new VRI photometry for 602 stars observed at the CTIO/SMARTS 0.9m, WIYN 0.9m, and ARCSAT 0.5m. We combine the photometry and distances and perform spectral energy distribution model fitting similar to the procedure outlined in Dieterich et al. (2014) to determine fundamental parameters --- temperature, luminosity, and radius --- for the stars. Comparison of our radii for 18 stars to values determined using long-baseline interferometry indicate offsets of 7%, and for 43 stars our temperatures match those derived by Mann et al. (2015) to 1.2 sigma. The comparative availability and ease, swiftness, and low cost of acquiring photometric data substantiates the distinct edge this technique has over those that rely on spectroscopic data. We compare the primary sample of stars to control samples of 51 pre-main sequence stars and 60 cool subdwarfs, which allows us to identify young/old stars via their correspondingly large/small radii that span a range of 0.08-1.1  $R_{\text{sun}}$ . We reveal several dozen each of young stars and cool subdwarfs, including both known and new identifications, leading us to a more complete census of the age populations within the solar neighborhood that represent our Galaxy's history. This effort has been supported by the NSF through grants AST-0908402, AST-1412026, and AST-1715551 and via observations made possible by the SMARTS Consortium.

**Author(s):** Jennifer Winters, Sergio Dieterich, Kenneth J. Slatten, Tiffany Clements, Wei-Chun Jao, Michele L. Silverstein, Todd Henry, Adric R. Riedel

**Institution(s):** Georgia State University, Department of Terrestrial Magnetism, Carnegie

#### **421 - Plenary Lecture: From Disks to Planets: Observing Planet Formation in Disks Around Young Stars, Catherine Espaillat (Boston University)**

##### **421.01 - From Disks to Planets: Observing Planet Formation in Disks Around Young Stars(Catherine Espaillat)**

We know that many pre-main-sequence stars are surrounded by protoplanetary disks, but how these disks evolve into planetary systems is a fundamental question in Astronomy.

Recently, observations have revealed remarkable structures in disks that may indicate the presence of forming planets. This talk will review these key observations and compare them to current theoretical predictions of planet formation. To conclude, I will discuss possibilities for future progress in the field.

**Author(s):** Catherine Espaillat

**Institution(s):** Boston University

## **422 - Extrasolar Planets: Detection - Transit and Microlensing Searches**

### **422.01 - Fast Cadence Planet-searches with the All-sky, Gigapixel-scale Evryscope (Jeff Ratzloff)**

The Evryscope is a 24-camera robotic telescope that continuously images 8,000 square degrees in 2-minute exposures, that has been collecting data continuously since deployment to CTIO in mid-2015. The telescope provides the fast cadence observations necessary for detecting minute to tens-of-minute time-scale exoplanet transits, which would occur around small, compact host stars including white dwarfs and hot subdwarfs. We are conducting surveys for each of these types of stars searching for potential planet transit signals. The surveys are also sensitive to short-time scale binaries including white dwarf - white dwarf eclipsing binaries and hot subdwarf - brown dwarf binaries. Our surveys will be the largest performed to date with several thousand targets in each group and years of observations with minute-scale cadence. We present the discoveries from the surveys.

**Author(s):** Octavi Fors, Henry T Corbett, Nicholas Law, Brad Barlow, Ward S Howard, Amy Glazier, Jeff Ratzloff

**Institution(s):** UNC Chapel Hill, High Point

### **422.03 - Exploring LSST's Ability to Find Planets around White Dwarfs (Michael B Lund)**

The Large Synoptic Survey Telescope (LSST) will observe the entire southern sky over ten years, providing reliable photometry over roughly 16th to 24th magnitude in 6 bands. In previous work, we have explored how LSST can contribute to the detection of exoplanets around main sequence stars. Here we examine how LSST can be used to look for earth-sized planets in transiting orbits around white dwarfs, and show that for much of the survey area, about 20% of earth-sized planets transiting white dwarfs can be identified for follow-up. With the large number of white dwarfs to be observed by LSST, this will provide a way to probe the underlying frequency of planets around white dwarfs in short-period orbits.

**Author(s):** Avi Shporer, Michael B Lund, Keivan G Stassun, Joshua Pepper

**Institution(s):** Vanderbilt University, MIT, Lehigh University, Fisk University

### **422.04 - Project PANOPTES: A Unique Approach for Exoplanet Transit Detection using DSLR Cameras (Wilfred Tyler Gee)**

PANOPTES is a citizen-science based project designed to recover transit information from a large number of exoplanets across the entire night sky. The scientific goals of the project include the ability to detect novel exoplanet transits as well as provide valuable follow-up capabilities for existing and future exoplanet surveys. A single PANOPTES unit is capable of recovering light curve transits using percent level photometry for  $V_{\text{mag}}=8$  to 12 stars and the project accuracy scales with the square root of the number of units observing the target. This overlaps well with early detections from the TESS mission while offering critical long-term follow up potential. The most significant technical challenge associated with the use of consumer digital cameras is the presence of the Bayer color filter array, which complicates photometry due to the inter-pixel variation associated with each color. Here we present a working demonstration of the novel algorithm developed for PANOPTES along with the light curve for the planet HD189733b obtained during a single transit observation. Data for the observation was taken on a PANOPTES unit constructed and operated by two Caltech summer interns during the summer of 2018. Future work will apply the algorithm to observations spanning multiple PANOPTES telescopes at diverse locations as well as continued improvements.

**Author(s):** David Coutts, Robert Thomas Zellem, Nemanja Jovanovic, Christian Schwab, Josh Walawender, Wilfred Tyler Gee, Olivier Guyon

**Institution(s):** Macquarie University, California Institute of Technology, Subaru Telescope, Keck Telescope, Jet Propulsion Laboratory - California Institute of Technology Contributing Team(s): Project PANOPTES

### **422.05 - Preccovery of TESS Single Transits from KELT (Xinyu Yao)**

The NASA Transiting Exoplanet Survey Satellite (TESS) mission will discover thousands of candidate transiting exoplanets. Due to the mission configuration, 74% of the area to be observed by TESS will only have an observational baseline of 27 days. For those planets with orbital periods longer than 13.5 days, TESS can only capture one or two transits, which means the true ephemerides will be difficult to determine from TESS data alone. Follow-up observations of the transits of these candidates to efficiently confirm and characterize them will require precise ephemerides. We explore the value of using data from the KELT ground-based survey to constrain the ephemerides of the single-transit candidates anticipated to be discovered by TESS. We find that KELT photometry can be used to confirm ephemerides with high accuracy for planets of Saturn size or larger with orbital periods as long as a year, and therefore span a wide range of planet equilibrium temperatures. In a large fraction of the sky we recover 30% to 50% of the hypothetical warm Jupiter systems (planet radii of 0.9 to 1.1  $R_J$

and  $13.5 < P < 50$  days), 50% to 80% of the hypothetical warm inflated Jupiters (planet radius of 1.1 to 2 RJ), 5% to 20% of the hypothetical temperate Jupiters ( $50 < P < 300$  days), 10% to 60% of the hypothetical temperate inflated Jupiters and 10% to 40% of the hypothetical warm Saturns (planet radius of 0.5 to 0.9 RJ and  $13.5 < P < 50$  days).

**Author(s):** B. Scott Gaudi, Keivan G Stassun, Joshua Pepper, Knicole Colon, Xinyu Yao

**Institution(s):** Lehigh University, Vanderbilt University, The Ohio State University, NASA Goddard Space Flight Center, Fisk University  
**Contributing Team(s):** KELT Collaboration

#### **422.06 - WFIRST: A Simple Approach for the Recovery of Planetary Parameters From Microlensing Light Curves(Somayeh Khakpash)**

Microlensing is a powerful tool for discovering cold exoplanets, and the WFIRST microlensing survey will discover over 1000 such planets. The full modeling of each planetary microlensing event often requires significant investment of human and computing resources. However, for a significant subset of microlensing events it may be possible to determine rough estimates of planetary parameters from a simple analytic light curve model. In this project, we examine thousands of simulated WFIRST light curves and investigate for what fraction of the events we can recover planetary parameters using this simple approach. Comparing the results with the true parameters of the systems (projected angular separation and planetary perturbation duration), we show that for systems with smaller planet/star mass ratios ( $10^{-7} < q < 10^{-5}$ ), we can determine the projected separation to about 5% accuracy, whereas for higher mass ratios ( $q > 0.001$ ), we can determine it to about 40% accuracy. For systems with different ranges of projected separation, we can determine the planetary perturbation duration to about 20% accuracy on average. Overall, our results show that this approach is more successful for microlensing planetary events caused by planetary caustics in a wide or close topology and when the mass ratio is lower. This approach can be used to do an initial fast analysis of WFIRST light curves to find approximate system parameters before investigating them thoroughly with other methods or prioritize rapid follow-up observations.

**Author(s):** Matthew Penny, Somayeh Khakpash, Joshua Pepper

**Institution(s):** Lehigh University, Ohio State University

#### **422.02D - Developing the infrastructure of bright-star exoplanet hunting: the Kilodegree Extremely Little Telescope (KELT) and the Network of Robotic Echelle Spectrographs (NRES)(Robert Siverd)**

The Kilodegree Extremely Little Telescope (KELT) is an ongoing, wide-field (26x26 deg) photometric survey for transiting exoplanets using small-aperture telescopes in Arizona, USA and Sutherland, SA to monitor ~70% of the sky at

~30-minute cadence. KELT was built to find high-value transiting exoplanets around bright host stars. Using off-the-shelf hardware, the KELT telescopes achieve better-than-1% precision for  $7.5 < V < 10$  stars. After ~10 years of data collection, the KELT survey has discovered over 20 bright exoplanets. Reaching the needed photometric precision is complicated by source blending (23"/pix) and PSF variability. Careful use of existing and modified difference imaging tools brought success but with significant compromises. Our new Catalog-Driven Extraction (CDE) is a set of key changes to both our reduction pipelines and data handling that markedly improve photometric accuracy and simplify the candidate identification process. Further, CDE-generated light curves are suited to a wider range of science tasks and will become a valuable community resource. Confirming a transiting exoplanet involves other hurdles beyond photometry. Chief among these is obtaining a radial velocity (RV) orbit. The scarcity of spectroscopic resources is a genuine bottleneck for exoplanet confirmation. To fill this void, Las Cumbres Observatory (LCO) has designed, built, and deployed the Network of Robotic Echelle Spectrographs (NRES) to its worldwide network of robotic 1-meter telescopes. NRES consists of four, optical, fiber-fed, R~45000 spectrographs designed for RV and stellar classification. Now operational, NRES is poised to become an important resource for exoplanet discovery and stellar astrophysics. The KELT and NRES presented very different development challenges despite related science goals. In this report I discuss the significant and different infrastructural challenges involved in these two projects and share important lessons learned. Finally, I discuss some of the exciting prospects for future work in bright-star time-domain science.

**Author(s):** Robert Siverd, Keivan G Stassun, Daniel Rolf Harbeck, Daniel J Stevens, Tim Brown, Michael B Lund

**Institution(s):** Vanderbilt University, Las Cumbres Observatory, Penn State University  
**Contributing Team(s):** the KELT Collaboration, Las Cumbres Observatory

#### **423 - TESS: Early Results and Future Plans II**

##### **423.01 - The Updated TESS Input Catalog and Target Selection(Joshua Pepper)**

The TESS mission is underway, monitoring millions of the brightest stars over most of the sky to detect transiting exoplanets. We have created the TESS Input Catalog (TIC) which guides the evaluation of TESS data and selection of 2-minute postage stamp targets. We attempt to identify the best stars for the detection of small planets, which includes all bright cool dwarf stars in the sky. I will describe the current version of the TIC, the overall properties of 2-minute target selection, and plans for further improvement.

**Author(s):** Guillermo Torres, Keivan G Stassun, Joshua Pepper, Ryan J. Oelkers, David W Latham, Martin Paegert

**Institution(s):** Lehigh University, Harvard / Center for Astrophysics, Vanderbilt University  
**Contributing Team(s):** The TESS Target Selection Working Group

#### **423.02 - Initial Performance of the TESS Science Pipeline(Jon Michael Jenkins)**

The Transiting Exoplanet Survey Satellite (TESS) Mission was launched April 18 2018 and started science observations July 25 2018, initiating NASA's search for Earth's closest cousins. TESS is expected to discover ~1,000 small planets with  $R_p < 4 R_E$  and measure the masses of at least 50 of these small worlds. The Science Processing Operations Center (SPOC) was developed at NASA Ames Research Center based on the Kepler Mission science pipeline and will generate calibrated 30-min full frame images (FFIs), and calibrated target pixels and light curves for 16,000+ 2-min postage stamps on the NASA Advanced Supercomputing Division's Pleiades supercomputer for each month of data. The SPOC will also search for periodic transit events and generate validation products for the transit-like features in the light curves. All TESS SPOC data products will be archived to the Mikulski Archive for Space Telescopes (MAST; [archive.stsci.edu/teess](http://archive.stsci.edu/teess)). Although TESS collects 13 times as much pixel data as Kepler did, improvements in both hardware and software allow us to process the raw image data much faster than was possible for Kepler. In fact, the SPOC is able to process a month's worth of data in typically 3-5 days. In this paper we describe the performance of the science pipeline and highlight key characteristics of the science data products. Initial results indicate that the photometric precision at 1 hour is better than 60 ppm for quiet stars brighter than 7.5 mag and better than 200 ppm for quiet stars brighter than 10 mag. While there is room for improving the performance of the pipeline in light of the fact that TESS's photometric precision appears to be pointing-dominated rather than focus-dominated, as was the case for Kepler, the initial photometric precision exceeds requirements and is more than sufficient to permit TESS to achieve her level 1 science goals. Funding for the TESS Mission has been provided by the NASA Science Mission Directorate.

**Author(s):** Jon Michael Jenkins  
**Institution(s):** NASA Ames Research Center Contributing Team(s): TESS Science Processing Operations Center

#### **423.03 - TESS Objects of Interest Catalog for Sectors 1-4 of the TESS Mission(Natalia Guerrero)**

The Transiting Exoplanet Survey Satellite (TESS) observed four partially overlapping sectors in the ecliptic Southern Hemisphere from July to November 2018, as part of its mission to observe ~85% of the entire sky in two years and measure masses for 50 planets less than 4 Earth radii. Each sector covers ~5% of the sky and the partially overlapping sectors 1-4 cover ~15% of the sky. We describe the TESS Objects of Interest (TOI) catalog from Sectors 1-4, consisting of planet candidates, known planets, and other astrophysical sources of transit-like signals, including eclipsing binaries and stellar variability. The TESS Follow-Up Observing Program (TFOP) has prioritized and observed TOIs using the Exoplanet Follow-up Observing Program (ExoFOP) to coordinate effort and share data. The TESS data products for sectors 1-4, including the TESS Object

of Interest catalog, light curves, full-frame images, and target pixel files, will be available to the public no later than January 2019.

**Author(s):** Natalia Guerrero

**Institution(s):** Massachusetts Institute of Technology  
Contributing Team(s): TESS Mission

#### **423.04 - Confirmation of TESS planet candidates with precise radial velocities from MINERVA-Australis(Robert Wittenmyer)**

NASA's Transiting Exoplanet Survey Satellite (TESS) will identify thousands of planets orbiting nearby bright stars in a two-year survey beginning in the Southern sky. MINERVA-Australis is the only southern hemisphere precise radial velocity facility wholly dedicated to follow-up of TESS planets. Mass measurements of these planets are critically necessary to maximise the scientific impact of the TESS mission, to understand the composition of exoplanets and the transition between rocky and gaseous worlds. MINERVA-Australis is now operational at the University of Southern Queensland's Mount Kent Observatory, with three of the planned six 0.7m telescopes in place. I present orbital solutions for planets from the first sectors of TESS observations, and give an update on the performance of MINERVA-Australis.

**Author(s):** Brendan Bowler, Ian Crossfield, Peter Plavchan, Jonathan Horner, Hui Zhang, Robert Wittenmyer, Chris Tinney, Stephen Kane, John Kielkopf, Duncan Wright

**Institution(s):** University of Southern Queensland, George Mason University, MIT, University of Texas at Austin, Nanjing University, University of Louisville, UNSW Sydney

#### **423.05 - HD202772A b: the first confirmation of a hot Jupiter discovered by TESS(Songhu Wang)**

We report the first confirmation of a hot Jupiter discovered by TESS: HD202772A b. The presence of light contamination from the bright stellar companion makes the confirmation of planetary nature technically hard. The talk will focus on the follow-up efforts made by TFOP collaboration that entirely rules out the false positives. HD 202772A b is one of few known transiting hot Jupiters orbiting bright, quickly evolved stars. I will also discuss the follow-up observational and theoretical efforts we are performing for the system. In the end, I will discuss the RV efforts we made with CHIRON for other TESS Alerts, shedding first light on the false positive rate of TESS Alerts of gas giants.

**Author(s):** Songhu Wang

**Institution(s):** Yale Contributing Team(s): TESS Collaboration

#### **423.06 - A Southern Hemisphere RV Follow-up Program for TESS with PFS/Magellan(Johanna Teske)**

With the launch in spring 2018 of the Transiting Exoplanet Survey Satellite (TESS), a new phase of transiting exoplanet detection, follow-up, and characterization began, starting in the Southern Hemisphere. In this talk, I will outline a cooperative effort to measure the masses of TESS planets using radial velocity observations with the Planet Finder Spectrograph (PFS) on the Magellan II 6.5m telescope at Las Campanas Observatory in Chile. This effort is coordinated by the Carnegie PFS team but brings together scientists from multiple Magellan partners, and is rooted in the spirit of the TESS Follow-up Observing Program (TFOP) to do the best science through collaboration. It can thus serve as a model for others working within TFOP. I will also describe the targeted, statistically-motivated investigation (and any preliminary results) by the Carnegie team, focused on understanding whether super-Earth and sub-Neptune planets (1) represent a continuous population that has been influenced by post-formation processes but formed in a similar way, (2) formed differently, or (3) formed differently and were also altered after formation.

**Author(s):** Johanna Teske, Jeff Crane, Sharon Xuesong Wang, Stephen A Shectman, Angie Wolfgang, R. Paul Butler

**Institution(s):** Carnegie DTM, Carnegie Observatories, Penn State University

#### **423.07 - Extending the period range of TESS planet candidates(Diana Dragomir)**

The TESS primary mission will search for transiting planets around bright stars, but will observe most regions of the sky for only 27 days. Even the stars in the TESS Continuous Viewing Zones will only be observed for one year. The traditional requirement for multiple transits in order to establish a signal as a planet candidate will therefore limit the orbital periods of planets that TESS can discover throughout the sky. I will discuss how we can surpass this limit by measuring the periods and masses of single-transit planet candidates. I will present single-transit planet candidates identified in the first TESS sectors, their transit and stellar properties, and the status of follow-up observations for these candidates. Once confirmed, these new long-period planets will facilitate the search for trends between planet properties and orbital period by extending the period range over which such investigations can be undertaken. They will also increase the number of long-period exoplanets with measured densities that are amenable to atmospheric characterization, and will be prime targets for terrestrial exomoon searches. These studies will in turn enable new constraints on the composition and formation of temperate exoplanets.

**Author(s):** Avi Shporer, Steven Villanueva, Diana Dragomir, Xu Huang

**Institution(s):** MIT

#### **423.08 - Resolving the TESS Planet Population with High Resolution Imaging (Steve Howell)**

High-resolution imaging is critical for both exoplanet validation and characterization of the system. Studies of the Kepler and K2 samples indicate that nearly 50% of all exoplanet host stars are in binary (or higher) systems, and their additional flux in the photometric aperture must be accounted for to accurately derive planet radii from the measured transit depths. Finding companion stars and correcting exoplanet radii for their influence is important both on a system-by-system basis, particularly for accurate density determination, and also allows the true planet radius distribution to be uncovered, providing key information for exoplanet population studies. Additionally, imaging at resolutions within 0.4" yields information on true bound binaries allowing exoplanet researchers to understand how host star companions influence planetary formation and evolution. We are part of the NASA NN-EXPLORE team that will provide to the community follow-up high-resolution imaging using our fleet of speckle interferometry instruments at WIYN, Gemini-N, and Gemini-S. In this talk, we will discuss the importance of our imaging and the details of the follow-up program as well as some results related directly to TESS exoplanet observations.

**Author(s):** Johanna Teske, Nicole Hess, Mark Everett, Steve Howell, David Ciardi, Rachel Matson

**Institution(s):** NASA Ames Research Center, NOAO, Carnegie / Hubble fellow, SCSU, Caltech/IPAC-NExSci

#### **423.09 - The first TESS re-discoveries of known exoplanets(Maximilian N. Günther)**

The Transiting Exoplanet Survey Satellite (TESS) has not only found its first new exoplanets (e.g. Pi Mensae c and LHS 3844 b); TESS also 're-discovered' all known exoplanets that fell in its first 28 day observing window (Sector 1). This detection efficiency from early on supports the confidence in TESS' performance and future detections of short period planets. We analyze all the new and archival data of known exoplanets in Sector 1 in a homogeneous way. I will highlight our search for new planetary companions, orbital modulation, and shallow secondary eclipses for these known systems. I will also discuss how we update planetary parameters and characterize the consistency with the literature. The information gain achieved by TESS is characterized using Bayesian methods, giving valuable insights into TESS' early impact.

**Author(s):** Tansu Daylan, Maximilian N. Günther

**Institution(s):** Massachusetts Institute of Technology  
Contributing Team(s): TESS team

## **424 - The VLA Sky Survey**

### **424.01 - The VLA Sky Survey - an overview(Mark Lacy)**

The VLA Sky Survey (VLASS) is an all-sky survey that is being carried out with the Very Large Array (VLA) in New Mexico over a frequency range of 2-4GHz. VLASS will be carried out in three epochs over seven years, with half the sky being observed each time the VLA is in B-configuration. The combination of high angular resolution (2.5-arcsec), sensitivity (69 microJy/beam in the final coadded data), imaging in the Stokes I, Q and U parameters, and the time domain aspect make it a uniquely powerful study of the radio sky. In this talk I will give an overview of the project, its current status, and some early results from the first survey campaign, which observed half the sky between September 2017 and February 2018.

**Author(s):** Mark Lacy

**Institution(s):** National Radio Astronomy Observatory

**Contributing Team(s):** VLASS team and VLASS Science Survey Group

### **424.02 - Extra-galactic Science with the Very Large Array (VLA) Sky Survey(Amy Kimball)**

The VLA Sky Survey (VLASS) is the highest-resolution all-sky radio survey to date, providing a brand new and important resource for studies of active galactic nuclei (AGN) and radio galaxies across cosmic time. VLASS measurements will include in-band spectral indices and full polarization at high angular resolution. When cross-matched with other all-sky multi-wavelength surveys, source catalogs from VLASS will provide large, statistically complete samples for probing studies related to AGN accretion and feedback activity, quasar demographics, dual AGNs, and radio source environments. In this talk, I will discuss the use of VLASS data in these topics, and highlight some new results that have already come out of the initial VLASS images.

**Author(s):** Amy Kimball

**Institution(s):** National Radio Astronomy Observatory

**Contributing Team(s):** Very Large Array Sky Survey Science Group

### **424.03 - Polarization Science with the Very Large Array Sky Survey(Lawrence Rudnick)**

The VLASS will produce the highest resolution and highest frequency all-sky maps of radio polarization. The combination of the 3 GHz central frequency, large bandwidth and high resolution allow studies of the spatial and Faraday structure of extragalactic sources, to characterize their interactions with their local thermal plasma environment. Distant polarized sources will also be used as probes of intervening magnetized plasmas in galaxies and clusters of galaxies. In this talk I will highlight some science areas where the VLASS should make significant progress, and show some early results from the first epoch observations. I will also describe the polarization

capabilities and limitations of the survey so that people can evaluate its suitability for their own science goals. Work on polarization probes of the intracluster medium is supported in part by NSF grant AST-1714205 to the University of Minnesota.

**Author(s):** Lawrence Rudnick

**Institution(s):** University of Minnesota

**Contributing Team(s):** Very Large Array Sky Survey Science Group

### **424.04 - The VLITE Commensal Sky Survey (VCSS): A 340 MHz Companion to the VLA Sky Survey (VLASS)(Wendy Peters)**

The VLA Low Band Ionosphere and Transient Experiment (VLITE; <<http://vlite.nrao.edu/>>) is a commensal observing system on the Karl G. Jansky Very Large Array (VLA) developed by the Naval Research Laboratory and NRAO. A 64 MHz sub-band centered at 340 MHz is recorded and correlated during nearly all regular VLA observations. Operating since November 2014 with 10 antennas, VLITE was updated in 2016 to support "on-the-fly" (OTF) continuous scanning observations. In 2017 the experiment was expanded to 16 antennas, which more than doubled the number of baselines and greatly increased image fidelity for short observations. Both of these upgrades were necessary to operate the experiment during rapid slew sky surveys. The VLA Sky Survey (VLASS;

<<https://science.nrao.edu/science/surveys/vlass>>), is an ongoing survey of the entire sky visible to the VLA at a frequency of 2-4 GHz using OTF observations. The first half-epoch was observed between 09/17 and 02/18. VLITE breaks the data into 2-second integrations and correlates these at a central "pointing" position every 1.5 degrees. The observations are made along rows of declination spaced by 7.25'; VLITE's field of view is 2 degrees across and provides a large overlap from one row to the next and thus a high tolerance for failed pointings. All data for each correlator position is imaged separately, corrected and weighted by an appropriately elongated primary beam model, and then combined in the image plane to create a mosaic of the sky. The typical mosaic resolution is 15" -20", and the typical RMS of the mosaics is 3 mJy/bm. A catalog of the sources is extracted to provide a 340 MHz sky model. These images and catalogs form the VLITE Commensal Sky Survey, or VCSS. In addition to providing a unique sky model at 340 MHz, VCSS complements VLASS by providing spectral indices for all cataloged sources, and intermediate resolution images for extended sources. The observations provide a rich database for transient searches. And, because the data are recorded simultaneously, VCSS may be used to verify transients detected at the higher frequency. In this talk we present first release images and catalogs for VCSS and discuss early verification and potential science.

**Author(s):** Walter Briske, William Cotton, Namir E Kassim, Wendy Peters, Tracy Clarke, Simona Giacintucci, Emil Polisensky

**Institution(s):** Naval Research Laboratory, National Radio Astronomy Observatory, National Radio Astronomy Observatory

**424.05 - Discovery of the Luminous, Decades-Long, Extragalactic Radio Transient FIRST J141918.9+394036(Casey Law)**

We present the discovery of a slowly-evolving, extragalactic radio transient, FIRST J141918.9+394036, identified by comparing a catalog of radio sources in nearby galaxies against new observations from the Very Large Array Sky Survey. Analysis of other archival data shows that FIRST J141918.9+394036 faded by a factor of  $\sim 1/450$  over 23 years, from a flux of  $\sim 1/426$  mJy at 1.4 GHz in 1993 to an upper limit of 0.4 mJy at 3 GHz in 2017. FIRST J141918.9+394036 is likely associated with the small star-forming galaxy SDSS J141918.81+394035.8 at a redshift  $z=0.01957$  ( $d=87$  Mpc), which implies a peak luminosity  $\sim 10^{38}$  erg/s. If interpreted as an isotropic synchrotron blast wave, the source requires an explosion of kinetic energy  $\sim 10^{51}$  erg some time prior to our first detection in late 1993. This explosion is most likely associated with a long gamma-ray burst (GRB), but the radio source could also be interpreted as the nebula of a newly-born magnetar. The radio discovery of either of these phenomena would be unprecedented. Joint consideration of the event light curve, host galaxy, lack of a counterpart gamma-ray burst, and volumetric rate suggests that FIRST J141918.9+394036 is the afterglow of an off-axis ("orphan") long GRB. The long time baseline of this event offers the best available constraint in afterglow evolution as the bulk of shock-accelerated electrons become non-relativistic. The proximity, age, and precise localization of FIRST J141918.9+394036 make it a key object for understanding the aftermath of rare classes of stellar explosion.

**Author(s):** Casey Law, Lorenzo Sironi, Eran Ofek, Brian Metzger, Bryan Gaensler

**Institution(s):** UC Berkeley, Weizmann Institute, Dunlap Institute, Univ of Toronto, Columbia University

**424.06 - Ultra-luminous extragalactic radio transients in Epoch 1.1 of the VLA Sky Survey(Dillon Dong)**

With its all-sky coverage and high resolution, the VLA Sky Survey (VLASS) is uniquely placed to transform our understanding of the transient radio sky. We have searched Epoch 1.1 of the VLASS and its precursor, the Caltech NRAO Stripe 82 Survey, for radio transients relative to the historical FIRST survey. Through broadband VLA follow-up and Keck / LRIS optical spectroscopy, we have identified a new population of ultra-luminous ( $> 10^{28}$  erg/s/Hz) radio transients that are located in star forming regions in local universe ( $d < 200$  Mpc) galaxies. For three of these events, Keck followup confirms ongoing evolving optical transients. In this talk I will discuss the observed and modeled characteristics of these explosions, as well as possible progenitors of these extremely luminous events.

**Author(s):** Kunal Mooley, Steven T. Myers, Dillon Dong, Gregg Hallinan

**Institution(s):** Caltech, NRAO

**425 - Computational Astrophysics**

**425.01 - The Dedalus project: open source science in astrophysics with examples in convection and stellar dynamos(Benjamin Brown)**

Numerical experiments are a powerful tool for developing insight into complex, astrophysical systems. These experiments are most useful to the community when they are easy to reproduce and to extend to new questions. Here we discuss recent developments in the open source Dedalus project, a flexible, python based, massively parallel, pseudospectral framework for solving partial differential equations. We discuss the benefits that flexibility in design has brought to the project, and how this has enabled science exploration. We show examples of astrophysical problems we have been studying using Dedalus. These include studies of convective overshoot in stratified systems similar to stellar interiors and planetary weather layers, and studies of magnetic dynamo action in rotating, stratified systems similar to fully convective M-dwarf stars.

**Author(s):** Daniel Lecoanet, Benjamin Brown, Jeffrey S Oishi, Geoffrey M Vasil, Keaton Burns

**Institution(s):** University of Colorado Boulder, Bates College, Princeton University, Center for Computational Astrophysics, Flatiron Institute, University of Sydney

**425.02 - Shear instabilities in stars(Pascale Garaud)**

Shear-induced turbulence could play a significant role in mixing momentum and chemical species in stellar radiation zones. I will review recent work on quantifying mixing by shear instabilities in stars, using Direct Numerical Simulations. This talk will cover standard and diffusive shear instabilities, including both vertical and horizontal shear. Comparisons with existing models for shear-induced mixing will be made, and new prescriptions will be described.

**Author(s):** Pascale Garaud

**Institution(s):** UC Santa Cruz

**425.03 - Penetration beneath the convection zone of solar-like stars of different age(Jane Pratt)**

To interpret the high-quality data produced from recent space-missions it is necessary to develop theoretical and computational modeling of convection under realistic stellar conditions. We use the multi-dimensional, time implicit, fully compressible, hydrodynamic, implicit large eddy simulation code MUSIC, to study the interaction between the convection zone and an interior radiative zone in solar-like stars of different ages. The amount of convective penetration and overshooting will be evaluated for several young sun models of different ages that possess a realistic stratification in density, temperature, and luminosity calculated using MESA. We

present a more sophisticated enhanced diffusion model for convective penetration, targeted for one-dimensional stellar evolution calculations, which takes into account the size of the convection zone as the sun ages.

**Author(s):** Jane Pratt, Kara Gartner, Isabelle Baraffe,

**Institution(s):** Georgia State University, ENS de Lyon, University of Exeter  
**Contributing Team(s):** MUSIC developers group

#### **425.04 - Merging Intermediate Mass Black Holes in LIGO and LISA(Deirdre Shoemaker)**

Intermediate mass black holes are one of the key sources for joint observing by ground and space based gravitational wave detectors. This talk explores the promises of their detection, what a lack of detection by ground-based detectors means for LISA, and the role numerical relativity plays on their detection and interpretation.

**Author(s):** Deirdre Shoemaker, Karan Jani

**Institution(s):** Georgia Institute of Technology

#### **426 - A NICER Exploration of Neutron Stars and Black Holes**

##### **426.01 - NICER: Expanding X-ray Astrophysics Horizons from the International Space Station(Zaven Arzoumanian)**

Nearing the end of its 18-month baseline-science mission, and soon to embark on a Guest Observer program, NASA's Neutron star Interior Composition Explorer (NICER) continues to pursue and fulfill the promises of its unique capabilities, namely fast and sensitive timing spectroscopy in soft (0.2--12 keV) X-rays, with unprecedented throughput for bright sources and scheduling agility to pursue rapidly evolving phenomena. As of late-November 2018, the NICER data archive at HEASARC offers public access to more than 9,000 ObsIDs for nearly 270 unique targets. This introductory presentation of the NICER Special Session briefly reviews the mission and science highlights from the last year.

**Author(s):** Zaven Arzoumanian

**Institution(s):** NASA GSFC  
**Contributing Team(s):** NICER Team

##### **426.02 - Constraining the Neutron Star Mass-Radius Relation with NICER Observations of Millisecond Pulsars(Slavko Bogdanov)**

One of the principal science objectives of the Neutron Star Interior Composition Explorer (NICER) mission is to carry out sensitive X-ray observations of neutron stars in order to constrain the poorly understood behavior of cold matter at densities beyond that of atomic nuclei. The NICER mission is focusing on measuring the masses and radii of several nearby thermally-emitting rotation-powered millisecond pulsars, by

fitting sophisticated models that incorporate all relevant relativistic effects and atmospheric radiation transfer processes to their periodic soft X-ray modulations. We will discuss the efforts by the NICER team towards estimating the masses and radii of these neutron stars, which would enable constraints on the dense matter equation of state.

**Author(s):** Slavko Bogdanov

**Institution(s):** Columbia University  
**Contributing Team(s):** The NICER Team

##### **426.03 - High-Precision X-ray Timing of Three Millisecond Pulsars with NICER: Stability Estimates and Comparison with Radio(Andrea Lommen)**

The Neutron Star Interior Composition Explorer (NICER) is an array of 56 X-ray detectors mounted on the outside of the International Space Station. It allows high-precision timing of millisecond pulsars without the pulse broadening and delays due to dispersion and scattering by the interstellar medium that plague radio timing. We present initial timing results from a year of data on the millisecond pulsars PSR B1937+21 and PSR J0218+4232, and nine months of data on PSR B1821-24. NICER time-of-arrival uncertainties for the three pulsars are consistent with numerical lower bounds and simulations based on the pulse shape templates and average source and background photon count rates. To estimate timing stability, we use the  $\dot{f}_z$  measure, which is based on the average of the cubic coefficients of polynomial fits to subsets of timing residuals. So far we are achieving timing stabilities  $\dot{f}_z \approx 3 \times 10^{-14}$  for PSR B1937+21 and on the order of  $10^{-12}$  for PSRs B1821-24 and J0218+4232. Within the span of our NICER data we do not yet see the characteristic break point in the slope of  $\dot{f}_z$  detection of such a break would indicate that further improvement in the cumulative root-mean-square (RMS) timing residual is limited by timing noise.

**Author(s):** Matthew Kerr, Kent S. Wood, Lucas Guillemot, H. Thankful Cromartie, Ismael Cognard, Scott M. Ransom, Julia Deneva, Zaven Arzoumanian, Keith C Gendreau, Natalia Lewandowska, Slavko Bogdanov, Andrea Lommen, Paul S Ray  
**Institution(s):** Haverford College, CNRS, Naval Research Labs, Columbia Astrophysics Laboratory, Columbia University, NRAO, West Virginia University, X-Ray Astrophysics Laboratory, NASA Goddard Space Flight Center  
**Contributing Team(s):** NICER Science Team, NICER Precision

##### **426.04 - Magnetars and Rotation-powered Pulsars with NICER(Teruaki Enoto)**

The large effective area and high time resolution of NICER provide a powerful diagnostic capability in soft X-rays for investigating surface and magnetospheric radiation from a variety of magnetic neutron stars. The mission's Magnetars and Magnetospheres (M&M) science working group performs regular monitoring and target-of-opportunity observations of magnetars, strong-field pulsars, bright rotation-powered



pulsars, and nearby isolated neutron stars. For example, we carried out follow-up observations of outbursts from a prototypical Anomalous X-ray Pulsar (4U 0142+61) and a radio-loud magnetar (PSR J1622-4950), a search for X-ray enhancement during giant radio pulses of the Crab pulsar, simultaneous radio monitoring of the Vela pulsar, and spectral and timing investigations of a bright rotation-powered pulsar (PSR B0656+14) and an X-ray isolated neutron star (RX J1605.3+3249). We review results from the first year of NICER observations.

**Author(s):** Teruaki Enoto

**Institution(s):** Kyoto University Contributing Team(s): the NICER Team

#### **426.05 - Spectral-Timing Studies of Accreting Neutron Star and Black Hole Systems(Abigail L. Stevens)**

The inner 100s of kilometers around compact objects in X-ray binaries are among the best laboratories for strong-field gravity. The X-rays originate from material in curved spacetime near the compact object, so they directly reveal the physical processes taking place in these extreme environments. NICER's unprecedented combination of temporal and spectral resolution has enabled an in-depth look into the soft X-ray spectral-timing properties of accreting compact objects. By studying broadband time variability and time-dependent spectral variability, the NICER science working groups have uncovered new details about accretion physics and the geometry of matter flows in the strong-gravity regime. In this talk I will feature results from the NICER science team on quasi-periodic oscillations showing energy-dependent time lags, thermonuclear X-ray bursts impacting the accretion environment, an accreting millisecond X-ray pulsar in an ultracompact binary, and the coronal evolution of a bright black hole. These results highlight the potential of NICER's upcoming Guest Observer program to shed more light on exciting X-ray sources.

**Author(s):** Abigail L. Stevens,

**Institution(s):** Michigan State University, University of Michigan Contributing Team(s): NICER team

#### **427 - Tech Innovations in Education**

##### **427.01 - Touch the Universe at Adler Planetarium: Combining 3D printing with visualizations to tell our universe stories(Maria Ann Weber)**

Our universe is inherently three-dimensional in nature, yet even within the planetarium experience, it is largely presented with two-dimensional imagery. At Adler Planetarium in Chicago, we have developed a new program called "Touch the Universe". This program utilizes 3D printed astrophysical objects in combination with visualizations to provide museum guests with a new way of exploring space and science concepts. Our project goals are three-fold: to encourage curiosity and exploration through multiple senses, to explore new avenues to present astrophysical data via 3D printed objects, and to provide more opportunities for engagement among our guests

with visual or cognitive impairment and those that are primarily tactile learners. This programming is delivered within Adler Planetarium's Space Visualization Lab (SVL), a unique space where local astrophysicists present their latest discoveries with immersive technologies in intimate conversations with museum guests. "Touch the Universe" presenters come from a pool of more than 70 volunteers, all provided with science communication training by Adler Planetarium. Working with our SVL volunteers, we identify the stories they want to tell about the universe and source related visualizations and 3D printed objects. Many of these stories have ties to Chicago-area institutions and Adler programs. Sometimes we make use of already available resources online, but often Adler Planetarium staff and the scientists themselves develop the associated visualizations or provide data to create new 3D printed objects. To facilitate the sharing of our material and the duplication of our program by other organizations, we make all of our materials available online via GitHub. Implementation of "Touch the Universe" within Adler's Space Visualization Lab has led to increased audience interaction and enquiry, making astronomy accessible to a broader audience.

**Author(s):** Mark Subbarao, Maria Ann Weber,

**Institution(s):** University of Chicago, Adler Planetarium

##### **427.02 - A Multiwavelength Visualization of Galactic Structure in the Whirlpool Galaxy(Frank Summers)**

The Whirlpool Galaxy provides a spectacular example of the striking appearance of a spiral galaxy. While visible light observations may showcase the bright stars and emission nebulae, infrared observations can provide greater detail into the dust distribution, and x-ray observations can highlight the largest of the star-forming regions. Using data from NASA's Hubble Space Telescope, Spitzer Space Telescope, and Chandra X-ray Observatory, we have developed correlated three-dimensional models of the Whirlpool Galaxy. Using those observations and models, we present a visualization that uses both 2D and 3D comparisons to demonstrate the variety of components in the structure of a spiral galaxy as well as the diverse insights and learning enabled by multi-wavelength astronomy.

**Author(s):** Kimberly Kowal Arcand, Robert Hurt, Frank Summers

**Institution(s):** Space Telescope Science Institute, Caltech, Smithsonian Astrophysical Observatory

##### **427.03 - NASA's Exoplanet Excursions Virtual Reality Experience: taking us places where we could not otherwise go... yet(Robert Hurt)**

As part of our communications work for the Spitzer Space Telescope, we have delved into the realm of Virtual Reality (VR). In this talk, we will share lesson-learned from our experience with development of NASA's Exoplanet Excursions experience, which we released for all major VR platforms

(Oculus, HTC Vive, YouTube360) as part of Spitzer's 15th anniversary activities in 2018 August. The experience takes the user on a guided journey through the TRAPPIST-1 system, known to be the home of 7 Earth-size exoplanets orbiting a star that is only a little larger than Jupiter, and is based on the best current understanding of what these worlds could be like given their sizes, densities, and distance to TRAPPIST-1. We followed an iterative development model, with significant input from user interviews and surveys over the course of the project. We will discuss future directions, and the potential of virtual reality as a vehicle for delivering astronomy communications and education content.

**Author(s):** Keith Miller, Janice Lee, Sean Carey, Robert Hurt, Gordon Squires

**Institution(s):** Caltech/IPAC

#### **427.04 - Telling Science Stories Through Tech: Virtual Reality(Joel Green)**

The James Webb Space Telescope (JWST), NASA's next great observatory launching in 2021, will routinely showcase astrophysical concepts that will challenge the public's understanding. Emerging technologies such as virtual reality bring the viewer into the data and the concept in previously unimaginable immersive detail. The new public release of WebbVR, a fully immersive virtual universe built by STScI and supported by Northrop-Grumman Aerospace Systems and NASA, explores concepts related to JWST science packaged into a thought-provoking framework. This experience demonstrates concepts specifically amenable to the virtual space at all size scales, including the kinematics of stars around supermassive black holes, photon-molecular interactions, and more. This type of engagement has garnered very positive reactions at exhibiting events where early versions of the VR have been deployed. WebbVR has been released to the public on the Steam platform.

**Author(s):** Joel Green, Alexandra Lockwood, Chad Smith, Brandon Lawton, Hussein Jirdeh, Denise Smith

**Institution(s):** Space Telescope Science Institute

#### **427.05 - Telling Science Stories Through Tech: Website as a Central Hub(Alexandra Lockwood)**

How does a website with numerous user pathways tell a coherent story? NASA's next great observatory, the James Webb Space Telescope (JWST), will routinely showcase astrophysical concepts that will challenge the public's understanding. The newly redesigned public-facing science website for Webb, [www.webbtelescope.org](http://www.webbtelescope.org), was developed to tell the main science stories of Webb while showcasing a variety of multimedia assets that target audiences with different knowledge levels. The aesthetic appeal and inviting navigation of the new site allows the user to begin engaging at whatever level they want, and to deepen their understanding as they click through the site. This idea of scaffolded messaging that reaches

a broad audience but also guides users to higher levels of interest and understanding can be applied to many communications formats, from websites to presentations and beyond.

**Author(s):** Alexandra Lockwood, Joel Green, Christine Pulliam, Denise Smith, Bonnie Meinke

**Institution(s):** Space Telescope Science Institute

#### **427.06 - Using Real Data in the Classroom with the Large Synoptic Survey Telescope(Travis Rector)**

The Education and Public Outreach (EPO) team of the Large Synoptic Survey Telescope (LSST) is developing investigations for formal education (K-12 and college) that will use real LSST data products. The investigations are being written as "notebooks" that will be accessed via a web browser. Embedded in the notebooks are widgets that enable students to interact with LSST data products. The six themes are: the Properties of Light, the Properties of Stars, the Milky Way and Galaxies, Cosmology, Variable Stars, and the Solar System. Each theme will consist of a foundational investigation and two "extension" investigations. The investigations are being designed to explore topics commonly taught in astronomy classes that are closely related to LSST science goals. All investigations will be populated with new LSST data products as they become available. Prior to LSST commissioning the investigations will use other datasets. To maximize adoptability, the notebooks are being written in HTML5 so they will function on all computers and tablets. No software will need to be installed nor will any datasets need to be downloaded, enabling students to use the investigations and embedded widgets in or outside of class (e.g., for online classes). The notebooks will be customizable to meet the needs of different instructors and classrooms. All of the widgets are being written in a way that will allow them to be used for open-ended inquiry. As part of my talk I will briefly describe the six investigations and their associated widgets and data products. A related poster by Amanda Bauer is also presented at this meeting.

**Author(s):** Claudia Araya Salvo, Travis Rector, Ardis Herrold, Edward Prather,

**Institution(s):** University of Alaska Anchorage, University of Arizona, Large Synoptic Survey Telescope Contributing Team(s): Education and Public Outreach (EPO) Team, Large Synoptic Survey Telescope

#### **427.07 - Science Communication and Education Through Online Astronomy Videos(Matthew Wenger)**

Online videos are an excellent way to reach modern digitally native audiences to teach them about astronomy. Online video platforms such as YouTube are both more important, and more competitive than ever. In this talk we will present current results from a science communication project called "Active Galactic Videos" and lessons learned about how to create online videos and work with undergraduate students to create high-

quality videos that communicate astronomy to public audiences. We will also discuss how we are using social media and collaborations to connect with other creators and grow our audience.

**Author(s):** Matthew Wenger, Alexander Danehy, Carmen Austin, Chris David Impey, Jenny Calahan

**Institution(s):** University of Arizona, University of Michigan, Kitt Peak National Observatory

## **428 - Large Scale Structure and Cosmology II**

### **428.02 - Exploring a novel probe for cosmology: cosmic voids(Elena Massara)**

There are still many unknowns that cosmological observations might help unveiling. Among these, the value for the sum of neutrino masses and the force driving the accelerated expansion of the Universe are some of the most interesting challenges. In this talk I will discuss a fairly new probe, the cosmic voids, to extract cosmological parameters and understand the nature of neutrinos and dark energy. First, I will discuss how voids can be used as cosmological tools and in particular to extract the neutrino masses. Second, I will present a theoretical framework to describe the matter density profile around voids and the void bias, which allow to understand the void evolution, provide the structure of fitting formulae for data analysis and give insights on the RSD analysis with voids.

**Author(s):** Elena Massara

**Institution(s):** Flatiron Institute

### **428.01D - A Perturbative Treatment of Intrinsic Alignments(Denise Schmitz)**

Intrinsic alignments (IA), correlations between the intrinsic shapes and orientations of galaxies on the sky, are both a significant systematic in weak lensing and a probe of the effect of large-scale structure on galactic structure and angular momentum. In the era of precision cosmology, it is thus especially important to model IA with high accuracy. Previous models for IA fall broadly into two categories: linear alignment models, which are linear in the matter density field, and tidal torquing models, which are quadratic in the matter density. More generally, these contributions can be considered part of an effective expansion in all potentially relevant cosmological fields at a given order. I have developed a full, self-consistent formalism up to third order in standard perturbation theory (SPT) for such a perturbative treatment of the IA field, analogous to the use of bias coefficients to quantify clustering. I will present this model and the associated power spectra -- the galaxy density-IA cross-correlation and IA-IA autocorrelation -- to one-loop order. I will then discuss the implications for weak lensing systematics as well as for studies of galaxy formation and evolution. This work includes a complete treatment of time-evolution effects, which is not only required for a self-consistent SPT expansion, but also allows for the use of IA to probe properties of galaxy formation. I will discuss how this

result can be used to constrain the redshift at which IA is determined, and provide forecasts for the relevant measurements.

**Author(s):** Denise Schmitz

**Institution(s):** California Institute of Technology

### **428.03D - N-body Cosmology with Abacus(Lehman Garrison)**

Interpreting galaxy surveys in a cosmological context requires an accurate forward model of large-scale structure. N-body simulations are the standard tool for this but are not without their drawbacks. For one, they are computationally expensive, requiring 10s of thousands of GPU node-hours for large simulations; for another, they are only as accurate as their discrete "macroparticle" representation of dark matter allows. In my dissertation, I address both of these challenges. Abacus is a code for cosmological N-body simulations based on an exact decomposition of the near-field and far-field force, making it exceptionally accurate and fast. Using one dual-GPU node, Abacus can solve a supercomputer-sized N-body problem in a fraction of the node-hours of other codes while retaining significantly higher force accuracy. This accuracy has allowed us to investigate and correct discreteness effects that arise from the macroparticle representation of dark matter. Using modified initial conditions, we can suppress discreteness errors in the small-scale late-time matter power spectrum by an order of magnitude. Additionally, a suite of halo catalogs and particle data from 165 Abacus N-body simulations spanning 40  $\Lambda$ CDM cosmologies is publicly available at <https://lgarrison.github.io/AbacusCosmos/>.

**Author(s):** Lehman Garrison

**Institution(s):** Harvard-Smithsonian Center for Astrophysics

### **428.04D - Multi-Variate Dependent Halo and Galaxy Assembly Bias(Xiaoju Xu)**

Galaxy forms in dark matter halo, its properties and distribution are connected to the host halo. Halo clustering is easy to study from N-body simulation, it plays an important role in learning galaxy formation physics and cosmology. I will talk about halo bias as function of halo mass and other halo properties (assembly bias), and the importance of studying halo assembly bias. I will show that it is unlikely to have a combination of halo variables to absorb all assembly bias effects. Together with galaxy-halo relationship, halo assembly bias can be connected to galaxy assembly bias, the later can be observed with large galaxy surveys. I will show the strength of galaxy assembly bias compared to that of halo, and its dependence on galaxy property-halo property relation.

**Author(s):** Zheng Zheng, Xiaoju Xu

**Institution(s):** University of Utah

### 429.01 - Nuclear Star Clusters and the Role of Environment(Chelsea Spengler)

**Author(s):** Alan McConnachie, Laura Ferrarese, Patrick CÃ´t , Thomas Puzia, Joel Roediger, Eric W. Peng, Chelsea Spengler, Laura Sales

## 429.03 - Star Clusters in Tidal Debris(Michael Rodruck)

**Author(s):** Jayanne English, Patrick R. Durrell, Debra Elmegreen, Iraklis Konstantopoulos, Jane Charlton, Karen

## 429.06 - The Dynamical Assembly of Disk Galaxies(Susan Kassin)

**Institution(s):** Space Telescope Science Institute, Johns Hopkins University

#### **429.07 - Searching for Lyman Continuum Photons in Young, Low-mass Starburst Galaxies at $z=1.3$ (Anahita Alavi)**

Searches for escaping Lyman continuum (LyC) emission from star-forming galaxies have been largely unsuccessful across a wide range of redshifts, seemingly in contradiction with the observed ionized universe. Most of these studies have focused on bright, massive sources, where an elevated production of ionizing photons is expected due to their high star formation activity. However, their high HI column density and dust obscuration prevents the ionizing radiation to escape to the IGM. Some theoretical studies predict a higher escape fraction of ionizing radiation in lower mass galaxies where stellar feedback (i.e., supernova winds) may be efficient in creating low HI column density chimneys in the interstellar medium. In this talk, we measure the escape fraction of LyC emission from a sample of 11 low-mass ( $109 M_{\odot}^{\text{TM}}$ ), emission line galaxies at  $1.2 < z < 1.4$  selected from the 3DHST survey. These galaxies have all been selected to have high ( $> 190 \text{ \AA}$ ...) H $\alpha$  equivalent width, indicating of young stellar population and low metallicity. We obtain deep, high sensitive HST/ACS SBC images probing the rest-frame LyC photons at  $z=1.3$ . Contrary to expectations, we do not detect any of the 11 galaxies (with  $S/N > 3$ ) in our LyC images. Our deep far-UV data enables us to place a robust limit on the absolute LyC escape fraction of  $< 4\%$  (and  $10\%$  for a couple of targets) for individual galaxies. We compare the physical properties (stellar mass, H $\alpha$  and [OIII] emission line equivalent widths, UV luminosity) of our sample to the LyC detections (and non-detections) in the literature at various redshifts, to understand why the current popular selection techniques are inefficient in identifying the LyC leakers.

**Author(s):** Anahita Alavi, Harry Isaac Teplitz, Claudia Scarlatta, Vihang Mehta, Brian Siana, James Colbert, Michael Rutkowski

**Institution(s):** Caltech/IPAC, UMN, UC Riverside, Stockholm University

#### **429.02D - HIRBS: The HI Rich Strongly Barred Sample(Lucy Claire Newnham)**

Strongly barred spiral galaxies are typically redder, more massive, less gas rich than unbarred spirals (e.g. Masters et al. 2011, 2012). It is clear from this that the formation of a bar correlates with the cessation of star formation. What is less clear is whether the link is casual: does the appearance of a bar create a process which stops star formation in disc galaxies, or is it merely a side effect of other processes? My PhD work has focused on an investigation of a sample of rare gas-rich and strongly barred systems with resolved HI observations (from both VLA and GMRT). Through this work we have revealed the distribution of the HI gas in the galaxies and provided observations for the largest ever sample of such galaxies (six in total) which can be used to test current theories and simulations of bar formation and growth. Through this we are investigating the impact of strong bars on gas in galaxies. We find a clear correlation between the growth of the strong bar,

and the distribution and amount of HI in the galaxies, especially relevant to the size and appearance of HI 'hole' in the centres of these galaxies.

**Author(s):** Lucy Claire Newnham

**Institution(s):** University of Portsmouth

#### **429.05D - Reconstructing Galaxy Star Formation Histories from Broad-band Photometry: The Dense Basis Approach(Kartheik Iyer)**

The star formation history (SFH) is a record of when a galaxy formed its stars. Observationally estimating the SFHs of galaxies allows us to study galaxy evolution by tracing individual galaxies backwards in time along their SFHs, as opposed to extrapolating average trends. We present the Dense Basis Spectral Energy Distribution (SED) Fitting method (Iyer & Gawiser '17), which uses a smooth, physically motivated basis to reconstruct the SFHs of individual galaxies along with uncertainties. The updated method uses a flexible parametrization along with Gaussian Processes to describe SFHs independent of the choice of a functional form. Applying the method to SEDs from CANDELS, we robustly estimated the stellar masses and star formation rates of nearly 100,000 galaxies while probing quantities that were previously inaccessible through SED fitting, including the number and duration of major star formation episodes in a galaxy's past. The Dense Basis method also provided a way to access the high-redshift low-stellar mass regime of the SFR- $M^*$  relation. By propagating galaxies backwards in time along their SFHs, we found that the SFR- $M^*$  correlation extends down to  $10^7 M_{\odot}$  at  $z \sim 6$ . We also estimated the stochasticity of SFHs on short timescales through simultaneously fitting a large ensemble of SEDs while varying a hyperparameter of the Gaussian Process model that controls the smoothness of the SFHs. In comparison to simulations, these SFHs allow us to place useful constraints on the strengths of feedback processes that regulate star formation in galaxies.

**Author(s):** Kartheik Iyer

**Institution(s):** Rutgers, the State University of New Jersey

#### **430 - Galaxy Formation and Evolution X 430.03 - Continuing to Push into the Early Universe with CANDELS(Steven Finkelstein)**

While the high-redshift component of the CANDELS survey was designed with the  $z \sim 6-8$  era in mind, these data do probe the far-UV of galaxies at even higher redshift. A few studies have ventured this far out, and have published conflicting results - some continue to find significant star-formation, while others conclude there is a steep decline in this quantity. I will report on a new search for  $z=9-10$  galaxies, making significant use of the Spitzer/IRAC data in the CANDELS fields. We have discovered a larger number of galaxies in this epoch than previous works, implying the SFR density may be higher than previously thought.

**Author(s):** Rebecca L Larson, Mimi Song, Mark Dickinson,

Norbert Pirzkal, Steven Finkelstein, Russell Ryan, Casey Papovich

**Institution(s):** The University of Texas at Austin, Texas A&M University, NASA Goddard, NOAO, STScI

#### **430.01D - HST ACS/G800L spectroscopy of red and dead intermediate redshift galaxies(Bhavin Joshi)**

I present analysis done on HST ACS/G800L grism spectroscopy of intermediate redshift galaxies at  $z \sim 1$ . Firstly, we investigate the accuracy of 4000Å break based redshifts derived by including grism data to existing photometry, i.e., the galaxies are selected such that they contain the 4000Å break in their grism spectra. We show evidence that below a break strength of  $D_{4000} \sim 1.6$  the spectrophotometric redshifts are only as accurate as photometric redshifts. Above a break strength of  $D_{4000} \sim 1.6$  we show that the spectrophotometric redshifts can improve the redshift accuracy over that of photometric redshifts. We argue that 4000Å break redshifts can complement emission line based redshifts for future space-based observatories like WFIRST and Euclid. Secondly, I present results from stacking grism spectra, on a color vs stellar mass diagram based grid, of galaxies at  $z \sim 1$ . We focus on red-sequence and green-valley galaxy populations to examine their quenching timescales for galaxies within different mass regimes.

**Author(s):** Bhavin Joshi

**Institution(s):** Arizona State University  
**Contributing Team(s):** PEARS collaboration

#### **430.02D - Analysis of the spatially-resolved V-3.6 $\mu$ m colors and dust extinction within 257 nearby NGC and IC galaxies(Duho Kim)**

I present and analyse spatially-resolved maps of the observed V to 3.6 $\mu$ m flux ratios and inferred dust extinctions for a sample of 257 nearby NGC and IC galaxies. Flux ratio maps are constructed using PSF-matched mosaics of SDSS g and r images, and Spitzer/IRAC 3.6 $\mu$ m images, with pixels contaminated by foreground stars or background objects masked out. Applying the " $I^2V$ " method Tamura et al. (2009, 2010) as recently calibrated as a function of redshift and morphological type by Kim et al. (2017), I then infer dust extinction maps for each galaxy. Radial extinction profiles are then compared with those from González Delgado et al. (2015) for each Hubble type, in order to translate our theoretical models to observed galaxy morphological type. I also highlight significantly low V to 3.6 $\mu$ m flux ratios at the center of galaxies embedding active galactic nuclei. Last, we discuss the applicability of the " $I^2V$ " dust correction method to more distant galaxies for which well-matched HST rest-frame visible and JWST rest-frame  $\sim 3.5\mu$ m images will become available in the near-future.

**Author(s):** Rolf A Jansen, Rogier Windhorst, Seth Cohen, Duho Kim

**Institution(s):** Arizona State University

#### **430.04D - Investigating the Shut-Down of Star Formation at High Redshift(Matthew Stevans)**

Understanding how the largest quiescent, spheroidal galaxies evolve from smaller star-forming, disk galaxies through the process of quenching is one of the most fundamental observational tests of galaxy evolution. There exists tension between existing models and observations partially due to observational studies lacking statistically significant sample of the most massive galaxies at high redshifts when the first quiescent galaxies formed. We present ensemble measurements of the star formation properties of the most massive galaxies ( $M > 10^{11} M_{\odot}$ ) during the epoch ( $z \sim 4$ ) when the most massive galaxies started shutting down. We assemble the largest sample of massive galaxies using the 12 photometric bands covering the unprecedentedly large (18 deg<sup>2</sup>) SHELA/HETDEX field. Using spectral energy distribution fitting and machine learning we find an enhanced number of sources at the bright end of the ultraviolet galaxy luminosity function where it intersects the faint end of the active galactic nuclei (AGN) luminosity function. Comparison to semi-analytical model results indicate no evidence for quenching due to AGN feedback and, if this excess is mostly comprised of galaxies, that star formation is more efficient at  $z = 4$  than today. We also present first results from the NEWFIRM-HETDEX Survey, the (24 deg<sup>2</sup>) K-band survey in the SHELA/HETDEX field and an analysis of the quiescent population of massive galaxies at  $z = 4$ .

**Author(s):** Isak Wold, Robin B Ciardullo, Jonathan Florez, Lalitwadee Kawinwanichakij, Rachel Somerville, Sydney Sherman, Matthew Stevans, Shardha Jogee, L. Y. Aaron Yung, Steven Finkelstein, Casey Papovich, Caryl Gronwall

**Institution(s):** The University of Texas at Austin, The Pennsylvania State University, Texas A&M University, Flatiron Institute, Rutgers University, NASA Goddard Space Flight Center  
**Contributing Team(s):** SHELA

#### **430.05D - Galaxy Overdensities and Emission Line Galaxies in the Faint Infrared Grism Survey(John Pharo)**

We improve the accuracy of photometric redshifts by including low-resolution spectral data from the Faint Infrared Grism Survey (FIGS), reducing the typical photometric redshift error of  $\hat{z} = 0.03 * (1+z)$  for purely photometric fits to  $\hat{z} = 0.02 * (1+z)$  for the spectra-supplemented objects. With higher redshift accuracy, we are able to search for galaxy overdensities in the FIGS fields. We find 24 significant overdensities across the 4 FIGS fields, including corroboration of independently spectroscopically verified clusters. We also present the redshifts, line identifications, and line fluxes for emission line galaxies (ELGs) with  $z \sim 0.3-3$  derived from the FIGS spectra, primarily detecting the  $H\delta \pm 6563 \text{ \AA}$ ,  $[OIII]5007 \text{ \AA}$ , and  $[OII]3727 \text{ \AA}$ , emission lines in rarely probed ELGs of faint

magnitude ( $F105W < 26.5$  mag) and low stellar mass ( $M^* \approx 10^{7.7} M_{\odot}$ ). Using the emission line fluxes combined with available optical and G141 spectra, we investigate properties of the ELGs, including gas-phase metallicity, star formation rates, and ionization states, in order to study the evolution of galaxies as functions of mass and redshift. By comparing the positions of ELGs with overdensity locations, we are able to investigate the density of galaxies in environments around ELGs over this redshift range. Thus, we are able to leverage FIGS spectra to conduct a comprehensive study of galaxy properties for a sample reaching unusually faint and low-mass galaxies.

**Author(s):** Norbert Pirzkal, James Rhoads, Russell Ryan, John Pharo, Sangeeta Malhotra

**Institution(s):** ARIZONA STATE UNIVERSITY, Space Telescope Science Institute, NASA Goddard Space Flight Center  
Contributing Team(s): The FIGS Team

### 431 - AGN Surveys & Lensing

#### 431.01 - X-ray & WISE AGN in the 37 deg2 SDSS-IV eBOSS Survey of Stripe 82(Stephanie LaMassa)

We summarize the results of a SDSS-IV eBOSS program to spectroscopically target WISE AGN candidates and X-ray sources in a  $\sim 37$  deg<sup>2</sup> area of Stripe 82,  $\sim 15.5$  deg<sup>2</sup> of which overlaps the largest contiguous portion of the Stripe 82 X-ray survey. This survey represents the largest spectroscopic survey of AGN selected on the basis of their WISE W1 - W2 colors and more than doubles the number of optically obscured X-ray and WISE AGN in the survey field. While the X-ray AGN detected by WISE and have WISE W1-W2 colors that do not meet the AGN color definition tend to be at low redshift ( $z < 1$ ) and luminosity ( $L_x < 10^{44}$  erg/s), about a quarter of the most luminous X-ray AGN ( $> 10^{44}$  erg/s) at  $z > 1$  are undetected by WISE. Approximately 70% of the WISE AGN are undetected by the X-ray observations in the field, though nearly half of the WISE AGN at  $z < 0.5$  could potentially be star forming galaxies and not AGN.

**Author(s):** Antonis Georgakakis, Mara Salvato, Chelsea L MacLeod, Tonima Tasnim Ananna, Stephanie LaMassa, Nic Ross, C. Megan Urry, Vivek Mariappan

**Institution(s):** Space Telescope Science Institute, Penn State University, National Observatory of Athens, Yale University, MPE, Royal Observatory of Edinburgh, Harvard-Smithsonian Center for Astrophysics

#### 431.04 - The BAT AGN Spectroscopic Survey (BASS) DR2, A Thousand New Spectra(Michael Koss)

The Burst Alert Telescope (BAT) instrument on the Swift satellite has surveyed the sky to unprecedented depth, increasing the all sky hard X-ray sensitivity by a factor of more than 20 compared to previous satellites. The goal of the BAT AGN Spectroscopic Survey (BASS) is to complete the first large ( $> 1000$ ) survey of hard X-ray selected AGN with optical spectroscopy. Here we present an overview of the second data release of spectra from Palomar/Doublespec and VLT/Xshooter

and several other telescopes which includes redshift determination, absorption and emission line measurements, and black hole mass and accretion rate estimates via broad lines and velocity dispersion for over 1000 AGN.

**Author(s):** Kyuseok Oh, Benny Trakhtenbrot, Daniel Stern, Meredith Powell, Claudio Ricci, Michael Koss, C. Megan Urry

**Institution(s):** Eureka Scientific, PUC Chile, ETH Zurich, JPL, Yale, Kyoto University  
Contributing Team(s): BASS Survey Team and Swift Survey Team

#### 431.05 - The Extragalactic Background Light in the Fermi-LAT era(Abhishek A Desai)

The collective emission of all sources over the history of the universe is encoded in the intensity of the extragalactic background light (EBL), the diffuse cosmic radiation field at ultraviolet, optical, and infrared wavelengths. A powerful technique to study the EBL is through the imprint it leaves in the spectra of distant gamma-ray sources via the photon-photon interaction ( $\gamma\gamma \rightarrow e^+e^-$ ). In this talk, I will report on the first unprecedented measurement of the EBL, in the UV, optical and IR wavelength regime, using GeV data from the Large Area Telescope on board the Fermi Gamma-ray Space Telescope and TeV data from ground based telescopes (like HESS, MAGIC, and VERITAS).

**Author(s):** Kari Helgason, Alberto Dominguez, Justin Finke, Vaidehi Paliya, Marco Ajello, Abhishek A Desai

**Institution(s):** Clemson University, US Naval Research Laboratory, University of Iceland, Universidad Complutense de Madrid  
Contributing Team(s): Fermi LAT collaboration

#### 431.06 - A Gravitationally Lensed Quasar at the Epoch of Reionization(Xiaohui Fan)

A high fraction of the most luminous high-redshift quasars was predicted to be lensed due to magnification bias. We report the discovery of a strongly lensed ultraluminous quasar at  $z = 6.51$ , the first such object detected at the epoch of reionization and the brightest quasar yet known at  $z > 5$ . High-resolution HST imaging reveals a multiple imaged system with a maximum image separation 0.2", best explained by a model of three quasar images lensed by a low luminosity galaxy at  $z \sim 0.7$ , with a magnification factor of  $\sim 50$ . This discovery suggests that a significant population of strongly lensed, high redshift quasars could have been missed by previous surveys, as standard color selection fails when the quasar color is contaminated by the lensing galaxy flux.

**Author(s):** David Thompson, Minghao Yue, Bram Venemans, Iskren Georgiev, Jiangtao Li, Xue-Bing Wu, Charles Keeton, Mario Bonaglia, Fabian Walter, Xiaohui Fan, Fuyan Bian, ran wang, Sebastian Rabieno, Feige Wang, Rohan Naidu, Ann Zabludoff, Jinyi Yang, Fabio Pacucci,

**Institution(s):** Peking University, OMPE, University of Arizona, Rutgers University, University of California, Santa Barbara, INAF, European Southern Observatory, University of

Michigan, MPIA, Yale University , Center for Astrophysics

#### **431.07 - A New Package to Simulate Quasar Microlensing(Jordan Koeller)**

Numerical simulation of gravitationally microlensed quasars provides a tool to determine the physical size and temperature profile of quasars' accretion disks, which is impossible through direct observation. Additionally we learn about the dark matter distribution of lensing galaxies by characterizing the frequency of microlensing-induced anomalies. In order to use microlensing as a tool, we develop a robust, large-scale simulator, written in Python, to model gravitationally lensed quasar source objects. The method consists of ray-tracing approximately  $10^9$  paths through a simulated starfield, taking advantage of the latest technologies in cluster computing, to calculate flux received by the observer from each lensed image from different regions of the accretion disk as the quasar moves relative to the lensing galaxy. We compare our simulations to observations of QSO2237+0305 in optical and X-ray wavebands to place constraints on the size of the quasar's accretion disk.

**Author(s):** David Pooley, Jordan Koeller

**Institution(s):** Trinity University

#### **431.08 - Phantom Quasars: a Missing Population of Lensed $z > 6$ Quasars(Fabio Pacucci)**

The discovery of the first strongly lensed quasar at  $z > 6$  (J0439+1634, Fan et al. 2018) represents a breakthrough in our understanding of the early Universe. Here I present the theoretical consequences of this detection. Pacucci & Loeb (2018) predict that the observed population of  $z > 6$  quasars should contain many sources with magnification factors lower than 10 and with image separations below the resolution threshold. Additionally, current selection criteria should have missed a substantial population of lensed  $z > 6$  quasars, due to the contamination of the drop-out photometric bands by lens galaxies. WFIRST will likely play a crucial role in revealing this population of "phantom quasars". The fraction of undetected quasars is estimated as a function of the slope of the bright end of the quasar luminosity function. For commonly accepted values of this parameter, the undetected lensed quasars could reach half of the population, whereas for steeper values the vast majority of the  $z > 6$  quasar population is lensed and still undetected. These "phantom quasars" would be misclassified and mixed up with low- $z$  galaxies. This would significantly affect the inferred black hole mass distributions, with profound implications for the UV, X-ray and infrared cosmic backgrounds and the growth of early quasars.

**Author(s):** Fabio Pacucci

**Institution(s):** Yale University

#### **431.02D - AGN Variability: Damped Harmonic Oscillator (DHO) model vs. the Damped Random Walk (DRW)(Jackeline Moreno)**

We present a study of SDSS Stripe 82 AGN variability using the Damped Harmonic Oscillator (DHO) model driven by colored noise. We explain the significance of three characteristic timescales provided by the DHO model and discuss how our results relate to the Damped Random Walk analysis of MacLeod et al. 2010. The accuracy of timescale estimation can be affected by noise, sampling cadence, and baseline length. Given our results, this investigation provides recommendations for next generation surveys like LSST. We also provide a methodology for applying Continuous Auto-Regressive Moving Average (CARMA) models to astrophysical variables and provide a guide for conducting ensemble studies in the DHO parameter landscape with machine learning methods like DBSCAN and t-SNE. We report the degree of correlations with luminosity, black hole mass and Eddington ratio with three timescales, amplitude (colored noise) parameters, and clusters in the DHO space.

**Author(s):** Jackeline Moreno, Michael S Vogeley, Gordon Richards

**Institution(s):** Drexel University

#### **432 - Astrobiology**

##### **432.01 - Quantifying upper limits in the radio search for technosignatures(Jean-Luc Margot)**

Astronomers often attempt to place upper limits on the occurrence of astrophysical sources or phenomena on the basis of observations and detection efficiencies. This practice occurs in the search for technosignatures, where authors of two recent, large surveys make claims about the number of technological species that are transmitting at radio wavelengths. Harp et al. (2016) suggest that it is not reasonable to rule out, based on data alone, the chance that 1 in 680 stars are transmitting. Enriquez et al. (2017) suggest that fewer than  $\sim 0.1\%$  of the stellar systems within 50 pc possess 100%-duty-cycle transmitters exceeding a certain power. However, both of these estimates neglect the fact that candidate signals are eliminated by the data processing pipelines, including many signals that match the detection criteria perfectly (e.g., narrowband signals with non-zero Doppler drift rates observed from unique directions on the sky). In some studies, certain bands known to include radio-frequency interference (RFI) are excised, but this excision is not taken into account in the calculation of upper limits. In other studies, candidate signals are eliminated if other candidate signals are found within hundreds of Hz of the original detection, on the questionable assumption that the proximity must be indicative of RFI, and this elimination is not taken into account in the calculation of upper limits. Attempting to place upper limits on the number of transmitting technological species after elimination of the signals that may reveal such species is problematic. Here, we describe a number of approaches that we are implementing to improve the thoroughness of radio searches and the reliability of upper limit calculations. First, we describe a new algorithm that minimizes



the rejection of candidate signals that are adjacent to other candidate signals in frequency space. Second, we describe estimates of the recovery of injected signals after processing by our pipeline (Margot et al., 2018) and similar pipelines. We find that probabilities of detection have been typically overstated, resulting in unreliable estimates of upper limits in this discipline.

**Author(s):** Jean-Luc Margot, Pavlo Pinchuk

**Institution(s):** University of California Los Angeles

#### **432.02 - Habitability of Post-Main Sequence Planetary Systems(Thea Kozakis)**

During the post-main sequence phase of stellar evolution the habitable zone moves out past the system's original frost line, introducing an opportunity for outer planetary system habitability. We model the evolution of star-planet systems with hosts ranging from 1-3.5 Solar masses throughout the post-main sequence, calculating stellar mass loss and its effects on planetary orbital evolution and atmospheric erosion. The maximum amount of time in the evolving habitable zone is calculated, and for several mass cases we use a coupled climate/photochemistry code to study the impact of the stellar environment on the planetary atmosphere throughout its time in the habitable zone. Particular focus is put on studying the ground UV environments Europa-like planets/moons that could have developed subsurface life on the main sequence, have is uncovered during the red giant branch, and then experience a relatively stable environment on the horizontal branch before heating up past runaway greenhouse conditions on the asymptotic giant branch.

**Author(s):** Thea Kozakis, Lisa Kaltenegger

**Institution(s):** Carl Sagan Institute, Cornell University

#### **432.03 - Astrobiology Science Strategy for the Search for Life in the Universe(Shelley A. Wright)**

Astrobiology is the study of the origin, evolution, distribution, and future of life in the universe. The National Academies convened the Committee on the Astrobiology Science Strategy for the Search for Life in the Universe in the fall of 2017. The committee's statement of task was to build on the foundation of the NASA 2015 Astrobiology Strategy, emphasizing key scientific discoveries, conceptual developments and technology advances since its publication. Rather than revisiting aspects that were already well covered in that document, the committee's work focused on additional insights from recent advances in the field, both intellectual (e.g. conceptual insights and frameworks, modelling), empirical (e.g. observations, discoveries, novel technologies), and programmatic. This updated strategy highlights areas of rapid scientific and technological growth and advancement that have occurred since publication of the 2015 strategy and highlights key scientific questions and technologies that are emerging. The results of the astrobiology science strategy, publicly released in October,

2018, will feed forward to the next decadal surveys in astronomy & astrophysics (2020) and planetary science (2021). This talk will cover highlights, findings, and recommendations of the report.

**Author(s):** Gerald F. Joyce, Shelley A. Wright, Roger E. Summons, James F. Kastingo, Nilton O. RennÃ³, Victoria Meadows, Britney E. Schmidt, Barbara Sherwood Lollar, Jack D. Farmer, Sushil Atreya, Frances Westall, Karyn Rogers, Alan P. Boss, Paul Falkowski, Philip M.

**Institution(s):** Teradata Corporation, oThe Pennsylvania State University, Rensselaer Polytechnic Institute, Blue Marble Space Institute of Science, Centre National de la Recherche Scientifique, Massachusetts Institute of Technology, Arizona State University, UC San

#### **432.05 - A search for technosignatures from TRAPPIST-1, LHS 1140, and 10 planetary systems in the Kepler field with the Green Bank Telescope at 1.15-1.73 GHz(Pavlo Pinchuk)**

As part of our ongoing search for technosignatures, we collected over three terabytes of data in May 2017 with the L-band receiver (1.15 - 1.73 GHz) of the 100-m diameter Green Bank Telescope. These observations focused primarily on planetary systems in the Kepler field, but also included scans of the recently discovered TRAPPIST-1 and LHS 1140 systems. We present the results of our search for narrowband signals in this data set with techniques that are generally similar to those described by Margot et al. (2018). Our improved data processing pipeline classified over 98% of the ~6 million detected signals as anthropogenic Radio Frequency Interference (RFI). Of the remaining candidates, 930 were detected outside of known RFI frequency regions. The data processing improvements presented in this work greatly enhanced the thoroughness of our search. We estimate that our current pipeline increases the Drake figure of merit associated with the search by a factor of five as compared with the pipeline described by Margot et al. (2018).

**Author(s):** Adam Greenberg, Ryan S Lynch, Jean-Luc Margot, Pavlo Pinchuk

**Institution(s):** Department of Physics and Astronomy, University of California, Los Angeles, Green Bank Observatory, Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, Center for Gravitational Waves and Cosmology, Department of P

#### **432.06 - The dawn of habitable conditions for complex life in the Universe(Paul Mason)**

The Universe evolved from a hot dense lifeless state to one capable of sustaining life as we know it. Complex life survives on Earth and presumably elsewhere throughout the Universe. Did life precipitate at many places at once, like a universal phase transition or not? Generally, the habitability of exoplanets has improved over time as essential chemical

abundances increased and threats such as supernovae, gamma-ray bursts, and AGN decreased in frequency and density. However, habitable conditions for complex life on planets are strongly constrained by host star and host galaxy properties. Environments promoting the emergence of life as a function of cosmic time and location are reviewed. It is suggested that a transition from an uninhabitable Universe to one capable of forming and sustaining complex life took place 5-6 Gy ago. However, many galaxies and stellar systems remain uninhabitable today.

**Author(s):** Paul Mason,

**Institution(s):** New Mexico State University, Picture Rocks Observatory - Astrobiology Research Center  
**Contributing Team(s):** Paul Mason

#### **432.04D - NO<sub>x</sub> on Early Earth and Early Mars as Electron Acceptors for Life's Emergence(Michael Wong)**

We quantify the amount of NO<sub>x</sub> produced in Hadean Earth's atmosphere and in Noachian Mars's atmosphere. Fixed nitrogen in the form of NO<sub>x</sub> is a critical component in some emergence-of-life scenarios: atmospherically generated nitrate (NO<sub>3</sub><sup>-</sup>) and nitrite (NO<sub>2</sub><sup>-</sup>) are the most attractive high-potential electron acceptors for driving the highly endergonic reactions at the entry points to autotrophic metabolic pathways at submarine alkaline hydrothermal vents (Ducluzeau, 2008; Russell, 2014). Early terrestrial atmospheres that are dominated by CO<sub>2</sub> and N<sub>2</sub> will produce nitric oxide (NO) when shocked by lightning and impacts (Ducluzeau, 2008; Nna Mvondo, 2001). Photochemical reactions involving NO, H<sub>2</sub>O vapor will then produce acids such as HNO, HNO<sub>2</sub>, HNO<sub>3</sub>, and HO<sub>2</sub>NO<sub>2</sub> that rain into an early ocean. There, they dissociate into or react to form nitrate and nitrite. Here, we present new calculations based on a novel combination of GCM and photochemical modeling, and predict the flux of NO<sub>x</sub> to early Earth's and early Mars's oceans. For the case of early Earth, our 0.1-, 1-, and 10-bar pCO<sub>2</sub> models result in NO<sub>x</sub> deliveries of 2.4 Å—105, 6.5 Å—108, and 1.9 Å—108 molecules cm<sup>-2</sup> s<sup>-1</sup>. After only tens of thousands to tens of millions of years, these NO<sub>x</sub> fluxes are expected to produce sufficient (micromolar) ocean concentrations of high-potential electron acceptors for the emergence of life. Turning to Mars, the Mars Science Laboratory recently discovered nitrate in sediments at Gale Crater: of particular interest is the 70-260 and 330-1,100 ppm nitrate in John Klein and Cumberland mudstone deposits, respectively, which sample the Noachian-aged sediments of Yellowknife Bay (Stern et al., 2015). These deposits are likely due to nitrogen fixation in Mars's early CO<sub>2</sub>-N<sub>2</sub> atmosphere. Using our modeling techniques, we seek to understand the state of Mars's climate that could have produced such a deposit of fixed nitrogen and what bearing that has for ancient Mars's habitability.

**Author(s):** Benjamin Charnay, Yangcheng Luo, Peter Gao, Michael Wong, Danica Adams, Michael Russell, Yuk Yung,

**Institution(s):** University of Washington, LESIA, Observatoire de Paris, Caltech, Jet Propulsion Laboratory, UC

Berkeley

#### **433 - Blazars and Changing-Look Quasars**

##### **433.01 - Changing-Look Quasar Candidates: First Results from Follow-up Spectroscopy(Chelsea L MacLeod)**

Active galactic nuclei (AGN) that show strong rest-frame optical/UV variability in their blue continuum and broad line emission are classified as "changing-look" AGN, or at higher luminosities changing look quasars (CLQs). These surprisingly large and sometimes rapid transitions challenge accepted models of quasar physics and duty cycles, offer several new avenues for study of quasar host galaxies, and open a wider interpretation of the cause of differences between broad and narrow line AGN. To better characterize extreme quasar variability, we present follow-up spectroscopy as part of a comprehensive search for CLQs across the full SDSS footprint. We employ photometry from the SDSS and Pan-STARRS 1 surveys and confirm CLQs using optical spectroscopy from the William Herschel, MMT, Magellan, and Palomar telescopes. For our adopted S/N threshold on variability of broad H $\beta$  emission, we find 16 new CLQs, which are at lower Eddington ratio relative to the overall quasar population. Among highly variable quasars, the CLQ fraction increases from 10% to roughly half as the 3420 Angstrom continuum flux ratio increases from 1.5 to 6. We release a catalog of over 200 highly variable candidates to facilitate future CLQ searches.

**Author(s):** Alastair Bruce, Nic Ross, John Ruan, Chelsea L MacLeod, Matthew Graham, Daniel Stern, Michael Eracleous, Andy Lawrence, Scott Anderson, Paul Green, David Homan, Amy Lebleu, Jessie Runnoe

**Institution(s):** Smithsonian Astrophysical Observatory, ROE, University of Washington, UCF, PSU, U Mich, McGill U, Cal Tech, JPL

##### **433.03 - Chandra X-ray Clues to the Origin of Changing-Look Quasars(John Ruan)**

Changing-look quasars display dramatic changes in repeat optical spectroscopy over surprisingly short timescales of just a few years, such as the appearance and/or disappearance of broad emission lines and continuum emission. However, the physical origin of these changes is still unclear, and thus we aim to use a combination of X-ray and optical observations to interpret these phenomena. I will present results from our Chandra observations of faded changing-look quasars in their current faint state. Despite their dramatic fading in the optical, all changing-look quasars in our sample are still detected in X-rays. I will discuss the implications of these results for the structure of the accretion flows and the origin of the dramatic fading.

**Author(s):** Chelsea MacLeod, John Ruan, Scott Anderson, Michael Eracleous, Daryl Haggard, Paul Green, Jessie Runnoe

**Institution(s):** McGill University, Pennsylvania State University, University of Washington, University of Michigan,

**433.04 - Recent Highlights from the VERITAS Gamma-ray Observatory(Amy Furniss)**

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is a ground-based gamma-ray observatory consisting of an array of four atmospheric Cherenkov telescopes located in southern Arizona. This instrument observes the gamma-ray sky at energies above 100 GeV. The majority of the sources detected by VERITAS are active galactic nuclei, with gamma-ray emission originating from the relativistic jets. Nearly 5000 hours of observations of active galactic nuclei (AGN) have been performed over the last 10 years. These observations have led to 36 detections up to the redshift of 0.9, including the FRI radio galaxy 3C 264, currently the most distant radio galaxy yet detected. Additionally, the VERITAS observations of blazars can be used to constrain the spectral energy distribution of the extragalactic background light, and the intergalactic magnetic field. VERITAS has also played a key role in multi-messenger astrophysics; as both gamma-rays and neutrinos are produced in hadronic interactions, a joint study has the potential for revealing powerful cosmic accelerators. VERITAS looks for connections between very-high-energy gamma-rays and astrophysical neutrinos by following up on highly-energetic neutrinos discovered by IceCube. In this talk I will present some recent highlights of particle-astrophysics studies carried out with VERITAS.

**Author(s):** Amy Furniss

**Institution(s):** California State University East Bay  
Contributing Team(s): VERITAS

**433.05 - A month-long QPO in gamma-ray emission from a blazar(Zhongxiang Wang)**

Since 2016 October, the candidate blazar source PKS 2247-131 has undergone a gamma-ray outburst, which we studied using data obtained with the Fermi Gamma-ray Space Telescope and those from multi-wavelength observations. As an optical spectrum we obtained during the outburst only shows a few weak absorption lines, typical of the BL Lacertae sub-class of the blazar class, we confirm that PKS 2247-131 is a blazar. From our analysis of the Fermi data, we find a month-long quasi-periodic oscillation (QPO) in the gamma-ray emission after the initial flux peak of the outburst. This QPO is the first clear case of a relatively short oscillation, compared to those year-long QPOs, previously apparently identified in blazars with Fermi. We show that the QPO is explained by considering a helical structure in the jet. The viewing angle to the dominant emission region in the jet undergoes periodic changes, producing the observed flux modulation through changes in the relativistic Doppler boosting effect. The time scale of the QPO suggests that a binary supermassive black hole system may exist in PKS 2247-131.

**Author(s):** Zhongxiang Wang

**433.07 - HAWC observations of hour-scale TeV flares from the blazars Markarian 421 and Markarian 501(David Burkhart)**

We present the detection of several very high energy (100 GeV-100 TeV) flares emitted by the blazars Markarian 421 and Markarian 501 by the HAWC (High-Altitude Water Cherenkov) Observatory. The HAWC Observatory is located near Puebla, Mexico and detects gamma rays in the TeV band. The detector is able to scan two-thirds of the sky over a 24-hour period of time, making it ideal to monitor a large number of sources. This presentation focuses on the HAWC real-time flare monitor, which is able to detect flares that vary from a few minutes to a few days. I will discuss several flares detected from Markarian 421 and 501 over a period from December 2014 to December 2017. After presenting the spectra, I will also discuss the implications of these results in the context of very high energy blazar emission models.

**Author(s):** Thomas Weisgarber, David Burkhart

**Institution(s):** University of Wisconsin-Madison  
Contributing Team(s): The HAWC Collaboration

**433.02D - Examining extreme nuclear variability in the galaxies that host Active Galactic Nuclei(Reza Katebi)**

In this dissertation talk, I will present research on two topics. The first one is about the “changing look” (CL) active galactic nucleus (AGN) PS1-13cbe. Understanding the nature of extreme variability in the nucleus of the galaxies that host AGN is very important to better understand the processes that fuel these events. Recently, a new type of AGN has been observed that change Type by showing the appearance/disappearance of broad emission lines that is accompanied by an increase/decrease in the continuum flux. These objects are called “changing look” and challenge the existing orientation based unification scheme. We present a transient called PS1-13cbe that was found in Pan-STARRS1/MDS survey. We obtained multi-epoch optical spectroscopy after the outburst. This object shows the dramatic appearance/disappearance of broad emission lines and a factor of  $\sim 8$  increase in the optical continuum and changes Type from Seyfert 2 to a Seyfert 1 and back to Seyfert 2 again. We argue that these dramatic changes are most likely caused by variability in the pre-existing accretion disk than a tidal disruption event, supernova, or variable obscuration. The turn-on timescale of  $\sim 70$  days observed in this transient is among the shortest ever observed in a CL AGN. The second topic is about the performance of a newly introduced neural network called Capsule Network on galaxy morphology prediction. Understanding morphological types of galaxies is a key parameter in studying their formation and evolution. Different types of Neural network structures have been used previously for galaxy morphology prediction

that have disadvantages such as not being invariant under rotation. We present our results on the performance of Capsule Network that is rationally invariant and spatially aware, on galaxy morphology prediction.

**Author(s):** Reza Katebi

**Institution(s):** Ohio University

## 434 - Seyferts and LINERs

### 434.01 - The KONA Survey: What Drives Black Hole Growth in Local Seyfert Galaxies?(Erin K S Hicks)

The Keck OSIRIS Nearby AGN (KONA) survey traces the inflow of the molecular gas within the central 400pc of local Seyfert galaxies down to scales of tens of parsecs. The KONA sample consists of 40 bona-fide Seyfert AGN spanning over three orders of magnitude in both K-band and X-ray luminosities. The two dimensional mapping of the distribution and kinematics of this circumnuclear gas, traced by H<sub>2</sub> 1-0 S(1) 2.12 micron emission, shows that the gas is generally in disk rotation with superimposed components of inflow and/or outflow. These kinematics are interpreted within the context of the dust morphology traced out to scales of kiloparsecs in visible-near infrared color maps, providing a framework for the identification of the primary mechanism driving the inflow of gas. The identified inflow of the molecular gas is used to test the theory that the primary fueling mechanism of the observed black hole growth is dependent on host galaxy type and environment. Trends in the properties of this circumnuclear molecular gas with AGN properties such as Seyfert type, X-ray luminosity, and the presence of a hidden broad line region, are also presented.

**Author(s):** Erin K S Hicks, Helen Kim, Francisco Mueller Sanchez, Matthew Malkan

**Institution(s):** University of Alaska Anchorage, University of California Los Angeles, University of Memphis

### 434.03 - Coronal Properties of Swift/BAT-Selected Seyfert 1 AGN observed with NuSTAR(Nikita Kamraj)

The continuum X-ray emission from Active Galactic Nuclei (AGN) is believed to originate in a hot, compact corona located above the accretion disk. Compton upscattering of UV photons from the inner accretion disk by coronal electrons produces a power law X-ray continuum with a cutoff at energies determined by the electron temperature. The NuSTAR observatory, with its high sensitivity in hard X-rays, has enabled detailed broadband modeling of the X-ray spectra of AGN, thereby allowing tight constraints to be placed on the high-energy cutoff of the X-ray continuum. Recent detections of low cutoff energies in Seyfert 1 AGN in the NuSTAR band have motivated us to pursue a systematic search for low cutoff candidates in Swift/BAT-detected Seyfert 1 AGN that have been observed with NuSTAR. We use our constraints on the cutoff energy to map out the location of these sources on the compactness - temperature diagram for AGN coronae, and discuss the implications of coronae whose high-energy cutoff

may indicate a low coronal temperature on the cooling and thermalization mechanisms in the corona.

**Author(s):** Murray Brightman, Anne Lohfink, Mislav Balokovic, Fiona Harrison, Nikita Kamraj

**Institution(s):** California Institute of Technology, Montana State University, Harvard-Smithsonian Center for Astrophysics

### 434.04 - X-ray and UV Monitoring of the Seyfert-1.5 Galaxy Markarian 817(Anthony Morales)

We report on long-term simultaneous X-ray and UV monitoring of the Seyfert 1.5 galaxy Mrk 817 using the Neil Gehrels Swift Observatory XRT and UVOT. Prior work has revealed that the X-ray flux from Mrk 817 has increased by a factor of ~40 over the last 40 years, but the UV emission has only changed by a factor of ~2.3. We find that the X-ray (0.3-10.0 keV) and the UVM2 (roughly 2000-2500 Å) fluxes have fractional variability amplitudes of 0.35 and 0.18, respectively, over the entire monitoring period (2017-02-01 to 2018-20-04). A cross-correlation analysis is performed on the X-ray (0.3-10.0 keV) and UVM2 light curves over the entire monitoring period, a period of less frequent monitoring, and a period of more frequent monitoring. The analysis reveals no significant correlation between the two at any given lag. Geometric beaming (e.g., a funnel in the inner disk) and/or relativistic beaming of the X-ray emission could explain the lack of a correlation. Alternatively, scattering in an equatorial wind could also diminish the ability of more isotropic X-ray emission to heat the disk itself.

**Author(s):** Mark Reynolds, Jon Miller, Edward Cackett, Anthony Morales, Abderahmen Zoghbi

**Institution(s):** University of Michigan, Wayne State University

### 434.05 - The Lick AGN Monitoring Project 2016: Velocity-Resolved H- $\beta$ Lags and Their Implications for Broad Line Region Kinematics(Vivian U)

In the 2016 campaign of the Lick AGN Monitoring Project, we carried out a 100-night spectroscopic monitoring program using the Kast spectrograph on the 3-m Shane Telescope at Lick Observatory from April 2016 to May 2017. Designed to probe luminosity-dependent trends in broad line region structure and dynamics, our reverberation-mapping campaign targeted 21 low-redshift Seyfert galaxies with luminosities of  $L(5100\text{\AA}...) \sim 1044$  erg/s and predicted black hole masses of 107-108.5 solar masses for photometric and spectroscopic monitoring. Here, we present our first results on the light curves of the V-band continuum and various optical emission lines in our sample. We will show our velocity-resolved lag measurements and discuss their implications for the kinematics of broad-line regions in this high luminosity regime.

**Author(s):** Vivian U

**Institution(s):** University of California, Irvine Contributing

Team(s): LAMPO6 Collaboration

#### **434.06 - Probing the active galactic nuclei (AGN) torus structure using X-ray spectral variability.(Sibasish Laha)**

It is still a big puzzle as to how the host galaxy gas (at kpc scales) feeds the accretion disk of a supermassive black hole (SMBH), at sub-pc scales, and thereby fuels the central engines of active galactic nuclei (AGN). Circumnuclear structures such as the cold, dusty "torus" are believed to be an active step in SMBH accretion, and understanding the structure of this medium is essential for understanding disk/SMBH fueling. However, the torus structure is still highly debated, with various theoretical models encompassing continuous or clumpy distributions. A major probe of the torus' properties is the variable absorption detected in the 0.3-10 keV X-ray spectra, which serves to probe the torus' morphology and location. Here, we present the latest results from an extensive X-ray spectral variability study of a sample of 20 Compton-thin Seyfert 2 galaxies using XMM, Chandra, Suzaku and NuSTAR. The column density variations (or lack thereof) enable us to probe various torus morphology scenarios and to also consider possible host galaxy contributions to total absorption.

**Author(s):** Mirko Krumpe, Sibasish Laha, Robert Nikutta, Alex Markowitz, Richard Rothschild

**Institution(s):** University of California, San Diego, NOAO, Leibniz Institute for Astrophysics

#### **434.07 - HERSCHEL OH SPECTROSCOPY OF SEYFERT, LINER, AND STARBURST GALAXIES(Jordan Runco)**

We select a sample of 179 local ( $0.05 < z < 0.35$ ) galaxies from the Herschel Science Archive to investigate possible relationships between the 65 $\mu$ m, 71 $\mu$ m, 79 $\mu$ m, 84 $\mu$ m, 119 $\mu$ m, and 163 $\mu$ m OH lines and the central region of the galaxy. The sample was observed using the PACS instrument, and contains a wide range of Seyfert galaxies, LINERs, and non-active star-forming galaxies. We fit the profiles of the six OH lines when available in each galaxy to obtain the equivalent width (EW). We find 24 galaxies with some P-Cygni or reverse P-Cygni line profiles, which indicate outflows and inflows. We find a significant correlation between the EW of the 79 $\mu$ m and 119 $\mu$ m OH lines and both the optical spectral type, and the dust temperature measured by 25 $\mu$ m/60 $\mu$ m slope. The more powerful the AGN, the more likely the OH lines are in emission. OH emission is more common in Seyfert-1's than in Seyfert-2's. The other four OH lines have fewer observations; they do not show these correlations. This could be related to the process by which the OH lines go into emission. For the 79 $\mu$ m and 119 $\mu$ m lines, this is thought to be from collisional excitation in the dense AGN environment. Emission in the other four lines is probably generated by radiative pumping, since they arise from much higher energy levels ( $E/k = 300-$

600K). Bivariate linear regressions reveal that the correlations are strongest with optical spectral type, and that the correlation with dust temperature is secondary, due to the warmer dust in Seyfert nuclei. Lastly, we use the [NUV - H] color to estimate the amount of dust obscuration. We find that more dust obscuration makes the 119 $\mu$ m line more likely to be in absorption, but not the other five OH lines. This additional correlation with EW(OH119) is driven by P-Cygni features in outflows which are particularly prominent in ULIRGs, where the absorption component often dominates the emission component.

**Author(s):** Juan Fernandez-Ontiveros, Jordan Runco, Matthew Malkan, Luigi Spinoglio

**Institution(s):** UCLA, Instituto di Astrofisica e Planetologia Spaziali, Instituto de Astrofisica de Canarias

#### **434.08 - False positives and significance testing in broad-line reverberation mapping(Aaron Barth)**

Broad-line reverberation mapping uses the time delay between AGN continuum and emission-line flux variations to measure the size of the broad-line region. The lag is measured by finding the peak of the cross-correlation function between the two light curves. A key question is the level of statistical significance of a putative cross-correlation peak: in other words, what is the probability that an observed peak could have arisen by chance between two intrinsically uncorrelated light curves? In multiwavelength variability studies of AGN, this question has frequently been addressed using Monte Carlo simulations to estimate the probability of a false positive detection of a correlation between light curves in different wavebands. However, for broad-line reverberation mapping, null hypothesis testing has almost never been used to quantify the significance of broad-line reverberation lags. Instead, a variety of ad hoc criteria have been employed with no general consistency between different programs. Null hypothesis testing is particularly critical when light curves have low S/N, poor sampling, or large temporal gaps, which will be the case for some campaigns targeting high-luminosity quasars due to their long variability timescales. We will discuss the importance of significance testing in broad-line reverberation mapping, describe methods that can be used to estimate the statistical significance of a lag detection, and provide examples and applications using published reverberation mapping data.

**Author(s):** Dale Mudd, Aaron Barth

**Institution(s):** UC Irvine

#### **434.02D - Demystifying the Diverse IR SEDs of Type-1 AGNs from $z \sim 0$ to $z \sim 6$ (Jianwei Lyu)**

To gain insights into the nature of AGN dust environment and explore its possible evolution, we have conducted a systematic research to reveal the connections behind the variations of AGN SEDs through a comparative study of local AGNs with high- $z$  objects, covering broad ranges of luminosity ( $L_{\text{AGN}} \sim 10^8 - 10^{14}$

L $\alpha$ <sup>S</sup><sup>TM</sup>) and redshift ( $z \sim 0-6$ ) (Lyu, Rieke & Alberts 2016, Lyu, Rieke & Shi 2017; Lyu & Rieke 2017; Lyu & Rieke 2018). We have shown a “minimalist” two-free-parameter semi-empirical model is good enough to reconcile the IR SED shapes of all major populations of type-1 AGNs, including local Seyfert-1 nuclei, normal blue quasars, extremely red quasars at  $z \sim 1/4-3$  (Ross et al. 2015), AGNs with mid-IR excess emission at  $z \sim 1/4-2$  (Xu et al. 2015), hot dust-obscured galaxies at  $z \sim 1/4-5-4$  (Eisenhardt et al. 2012), and dust-free quasars at  $z \sim 1/4-6$  (Jiang et al. 2010). In fact, the commonly seen UV-optical extinction, the unexpected strong mid-IR polar dust emission, and the poorly-understood near- to mid-IR SED variations in type-1 AGNs can be physically connected in a similar fashion. It is highly likely that most type-1 AGNs, regardless of their luminosities and redshifts, share similar torus properties but differ mainly due to the extended (sub-kpc to kpc scales) polar dust component. By grouping similar SED behaviors together and summarizing observations in the literature, we have proposed that the AGN environment could be grouped into three general categories, in which feedbacks from the AGN and/or the host galaxy would influence the behavior of the polar dust component. The possibly frequent appearance of the AGN polar dust emission greatly complicates the interpretation of AGN IR properties and undermines the validity of estimating the torus dust covering factor from SEDs. The templates developed from this work can be generally applied in e.g., SED decompositions of galaxies with possible AGN contribution, IR AGN selections and the search for AGN candidates with strong polar dust emission.

**Author(s):** Jianwei Lyu, George Rieke

**Institution(s):** Steward Observatory

### **435 - Dwarf & Irregular Galaxies IV: Leaking, Bursting, Black Holes, and More**

#### **435.01 - Ionization-Parameter Mapping and Lyman Continuum Escape in Tololo 1247-232 (M. Oey)**

Tololo 1247-232 is a low-redshift, interacting starburst system that is a confirmed Lyman-continuum (LyC) emitter. We have obtained narrow- and broad-band imaging with WFC3 and ACS aboard the Hubble Space Telescope. Using these data, we present ionization-parameter mapping (IPM) of Tol 1247-232 in [O III]  $\lambda 5007$  / [O II]  $\lambda 3727$  to clarify the location and radiative transfer of the regions that are optically thin in the LyC. We also carry out photometry and SED fitting of the super star clusters (SSCs) in this system. The central starburst is responsible for the LyC escape, and this complex is dominated by two, extremely massive SSCs that differ in age by about 8 Myr. Mechanical feedback from the older cluster may promote a large escape fraction from the second, and we suggest that this synergy may be relevant to LyC escape in other systems as well.

**Author(s):** Anne Jaskot, M. Oey, Bethan James, Genoveva Micheva, Ryan P. Keenan

**Institution(s):** University of Michigan, University of Arizona, Leibniz Institute for Astrophysics, STScI, University of

Massachusetts

#### **435.02 - JVLA continuum observations of extreme star-forming dwarf galaxies (Jacqueline Monkiewicz)**

Many of the canonical star-forming laws commonly used in the local universe are found to deviate at extreme metallicities, typically at nebular oxygen abundances below  $12 + [\text{O}/\text{H}] < 8.1$ , or  $1/5-1/10$  the Solar abundance. The behavior of the infrared-radio relationship at low metallicities is not well known, however, largely due to lack of radio continuum detections at the low luminosity end. It is possible to correct this situation with the upgraded Jansky Very Large Array (JVLA). Using a sample of 10 extreme dwarf galaxies with archival mid- and far-infrared data, and nebular oxygen abundances ranging from  $8.1 < 12 + [\text{O}/\text{H}] < 7.1$ , I investigate the effects of extreme metallicities on the infrared-radio relationship using 40 hours of C, S, and L-band observations with the JVLA. C-band (4-8 GHz) radio continuum emission is detected from all 10 of these galaxies. These represent the deepest observations at these frequencies for all of these galaxies, and the first radio continuum detections from five galaxies: Leo A, UGC 4704, HS 0822+3542, SBS 0940+544, and SBS 1129+476. The radio continuum in these galaxies is strongly associated with the presence of optical H-alpha emission, with flat spectral slopes suggesting a mix of thermal and non-thermal continuum.

**Author(s):** Jacqueline Monkiewicz

**Institution(s):** Arizona State University

#### **435.03 - An Accreting $\sim 10^5$ Msun Black Hole at the Center of Dwarf Galaxy IC 750 (Ingyin Zaw)**

The dwarf galaxy IC 750 is a rare system which hosts an AGN, found in  $\sim 0.5\%$  of dwarf galaxies, with circumnuclear 22 GHz water maser emission, found in  $\sim 3-5\%$  of Type 2 AGNs. Water masers, currently the only known tracer of warm dense gas in the central parsec of AGN resolvable in position and velocity, provide the most precise and accurate mass measurements of SMBHs outside the local group. We have mapped the masers in IC 750 and find that they trace a trace a nearly edge-on disk,  $\sim 0.2$  pc in diameter, around a black hole with a best fit mass of  $7.1-7.9 \times 10^4$  Msun and a mass upper limit of  $\sim 1 \times 10^5$  Msun. This mass is one to two orders of magnitude below what is expected from the M-sigma (sigmas reported in literature range from 70 km/s to 119 km/s) and M-Mstar ( $\log(\text{Mstar}) = 9.1$  Msun) relations, perhaps because IC 750 does not have a prominent bulge. Using [OIII] $\lambda 5007$  and 2-10 keV X-ray luminosities to estimate the bolometric luminosity, we find that the central black hole is accreting at  $\sim 3-10\%$  of its Eddington limit.

**Author(s):** Walter Brisken, Michael Rosenthal, Hind Al Noori, Lincoln Greenhill, Ingyin Zaw, Yanping Chen

**Institution(s):** New York University Abu Dhabi, Long Baseline Observatory, Harvard Smithsonian Center for

**435.04 - Black Holes as Tracers of Simulated Dwarf Galaxy Properties(Ramon Sharma)**

Supermassive black holes are thought to be ubiquitous among high-mass galaxies, and are thought to heavily influence their structural evolution through a variety of feedback mechanisms. However, the occupation fraction of black holes in dwarf galaxies and the effects of black holes on their structural evolution are not observationally well-constrained. Simulations provide a way forward for making predictions on the coupling between black holes and low-mass galaxy structure. We utilize the Romulus25 cosmological hydrodynamic simulations to study the cosmic population of massive black holes in dwarf galaxies, and to study the effects of massive black holes on various structural properties of the host which may be observable in the near future. We find that massive black holes may not strongly couple to their host dwarf galaxy, but instead may act as tracers of the early star formation history.

**Author(s):** Alyson Brooks, Ramon Sharma  
**Institution(s):** Rutgers University

**435.05 - Small Statistics No More: a suite of simulated dwarf galaxies to interpret observations(Alyson Brooks)**

I will introduce a suite of fully cosmological zoom simulations designed to produce hundreds of dwarf galaxies in order to interpret and prepare for upcoming Local Volume observations (and beyond). We simulate field regions that contain many dwarfs (the Marvel suite) as well as the highest-ever resolution Milky Way-mass galaxies and their environments (the Justice League runs). For the first time, we are able to make predictions for the population of ultra-faint dwarfs that will be discovered in the Local Group with LSST due to the ultra-high resolution of the simulations. I will highlight science that is being done with this suite, including (1) predictions for the stellar mass-to-halo mass relation and its scatter at the faint end, (2) mock observations of the circum-galactic medium in dwarfs, and (3) predictions for the merger rate of massive black holes in dwarfs that can be probed by LISA all the way back to the “dark ages” before reionization. This work is supported by NSF-AST-1813871, NSF-AST-1813961, HST-AR-14281, and HST-AR-13925. Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center. This research is also part of the Blue Waters sustained-petascale computing project, which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-Champaign and its National Center for Supercomputing Applications. This work was supported by a PRAC allocation NSF award number OCI-1144357.

**435.06 - The morphology and structure of stellar populations in the Fornax dwarf spheroidal galaxy from Dark Energy Survey Data(Mei-Yu Wang)**

Using deep wide-field photometry three-year data (Y3) from the Dark Energy Survey (DES), we present a panoramic study of the Fornax dwarf spheroidal galaxy down to a depth of  $g, r < 23.5$ . We use this data to study the structural properties of Fornax, overall stellar population, and its member stars in different evolutionary phases. Fornax is found to be more spatially extended than what early studies suggested and shows no significant distortions or signs of tidal disturbances down to a surface brightness limit of  $\sim 32.1 \text{ mag/arcsec}^2$ . There are many rich substructures revealed within Fornax, including clumpy overdensities in the young main-sequence populations at the Fornax center, and hints of shell-like features that depart from a symmetric and smooth overall light profile. The high quality DES Y3 data allows us to study these features in great accuracy, and provides insights into Fornax’s complex formation history.  
**Author(s):** Sergey Koposov, Mei-Yu Wang, Thomas de Boer, Adriano Pieres  
**Institution(s):** Carnegie Mellon University, Instituto de Fisica, UFRGS, University of Surrey Contributing Team(s): the DES Collaboration

**436 - Circumstellar Disks III****436.01 - A Gap in the HD 15115 Debris Disk Detected with ALMA(Meredith Ann MacGregor)**

Debris disks are considered to be the end stage of circumstellar evolution, surrounding mature planetary systems that formed earlier. It is expected that any interior planets should interact with the dusty material in these disks, sculpting it through gravitational perturbations. HD 15115, an F-type star, hosts a nearly edge-on debris disk (originally dubbed the 'Blue Needle') that shows an extreme asymmetry in optical scattered light, with an extent almost two times larger to the west of the star than to the east. We present new observations from the Atacama Large Millimeter/submillimeter Array (ALMA) at 1.3 mm that capture this intriguing system with the highest resolution at millimeter wavelengths to date. For the first time, we see evidence in this new ALMA image for multiple rings or a gap in the HD 15115 debris disk. By fitting models directly to the observed visibilities within a Markov Chain Monte Carlo (MCMC) framework, we are able to characterize the millimeter continuum emission and place robust constraints on the disk structure. We use this model fitting to infer the characteristics of a planet that could be producing the detected gap.  
**Author(s):** Glenn Schneider, Aki Roberge, Alycia J Weinberger, John Debes, David Wilner, Meredith Ann MacGregor, Thayne Currie, Seth Redfield, A. Meredith Hughes  
**Institution(s):** Carnegie

#### **436.02 - HIGH-CONTRAST IMAGING OF A NEW CIRCUMBINARY DISK AROUND A YOUNG SPECTROSCOPIC BINARY(Marie Ygouf)**

Since the Kepler mission discovered extrasolar planets orbiting binary stars, we know that these circumbinary planets are relatively common. The scenario for their formation is however still unclear. Did they form in the perturbed environment close to their host stars or did they form further out and then migrate inwards? Solving this mystery requires detailed study of the morphology, composition, and dynamics of young binary-disk systems where planets may still be forming. We report the most detailed high-resolution images in scattered light of a new disk around a spectroscopic binary, embedded in a multi-stellar system. With a ring, a cavity and at least two spiral arms the disk's structure indicates possible interactions with close stellar companions or with forming planets. Our study raises additional questions that may be addressed with JWST and ALMA follow-up.

**Author(s):** Johannes Sahlmann, Steve Lubow, Ruobing Dong, Marie Ygouf, Alycia J Weinberger, Jos de Boer, Charles Beichman, John Debes, Gaspard Duchene, Rahul Patel, Rachel Akeson, Julien H Girard, Laurent Pueyo, Marshall Perrin, Tiffany Meshkat, Elodie Choq

**Institution(s):** STScI, Carnegie, UC Berkeley, Caltech, LAM, University of Arizona, IPAC, Leiden University

#### **436.03 - The surprising scattering phase function of the HR 4796 debris disk(Johan Mazoyer)**

We have obtained J, H, K1 and K2 observations of the iconic debris disk around HR 4796 with the Gemini Planet Imager. The unique inclination and geometry of this disk is a great opportunity to obtain the scattering properties of debris dust at scattering angles that usually cannot be probed in details. HR 4796 shows unique scattering properties, not reproduced in the small sample of debris disks for which these observables have been obtained so far. We have used several recently developed methods of reduction for high-contrast imaging (reference and angular differential imaging, mask and interpolate and Non-negative matrix factorization) to obtain images of this disk. We will present a comparison of the performance of these reduction methods for this debris disk imaging. These unique scattering properties are greatly constraining the dust properties of this object and we will also present the grain properties derived using a radiative transfer code.

**Author(s):** Paul Kalas, Max Millar-Blanchaer, Justin Hom, Christine Chen, Stanimir Metchev, Marshall Perrin, Gaspard Duchene, Mike Fitzgerald, Brenda Matthews, Christopher Stark, Glenn Schneider, Alycia Weinberger, Thomas Esposito, Rémi Soummer, Charles Poteet, Dea

**Institution(s):** University of California, Berkeley, oUniversity of Arizona, University of Western Ontario, National Research Council of Canada Herzberg Astronomy and Astrophysics Programs, University of Exeter, Wesleyan University, Johns

Hopkins University, Space te

#### **436.05 - A high resolution mid-infrared survey of water emission from protoplanetary disks(Colette Salyk)**

We will present results from the largest survey of spectrally resolved mid-infrared water emission to date, with data obtained with the Michelle and TEXES spectrographs on the Gemini North telescope. Water emission is successfully detected in 6 out of 8 disks associated with classical T Tauri stars within our sample. In contrast, water emission is not detected in the transitional disks SR 24 N and SR 24 S, in spite of SR 24 S having pre-transitional disk properties like DoAr 44, which does show water emission (Salyk et al. 2015). With R = 100,000, the TEXES spectra represent the highest spectral resolution observations of water vapor possible at this time, and allow for detailed analysis of emission lineshapes. We find that the mid-IR water emission lines are similar to the "narrow component" seen in CO rovibrational emission (Banzatti et al. 2015), consistent with disk radii of a few AU, in contrast to the 3 micron water emission lines which originate closer to the star. The emission lines are either single peaked, or broader and consistent with a double-peaked profile. Single-peaked emission lines are difficult to produce with a standard disk model, and may suggest that water participates in the disk winds proposed to explain similarly shaped CO emission lines (Bast et al. 2011; Pontoppidan et al. 2011). Double-peaked emission lines can be used to determine the radius at which the line emission luminosity drops off. For HL Tau, the lower limit on the measured dropoff radius is consistent with the measured 13 AU dark ring (ALMA partnership et al. 2015). We also report variable line/continuum ratios from the disks around DR Tau and RW Aur, which we attribute to continuum changes and line flux changes, respectively. The reduction in RW Aur line flux corresponds with an observed dimming at visible wavelengths, and is consistent with the tidal arm blocking scenario suggested by Rodriguez et al. (2013).

**Author(s):** Colette Salyk, Geoffrey Blake, John Lacy, John S. Carr, Ke Zhang, Matthew Richter, Joan Najita, Klaus Martin Pontoppidan

**Institution(s):** Vassar College, University of California at Davis, The University of Texas at Austin, Space Telescope Science Institute, The University of Michigan, NOAO, Naval Research Laboratory, California Institute of Technology

#### **436.07 - Investigating Circumstellar Disk Destruction in the HII Region W4(Matt Wentzel-Long)**

The formation of planets is directly dependent on the evolution of the circumstellar disk which surrounds its host protostar as it approaches the main sequence. In star forming regions the survival of disks around young stars can depend on their proximity to a source of ionizing radiation, an O or early B type star. The OB association IC 1805 is host to around 10 O-type



stars, which is central in the encompassing W4 superbubble. Theory suggests that a sparse distribution of disks in this environment minimizes the destruction of disks and disruption of planet formation around the YSOs. We present spectroscopic data for ~2000 stars in the direction of W4 which were used to derive spectral types that then allowed the production of SEDs using PanSTARRS, 2MASS, and Spitzer photometry for the identification of 62 YSOs to date exhibiting excesses in infrared flux. Empirical cumulative distribution functions (ECDFs) were created to test for disk destruction relative to the 8 O-stars in this region. Finally, the disk candidate SEDs were fit using a simple blackbody disk+star model based upon the work of Chiang & Goldreich (1997) in a Markov-Chain Monte Carlo-based code.

**Author(s):** Jinyoung Kim, Matt Wentzel-Long, Bruce Wilking, Justin Bryan

**Institution(s):** University of Missouri - StLouis, Steward Observatory, University of Arizona

#### **436.04D - Modeling the Evolution of Carbon and Nitrogen Reservoirs in Circumstellar Disks(Dana Anderson)**

Circumstellar disks initially form from materials of interstellar composition. However, the extent to which these materials are reprocessed in the disk prior to and during planet formation is not well known. In this study, we use chemical modeling and ALMA observations to investigate the evolution of the bulk carbon and nitrogen reservoirs in circumstellar disks. First, we seek to explain the low carbon abundances observed in meteorites and the Earth relative to the interstellar dust that seeded their formation. We model the destruction of solid, refractory carbon grains in disks via oxidation and UV photolysis. In a passively-heated and uniformly turbulent disk around a T-Tauri star, we find that these processes are only effective at releasing carbon prior to significant growth of the grains. This suggests that much of the carbon loss may have occurred under a distinctly different disk environment present during another stage of the disk lifetime. Second, we explore the volatile carbon chemistry in the inner disk midplane, the terrestrial-planet-forming region of the disk. We model the release and subsequent chemistry of CO<sub>2</sub> and CH<sub>3</sub>OH ices, potential carbon reservoirs in the outer disk, once introduced to hotter and denser conditions in the inner disk. Carbon is rapidly transferred to CO in optically-thin disk regions, consistent with Spitzer observations. However, this may not be representative of carbon reservoirs closer to the disk midplane. Finally, we investigate a nitrogen-based tracer to supplement CO in determining the gas masses of disks and ultimately the timescales of disk dissipation and gas-giant planet formation. Our ALMA detections of N<sub>2</sub>H<sup>+</sup> in two 5-11 Myr-old disks in the Upper Scorpius region reveal the presence of precursor H<sub>2</sub> gas in these disks. We also find that the Upper Sco disks have enhanced N<sub>2</sub>H<sup>+</sup>/CO flux ratios relative to a sample of gas-rich, CO-bright disks. Chemical models reveal that this is likely the result of selective depletion of CO relative to N<sub>2</sub> and H<sub>2</sub> in the disk gas. For disks with such CO depletion, total gas masses

determined based on CO measurements alone would be underestimates.

**Author(s):** Dana Anderson

**Institution(s):** California Institute of Technology

#### **436.06D - Tracing chemical complexity in protoplanetary disks(Jennifer Bergner)**

Nascent planetary compositions are set by the inventories and distributions of molecules in protoplanetary disks. Understanding how planets are seeded with complex (6+ atom) organic molecules, the building blocks for prebiotic chemistry, is key to assessing the habitability of other worlds. To date, only three complex organics (CH<sub>3</sub>CN, HC<sub>3</sub>N, and CH<sub>3</sub>OH) have been detected in disks, and until recently each has been characterized in only a single disk. I will present ALMA observations of CH<sub>3</sub>CN and HC<sub>3</sub>N in a sample of six protoplanetary disks, greatly expanding our understanding of their chemistry. Despite significant physical variation in the disk sample, the abundances of each molecule with respect to HCN are remarkably consistent, suggestive of a robust chemistry insensitive to its environment. Based on measured rotational temperatures, we can map the CH<sub>3</sub>CN and HC<sub>3</sub>N emission to warm, elevated layers of the disk. Thus, complementary constraints are needed to understand complex chemistry in the midplane where planet and comet formation takes place. To this end, we use laboratory experiments of astrophysical ice analogs to explore channels to complex molecule formation in very cold, midplane-like environments. A promising pathway is the reaction of oxygen atoms with hydrocarbons, which is efficient even at very low temperatures and can explain the formation of molecules including CH<sub>3</sub>OH, CH<sub>3</sub>CHO, and CH<sub>2</sub>CO. By synthesizing observational and laboratory studies of complex chemistry in disks, we are providing important constraints on how the ingredients for prebiotic chemistry are formed in disks where solar systems are assembling.

**Author(s):** Viviana V. Guzm  n, Jennifer Bergner, Ryan A Loomis, Jamila Pegues, Karin I   berg

**Institution(s):** Harvard University, Joint ALMA Observatory, NRAO

#### **437 - Instrumentation: Improving Ground Based Techniques**

##### **437.01 - Polarization effects due to the segmented primary mirror of the Thirty Meter Telescope(Ramya Manjunath Anche)**

The instrumental polarization (IP) and crosstalk (CT) due to the telescope optics affect the accurate polarimetric measurements. In the case of the Cassegrain focus telescopes, they are found to be negligible. The next-generation telescopes such as Thirty Meter Telescope (TMT) consists of segmented primary mirror and an inclined Nasmyth mirror. The effect of these two mirrors on the polarimetric measurements need to be estimated. Towards that, a polarization model for TMT has been already

developed with primary mirror approximated as a monolith. The model estimates an IP of 1.2% and CT of 40% at 600nm for on axis rays. Here we present the results based on a more realistic approach considering the effect of individual mirror segments. A total of 492 hexagonal segments are divided into six sectors with 82 unique segments in each sector. We performed the polarization ray tracing in Zemax for this configuration and obtained the polarization pupil maps. The Mueller matrices are estimated which gives the IP and CT. The difference between the IP for the monolith and segmented mirror is in the order of  $10^{-4}$  and CT in the order of  $10^{-3}$  respectively. We have analysed the cases of missing segments and their effect on the Mueller matrices. We find that as the number of missing segments increases, though the I->Q and U->V does not change considerably, the I->U, I->V and Q->V components appear in the Mueller matrices. As a part of coating non-uniformity study, we generated six different coating recipes with 5-10% variation in the refractive index of silver. The Mueller matrices showed the changes in the IP and CT elements. Along with these, the cases of random segment tilts and piston error on the Mueller matrices have been estimated. The variation in the piston of the segments is found to have no effect on the polarization measurements where as tip-tilt causes changes in some of the Mueller matrix elements. As, none of the first-generation instruments for the telescope have a polarimetric capability, these estimations would help in the design aspects of a second-generation instrument with the polarimetric capability.

**Author(s):** S Sriram, G C Anupama, K Sankarasubramanian, Ramya Manjunath Anche

**Institution(s):** Indian Institute of Astrophysics, ISRO Satellite Center

#### **437.03 - Investigating the photometric performance and PSF-reconstruction capabilities of the InfraRed Imaging Spectrograph (IRIS) for TMT(Nils-Erik Bjorn Rundquist)**

The InfraRed Imaging Spectrograph (IRIS) is a first-light instrument for the Thirty Meter Telescope (TMT) which will utilize a near infrared (0.84 - 2.4 $\frac{1}{4}$ m) integral field spectrograph (IFS) and imager operating at (or near) the diffraction limit afforded by the Narrow-Field InfraRed Adaptive Optics System (NFIRAOS). The imager will operate at a 4 milliarcsecond (mas) plate scale over a 34" x 34" field of view. The IFS will consist of two spatial sampling methods: a slicer that samples at plate scales of 25 and 50 mas, and lenslet array at 4 and 9 mas scales. IRIS coupled with NFIRAOS will offer new scientific capabilities to astronomers in near-infrared imaging and spectroscopy. In order to properly assess the photometric precision and accuracy, we simulate IRIS data sets with Point Spread Function (PSF) images provided by NFIRAOS in varying performances and field locations across the imager and IFS. We analyze a variety of science cases with single source, binary source, and crowded fields using both PSF-fitting algorithm Starfinder and aperture photometry. Additionally, we investigate the current PSF-reconstruction

(PSF-R) algorithms by comparing the true simulated PSF photometry results with that of predicted reconstructed PSFs. We report the predicted IRIS photometric performance and capabilities and discuss the current metrics for the quality of PSF-reconstruction needed for TMT and IRIS.

**Author(s):** Shelley A. Wright, Tuan Do, Arun Surya, Nils-Erik Bjorn Rundquist, Gregory Walth, Paolo Turri, Jessica R. Lu, Matthias Schoeck, Eric Chisholm, Luc Gilles, Lianqi Wang, James E. Larkin, Ryuji Suzuki

**Institution(s):** UCSD Center for Astrophysics and Space Sciences, Thirty Meter Telescope Observatories, UCLA Physics & Astronomy Department, UC Berkeley Department of Astronomy, Caltech Optical Observatories, Carnegie Observatories, National Astronomical Observatory

#### **437.04 - Wide-field speckle techniques for small, urban telescopes.(Nicole Granucci)**

Recent work with the NESSI speckle camera at Kitt Peak and the 'Alopeke speckle camera at Gemini-North indicates that reduction techniques borrowed from speckle imaging can be successfully modified to produce high-resolution images over fields that are at least tens of arc seconds across. While these ``wide-field" speckle image reconstructions are not diffraction-limited, the improvement in resolution over the seeing-limited case can be substantial. These techniques were applied to images taken with a small (0.6-m) telescope at Southern Connecticut State University, where seeing conditions are generally much worse than at large, mountaintop observatories, and where poor telescope tracking and collimation are factors in image quality. By using the wide field speckle techniques presented here, we show that the campus telescope can give much improved image quality in this urban, sea-level setting with relatively little additional cost. We present data using our initial set-up and discuss the potential for this approach for improving the imaging capabilities of small telescopes on our campus and beyond.

**Author(s):** Nicole Granucci, Elliott Horch

**Institution(s):** Southern CT State University

#### **437.06 - Detecting and Characterizing Systematic Effects in Simulations and Measurements for Low Frequency Transit Interferometers(James Aguirre)**

A number of experiments are currently seeking to make measurements of the highly-redshifted 21 cm signal from neutral hydrogen. The calibration and systematic contamination requirements for these experiments are daunting. Many of these, including the Hydrogen Epoch of Reionization Array (HERA) and the Precision Array for Probing the Epoch of Reionization (PAPER), use an interferometric transit array where the visibilities are phased at each moment to the local zenith. In this work, we examine a simple but sensitive statistic for detecting and measuring common systematic effects in close-packed, short-baseline, wide-field-of-

view, redundant-spacing interferometers such as HERA and PAPER: the spectrum formed from the time-averaged visibility (TAV) for each interferometric baseline, where the averaging time is long compared to the transit time for a source across the primary beam. Such a spectrum will contain contributions from several sources: stationary signal on the sky (corresponding to those angular modes with spherical harmonic  $m=0$  to which a given baseline is sensitive); copies of such signals delayed by cable reflections or cross-talk between antennas (where the cross-talk may either be through the electronics or through reflections between antennas); and stationary noise correlated between antennas. The identification and characterization of even low levels of cable reflections, cross-talk, and correlated noise in an antenna-based framework is important for both data quality and for the improvement of future iterations of instrument design. In this study, we use commissioning data from the HERA instrument combined with simulations to model these non-ideal terms in the TAV and attempt to identify the relative contributions of each to the observed signal. We find that there are also subtleties involved in the simulation of wide-field interferometer visibilities using the standard equations, and discuss corrections to the simulation to better reflect the interferometer response near the horizon.

**Author(s):** James Aguirre

**Institution(s):** University of Pennsylvania Contributing Team(s): HERA Collaboration, PAPER Collaboration

#### **437.02D - Complex Radiation Pattern Measurements of Direct Detector Focal Plane Array Instruments(Kristina Davis)**

In the age of high precision astronomy, detailed instrument characterization will be required to advance scientific observations. In the millimeter and sub-millimeter regime ( $\sim 90$  GHz-5THz) beam characterization of independent pixels in a large format array can be measured for accurate image reconstruction. Broadly speaking, there are two types of beam characterization methods available in this regime: thermal beam mapping and complex beam mapping. The former method is the most basic type of beam measurement, where beams are probed with a single, thermal source and the response of the detector is recorded as a function of source probe position. With complex field patterns, the amplitude and phase pattern of the instrument's beam is measured. Assuming a Gaussian beam, the fundamental beam parameters can be determined by fitting a model function to the measured complex field. The model function can then be used for further optical analysis. With just two orthogonal measurements using a polarized source probe, the beam pattern measurement in a single scan plane can simultaneously characterize a beam's ellipticity, astigmatism, polarization orientation, side lobe level, and coupling fraction to a simulated profile. We present a robust measurement system capable of acquiring complex field radiation pattern measurements of direct detector arrays, which are inherently phase-insensitive. This technique has been demonstrated with microwave kinetic inductance detectors (MKIDs) but can be expanded to transition edge sensor (TES)

arrays with frequency domain multiplexing techniques. We also present an analysis pipeline to extract relevant optical properties from the system. These advantages may be particularly attractive for the next generation of cosmic microwave background (CMB) mapping missions envisioned for both ground and space-based CMB Stage 4 (CMB-S4) direct-detector based instruments, or for imaging instruments studying extended sources, such as the polarization of thermal emission from dusty molecular clouds as the grains align to the galactic field lines.

**Author(s):** Kristina Davis

**Institution(s):** University of California Santa Barbara

#### **437.05D - Simultaneous Full-Stokes Polarimetry with Stress-engineered Optics(Tristan M Wolfe)**

This dissertation talk presents a new single-shot, full-Stokes optical polarimeter using stress-engineered optics (SEOs), the first in the field of astronomy to do so (Wolfe et al. 2018, Proc. SPIE 107063B). SEOs are cylindrical glass windows under static stress by radially inward forces in three symmetrically-spaced regions, producing spatially varying birefringence throughout. Light from a telescope and collimated through the SEO acquires a point spread function (PSF) dependent on the source's full polarization vector (Stokes parameters). The polarization of light from a point source is thus encoded within a single image, from an instrument with no temporal modulation or division of amplitude. Our instrument, "Polvis", obtained first light in May 2018. This presentation provides comparisons of lab data with on-sky results (both simulated and experimental) of our polarimeter on a 0.2m (8in) telescope at the University of Denver. As Earth's atmospheric turbulence interferes with the ideal polarization-dependent PSFs, studying these effects and how to reproduce a polarization measurement through turbulence have been crucial to creating the instrument. Lab experiments compare measurement efficiency as a function of spectral bandwidth. Also presented is a look at the variability of polarized and unpolarized "standard" stars, plus an argument to further studies of interstellar circular broadband polarization, which has been historically under-measured but contains useful physical information about the ISM. Applications of this instrument also exist in improving exoplanet polarimetry and High Time Resolution Astrophysics. Next steps include proposing to observe with the instrument on larger telescopes, and modeling the performance of such an instrument in space-based applications. The original descriptions of SEOs from the Institute of Optics at the University of Rochester can be found in Spilman and Brown, 2007 (Applied Optics IP, 46, 2007), and the description of polarimetry in Beckley and Brown 2010 (Proc. SPIE, 757011). The presenter is grateful to the estate of William Herschel Womble for the support of astronomy at the University of Denver.

**Author(s):** Tristan M Wolfe

**Institution(s):** University of Denver Contributing Team(s): Institute of Optics at the University of Rochester (NY)

## **438 - Clusters of Galaxies II**

### **438.01 - Multiwavelength Confirmation of Massive Galaxy Clusters from the Planck Sunyaev Zel'dovich Survey(John Hughes)**

We recently reported first results from our optical program at the KPNO Mayall 4-meter telescope to identify high signal-to-noise unconfirmed Planck cluster candidates selected via the Sunyaev Zel'dovich (SZ) effect (Boada et al. 2018, ApJ, submitted, arXiv:1809.06378). Eighty-five candidates were observed in four optical bands (griz) to a typical i-band limiting magnitude of 23.2 allowing for confident detection of an optical cluster to redshifts of 0.75. We found 15 high confidence optical clusters of which 12 were not previously identified with the Planck candidate. In this presentation we report on additional efforts to confirm Planck SZ cluster candidates using infrared observations with the NEWFIRM instrument and X-ray observations with the Swift X-ray telescope. This work is supported by NSF Astronomy and Astrophysics Research Program award number 1615657.

**Author(s):** David Burrows, Leopoldo Infante, Steven Boada, Luis Felipe Barrientos, Peter Doze, John Hughes, Felipe Menanteau

**Institution(s):** Rutgers University, Pontificia Univ Catolica de Chile, NCSA, Penn State University

### **438.02 - Fossil System Progenitors Through the Eyes of Chandra(Lucas Edward Johnson)**

Fossil galaxy systems have long been thought to be the relics of old, undisturbed systems where dynamical friction has caused most bright member galaxies to lose angular momentum and merge with the brightest group galaxy (BGG). However, the notion that all fossils are old and relaxed has been challenged by both simulations and observations, as progenitors to today's fossil systems have been found in the CASSOWARY catalog of strong lensing systems in SDSS at various stages of fossil formation. While an obvious optical evolution can be seen as a system transitions into a fossil (as member galaxies are cannibalized by the BGG), does the hot X-ray gas follow suit? To begin to answer this, we obtained Chandra snapshots of eight fossil progenitors ranging in fossil transition time from 5 Gyr to ~100 Myr to see if the progenitors' LX showed any variation with fossil transition time. We find that there does not seem to be any correlation between time until a system becomes a fossil and its X-ray properties, however we did observe that progenitors are significantly over-luminous in X-rays (some by an order of magnitude) and hotter than galaxy group/cluster scaling relations predict. This discrepancy worsens when comparing progenitors to non-fossils of similar richness, implying that some fossils and their progenitors may possess different halo properties than comparable non-fossils. These results give new clues as to the viable formation channels fossils can use and aid in offering an explanation for the puzzling existence of nearby fossils that lack cool X-ray cores.

**Author(s):** Jimmy Irwin, Ka-Wah Wong, Renato A Dupke, Lucas Edward Johnson

**Institution(s):** The University of Alabama, Eureka Scientific

### **438.05 - Unravelling cosmic ray composition of AGN bubbles with AXIS and Lynx(Mateusz Ruszkowski)**

Relativistic particles (aka cosmic rays; CR) are present in the intracluster medium (ICM). Recent theoretical results suggest that CRs may play a very important role in the heating of the ICM by AGNs in cool core clusters. CR electrons are seen through synchrotron emission in the radio band, and these same electrons should be visible in the hard X-rays (2-30 keV) due to inverse Compton (IC) scattering of the cosmic microwave background. The IC signal therefore constrains the particle content of AGN outflows and their long-term impact on the cluster. However, this theoretically expected IC signal has so far eluded detection. We discuss the feasibility of detecting an IC signal in the 0.3-10 keV band with AXIS and Lynx based on synthetic images and spatially resolved spectra from a state-of-the-art magneto-hydrodynamical simulation of AGN feedback in a galaxy cluster, in which CRs are an important feedback agent. We find that, under certain conditions, an IC signal will be detectable with AXIS and Lynx missions.

**Author(s):** H.-Y. Karen Yang, Edmund Hodges-Kluck, Mateusz Ruszkowski

**Institution(s):** University of Michigan, University of Maryland, Goddard Space Flight Center

### **438.04D - Galaxy Cluster Mass Estimates in the Presence of Substructure(Evan Tucker)**

I will present a dynamical analysis of Abell 267 ( $z \sim 0.23$ ) using over 1000 galaxy redshifts from new spectra observed with Magellan/M2FS combined with publicly available redshifts from the HectoSpec Cluster Survey. For each galaxy, we measure redshift as well as mean age, metallicity, alpha enrichment, and internal velocity dispersion of the stellar population. We applied a new method to simultaneously obtain Bayesian estimates for the internal kinematics and substructure of the cluster. For the main cluster population, we implement a Jeans analysis in order to fit the cluster's dark matter halo, which is embedded within a mixture model that explicitly accounts for member and contamination galaxies as well as any subpopulations. We find that with this comprehensive model, we are able to disentangle effects of subpopulations and cluster rotation, revealing a relatively clear view of Abell 267's dynamical status and gravitational potential.

**Author(s):** Matthew G Walker, Evan Tucker

**Institution(s):** Carnegie Mellon University

#### **438.06D - The Interplay of Radiative and Kinetic Feedback in Galaxy Clusters(Yu Qiu)**

Motivated by recent observational findings that some cool-core clusters (CCCs) host quasars in their brightest cluster galaxies (BCGs), we use 3D radiation-hydrodynamic simulations to explore the joint role of the radiative and kinetic feedback from supermassive black holes (SMBHs) in BCGs. In our simulations, the central SMBH transitions between the radiatively efficient and radiatively inefficient states on time scales of a few Gyr, as a function of its accretion rate. The time scale for this transition depends on the fraction of power allocated to each feedback mode, and the overall feedback luminosity of the active galactic nucleus (AGN). We find that (a) kinetic feedback must be present at both low and high accretion rates in order to prevent the cooling catastrophe, and (b) its contribution likely accounts for  $> 10\%$  of the total AGN feedback power, since below this threshold simulated BCGs tend to host radio-loud quasars most of the time, in apparent contrast with observations. In addition, we find a positive correlation between the AGN feedback power and the mass of the cold gas filaments in the cluster core, indicating that observations of  $\text{H I} \pm$  filaments can be used as a measure of AGN feedback.

**Author(s):** Tamara Bogdanovic, KwangHo Park, John H. Wise, Yuan Li, Yu Qiu

**Institution(s):** Georgia Institute of Technology, University of California, Berkeley, Flatiron Institute

### **439 - CMB, Dark Matter & Dark Energy II**

#### **439.01 - The Power Spectra of Polarized Filaments(Kevin Huffenberger)**

Polarized dust emission is a significant foreground for current and future Cosmic Microwave Background measurements. Observations of the interstellar medium show that filamentary structures correlate closely with the magnetic field implied by the polarization of the dust. Although turbulent magnetohydrodynamic interactions govern this behavior, here we use simple semi-analytic models to predict the power spectra of a population of polarized filamentary objects. These simplified, tunable models help to elucidate the relationships between the properties of filaments (such as the distributions of size and alignment to the magnetic field) and the properties of their polarization power spectra (including the shape, E/B power ratio, and TE cross-correlation). We compare the predictions to the dust power spectra observed by the Planck mission.

**Author(s):** Kevin Huffenberger, Aditya Rotti, David C Collins

**Institution(s):** Florida State University, University of Manchester

#### **439.03 - Constructing a Low-Cost Cosmic Microwave Background Receiver(Antonio Ivan Hernandez)**

The construction and operation of a low cost 10 GHz “tipping” radiometer will be described. The low noise front-end of the receiver is a Ku-band satellite TV low noise block with an effective noise temperature of 85 K. Data collection is automated by using an Arduino Mega clone as the microcontroller. This enables quick measurement of the receiver noise temperature using hot (room-temperature) and cold (liquid nitrogen) loads, as well as measurement system noise when looking at various elevations on the sky. This allows estimation of noise contribution from the atmosphere, thereby enabling calculation of the noise temperature of the cosmic microwave background. The presentation will provide details of the necessary calculations along with measured results from the test receiver that is intended to be used by the NRAO Central Development Laboratory at future outreach events.

**Author(s):** Antonio Ivan Hernandez, Kamaljeet Saini,

**Institution(s):** University of Virginia, National Radio Astronomy Observatory

#### **439.04 - Cosmological implications of the axiverse(Tristan Smith)**

Ultra-light axions (ULAs) provide a rich phenomenology to explain a variety of observed cosmological phenomena such as dark matter and dark energy. The cosmological dynamics of ULAs are initially frozen at some non-zero value due to Hubble friction and become dynamical when the Hubble term drops below a critical value (set by the mass of the field). The field then rolls down its potential and eventually starts to oscillate. While frozen, the field behaves as a dark energy component with  $w \approx -1$ ; once oscillating the field has an average equation of state  $w \approx (n-1)/(n+1)$  where the ULA potential around the minimum is proportional to  $\phi^2$ . If a ULA becomes dynamical at a redshift  $z \approx 10^5$  then it can produce a potentially observable period of dark energy evolution followed by a period of dilution of its energy density. In this way, ULAs may provide an explanation for the anomalously low baryon temperature recently measured by the EDGES experiment and may explain the tension between low and high redshift estimates of the Hubble constant. In this talk, I will present the best cosmological constraints on such ULAs and show that they cannot explain the EDGES anomaly but may provide a viable explanation for the discrepant measurements of the Hubble constant. Finally, certain string theories generically predict a collection of ULAs with properties that are determined stochastically, known as the 'axiverse'. I will show how to compute the probability that the axiverse can account for dark matter and dark energy and be consistent with current cosmological observations.

**Author(s):** Kamionkowski Marc, Daniel Grin, Vivian Poulin, Tanvi Karwal, Tristan Smith

**Institution(s):** Swarthmore College, Haverford College, Johns Hopkins University

#### **439.06 - Mapping the Dark Matter at $z > 1$ in the Near-infrared: Galaxy ellipticity measurements in the near-infrared for Weak Lensing (Bomee Lee)**

Weak gravitational lensing, a powerful probe of the distribution of dark matter, is one of the key science goals of future large, extragalactic surveys with LSST, Euclid, and WFIRST. Current surveys have primarily been at optical wavelengths and have yielded weak lensing mass maps at  $z < 1$ . Near-infrared (NIR) imaging has thus far, never been used for blank-field weak lensing measurements. In this study, we investigate the value of the near-infrared imaging from upcoming surveys for constraining the ellipticities of galaxies. We select galaxies between  $0.5 < z < 3$  that are brighter than expected Euclid sensitivity limits from the GOODS-S and N fields in CANDELS. The co-added CANDELS/HST V+I and J+H images are degraded in resolution and sensitivity to simulate Euclid - quality optical and near-infrared (NIR) images. We then run GALFIT on these simulated images and find that optical and NIR provide similar performances in measuring galaxy ellipticities at redshifts  $0.5 < z < 3$ . At  $z > 1$ , the NIR-selected source density is higher by a factor of 1.4 and therefore the standard error in NIR-derived ellipticities is about 30% smaller, implying a more precise ellipticity measurement. Despite the worse spatial sampling and resolution of Euclid NIR compared to optical, the NIR approach yields equivalent or more precise galaxy ellipticity measurements. If systematics that affect shapes such as dithering strategy and point spread function undersampling can be mitigated, inclusion of the NIR can improve galaxy ellipticity measurements over all redshifts. This is particularly important for upcoming weak lensing surveys, such as with Euclid and WFIRST.

**Author(s):** Ranga-Ram Chary, Bomee Lee

**Institution(s):** Caltech/IPAC

#### **439.07 - Quantifying the Dark Matter Subhalo Mass Function in $z \sim 0.5$ Galaxies using Lensed Lyman- $\alpha$ Emitting Galaxies. (Matthew Cornachione)**

The small-scale distribution of dark matter is, at present, poorly understood. Cosmological simulations predict a large number of low-mass subhalos within galaxies, but observations in our Local Group find a lower number of corresponding satellite galaxies. This tension may be addressed by quantifying low-mass subhalos at cosmological distances. One of the few methods capable of this measurement is galaxy-scale strong gravitational lensing. We identify a set of lensed Lyman- $\alpha$  Emitting galaxies (LAEs) whose compact angular scales allow us to achieve lower mass detection thresholds, down to  $\sim 10^7$  solar masses. These galaxies are imaged at high-resolution with the HST WFC3 to allow precise measurement of surface brightness profile anomalies associated with mass substructure in the lensing galaxy. Rather than directly detecting subhalos, we use the Bayesian evidence to infer the probability of each galaxy hosting a subhalo. From this statistical framework, we constrain the mass fraction and slope of the subhalo mass function (SHMF) in this sample. Our procedure is sensitive to

subhalos ranging from  $10^7 - 10^9$  solar masses. We find a substructure mass fraction  $f = 0.0020 \pm 0.0027 - 0.0013$  and a slope  $\hat{\Gamma} = 0.968 \pm 0.485 - 0.524$ . This mass fraction is consistent with both observational results and theoretical predictions. The slope, however, is significantly lower than cosmological predictions. Our results are qualitatively in agreement with the number of satellites found in the Local Group. We discuss the implications for warm dark matter (WDM), one possible modification to dark matter theory. We also explore sources of systematic error.

**Author(s):** Matthew Cornachione,

**Institution(s):** United States Naval Academy, University of Utah  
**Contributing Team(s):** BELLS

#### **439.02D - There is No Missing Satellites Problem (Stacy Kim)**

A critical challenge to the cold dark matter (CDM) paradigm is that there are fewer satellites observed around the Milky Way than found in simulations of dark matter substructure. We show that there is a match between the observed satellite counts corrected by the detection efficiency of the Sloan Digital Sky Survey (for luminosities  $L \approx 340 L_{\odot}^{\text{TM}}$ ) and the number of luminous satellites predicted by CDM, assuming an empirical relation between stellar mass and halo mass. The "missing satellites problem", cast in terms of number counts, is thus solved. We also show that warm dark matter models with a thermal relic mass smaller than 4 keV are in tension with satellite counts, putting pressure on the sterile neutrino interpretation of recent X-ray observations. Importantly, the total number of Milky Way satellites depends sensitively on the spatial distribution of satellites, possibly leading to a "too many satellites" problem. Measurements of completely dark halos below  $10^8 M_{\odot}^{\text{TM}}$ , achievable with substructure lensing and stellar stream perturbations, are the next frontier for tests of CDM.

**Author(s):** Stacy Kim, Annika Peter, Jonathan Hargis

**Institution(s):** The Ohio State University, Space Telescope Science Institute

#### **440 - Plenary Lecture: From Data to Dialogue: Confronting the Challenge of Climate Change, Heidi Roop, (University of Washington)**

##### **440.01 - From Data to Dialogue: Confronting the Challenge of Climate Change (Heidi Roop)**

Scientific research informs our understanding of past and future climatic changes and is central to our understanding of the multi-dimensional impacts of climate change on human and natural systems. Despite thousands of peer-reviewed studies and strong scientific consensus on the human-driven nature of current climate change, why do we still see little political will and limited social acceptance and behavior change? Climate change is clearly not only a science challenge. It is a significant societal challenge and we need solutions, action and adaptation

now. This plenary talk will explore the current landscape of climate impacts, dissect the science of climate change communication, and propose steps that the broader scientific community can take to catalyze the action needed to confront the climate change challenge head-on.

**Author(s):** Heidi Roop

**Institution(s):** University of Washington Climate Impacts Group

#### **441 - Plenary Prize Lecture: Lancelot M. Berkeley Prize: The XENON Project: at the Forefront of Dark Matter Direct Detection, Elena Aprile (Columbia University)**

##### **441.01 - The XENON project: at the forefront of Dark Matter Direct Detection(Elena Aprile)**

What is the Dark Matter which makes 85% of the matter in the Universe? We have been asking this question for many decades and used a variety of experimental approaches to address it, with detectors on Earth and in space. Yet, the nature of Dark Matter remains a mystery. An answer to this fundamental question will likely come from ongoing and future searches with accelerators, indirect and direct detection. Detection of a Dark Matter signal in an ultra-low background terrestrial detector will provide the most direct evidence of its existence and will represent a ground-breaking discovery in physics and cosmology. Among the variety of detectors used for direct detection in underground laboratories, liquid xenon time projection chambers (LXeTPCs) have shown to be the most sensitive to Dark Matter interactions with standard matter, thanks to a combination of very large target mass, ultra-low background and excellent signal-to-noise discrimination. Experiments based on this technology have led the field for the past decade. I will discuss how upcoming experiments will further explore Dark Matter signatures during the next decade. I will focus on experiments using the most massive targets made of noble liquids, and on the XENON project in particular.

**Author(s):** Elena Aprile

**Institution(s):** Columbia University Contributing Team(s): XENONT Collaboration

#### **442 - Computational Astrophysics -- Posters**

##### **442.01 - ExoPhotons: Exoplanet Monte Carlo Radiative Transfer(Pramod Gupta)**

Monte Carlo Radiative Transfer (MCRT) is a powerful technique for radiative transfer since it can handle any geometry. The ExoPhotons code for Exoplanet Monte Carlo Radiative Transfer uses spherical layers with absorption and scattering for the atmosphere. The planet's atmosphere is divided into cells using the spherical polar coordinates ( $r, \hat{r}, \hat{\tau}$ ) and the planet's surface is divided into surface elements using the coordinates ( $\hat{r}, \hat{\tau}$ ). The ExoPhotons code can handle the  $4 \times 4$  scattering matrices for Rayleigh scattering, spherical aerosols or randomly oriented non-spherical aerosols. The code includes the physics for polarization and it computes the Stokes

vector (I,Q,U,V) as a function of the direction to the observer.

**Author(s):** Pramod Gupta

**Institution(s):** University of Washington

#### **442.02 - Quantifying inhomogeneities in the HI distributions of simulated galaxies(Hind Al Noori)**

The NIHAO cosmological simulations form a collection of a hundred high-resolution galaxies. We used these simulations to test the impact of stellar feedback on the morphology of the HI distribution in galaxies. We ran a subsample of twenty of the galaxies with different parameterizations of stellar feedback, looking for differences in the HI spatial distribution and morphology. We found that different feedback models do leave a signature in HI, and can potentially be compared with current and future observations. These findings can help inform future modeling efforts in the parameterization of stellar feedback in cosmological simulations of galaxy formation and evolution.

**Author(s):** Aaron Dutton, Hind Al Noori, Andrea MacciÀ<sup>2</sup>,

**Institution(s):** New York University Abu Dhabi, Max Planck Institute for Astronomy Contributing Team(s): the NIHAO team

#### **443 - A Hubble Space Telescope for the 2020s: Capabilities and Opportunities -- Posters**

##### **443.01 - An Overview of the Active Photometric and Spectroscopic Modes on the Space Telescope Imaging Spectrograph(Doug Branton)**

The Space Telescope Imaging Spectrograph (STIS) is one of the oldest active instruments on the Hubble Space Telescope (HST). STIS was installed in 1997 and served the community until 2004, when it experienced a power failure. In 2009, it was revived during Servicing Mission 4 (SM4) and has been a productive scientific instrument ever since. In fact, it is responsible for a large fraction of total HST observing time (13% GO observations in cycle 24). STIS is an incredibly versatile and highly configurable instrument. Through numerous filters, gratings, and apertures, a large variety of unique photometric and spectroscopic modes provide access to high spatial resolution observations in the UV and optical wavelength regimes. This versatility ensures that STIS will have a continued vital role to play in UV and optical astronomy for years to come. In light of this, we provide an overview of the modes that are unique to STIS as well as those that may be of particular value to the astronomical community in upcoming cycles.

**Author(s):** TalaWanda R. Monroe, Paule G. Sonnentrucker, Theodore Gull, Sean Lockwood, Daniel Welty, John Debes, Allyssa Riley, Doug Branton, S. Tony Tony Sohn, Matthew Maclay, Joleen K Carlberg

**Institution(s):** Space Telescope Science Institute, NASA/GSFC Contributing Team(s): STIS Team

#### **443.02 - Optical design for CETUS: a wide-field 1.5m aperture UV payload being studied for a NASA probe class mission study.(Robert Woodruff)**

As part of a study funded by NASA Headquarters, we are developing a Probe-class mission concept called the Cosmic Evolution Through UV Spectroscopy (CETUS). CETUS includes a 1.5-m aperture diameter telescope with a large field-of-view (FOV). CETUS includes three scientific instruments: a Far Ultraviolet (FUV) and Near Ultraviolet (NUV) imaging camera (CAM); a NUV Multi-Object Spectrograph (MOS); and a dual-channel Point Source Spectrograph (PSS) in the Lyman Ultraviolet (LUV), FUV, and NUV spectral regions. The large FOV Three Mirror Anastigmatic (TMA) Optical Telescope Assembly (OTA) simultaneously feeds the three separate scientific instruments. That is, the instruments view separate portions of the TMA image plane, enabling parallel operation of the three instruments. The field viewed by the MOS, whose design is based on an Offner-type spectrographic configuration to provide wide FOV correction, is actively configured to select and isolate numerous field sources using a next-generation Micro-Shutter Array (MSA). The two-channel camera design is also based on an Offner-like configuration. The Point Source Spectrograph (PSS) performs high spectral resolution spectroscopy on unresolved objects over the NUV region with spectral resolving power,  $R \sim 40,000$ , in an echelle mode. The PSS also performs long-slit imaging spectroscopy at  $R \sim 20,000$  in the LUV and FUV spectral regions with two aberration-corrected, blazed, holographic gratings used in a Rowland-like configuration. The optical system also includes two Fine Guidance Sensors (FGS), and Wavefront Sensors (WFS) that sample numerous locations over the full OTA FOV. In-flight wavelength calibration is performed by a Wavelength Calibration System (WCS), and flat-fielding is also performed, both using in-flight calibration sources. This paper will describe the current optical design of CETUS and the major trade studies leading to the design.

**Author(s):** William Danchi, Robert Woodruff

**Institution(s):** Woodruff Optical Consulting, Goddard Space Flight Center

#### **443.03 - New Cenwave 800 for Hubble's Cosmic Origins Spectrograph(William J. Fischer)**

Starting in Fall 2018 (Cycle 26), two new central wavelength settings (cenwaves) are being offered for the far-ultraviolet (FUV) channel of Hubble's Cosmic Origins Spectrograph. This poster introduces the G140L/800 cenwave, which enables background-limited science at wavelengths below 1100 Å... With the G140L low-resolution grating, it places wavelengths from 780 to 1950 Å... on segment A of the FUV detector. This range is about 300 Å... below that of the G140L/1105 cenwave, and it lacks the gap between detector segments that affects the G140L/1280 cenwave. The focus for this setting is chosen to minimize the astigmatic height of the spectrum and therefore the detector background rate below 1100 Å..., allowing higher

S/N to be reached for background-dominated targets than possible in this wavelength range with G140L/1280. We characterize the new mode based on our recently completed calibration effort.

**Author(s):** Dzhuliya Dashtamirova, Thomas Ake, Robert Jedrzejewski, David J. Sahnou, Nick Indriolo, Andrew J Fox, Rachel Plesha, Ravi sankrit, Cristina Oliveira, James White, Bethan James, Camellia Magness, Julia Roman-Duval, William J. Fischer, Gisella De Rosa, Elai

**Institution(s):** Space Telescope Science Institute

#### **443.04 - New Cenwave 1533 for Hubble's Cosmic Origins Spectrograph(Andrew J Fox)**

Starting in Fall 2018 (Cycle 26), two new central wavelength settings (cenwaves) are being offered for the far-ultraviolet (FUV) channel of Hubble's Cosmic Origins Spectrograph. This poster introduces the G160M/1533 cenwave, which improves observing efficiency. It extends the coverage of the G160M medium-resolution grating by 44 Å... toward shorter wavelengths, ranging from 1339 to 1520 Å... (FUVB) and from 1530 to 1710 Å... (FUYA), with the usual gap between the two detector segments. In concert with the G130M/1222 cenwave, medium-resolution spectra can now be obtained at high S/N (using four spectral dithers) over the entire FUV range from 1067 Å... to 1710 Å... (except for the two detector gaps near 1222 and 1533) with two cenwaves instead of the three that were previously necessary. We characterize the new mode based on our recently completed calibration effort.

**Author(s):** Dzhuliya Dashtamirova, Thomas Ake, Robert Jedrzejewski, David J. Sahnou, Nick Indriolo, Andrew J Fox, Rachel Plesha, Ravi sankrit, Cristina Oliveira, James White, Bethan James, Camellia Magness, Julia Roman-Duval, William J. Fischer, Gisella De Rosa, Elai

**Institution(s):** STScI

#### **443.05 - Investigating Interstellar Dust in Local Group Galaxies with New UV Extinction Curves Using HST/STIS Spectra(Geoffrey C Clayton)**

It is well known that the standard Milky Way UV extinction curve does not hold even in the most nearby galaxies, the LMC and the SMC. It is not even known whether the standard curve holds throughout our own galaxy because our position in the disk of the Milky Way, where extinction is high, prevents us from seeing most of our galaxy at UV wavelengths. We have a unique opportunity, while we still have the capability to obtain UV spectra with HST, to map out the UV extinction properties of interstellar dust across other nearby galaxies. We are engaged in a long-term program to relate the properties of interstellar dust across a sample of Local Group galaxies with different global characteristics such as metallicity and star formation activity. We will present results from our recent HST programs, which obtained new STIS UV spectra of reddened stars in the SMC, M31, and M33.



**Author(s):** Karl D Gordon, Geoffrey C Clayton

**Institution(s):** Louisiana State University, Space Telescope Science Institute

#### **443.06 - Spectral mapping with the STIS(Theodore Gull)**

Studies of non-stellar objects may require spatial resolution in combination with spectral dispersion. Such can be obtained with the STIS utilizing long apertures in mapping mode. Applications include studies of solar system objects, galactic nuclei, binary systems and complex nebular structures. Spectro-imagery, extractions of the obtained spectra at specific wavelengths, or in the case of a spatially extended emission line, has successfully pulled out 3-D structures using velocity as the third dimension. Pointing stability and spectro-photometric stability are two concerns. Examples will be provided of successful studies.

**Author(s):** Theodore Gull, Charles Proffitt, John Debes, Steven Kraemer, Daniel Welty, Matthew Maclay

**Institution(s):** NASA/GSFC, Space Telescope Science Institute, Catholic University of America

#### **443.07 - Spatial Scans with the STIS CCD(Matthew Maclay)**

Spatial scanning with the STIS CCD is a recently enabled, available-but-unsupported mode for obtaining high S/N ratio spectra of relatively bright targets by trailing the target in the cross-dispersion direction within one of the long STIS apertures. Expected scientific applications include the reliable detection of weak stellar and interstellar absorption features (particularly in the red and near-IR, where ground-based observations can be severely compromised by strong telluric absorption) and accurate time-series monitoring of bright sources (e.g., for characterizing brown dwarfs and transiting exoplanets). Advantages of the spatial scanning mode include: (1) collecting more photons before reaching detector saturation; (2) spreading the photons over a larger area of the detector (enabling better averaging over flat-field variations); (3) improved removal of the IR fringing pattern; and (4) the availability of a wider variety of methods to detect and remove hot pixels and cosmic rays. In this contribution, we discuss possible/recommended uses for this relatively new observing mode and provide information on how to design the observations.

**Author(s):** Hannah R Wakeford, Charles Proffitt, S. Tony Tony Sohn, Martin Cordiner, Ted Gull, John Debes, Kevin Stevenson, Daniel Welty, Matthew Maclay

**Institution(s):** Space Telescope Science Institute, NASA - Goddard Space Flight Center

#### **443.08 - The Synergy Between HST and Keck in the**

#### **Study of Stellar Dynamics in the Local Group(Puragra Guhathakurta)**

There is excellent synergy between Hubble Space Telescope (HST) imaging, especially deep wide-field mosaic imaging, and multi-object spectroscopy with the Keck 10-meter telescope and DEIMOS instrument. HST is an excellent tool for carrying out precise multi-band photometry of resolved stellar populations and precise astrometric measurements repeated over a long time baseline to measure proper motions. Deep medium resolution spectra obtained with Keck DEIMOS, on the other hand, allow for the measurement of radial velocities and spectral types. Our group has used this HST + Keck combination to good effect in carrying out surveys of the Milky Way, M31, M33, and dwarf satellite galaxies in the Local Group: (1) Panchromatic Hubble Andromeda and Triangulum (PHAT) surveys, (2) Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) survey, and (3) Halo Assembly in Lambda-CDM: Observations in Seven Dimensions (HALO7D) survey. I will present highlights from a decade of HST and Keck studies of the dynamics of resolved stellar populations in these galaxies. More surveys like these are being / have been proposed and it is reasonable to expect that such surveys will continue into the decade of the 2020s. HST will of course become a more and more powerful proper motion measuring engine as we get into the decade of the 2020s and the time baseline grows longer (and the PM signal grows linearly with time). The research highlights presented in this poster are drawn from surveys that were funded in part by the National Science Foundation and the National Aeronautics and Space Administration/Space Telescope Science Institute.

**Author(s):** Puragra Guhathakurta

**Institution(s):** University of California Santa Cruz  
Contributing Team(s): SPLASH, PHAT, HSTPROMO

#### **443.09 - The Eroding Disk of the Young M Star AU Mic(C. A. Grady)**

AU Mic (M1V) is a young star (BPMG, 23+/-3 Myrs old) hosting the first M-star debris disk to be imaged. At  $d=9.72$  pc, HST and ground-based imagery offers unprecedented detail. A distinctive feature of the disk is the presence of a series of out-of-plane arc-like features first seen in the SE arm in 2004. In 2014, comparison of SPHERE commissioning data with HST coronagraphy from 2010/2011 revealed that the features were moving outward in the disk, and that 3 had projected velocities greater than escape velocity. The motion has continued into 2017/2018. The disk features seen previously are now more diffuse. A small velocity component vertical to the disk midplane is now resolved. Using the disk mass estimate of Daley et al. (2018), the feature mass estimate of Chiang & Fung (2017), and the number of escaping features noted by Boccaletti et al. (2015), we estimate the residual lifetime of the disk and find the disk can be exhausted in  $\sim 1.4$  Myr. This has implications for delivery of water and organics to planets in the Habitable Zone. In particular, if AU Mic is representative, it implies that little will remain in the disk at the time when

planets in the habitable zone have cooled sufficiently to retain volatiles, and suggests that the evolution of HZ planets with M star hosts may be very different from terrestrial planets around G stars. Our remaining lifetime estimate is consistent with the previously known paucity of IR Excess detections around M stars (Binks & Jeffries 2017). We discuss the implications for future HST coronagraphic studies. Support for this work was provided by NASA through grant number HST-GO-15219 from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555.

**Author(s):** John Wisniewski, Glenn Schneider, J. C. Augereau, Anthony Boccaletti, Andras Gaspar, Anne-Marie Lagrange, Christopher Stark, J. Milli, John Debes, Dean Hines, Thomas K. Henning, C. Thalmann, Marc J Kuchner, C. A. Grady, Elie Sezeestre

**Institution(s):** European Southern Observatory, oNASA Goddard Space Flight Center, Eureka Scientific, University of Arizona, University of Oklahoma, LESIA, Observatoire de Paris, STScI, Universite de Grenoble I., Institut Pla

#### **443.10 - Enabling Efficient HST UV Exploration of the Low Surface Brightness Universe(David Thilker)**

We present a pilot program with HST to broadly enable high-resolution UV exploration of star formation at low densities in nearby galaxies using a strategy to increase observing efficiency by up to a factor of two. The increased efficiency achieved with WFC3's eXtra-wide filter set makes more tractable programs which require several tens to hundreds of orbits to aggregate sufficient numbers of resolved massive stars, young star clusters, and clumps to build statistical samples. We aim to enable basic characterization of the ensemble properties of star formation in the low density regime in its primary units. We will discuss first results based on a Local Volume dwarf galaxy (Holmberg I) and a more distant low surface brightness spiral (UGC 9024).

**Author(s):** Mark Krumholz, Marc Rafelski, Bruce G. Elmegreen, Harry Isaac Teplitz, David Thilker, Monica Tosi, Deidre Hunter, Aida Wofford, Janice Lee, Ben Sunnquist, Armando Gil de Paz, Debra Elmegreen, John MacKenty, Gerhardt Meurer, Michele Cignoni, Samuel Boissi

**Institution(s):** University of Western Australia, oAustralian National University / Mount Stromlo Observatory, INAF, Osservatorio Astronomico di Bologna, Caltech, Instituto de Astronomia - Universidad Nacional Autonoma de Mexico, Johns Hopkins University, STScI, IPAC

#### **443.11 - WFC3 PSF Database and Analysis Tools(Clare Shanahan)**

A database of nearly 22 million high signal-to-noise images of non-saturated point sources in WFC3/UVIS observations is accessible from the "WFC3 UVIS PSF advanced search" interface on the MAST portal. The dataset was collected between May 2009 and May 2017, and is updated yearly to

include new sets of non-proprietary observations. Users can search the database to select sources based on various parameters including filter, telescope focus level, exposure time, as well as by parameters associated with the PSF fit. The online portal allows users to preview and download 21x21 pixel cutouts from the original UVIS files. The images are intended for those projects that would benefit from an accurate understanding of the UVIS point spread function and its dependence on the telescope focus on a specific location, but do not have enough sources to create an accurate model. In the coming year the team will release a similar database for the WFC3/IR channel, along with python-based data analysis tools to assess the focus level of an image and to perform focus-dependent PSF fitting analysis in crowded fields. The Python tools provide an interface for running Jay Anderson's Fortran PSF fitting on individual images, and for matching and averaging the measurements across all of the images.

**Author(s):** Kailash Sahu, Elena Sabbi, Jay Anderson, Clare Shanahan, Varun Bajaj, Linda Dressel

**Institution(s):** Space Telescope Science Institute

#### **443.12 - HST Advanced Camera for Surveys Performance in 2025(Roberto J Avila)**

We provide a summary of extrapolations out to the year 2025 of the primary instrument performance metrics of HST's Advanced Camera for Surveys. We discuss the increase in the underlying dark current and the number of hot and warm pixels on the Wide Field Channel (WFC) CCDs. Regarding the steadily degrading charge transfer efficiency (CTE) of the WFC CCDs, time-extrapolated comparisons are made between the pixel-based CTE correction and the CTE photometry correction formula. A simulated WFC image containing all of the effects is compared to images taken at various points in the mission. Estimates are made of how scientific results might be affected. Extrapolated performance metrics for the Solar Blind Channel are also presented.

**Author(s):** Andrea Bellini, Nathan Miles, Melanie Olaes, Nimish Hathi, Norman Grogin, Jenna Ryon, Samantha Hoffmann, Tyler Desjardins, Jay Anderson, Ray Lucas, Vera Kozhurina-Platais, Roberto J Avila, Marco Chiaberge, Ralph Bohlin

**Institution(s):** Space Telescope Science Institute

#### **443.13 - Advances in Observational Studies of the Interstellar Medium Enabled by High-Quality HST/STIS Spectra(Adam Ritchey)**

With its ability to provide high-resolution spectra at high signal to noise in the near and far ultraviolet wavelength regimes, the Space Telescope Imaging Spectrograph of the Hubble Space Telescope has enabled numerous breakthroughs in our understanding of the processes that govern the gas-phase abundances and physical conditions in the local Galactic interstellar medium. Over the past ten years we have been

involved in a number of projects that have benefited greatly from the unique capabilities of HST to provide high-quality UV spectra. Here, we provide an overview of that work, which has included investigations into the gas-phase abundances and depletion behaviors of rare elements in the interstellar medium, examinations of the interactions between supernova remnants and the interstellar gas in their environs, and a broader survey of the physical conditions in the neutral, diffuse ISM. A common theme to much of this work has been our reliance on intrinsically weak interstellar absorption lines, which would be difficult if not impossible to detect were it not for the unique ability of STIS to deliver high-resolution UV spectra at high signal to noise. These past successes should inform the future direction of HST as we begin to prepare for the next decade of science operations.

**Author(s):** Adam Ritchey

**Institution(s):** Eureka Scientific Inc

#### **443.14 - Supernova Progenitor Identification with HST in the 2020s(Schuyler D. Van Dyk)**

Supernovae (SNe) are among the most influential events in the Universe, affecting galactic chemical evolution, the formation of new stellar generations, and the creation of compact neutron star and black hole stellar remnants. Thermonuclear SNe also have served as excellent cosmological probes, leading to the discovery of the accelerating Universe. One of the primary means of constraining the nature of the SN progenitor star is via direct identification in pre-explosion imaging data of the host galaxy. For the past 20 years we have been taking great advantage of the superior spatial resolution of the Hubble Space Telescope (HST) to identify and characterize progenitors, comparing new images of SNe obtained with HST to pre-SN HST images available from the Mikulski Archive for Space Telescopes (MAST). We argue here that much discovery space remains to be explored with HST into the 2020s, in order to advance our understanding of SN progenitors. We further contend that a necessary step forward on into the next decade is to acquire UV-to-near-infrared legacy imaging for many potential future SN host galaxies in the Local Volume.

**Author(s):** Patrick Kelly, Dan Milisavljevic, Melina C. Bersten, Alexei Filippenko, Dale Howell, Nathan Smith, Ori Fox, Gaston Folatelli, WeiKang Zheng, Jon C. Mauerhan, Schuyler D. Van Dyk

**Institution(s):** California Institute of Technology, UC Berkeley, FCGALP, UNLP, LCO/UCSB, Space Telescope Science Institute, Aerospace Corporation, University of Minnesota, University of Arizona, Purdue University

#### **443.15 - The Global Climate and Clouds of KELT-1b Revealed via WFC3 Spectrally-Resolved Phase Curves(Thomas Beatty)**

KELT-1b is a 27MJ brown dwarf on a short 1.22 day orbit around an F5V star. The system is unique, in that it contains the

only known highly irradiated brown dwarf on which it is possible to perform high precision atmospheric measurements. Observations of KELT-1b can serve as a bridge between our understanding of hot Jupiters and isolated brown dwarfs, revealing the similarities -- and differences -- between the two types of objects, and uniquely expand our understanding of the atmospheric circulation, structure, and composition of both. We observed a full orbital phase curve of KELT-1b using WFC3/G141, and strongly detect the planetary phase modulation. Together with our recently published Spitzer phase curves of this object, these observations allow us to examine the global climate of KELT-1b over a range of atmospheric pressures. In particular, we can investigate the role clouds play in setting the emission properties of KELT-1b's nightside by spectrally-resolving the dusk and dawn transitions that occur in KELT-1b's atmosphere.

**Author(s):** Thomas Beatty

**Institution(s):** University of Arizona

#### **443.16 - Unique Visible Light Coronagraphy with the HST/STIS Coronagraphic Apertures(John Debes)**

The Hubble Space Telescope (HST)/Space Telescope Imaging Spectrograph (STIS) contains the only currently operating coronagraph in space that is not trained on the Sun. In an era of extreme-adaptive-optics-fed coronagraphs, and with the possibility of future space-based coronagraphs, we re-evaluate high contrast capabilities of the STIS coronagraphic aperture 50CORON. This coronagraphic aperture consists of a series of occulting wedges and bars, including the recently commissioned BAR5 occulter. We discuss the latest procedures in obtaining high contrast imaging of circumstellar disks and faint point sources with STIS. For the first time, we develop a noise model for the coronagraph, including systematic noise due to speckles, which can be used to predict the performance of future coronagraphic observations. Further, we present results from a recent calibration program that demonstrates better than  $10^{-6}$  point-source contrast at 0.6", ranging to  $3 \times 10^{-5}$  point-source contrast at 0.25". These results are obtained by a combination of sub-pixel grid dithers, multiple spacecraft orientations, and post-processing techniques. Some of these same techniques will be employed by future space-based coronagraphic missions. We also report the impact of HST's increased jitter from April to October of 2018 on coronagraphic observations.

**Author(s):** Bin Ren, John Debes

**Institution(s):** STScI, JHU

## **444 - A NICER Exploration of Neutron Stars and Black Holes -- Posters**

### **444.01 - AMXP Science with NICER(Peter Bult)**

Accreting millisecond X-ray pulsars show a dual character: they exhibit the stochastic variability that low-mass X-ray binaries are known for, but also the strictly periodic emission of a pulsar. Taken together, these signals make for powerful probes of the neutron star and the processes by which it interacts with its environment. Finding these AMXPs, however, is difficult, and their diagnostic power depends on frequent follow-up. In the past months NICER has been instrumental in both aspects - and has proven to be a powerhouse of AMXP science. This contribution reviews new AMXPs discovered with NICER and their respective follow-up campaigns. Additionally, it presents the results we have already been able to obtain, and highlights what we may be able to learn from these systems in the future.

**Author(s):** Craig Markwardt, Peter Bult, Tod E Strohmayer, Paul S Ray

**Institution(s):** NASA/GSFC, NRL Contributing Team(s): NICER Searches and Multiwavelength Coordination Working Group

## **445 - Kepler and K2's 500,000 High-precision Light Curves: Prospects for Future Discoveries -- Posters**

### **445.01 - Lightkurve v1.0: Kepler, K2, and TESS time series analysis in Python(Jessie Dotson)**

The Lightkurve open source Python package offers a user-friendly way to analyze astronomical flux time series data, in particular the pixels and light curves obtained by NASA's Kepler, K2, and TESS missions. The package aims to lower the barrier for students, astronomers, and citizen scientists interested in analyzing Kepler and TESS space telescope data. Lightkurve does this by providing the building blocks for users to create their own pipelines, and is supported by a large syllabus of tutorials. Our package easily allows users to download and inspect data from all three NASA exoplanet missions, with simple tools for inspection and plotting. Our tutorials teach users how to get started with the data from the basics, progressing to more advanced topics such as building tailored data analyses and advanced automated pipelines. Our tutorials cover a range of topics from correcting roll systematics in K2, detecting exoplanet transits, and building asteroseismology power spectra to study stellar oscillations. In this contribution, we will provide an overview of the features of the first release, summarize the future goals, and describe how new contributors can become involved.

**Author(s):** Geert Barentsen, Michael A. Gully-Santiago, Thomas Barclay, Nicholas Saunders, Jessie Dotson, Ann Marie Cody, Christina L Hedges, Jose Vinicius De Miranda Cardoso

**Institution(s):** NASA Ames Research Center, NASA GSFC

### **445.02 - Exoplanet Science with the Lightkurve Python Package(Nicholas Saunders)**

The lightkurve open source Python package offers a user-friendly way to analyze data from NASA's Kepler, K2, and TESS missions. In this poster, we will highlight the features of lightkurve which enable the discovery and characterization of exoplanets. In particular, we will demonstrate how lightkurve provides tools to assist with the removal of systematics from lightcurves, the identification of candidate planets using the BLS algorithm, and the application of aperture photometry using custom apertures to analyze exoplanets. This package can also be used to visualize and interact with time series observations, and we will show a number of simple user examples. We will additionally provide a set of tutorials which demonstrate how different transit-fitting packages can be used to measure planet parameters.

**Author(s):** Geert Barentsen, Michael Gully-Santiago, Nicholas Saunders, Jessie Dotson, Ann Marie Cody, Christina L Hedges,

**Institution(s):** NASA Ames, Bay Area Environmental Research Institute Contributing Team(s): Lightkurve Developers

### **445.03 - Stellar rotation and asteroseismology with the lightkurve Python package(Michael Gully-Santiago)**

The Lightkurve open source Python package offers a user-friendly way to analyze data from NASA's Kepler, K2, and TESS missions. In this poster, we highlight the features of Lightkurve that enable the extraction and analysis of astrophysical signals using the new "Periodogram" object and affiliated methods. These tools are useful to both asteroseismology and stellar rotation studies. Stellar surface inhomogeneities such as starspots and faculae induce periodic stellar brightness variations as the dominant longitudinally-asymmetric active regions rotate into-and-out-of view on modestly inclined stars. Periodicity can be seen in hundreds of thousands of stars in Kepler/K2. We highlight strategies for assessing rotation in stars, including mitigation of instrumental artifacts. Routine operations include multi-term Lomb-Scargle Periodogram analysis and custom aperture mask selection. We also highlight the value of combining Kepler/K2 lightcurves with sparse time-series photometry covering longer baselines and/or multiple wavelength windows, such as ASASSN, Pan-STARRS, Gaia DR2 variable catalog, or AAVSO. These complementary datasets can constrain stellar cycles as the stellar surface evolves secularly in time. New in the current version, lightkurve now offers tools to produce asteroseismic power spectra and find oscillation modes in Kepler and K2 data. New tutorials show how to produce asteroseismic power spectra, varying a range of detrending and systematics corrections. Users can seamlessly access data products from MAST and instantly gauge data quality. Advanced and experimental strategies include Point Spread Function photometry, dimensionality reduction, Fourier decomposition, cross-validation, and Gaussian Process regression.

**Author(s):** Michael Gully-Santiago,  
**Institution(s):** NASA Ames Research Center, Baeri.org  
**Contributing Team(s):** lightkurve developers, Kepler/K Guest Observer Office

#### **445.04 - A Data Visualization and Manipulation Tool to Improve the Scientific Return of Kepler/K2 Short-Cadence Light Curves(Kenneth Mighell)**

Since early 2018, the Kepler/K2 project has been performing a uniform global reprocessing of K2 observations of K2 Campaigns 0 through 14. Subsequent K2 campaigns (C15-C18+) are being processed using the same reduction pipeline. One of the major benefits of the reprocessing effort is that, for the first time in the K2 Mission, short-cadence (1-min) light curves are produced in addition to the standard long-cadence (30-min) light curves. Users have been cautioned that the Kepler Mission's pipeline detrending module (PDC) has not been modified to work well on short-cadence K2 observations. Some station-keeping activities during K2 observations, such as thruster firings, are sometimes poorly corrected for most short-cadence targets. A Python data visualization and manipulation tool is presented which identifies and removes cadences associated with thruster events, which are not well detrended by the PDC algorithm, thus producing better light curves. We anticipate releasing this software on the website:

<http://code.nasa.gov>. The enhanced scientific return of short-cadence K2 observations is demonstrated with the analysis of short-cadence PDCSAP\_FLUX measurements of two targets: the exoplanet K2-99b and EPIC-206003187, an ab-type RR Lyrae star exhibiting the Blazhko effect.

**Author(s):** Kenneth Mighell, Jeffrey Coughlin

**Institution(s):** SETI Institute / NASA Ames

#### **445.05 - Using Kepler DR25 Products to Compute Exoplanet Occurrence Rates(Steve Bryson)**

NASA's Kepler mission is the premiere source of data on small exoplanets with orbital periods up to several hundred days. Kepler's final data release (DR25) provides a uniform, well-characterized exoplanet catalog that is well suited for occurrence rate calculation. Computing exoplanet occurrence rates from Kepler data requires correction for detection completeness (fraction of exoplanets detected), vetting completeness (fraction of detected exoplanets correctly identified as exoplanets) and reliability (the fraction of identified exoplanets that are actually false positives). Kepler's DR25 includes several products that support these corrections: injected transit signals that measure detection and vetting completeness, and inverted and scrambled data that measure reliability. We summarize the DR25 products and describe their use in occurrence rate computations. We give example calculations and illustrate the impact of various corrections. We briefly describe the challenge of creating similarly well-characterized catalogs using data from K2, TESS, and other

exoplanet detection methods.

**Author(s):** Jeffrey Coughlin, Natalie Marie Batalha, Jessie Christiansen, Steve Bryson, Susan E Mullally

**Institution(s):** NASA Ames Research Center, SETI Institute  
**Contributing Team(s):** The Kepler Team

#### **445.06 - The K2 Mission Global Uniform Reprocessing Effort(Jeffrey Coughlin)**

Since early 2018, the Kepler/K2 mission has been performing a uniform reprocessing of the Co-C14 K2 data using an upgraded version of its data processing pipeline - the same version used for C15 and subsequent campaigns. This includes several new features and improvements, such as more sophisticated pixel-level calibration, better identification of spacecraft pointing, improved cosmic ray correction, and production of short-cadence lightcurves, along with several other minor improvements. This effort should enhance the scientific return of the K2 mission by providing users with a high quality, uniformly processed and documented K2 dataset - examples include exoplanet detection and occurrence rate calculation, galactic archeology and comparison of stellar populations, and supernovae/transient detrending and detection. The newly processed data is made available at the Mikulski Archive for Space Telescopes (<https://archive.stsci.edu/k2>) as each campaign is reprocessed. See

<https://keplerscience.arc.nasa.gov/k2-uniform-global-reprocessing-underway.html> for details!

**Author(s):** Jeffrey Coughlin,

**Institution(s):** SETI Institute, NASA Ames  
**Contributing Team(s):** Kepler Team

#### **445.07 - The Kepler photometer: nearing 10 years and still going strong(Douglas Caldwell)**

The Kepler spacecraft was launched in March 2009 to carry out a planned 3 1/2 year mission. Now nearing a decade in space, the Kepler photometer has taken more than 44 million 6.5 second exposures, revealing thousands of planets and enabling diverse scientific discoveries across all of astronomy. As the spacecraft nears the end of its operational life due to lack of fuel to power the attitude control thrusters, the photometer continues to meet design requirements. We will report on the aging of the focal plane through the Kepler Mission and K2, detailing the changes in low-level photometer characteristics and offering an indication of how they might affect scientific investigations. The most significant changes have been the loss of focal plane modules in 2010, 2014, and 2016, reducing the science field of view to just under 100 square degrees. More subtle changes have been seen throughout the missions; for example, the overall system throughput has dropped by 1% per year, resulting in a ~5% increase in star shot noise after 10 years. In addition to the expected aging, the focal plane hosts a number of electronic artifacts that are sensitive to temperature and position, the most notorious of which is the "rolling band

artifact," a high-frequency instability in the electronics that is aliased into the science data. With the larger and more rapid temperature changes in K2, these artifacts are more prominent and changing on faster timescales. We will describe the behavior and potential impacts of the rolling band and other artifacts for Kepler and K2 data, as well as how the rolling band flags in the archive products can best be used to track them.

**Author(s):** Douglas Caldwell,

**Institution(s):** SETI Institute, NASA Ames Research Center  
Contributing Team(s): Kepler/K Science Office

#### **445.08 - Problems with and Prospects for K dwarf Gyrochronology: Insights from the K2 Survey of Ruprecht 147(Jason Curtis)**

Gyrochronology has been demonstrated to work at least up to the age of the Sun for F and G dwarfs. What comes later remains controversial, where periods for Kepler's asteroseismic touchstone stars have been used to argue for a reduced braking efficiency at older ages (van Saders et al. 2016). However, this effect should not affect K dwarfs (0.6-0.9 solar masses), which are even more problematic to age-date with isochrone methods than F and G dwarfs. The difficulty with calibrating K dwarfs gyrochronology is that few are known with published periods that have precise ages older than the Hyades or Praesepe (~650 Myr). This is because asteroseismology is not effective for this class of stars and those located in the older clusters surveyed with Kepler (NGCs 6811 and 6819) are too faint. Our "K2 Survey of Ruprecht 147" program (GO 7035) remedies this by expanding the sample of 2.5 Gyr rotators from 0.85 solar masses from NGC 6819 down to 0.5 solar masses in Ruprecht 147. Our new sample shows tension with expectations from various empirical models (e.g., Mamajek & Hillenbrand 2008, Barnes 2010, Angus et al. 2015), semi-physical models (e.g., van Saders et al. 2013, Matt et al. 2015), and the observed Praesepe period sequence projected forward in time to the age of Ruprecht 147 with the Skumanich Law, all of which predict periods for K dwarfs much longer than observed in the Ruprecht 147. This result is consistent with the mass-dependent epoch of stalled braking suggested by Agüeros et al. (2018).

**Author(s):** Jason Curtis, Marcel Agüeros

**Institution(s):** Columbia University

#### **445.09 - Fundamental and Magnetic Characteristics of M Dwarfs in the Kepler Field(Ellianna Schwab)**

M dwarfs have much longer main sequence lifetimes than the Sun and provide stable habitable zones for tens of billions of years, perhaps making M dwarf planets some of the most habitable in the galaxy. Additionally, the smaller radii of M dwarfs allow us to more easily detect transiting Earth-analog planets, due to the higher planet/star radius ratio of the system than of FGK stars. We seek to better understand the M dwarfs (known and new) in the Kepler field, using the wealth of information provided by the Kepler. We confirm a sample of M

dwarfs using the crossmatch between the initial Kepler dataset and the second Gaia data release. We calculate the spectral energy distributions (SEDs) of these objects, using distances from Gaia and available archival photometry (e.g., AllWISE, 2MASS, SDSS, and PANSTARRS). We use the SEDs to measure updated luminosities, temperatures, masses and radii using empirically based calculations for these stars, rejecting those that don't qualify as M dwarfs. Using Kepler light curves, we calculate rotation rates of these stars and compile,  $H\beta$ , UV, X Ray and flare rate information from archival surveys. We show that white light (Kepler bandpass, Kp) flare strength is highly correlated with rotation rate for M dwarfs and that M dwarfs with fast rotation rates and higher flare strengths in the initial Kepler dataset do not have any confirmed exoplanet detections. While the majority of the stars that we investigate have no confirmed exoplanet detections, a small part of this subsample are known to host transiting exoplanets. We measure updated planetary radii and equilibrium temperatures for these transiting exoplanets. Comparing stellar populations with and without confirmed planets will allow us to examine how M dwarf magnetic strength and activity impact planetary occurrence.

**Author(s):** Jacqueline K Faherty, Courtney Dressing, Ruth Angus, James Davenport, Ellianna Schwab,

**Institution(s):** American Museum of Natural History, Flatiron Institute, University of California, Berkeley, University of Washington, Seattle

#### **446 - The VLA Sky Survey -- Posters**

##### **446.01 - Self-organizing Maps and Machine Learning with VLA Sky Survey Imaging(Brian R. Kent)**

We present a preliminary analysis of the VLA Sky Survey (VLASS) wide-band continuum imaging using the machine learning technique of self-organizing maps (SOMs). As artificial neural networks, SOMs can be used to display similarities of data quantities in a lower dimensional space. The imaging dataset from VLASS is produced by the quicklook imaging pipeline, and provides  $1 \times 1$  degree cutout images in a frequency range of 2 to 4 GHz. The first epoch of observations has produced imaging with 2.5 arcsecond resolution. Using previously known catalogs to identify candidate sources of different morphologies, we describe how a training set is built using this SOM unsupervised machine learning technique.

**Author(s):** Brian R. Kent

**Institution(s):** NRAO

##### **446.02 - Calibration of the VLA Sky Survey(Joshua Marvil)**

The VLA Sky Survey (VLASS) recorded data for over 40% of the celestial sphere between September 7, 2017 and February 20, 2018, with observations totaling approximately 940 hours divided among 170 unique scheduling blocks. Initial calibration of these data was performed prior to "quicklook" imaging using a modified recipe for the VLA CASA pipeline. During this

process, several system issues were uncovered for which pipeline modifications were required, and other pipeline improvements were identified and implemented. An effort is currently underway to recalibrate these data to prepare for the creation of final “‘single epoch’ image products. I will present a summary of the VLASS calibration progress and review the current calibration pipeline architecture, highlighting recent improvements and their integration with the standard VLA CASA pipeline for use by the broader user community.

**Author(s):** Steven T. Myers, Joshua Marvil, Brian R. Kent, Frank Schinzel, Claire Chandler

**Institution(s):** NRAO, NRAO Contributing Team(s): VLASS

## **447 - Circumstellar Disks -- iPosters**

### **447.01 - Multiple Large Impacts Revealed by Disk Variability in the NGC 2547-ID8 System(Kate Su)**

The most dramatic phases of terrestrial planet formation are thought to be oligarchic and chaotic growth, roughly up to ages of 150 Myr, when violent collisions occur between large asteroid-size bodies of sizes up to proto-planets. Such events are marked by the production of huge amounts of debris, including clouds of dust, as has been observed in some exceptionally bright and young debris disks (termed extreme debris disks). Here we report five-year, warm Spitzer measurements from such a system around a solar-type star ID 8 in the 35 Myr-old open cluster NGC 2547. The short-term (weekly to monthly) and long-term (yearly) disk variability is consistent with the aftermaths of two large impacts involving large asteroid-size bodies. Using 3-D radiative transfer calculations, we demonstrate that an impact-produced clump of optically thick dust, under the influence of the dynamical and geometric effects, can produce short-term modulation in the disk light curves. The long-term disk flux variation is related to the collisional evolution within the impact-produced fragments once released into a circumstellar orbit. The long-term variation observed in the ID8 system is consistent with the collisional evolution of two different populations of impact-produced debris dominated by either vapor condensates or escaping boulders. The bright, variable emission by the dust produced in the aftermaths of large impacts in extreme debris disks provides a unique opportunity to study the violent events during the era of terrestrial planet formation.

**Author(s):** Kate Su, Ruobing Dong, George Rieke, Andras Gaspar, Johan Olofsson, Grant Kennedy, Alan Jackson

**Institution(s):** Steward Observatory, University of Arizona, Department of Physics and Astronomy, University of Victoria, Centre for Planetary Sciences, University of Toronto, Department of Physics, University of Warwick, Instituto de Física y Astronomía, Universidad de Chile

## **448 - Binary Stellar Systems – iPosters**

### **448.01 - B Star Multiplicity Survey: Emission Line Stars(Keefe Kamp)**

B Type stars are the progenitors of such phenomena as Supernovae, Cepheid Variable, and Be Type stars. With the recent discovery of gravitational waves in 2015, Binary B type stars are a viable path to create such neutron star-neutron star and black hole-black hole mergers required to create these waves. The purpose of this project is to search the B type stars in the Michigan Spectral catalog, and by extension the Henry Draper catalog, in order to carry out a census of B-type binary systems. The survey uses the Southeastern Association for Research in Astronomy (SARA) telescopes at Cerro Tololo Interamerican Observatory in Chile, Roque de Los Muchachos Observatory in the Canary Islands, and Kitt Peak National Observatory in Arizona. We combine new photometric and spectroscopic observations using these 1-m class telescopes along with the recent GAIA DR2 to look for companions of B - type stars showing emission lines in their spectra. The Be stars phenomena are likely to have companions that are causing the B-type star to rotate rapidly and form a decretion disk that shows emission lines. The emission B-type stars account for 550 of the total 5,553 stars in the complete sample. We plan to expand the survey for all 5,553 stars in the sample to have a complete multiplicity census of a possible channel that leads to supernovae, gravitational waves or Cepheid variables.

**Author(s):** Keefe Kamp, Saida Maria Caballero-Nieves

**Institution(s):** Florida Institute of Technology

### **448.02 - Testing Radiative Braking with XMM and NuSTAR observations of the closest Colliding Wind Binary $\hat{\Gamma}^32$ Velorum(Noel Richardson)**

We obtained multiple epochs of XMM observations of  $\hat{\Gamma}^32$  Velorum in late 2016, as well as joint XMM/NuSTAR observations in late 2018. These new x-ray observations are compared to smoothed-particle hydrodynamical models for the system based on the visual and spectroscopic orbit and the inferred mass-loss rates for the component stars. Our models are able to qualitatively describe spectroscopic variability in the optical, including absorption profiles in neutral helium and emission excess in C III. However, these models are not yet able to reproduce the X-ray fluxes and the variable absorption as the shock cone moves in and out of our line of sight. We think the modeling problems with the x-ray emission are due to radiative braking not being taken into effect yet, and we describe new modeling efforts to better understand this key system to our understanding of colliding winds.

**Author(s):** Michael Francis Corcoran, Kenji Hamaguchi, Christopher Russell, A. Pollock, Noel Richardson

**Institution(s):** University of Toledo, NASA's GSFC, Pontificia Universidad Católica de Chile, University of Sheffield, The Catholic University of America

#### **448.03 - NICER Observations of Cygnus X-3 During a Flaring State(Michael L. McCollough)**

In early July of 2018 Cygnus X-3 descended into a quenched/hypersoft state, which marked the start of a flaring activity which culminated in several radio flares in excess of 1.0 Jy. As part of a multi-wavelength campaign, NICER observations were made throughout this activity, initial results of which are presented here. We will review the evidence for the possible first detection of a high-frequency QPO (140 Hz) in Cygnus X-3. We will also examine the line-rich NICER spectra and investigate how these spectra vary with both time and orbital phase. Finally we place these results in the context of the multi-wavelength campaign, during which observations were made in the gamma-ray (AGILE, Fermi), hard X-ray (Swift/BAT), X-ray (Swift/XRT), submillimeter (SMA), and radio (AMI-LA, RATAN-600).

**Author(s):** Giovanni Piano, Timothy R. Kallman, Tod E. Strohmayer, Michael L. McCollough, Marco Tavani, Karri Koljonen, Ronald Remillard, Zaven Arzoumanian, Michael Francis Corcoran, Keith C. Gendreau, T. J. Maccarone, David Green, Dheeraj R. Pasham, Sergei A. Trushkin

**Institution(s):** Harvard-Smithsonian, CfA, Michigan State University, GSFC/NASA, FINA, MIT, MRAO, Texas Tech University, IAPS/INAF, SAO/RAS

#### **448.04 - Numerical Simulation of Accretion Induced Collapse in a Double White Dwarf Binary(Patrick Motl)**

We present a simulation of dynamically unstable mass transfer and merger of a double white binary. The binary components have initial masses of 0.6 and 0.9 solar masses so that the merged object will have a mass exceeding the Chandrasekhar mass. The simulation proceeds from an equilibrium binary system that is driven into contact and evolved with a fully three-dimensional fluid code that also solves Poisson's equation to incorporate the self-gravity of the fluid. While this simulation does not include nuclear burning and its associated injection of energy, we explore this initial simulation to determine the temperature and angular momentum structure of the merged object as well as characterize the material ejected from the system.

**Author(s):** Patrick Motl

**Institution(s):** Indiana University Kokomo

#### **448.05 - A New Dynamical Class of High Period Derivative Contact Binaries(Lawrence A Molnar)**

We present a new dynamical class of contact binary stars with relatively long orbital periods ( $>0.8$  d) and very large, negative orbital period derivatives ( $dP/dt < -1.6 \times 10^{-8}$ ). We used the survey of Pietrukowicz et al. (2017), which found 108 systems with large  $|dP/dt|$  in a sample of 22,462 binaries. We recomputed  $dP/dt$  using the methods of Molnar et al. (2017).

All were in or near contact. Our new class consists of 7 of the 8 most extreme values of  $dP/dt$  and the only 7 systems with  $P > 0.8$  d (a period range containing  $<5\%$  of contact binaries). The remaining systems have  $|dP/dt| < 1.4 \times 10^{-8}$ , with values distributed symmetrically about zero. Their period changes are likely caused by third bodies. We propose that period change in the new class may be caused by the Darwin secular tidal instability. Nuclear evolution of the primary star is thought to gradually drive contact binaries to longer orbital periods and more extreme mass ratios (e.g., Webbink 1976). When a critical mass ratio is reached (Rasio 1995), tidal instability will drive the systems rapidly towards shorter periods. Tylenda et al. (2011) suggested this as a possible mechanism for the period changes seen in V1309 Sco before its 2008 red nova outburst. However,  $|dP/dt|$  in that system was too great for this to apply (Pejcha 2014). Nonetheless a tidal instability stage may have driven V1309 Sco into a more rapid final stage of L2 mass loss (Pejcha et al. 2018). Using moments of inertia from MESA stellar models, we find critical mass ratios in the range 0.12-0.15. Fits to the light curve shapes of all 7 class members are consistent with this range. We have proposed spectroscopic observations that could be used for more stringent tests of our proposal. If successful, this result would constitute observational validation that the critical mass ratio is the relevant initial condition for the final stage of mass loss. This work was supported by NSF grant 1716622. Molnar et al. 2017, ApJ, 840, 1. Pietrukowicz et al. 2017, Acta Astronomica, 67, 115. Pejcha 2014, ApJ, 788, 22. Pejcha et al. 2018, ApJ, 850, 59. Rasio 1995, ApJL, 444, L41. Tylenda et al. 2011, A&A, 528, A114. Webbink 1976, ApJ, 209, 829.

**Author(s):** Evan M Cook, Sarah M Whitten, Lawrence A Molnar, Michaela G Blain, Henry Kobulnicky

**Institution(s):** Calvin College, University of Wyoming

#### **448.06 - Knowing the dancer from the dance: Line polarization simulations of colliding-wind binaries(Jennifer L. Hoffman)**

Massive binary systems most likely play pivotal roles in producing energetic phenomena such as stripped-envelope supernovae, gamma-ray bursts, and compact mergers. However, the complex wind interactions in such systems are yet not well enough understood to test stellar evolution theories or establish connections between the characteristics of massive binaries and those of their potential descendants. Our group is pioneering the use of spectropolarimetric analysis of WR+O binaries to probe their complex wind collision structures and thereby diagnose the mass loss and mass transfer properties that determine their future evolution. However, because the scattering regions that produce polarization in these systems are highly asymmetric and change their orientation over the course of the orbital cycle, interpreting the observed time-dependent line polarization behavior is highly nontrivial. To aid in this interpretation, we have developed a version of the 3-D Monte Carlo radiative transfer code SLIP that specifically treats binary systems with completely asymmetric circumstellar material (CSM) configurations viewed at arbitrary inclination



angles. The binary code considers multiple scattering effects, eclipses and occultations, and both stellar and non-stellar emission sources to allow for differing line and continuum polarization behavior. We present initial results from this code, which represent the first quantitative models of time-variable integrated line polarization in WR binary systems. Investigating the range of line polarization behavior produced by various configurations of emission and scattering material will not only illuminate the nature of the WR+O binaries for which we have spectropolarimetric data, but also light the path toward a larger-scale analysis of the wind and CSM structures in a variety of interacting binary systems.

**Author(s):** Jennifer L. Hoffman, Rachel A. Johnson, Andrew Fullard

**Institution(s):** University of Denver

## **449 - Dwarf & Irregular Galaxies -- iPosters**

### **449.02 - Star Formation History of the WLM dIrr(Joanne D Hughes)**

The HI-gas-rich, WLM dwarf irregular galaxy has been forming stars for at least 11 Gyr. It is one of the nearest examples of isolated, metal-poor star formation in the Local Group, and contains a single globular cluster. We explore the spatial distribution, ages, and chemical evolution of its stellar population, particularly in the metal-poor halo, compared to the rotating bulge/disk system. We present an extensive imaging survey in BVRI filters (based largely on archival data) as a supplement to previous spectroscopy of a limited sample of giants and supergiants. In addition, a Washington-C survey has been carried out along the rotation (minor) axis into the halo, where the Washington color, C-T1(where the R-filter can be used) can be up to 3 times more sensitive to metallicity than V-I for giant-branch populations.

**Author(s):** Zalia Cook, Ryan Leaman, Peter B Stetson, Joanne D Hughes, George Wallerstein

**Institution(s):** Seattle University, Max-Planck-Institut für Astronomie, Canadian Astronomy Data Centre, Loyola University of Chicago, University of Washington

### **449.04 - The Nature of the Peculiar Milky Way Satellite Sagittarius II(Joshua Simon)**

The Milky Way satellite Sagittarius II (Sgr II) sits in a previously unoccupied portion of the size-luminosity plane, in between dwarf galaxies and globular clusters. To ascertain the nature of this satellite, we present Magellan/IMACS and Keck/DEIMOS spectra of Sgr II member stars. We measure a line-of-sight bulk velocity of  $-177.3$  km/s, and a velocity dispersion of  $\sigma_v = 1.6 \pm 0.3$  km/s. The corresponding mass-to-light ratio within the half-light radius of Sgr II is  $8 \pm 3$   $M_{\odot}/L_{\odot}$ , consistent with a purely baryonic composition. We measure the metallicity of Sgr II to be  $[Fe/H] = -2.28$ , with an upper limit on its metallicity dispersion of 0.08 dex. We use Gaia DR2 proper motions to infer the orbit of Sgr II, and determine that it is unlikely to have experienced tidal

interactions with the Milky Way. Finally, we present chemical abundances for one of the brightest stars in Sgr II, derived from high-resolution Magellan/MIKE spectroscopy. We tentatively suggest that the properties of Sgr II are consistent with classification as an unusually extended globular cluster.

**Author(s):** Marla Geha, Alex G Alarcon Jara, Sal Wanying Fu, Daniel D. Kelson, Joshua Simon

**Institution(s):** Carnegie Observatories, Yale University, Pomona College, Universidad de Concepcion

## **450 - Spiral Galaxies -- iPosters**

### **450.01 - Physics at High Angular resolution in Nearby Galaxies (PHANGS)(Erik Rosolowsky)**

The PHANGS project studies the population of nearby galaxies at high angular resolution (1") to understand how the star-forming sequence of galaxies is established by the internal physics of galactic systems. The PHANGS sample consists of 74 nearby (<17 Mpc), low-inclination systems that are being observed in a suite of tracers notably (1) complete sample coverage in molecular gas traced by CO(2-1) emission observed with the Atacama Large Millimetre/submillimetre Array (ALMA), and (2) optical integral-field spectroscopy from 20 targets using the Multi-unit Spectroscopic Explorer (MUSE) instrument on the Very Large Telescope (VLT). Both the ALMA and the VLT/MUSE surveys are delivering their initial rounds of data. In this contribution, I will present the team's first analysis efforts. In particular, the contribution will describe the sample construction and the new imaging combined with existing multi-waveband work. The first science results from PHANGS reveal that the dynamical state of the molecular medium is remarkably consistent with being marginally self-gravitating (Sun et al., 2018) and that the star formation efficiency per free-fall time is approximately 0.7% across the sample, with real variation among galaxies (Utomo et al., 2018). Combining the MUSE and ALMA data, Kreckel et al. (2018) resolve individual molecular clouds and HII regions to show that the gas depletion times for molecular clouds in NGC 628 are much longer (>1 Gyr) than similar analyses executed in the Milky Way (~0.2 Gyr). Learn more at [phangs.org](http://phangs.org)

**Author(s):** Toshiaki Saito, Kathryn Kreckel, Erik Rosolowsky, Eva Schinnerer, Guillermo Blanc, Karin Sandstrom, Adam Leroy, Chris Faesi, Andreas Schrubba, I-Ting Ho, Rebecca McElroy, Eric Emsellem, Cinthya Herrera, Brent Groves, Antonio Usero, Jerome Pety, Daizhong Li

**Institution(s):** Australian National University, University of California, San Diego, University of Alberta, Max Planck Institute for Astronomy, The Ohio State University, Max Planck Institute for Extraterrestrial Physics, IRAM, European Southern Observatory, OAN,

#### **450.02 - Energy Balanced Global SED Fitting of the Local Volume Legacy Sample of Star-Forming Galaxies(Jordan Turner)**

The Spitzer Local Volume Legacy (LVL) provides a volume-limited sample of 258 nearby galaxies ( $D < 11$  Mpc) with wavelength coverage from the FUV to the FIR. Global spectral energy distributions (SEDs) are modelled with the Code Investigating GALaxy Emission (CIGALE) which takes a Bayesian approach to the modelling while assuming a self-consistent energy balance between the absorption of stellar light by dust and the energy re-emitted by the dust. We present the model SEDs which provide numerous global physical parameters including star-formation rates, ages, dust masses, stellar masses, gas masses, and metallicities.

**Author(s):** Daniel Dale, Jordan Turner

**Institution(s):** University of Wyoming Contributing Team(s): LVL Team

#### **451 - Clusters of Galaxies -- iPosters**

##### **451.01 - Globular Clusters in the Hubble Frontier Field cluster Abell 2744 at $z \sim 0.31$ (Justin Matthew Cada Barber)**

We present a study of globular clusters (GCs) in the Hubble Frontier Field cluster Abell 2744, also known as Pandora's cluster, located at  $z \sim 0.31$ . This cluster is extraordinarily rich in the number and variety of galaxies it contains. It exhibits multiple peaks in the weak gravitational lensing based dark matter, X-ray, and galaxy density distributions, suggesting that we are witnessing an ongoing collision of several massive clusters. Our goal is to use compact stellar systems, GCs, as fossil records of the violent interactions that shaped the Pandora's cluster and the galaxies in it to gain new insight into cluster formation processes. In our study, we use the publicly available point-source catalogs published by Livermore et al. (2017) and Shipley et al. (2018). These two teams use different and independent methods to model and remove the more diffuse starlight of the cluster galaxies and intracluster light of the cluster in all the seven optical and infrared bands and provide multiwavelength point-source catalogs selected in the deepest photometrical images obtained after stacking all multiwavelength cleaned images; thus the detection is performed with the lowest spatial resolution. We are in the process of generating a single-band point-source catalog in F814W, where the spatial resolution is significantly higher. Although our detection cannot go as deep as Shipley et al. and Livermore et al., we have better control of the removal of stellar light, specially around the centers of galaxies, which makes these methods complementary. Preliminary analysis shows that the Shipley et al. catalog lacks a large number of faint point sources, especially near the centers of large galaxies where we expect to find the largest number of GCs. Conversely, the Livermore et al. catalog contains many more sources, although a large number of instrumental artifacts and spurious sources are included as point-sources in their catalog. We are combining the Shipley et al. and Livermore et al. catalogs with our own catalog with the aim of obtaining the most complete

sample of GCs in Abell 2744. This research is funded in part by NASA/STScI.

**Author(s):** Elisa Toloba, Guillermo Barro, Puragra Guhathakurta, John Blakeslee, Justin Matthew Cada Barber, Eric W. Peng

**Institution(s):** University of the Pacific, University of California Santa Cruz, Gemini South Observatory, Peking University

#### **452 - Observatory Operations -- iPosters**

##### **452.01 - Gemini Observatory Cloud Cameras: Usage in Remote Operations and Public Outreach(Adam Smith)**

In 2016, the Gemini 8m telescopes in Hawai'i and Chile both began remote operations from their sea-level base facilities. As part of the move to remote operations, requirements for the ability to monitor clouds were developed to make up for the inability of the operator to walk outside and determine by eye and night vision goggles the current cloud conditions. Gemini commissioned 6 commercial Digital Single-Lens Reflex (DSLR) cameras modified with custom-built beagle-bone controllers, for each facility and developed a variety of scripts to take images, create nighttime gif-loops for the operators and a high-definition video of the entire night. The images and videos are both publicly available for use by other telescopes on Maunakea as well as citizen scientists and the public around the world. Here we present how the Gemini cloud cameras were developed to their current state and how they are used operationally throughout the night and as part of daytime data assessment. We also present several interesting things, both earth and space based, that have been seen with the cameras. The videos and stills from the Gemini Observatory Cloud Cameras can be found here:

<https://www.gemini.edu/sciops/telescopes-and-sites/weather/>

**Author(s):** Tom Cumming, Adam Smith, Kanoa Withington

**Institution(s):** Gemini Observatory, CFHT Contributing Team(s): Steve Cullen

#### **453 - Astro Publishing -- iPosters**

##### **453.01 - Trends in the Astronomy Publication Landscape - Multidisciplinarity and Impact(Edwin Henneken)**

On this poster we explore some trends in the astronomy publication landscape. Multidisciplinarity has increased in science as a whole; astronomy and astrophysics are no exception to this trend. Astronomers now regularly publish in journals that are not typical for the discipline. For example, exoplanet research draws in expertise from geophysics, biology and chemistry. A mission like LSST will need big data science for the processing and interpretation of data produced; the mission needs a new type of astronomer. Data science in general will learn from techniques developed in the LSST context. Since scholarly publishing is the main vehicle to transfer knowledge, increased multidisciplinarity will have consequences for the publication landscape in astronomy. Because citations remain the gold standard for measuring

scholarly activity and impact, we use citations aggregated on journal level to look for trends that reflect these changes. The ADS pioneered the use of citation indices on the WWW; as a result the citation network represented in the ADS holdings provides a unique data set to study these trends. We will also discuss changes in journal impact, resulting from the changes in citation behavior.

**Author(s):** Michael J Kurtz, Edwin Henneken

**Institution(s):** Smithsonian Astrophysical Observatory  
Contributing Team(s): ADS Team

#### **453.02 - A Bibliometric Analysis of Observatory Publications for the Period 2012-2016(Dennis Crabtree)**

This paper presents the productivity and impact of observatory publications. The primary scientific output of a telescope is the collection of papers published in refereed journals based on data from that telescope. A telescope's productivity is measured by the number of papers published, while its scientific impact is the sum of each individual paper's impact as measured quantitatively by the number of citations that the paper receives. The period covered by this paper for the years between 2012 and 2016.

**Author(s):** Dennis Crabtree

**Institution(s):** National Research Council Canada

#### **454 - AGN, QSO & Blazars: Late Posters**

##### **454.01 - Exploring Reionization-Era Quasars: Quasar Luminosity Function and Contribution to the Cosmic Reionization at $z \sim 7$ (Feige Wang)**

Which sources dominate the ionizing photon budget is a key question in understanding the cosmic reionization history. Measurement of quasar luminosity function (QLF) at the epoch of reionization (EoR) directly yields the ionizing radiation output from quasars and will help to solve this longstanding question. However, to determine the QLF accurately at the EoR is extremely difficult. Not only does it require a large uniformly selected quasar sample, but the sample needs to be statistically complete. By combining DESI Legacy imaging Surveys (DELS) and near-infrared imaging surveys, as well as the Wide-field Infrared Survey Explore (WISE) mid-infrared survey, we constructed the first statistically complete quasar sample with  $\sim 20$  luminous quasars at  $6.5 \leq z \leq 7.0$  over a sky area of  $\sim 13,000 \text{ deg}^2$ . We measured the QLF follows  $\dot{N}(L1450) \hat{=} L^{-2.35}$  in the magnitude range of  $-27.6 < M1450 < -25.5$ . We determined the quasar comoving spatial density at  $\hat{\rho}^{\text{com}} = 6.7$  and  $M1450 < -26.0$  to be  $0.39 \pm 0.11 \text{ Gpc}^{-3}$  and found that the exponential density evolution parameter to be  $k = -0.78 \pm 0.18$  from  $z \sim 6$  to  $z \sim 6.7$ , corresponding to a rapid decline by a factor of  $\sim 6$  per unit redshift towards earlier epoch, a rate significantly faster than that at lower redshifts. The cosmic time between  $z \sim 6$  and  $z \sim 6.7$  is only  $\sim 120 \text{ Myrs}$ . The quasar density declined by a factor of more than three within such short time requires that SMBHs must grow rapidly or they are less

radiatively efficient at higher redshifts. We measured quasar comoving emissivity at  $z \sim 6.7$  which indicate that high redshift quasars are highly unlikely to make a significant contribution to hydrogen reionization.

**Author(s):** Xue-Bing Wu, Minghao Yue, Jinyi Yang, Xiaohui Fan, Feige Wang

**Institution(s):** UC Santa Barbara, Kavli Institute for Astronomy and Astrophysics, Steward Observatory  
Contributing Team(s): Exploring Reionization-Era Quasars Team

##### **454.02 - The Diversity in the Optical Variability of Radio-loud Quasars(Zhuyun Zhuang)**

We present optical monitor of 142 radio-loud quasars with 10-15 day cadence for about 1.5 years through LCO, seven of which are appended with data from SDSS Stripe 82, with the overall goal to characterize the variability of individual objects. Combining with the photometric and spectroscopic data in SDSS database, we obtain the light curves for individual quasars spanning  $\sim 10 \text{ yr}$ . Our various analysis of this dataset did reveal the presence of the diversity of quasars' variability, through structure function and the comparison with damped random walk (DRW) model. While the majority of the sample are consistent with DRW model, six quasars are found to have the abnormal shape of individual SFs and nine show great deviations from DRW model on short timescales ( $\leq 1 \text{ yr}$ ), implying that the accretion physics of certain radio-loud quasars may differ from that of the radio-quiet ones.

**Author(s):** Zhuyun Zhuang, Zi-Teng Wang, Yong Shi, Kan Wang

**Institution(s):** Nanjing University

##### **454.03 - A Long Hard-X-Ray Look at the Dual Active Galactic Nuclei of M51 with NuSTAR(Murray Brightman)**

We present a broadband X-ray spectral analysis of the M51 system, including the dual active galactic nuclei (AGNs) and several off-nuclear point sources. Using a deep observation by NuSTAR, new high-resolution coverage of M51b by Chandra, and the latest X-ray torus models, we measure the intrinsic X-ray luminosities of the AGNs in these galaxies. The AGN of M51a is found to be Compton-thick, and both AGNs have very low accretion rates ( $\dot{M} \gg \dot{M}_{\text{Edd}} < 10^{-4}$ ). The latter is surprising considering that the galaxies of M51 are in the process of merging, which is generally predicted to enhance nuclear activity. We find that the covering factor of the obscuring material in M51a is  $0.26 \pm 0.03$ , consistent with the local AGN obscured fraction at  $L_X \hat{=} 10^{40} \text{ erg s}^{-1}$ . The substantial obscuring column does not support theories that the torus, presumed responsible for the obscuration, disappears at these low accretion luminosities. However, the obscuration may have resulted from the gas infall driven by the merger rather than the accretion process. We report on several extranuclear sources

with  $L_X > 10^{39}$  erg s<sup>-1</sup> and find that a spectral turnover is present below 10 keV in most such sources, in line with recent results on ultraluminous X-ray sources.

**Author(s):** Mislav Balokovic, Ady Annuar, Dominic Walton, David Alexander, Poshak Gandhi, Hannah Penn Earnshaw, Andreas Zezas, Fiona Harrison, Murray Brightman, Andrew Ptak, Blagoy Rangelovo, Meredith Powell, Timothy Roberts, Daniel Stern, Ann Hornschemeier, Bret Leh

**Institution(s):** Jet Propulsion Laboratory, UTexas State University, University of Crete, Institute of Astronomy, California Institute of Technology, Eureka Scientific, Harvard-Smithsonian Center for Astrophysics, Universiti Kebangsaan Malaysia, Durham University, NA

#### **454.04 - The first results from the SNU AGN Monitoring Project(Jong-Hak Woo)**

We have been carrying out a long-term AGN monitoring program over the last 3 years to measure the time lag of broad emission lines and investigate the size-luminosity relation for moderate-to-high luminosity AGNs. Using the photometry data obtained with several telescopes including the MDM 1.3m, LOAO 1m, and DOAO 1m, and the spectroscopy data obtained with the Lick 3m and MDM 2.4m, we present the initial results, discussing the lag measurements, variability, and the size-luminosity relation.

**Author(s):** Jong-Hak Woo

**Institution(s):** Seoul National University   Contributing Team(s): SAMP Collaboration

#### **454.05 - Testing the Isotropy of Very High Energy Gamma-ray Emitting Galaxies(Tibor Svarka)**

Very high energy gamma-ray emitting galaxies are the most commonly detected types of sources above 100 GeV. With more than 100 sources detected so far, population studies to help understand the nature of them are possible. One of the most natural questions surrounding these objects is regarding their relative locations as compared to the large-scale structure of the universe and how this may affect the gamma-ray emission that is observable from Earth. We share an on-going analysis of these extreme galaxies to determine if a cluster of gamma-ray emitting blazars is statistically significant. The analysis is completed using Python code in order to find the angular distances between each blazar. From our preliminary investigations, we have seen a number of sources in the northern sky that appear to be clustered and are located after the largest known void in the universe. They are appearing as outliers with angular distances between 5 and 12.5 degrees. We will investigate the significance of these outliers and summarize some possible physical explanations of what could cause the non-isotropic detection of gamma-ray blazars above 100 GeV. If the clustering is found to be significant, the analysis could show that the size of a void directly relates to the number of gamma-ray emissions that we can observe from Earth in a given area of

the universe.

**Author(s):** Tibor Svarka

**Institution(s):** California State University, East Bay

#### **454.06 - The KONA Survey: Characterizing the Dust Morphology in Nearby Active Galaxies(Helen Kyung Kim)**

The Keck OSIRIS Nearby AGN survey (KONA) provides a statistically significant sample of local Seyfert galaxies that, when combined with archival HST imaging, allows for characterization of gas inflows and outflows within the central 200 pc. Understanding the inflow and outflow characteristics is crucial for constraining models of black hole and host galaxy evolution. In this work, we present visible-near infrared (V-H) color maps of 8 Seyfert galaxies obtained from recent Keck/NIRC2 observations and archival HST data. These color maps are used to trace the dust morphology out to larger radii than structure maps.

**Author(s):** Erin K S Hicks, Matthew Malkan, Francisco Mueller Sanchez, Helen Kyung Kim

**Institution(s):** University of California, Los Angeles, University of Colorado at Boulder, University of Alaska Anchorage

#### **454.07 - Exploring the host galaxy of the most distant lensed quasar at $z=6.51$ (Jinyi Yang)**

We present IRAM/NOEMA, JCMT/SCUBA-2 and JVLA observations of the most distant known lensed quasar J0439+1634 at  $z = 6.51$ . We report the detections of dust emission, [CII], [CI], CO(6--5), CO(7--6), CO(9--8), CO(10--9) lines and water vapor emissions in the interstellar medium of its host galaxy. The strong gravitational lensing makes J0439+1634 be the far-infrared (FIR) brightest quasar at  $z > 6$ , with a gravitationally-amplified FIR luminosity of  $3.5 \times 10^{13} L_{\text{sun}}$  and the brightest [CII] line ( $f_{\text{peak}} = 40 \text{ mJy}$ ) ever detected at  $z > 6$ . These observations allow us to constrain the excitation model, dust emission model, molecular gas mass, dust mass and dynamical mass.

**Author(s):** Jinyi Yang, Bram Venemans, Xiaohui Fan, Feige Wang

**Institution(s):** University of Arizona, MPIA, UCSB

#### **454.08 - Determining the Nature of Galactic Center Radio Source N3(Riley Dunnagan)**

We present short-term variability and spectral line radio observations of the point source N3 located along the line of sight to the Galactic Center. VLA spectral line observations reveal that N3 lies behind the compact molecular cloud adjacent to N3 in projection. Long-term variability for N3 was established in Ludovici et al. (2016). We also examine N3 for variability in 4.288GHz - 5.312GHz, 5.838GHz - 6.862GHz,

8.238GHz - 9.262GHz, and 9.738GHz - 10.762GHz bands to compare to our calibration sources as well as the presence of certain absorption and emission spectral lines. Our observations reveal the existence of a CH<sub>3</sub>OH (5-6) absorption, H<sub>2</sub>CO 1(1,0)-1(1,1) absorption, and a likely HC<sub>3</sub>N emission maser in the J=1-0 transition. Our observations conclude that N<sub>3</sub> lies behind the molecular cloud and shows no significant, thus N<sub>3</sub> is likely a background AGN.

**Author(s):** Riley Dunnagan, Katana Colledge, Dominic Ludovici

**Institution(s):** Rose Hulman Institute of Technology  
Contributing Team(s): N.OButterfield, C.CLang, A.GGinsburg, R.LMutel, M.RMorris, N.Jones, DPare

#### **454.09 - A Spectral Exploration of Obscured and Unobscured AGN(Antoine Washington)**

There is an ongoing debate as to whether the differences we observe in certain active galactic nuclei (AGN) is due simply to their orientation relative to their observer or if there exists some real, physical difference in these objects that drive these differences. The unification model stresses the former, that these objects are simply look different at different orientations, and otherwise, these objects are all essentially the same. Andy Goulding at Princeton University devised a method of differentiating between obscured and unobscured AGN using Wide-field Infrared Survey Explorer (WISE) and Hyper Suprime-Cam (HSC) data. However, this method cannot function on objects at lower redshifts. I look into the spectral data of these objects to determine how well Andy's classification functions, and I ultimately find that this method works better with more luminous, higher redshift objects.

**Author(s):** Andy Goulding, Jenny Greene, Antoine Washington,

**Institution(s):** Rutgers University, Princeton University

#### **454.10 - Correlated Infrared-Gamma-ray Variability in Bright, Well-Monitored Blazars 2008-2017(Kenji Yoshida)**

We present cross correlations of the J-band SMARTS light curves and Fermi gamma-ray light curves for 8 bright blazars that have been monitored extensively on sub-weekly time scales over the past decade. Because of the uneven temporal sampling, we use the Discrete Correlation Function (DCF) and we create an empirical boot-strapping method to assess the significance of the DCF amplitude for each blazar. Our results are perhaps surprising. Early on in the Fermi mission, the flaring blazar 3C454.3 showed zero lag between optical and gamma-ray or infrared and gamma-ray fluxes, which Bonning et al. (2012) suggested was consistent with the gamma rays being produced by inverse Compton scattering of ambient photons by synchrotron-emitting electrons. However, of the 8 blazars we examine, only one - 3C454.3 - shows a significant peak at zero lag. The other seven show no significant peak at zero lag. Some

blazars show broad peaks at lags of 10s of days, at or just below 3 sigma significance. In addition, analyses of time periods of a year or two only, for a given blazar, show strong changes from one epoch to the next. These results complicate our understanding of blazar emission mechanisms. Possible physical explanations are discussed.

**Author(s):** Bryndis Cruz, Georgios Vasilopoulous, Charles Bailyn, Kenji Yoshida, Maria Petropoulou, Paolo Coppi, C. Megan Urry

**Institution(s):** Shibaura Institute of Technology, Princeton University, Yale University

#### **454.11 - A powerful AGN-driven outflow in a low-luminosity AGN.(Ethan Avery)**

We present results of an on-going program to measure AGN Feedback in Seyfert galaxies using integral- field spectroscopy and adaptive optics at Keck Observatory. Our integral-field observations reveal an AGN-driven outflow of highly- ionized gas in the Seyfert 2 galaxy NGC 3081, one of the galaxies of the Keck Osiris Nearby AGN (KONA) survey. By resolving the inner 10 parsecs, we have successfully modeled the outflow geometry as a bicone, in which the ionized gas first accelerates and then decelerates. The ratio of kinetic power to bolometric luminosity of the AGN is  $E_{\text{out}}/L_{\text{bol}} \sim 0.005$ , which is in the regime of values required by AGN feedback models. These results suggest that the outflow is probably not a single wind originating near the AGN, but is actually a product of the interaction of an already accelerated wind with its ambient medium. Since NGC 3081 is a low luminosity AGN with a bolometric luminosity of  $\sim 15 \times 10^{42} \text{ erg s}^{-1}$ , these results suggest that powerful outflows can exist in local low-luminosity AGN.

**Author(s):** Erin K S Hicks, Francisco Mueller Sanchez, Matthew Malkan, Ethan Avery

**Institution(s):** University of Memphis, University of Alaska Anchorage, University of California, Los Angeles, University of Colorado Boulder  
Contributing Team(s): KONA

#### **454.12 - Is there a relativistic Fe K line in quasar 4C 74.26?(Panayiotis Tzanavaris)**

X-ray data for quasar 4C 74.26 have previously been modeled with a broad Fe K $\pm$  line emission consistent with an origin in the strong gravity regime in the inner part of the accretion disk, thus allowing estimates of supermassive black hole spin. We extracted broadband X-ray spectra from Suzaku and NuSTAR data and for the first time modeled them self-consistently with both direct and reflected continuum, as well as Fe K, emission using MYTORUS. We found that all spectra can be modeled well only with narrow Fe K $\pm$  line emission from a distant X-ray reprocessor, precluding the need for broad, relativistic components, so that supermassive black hole spin measurements cannot be carried out. We further obtained results for the equivalent neutral hydrogen column density both in and out of the line of sight, finding that all spectra are

consistent with at least moderate Compton thick column density values.

**Author(s):** Andrew Ptak, Tahir Yaqoob, Mihoko Yukita, Panayiotis Tzanavaris, Stephanie LaMassa

**Institution(s):** NASA/GSFC, STSCI, NASA/GSFC/CRESST/UMBC/JHU

#### **454.13 - Hunting for High-Redshift Water Masers: Searching for Circumnuclear Megamasers Using the VLA(Madelyn Broome)**

Astrophysical water masers are the result of population inversion of warm ( $T_{\text{kin}} > 300\text{K}$ )  $\text{H}_2\text{O}$  molecules of  $n(\text{H}_2) \approx 10^7 \text{ cm}^{-3}$  and velocity coherence over sufficiently long gain path. Circumnuclear water megamasers (thus called for their luminosity of  $\approx 10$  solar luminosities) are found in high-density molecular gas within parsecs of active galactic nuclei (AGN) in Seyfert Type 2 and LINER galaxies and are thought to be the result of post-shocked molecular clouds due to jets or outflows or X-ray heating of the accretion disk in the AGN. Water masers brightness and proximity to the supermassive black hole makes them invaluable tools for measuring accurate black hole masses, spatial and kinematic distribution of molecular gas in the galactic center, extragalactic distances (e.g. Hubble's constant), and the distribution of AGN as a function of redshift. At high-redshift, however, the emission line is buried in the noise, making water masers extremely difficult to detect - only one has been detected at  $z = 2.64$ , with the next closest at  $z = 0.66$ . From VLA observations of a sample of lensed, dust-obscured, far-infrared-bright AGN candidates with well-known redshifts, we present a 3- and potential 4-sigma detection of circumnuclear water masers at  $z=2.311$  and  $z=2.965$ , respectively.

**Author(s):** Hugo Messias, Violette Impellizzeri, Madelyn Broome, Rob Ivison

**Institution(s):** Princeton University, European Southern Observatory (ESO), Atacama Large Millimeter/submillimeter Array (ALMA)

#### **455 - Astrobiology, Lab Astro & Misc.: Late Posters**

##### **455.01 - Look Who's Talking: An Investigation of Gender Representation at Astrobiology Meetings(Nicole Cabrera)**

High-profile cases of sexual harassment and bullying in the sciences have sparked myriad conversations about equity and inclusion in academia. While no such cases have been publicly reported in the field of Astrobiology or the Origins of Life (OoL), there are concerns about low representation of white women, women and men of color, and other marginalized groups at conferences in this field. This is a subject of equal importance, since low representation can lead to isolation, a higher risk of abuse in the workplace, and stronger inclinations to leave a field of study. We present data on gender demographics at three Astrobiology/OoL conferences: the

Gordon Research Conference on the Origins of Life (1994 - 2018), meetings of the International Society for the Study of the Origins of Life (2011 - 2017), and the Astrobiology Science Conference (2015 - 2017). Specifically, we report on the distribution of male and female participants as discussion leaders and speakers, and in invited and elected roles, including conference organizer. We find that women in these positions are underrepresented in proportion to their attendance at the meetings.

**Author(s):** Nicole Cabrera

**Institution(s):** Movement Consulting

#### **455.02 - Mult-Isotopic Fractionation of Water From Sublimation at Low Temperatures(Lauren Rose Tafla)**

Understanding how astrophysical processes like diffusion, evaporation, and condensation of volatile ices affects the ratios of isotopes can help us better understand observations of isotopic variation in astrophysical systems. For example, the sublimation of water-ice from astrophysical and planetary surfaces such as interstellar dust, comets and asteroids at low temperatures is expected theoretically to result in significant shifts in the isotopic composition of the residual water ice. Using a UHV system with closed-cycle He cryostat and a cavity ring-down isotope spectrometer (CRD), we developed a protocol for measuring changes in the ratios of D/H,  $18\text{O}/16\text{O}$ , and  $17\text{O}/16\text{O}$  that result from the sublimation of water ice at 155 K. In this presentation, we discuss the challenges and lessons learned to achieving experimental conditions that mimic astrophysical environments. Results from our experiments, including instantaneous fractionation factors associated with hydrogen and oxygen isotopes will be presented. The role that experimental conditions such as sample size and surface temperature and composition play will also be discussed. To assess whether the experimental conditions present in the UHV chamber are adequate for simulating sublimation into the near perfect vacuum of space, we developed a detailed model of the isotopic fluxes associated with the water-ice surface, vacuum chamber walls, and pumping provided by a magnetically levitated turbo pump. This model incorporates a transition-state-theory (TST) based representation of surface potential energies and associated isotopic fractionation factors. Using this model, we estimated the magnitude of water recondensation onto the cold-surface and calculated the associated effects on the isotopic composition of the residual water ice compared to the theoretical values expected for pure sublimation.

**Author(s):** Carina Maciel, Lauren Rose Tafla, Gerardo Dominguez, Farrah Glick, Michelle Salem, Josh Lucas

**Institution(s):** California State University San Marcos

#### **455.03 - The Gemini Fast Turnaround program(Morten Andersen)**

Gemini Observatory introduced the Fast Turnaround proposal cycle for 3 years as part of the different paths to apply for observing time. This novel distributed peer review concept is aimed at a more agile and rapid proposal cycle than the usual semester based approach. We review the program and its status and the lessons learned over its lifetime. The oversubscription is compared to that of the semester based proposals and the publication rate from accepted programs is discussed. Finally we discuss the mentoring part of the program where graduate students can be involved in the review process under the supervision of a mentor.

**Author(s):** Ricardo Salinas, Matthew Taylor, Kristin Chiboucas, Jared Eckersley, Julia Scharwaechter, Hwi Hyun Kim, Morten Andersen, Trent Dupuy, David Sanmartin, Thomas Geball

**Institution(s):** Gemini Observatory

#### **455.04 - Increasing Gender Diversity and Inclusion in Scientific Committees and Related Activities at Space Telescope Science Institute(Carol Christian)**

We present a new initiative by the Women in Astronomy Forum at Space Telescope Science Institute (STScI) to increase gender diversity and inclusion in STScI's scientific committees and the activities they generate. This initiative offers new and uniform guidelines on binary gender representation goals for each committee, and recommendations on how to achieve them in a homogenous way, as well as metrics and tools to track progress towards defined goals. Diversity and Inclusion are key components of STScI's Core Values and this latest initiative follows in line with other initiatives that STScI has taken to increase diversity and inclusion. For example, past efforts have focused on creating internal inclusion and diversity groups, creating all-gender restroom, lactation, and health room facilities, offering medical coverage for transgender transition procedures and same sex/domestic partner medical/dental benefits, offering teleworking options and flexible schedules, offering paid parental leave, and offering mentoring and career advancement motivation in addition to balanced high quality science, amongst other initiatives. While the new guidelines presented here focus on binary gender representation, they can be adapted and implemented to support all minority groups. By creating diverse committees and making them aware of, and trained on implicit bias, we expect to create a diverse outcome in the activities they generate, which in turn will advance science further and faster.

**Author(s):** Carol Christian

**Institution(s):** STScI Contributing Team(s): Women in Astronomy Forum at STScI

#### **455.05 - Estimating The Polarization Of Neutrino Events At The Askaryan Radio Array (ARA)(Charles Robertson)**

The Askaryan Radio Array (ARA) is an ultra-high energy neutrino detector at the South Pole that aims to extend the new field of neutrino astronomy to energies of 10<sup>18</sup> eV and above. As messenger particles unaffected by intervening matter or magnetic fields, ultra-high energy neutrinos can provide key insights into the highest energy astrophysical processes in the Universe. ARA aims to detect neutrinos using the radio emission from neutrino interactions in the ice. Neutrino properties can be determined by reconstructing the neutrino event from the observed radio pulse using both horizontally- and vertically-polarized antennas. ARA can use radio interferometry to determine the direction to the neutrino interaction vertex and polarization information to determine the neutrino direction. By unfolding the antenna response from both types of antennas, polarization information can be extracted from the measured electric field. This work demonstrates a method to measure the event polarization based on Monte Carlo simulations of neutrino events. Measuring the polarization is critical for neutrino directional reconstruction and thus for neutrino astronomy.

**Author(s):** Albrecht Karle, Charles Robertson, John L. Kelley

**Institution(s):** University of Kansas, University of Wisconsin-Madison Contributing Team(s): ARA Collaboration

#### **456 - Black Holes & Supernovae: Late Posters**

##### **456.01 - AT2018cow: a luminous millimeter transient(Anna Yen Qin Ho)**

We present detailed submillimeter- through centimeter-wave observations of the extraordinary extragalactic transient AT2018cow. The apparent characteristics -- the high radio luminosity, the long-lived emission plateau at millimeter bands, and the sub-relativistic velocity -- have no precedent. A basic interpretation of the data suggests  $E_k > 10^{48}$  erg coupled to a fast but sub-relativistic ( $v \approx 0.13c$ ) shock in a dense ( $n \approx 3 \times 10^3$ – $10^5$  cm<sup>-3</sup>) medium. We find that the X-ray emission is not naturally explained by an extension of the radio-submm synchrotron spectrum, nor by inverse Compton scattering of the dominant blackbody UVOIR photons by energetic electrons within the forward shock. By  $t \approx 20$  days, the X-ray emission shows spectral softening and erratic inter-day variability. Taken together, we are led to invoke an additional source of X-ray emission: the central engine of the event. Regardless of the nature of this central engine, this source heralds a new class of energetic transients shocking a dense medium, which at early times are most readily observed at millimeter wavelengths.

**Author(s):** Varun Bhalerao, Dougal Dobie, Ilsang Yoon, Shrinivas Kulkarni, Daniel Perley, Bjorn Emonts, Tara Murphy, S. Bradley Cenko, TK Sridharan, Glen Petitpas, Ryan Howie, Raymond Blundell, Anna Yen Qin Ho, Mansi Kasliwal, Vikram Ravi, Sterl Phinney, Nikita

**Institution(s):** Caltech, Harvard-Smithsonian Center for

Astrophysics, Astrophysics Science Division, NASA Goddard Space Flight Center, Department of Physics, Indian Institute of Technology Bombay, National Radio Astronomy Observatory, Sydney Institute for Astronomy,

**456.02 - Neutrinos from galaxies in the local universe( $d < 10$  Mpc): Multi-messenger implications(Samalka Anandagoda)**

Neutrinos, one of the most elusive particles in the universe are emitted in copious numbers by core-collapse supernovae. Over the course of time, these particles create a faint cosmic background known as the Diffuse Supernova Neutrino Background(DSNB). The DSNB, if detected, can prove to be a powerful tool to constrain the cosmic star formation history and place significant constraints on the core-collapse supernova physics. In this work, we investigate this background field and predict the number of neutrinos released from individual supernova events from galaxies within the local volume(LV), i.e. distances less than 10 Mpc. This prediction will not only help us better resolve the DSNB but also help in future detection of neutrinos from observatories like Super-Kamiokande, Ice cube, etc. Furthermore we discuss the role neutrinos play in the multi-messenger era compared to high energy photons and gamma rays.

**Author(s):** Abhishek A Desai, Dieter Hartmann, Samalka Anandagoda, Marco Ajello

**Institution(s):** Clemson University

**456.03 - A hyper-runaway white dwarf in Gaia DR2 as a single degenerate Type Ia Supernova donor remnant candidate(Nicholas James Ruffini)**

The progenitor systems to Type Ia Supernovae remain uncertain. One possible explanation is the so-called "single-degenerate" scenario, in which a primary white dwarf accretes matter from a non-degenerate companion. The single-degenerate scenario is thought to produce a population of kicked donor remnants moving with high velocity, but no example of a kicked donor remnant has been found. Here we report the likely first known example of an unbound white dwarf that is consistent with being an evolved donor remnant to a Type Ia supernova. The candidate, LP 93-21, is traveling with a galactocentric velocity of  $v_{gal} = 605 \text{ km s}^{-1}$ , making it gravitationally unbound to the Milky Way. At 57 pc from the Sun, it is also the closest hyper-runaway candidate known. The estimated cooling age for LP 93-21 is 2.7 Gyr, implying that it has traveled at least 1.6 Mpc since donating mass to its companion. Integrating the orbit backwards suggests that NGC 6822 is the plausible host galaxy. This discovery is consistent with recent Type Ia Supernovae models that suggest this event likely occurs often, and that there could be a substantial population of kicked donor remnants passing through the Milky Way. Unfortunately the intrinsic faintness of white dwarfs makes it difficult to detect such donors.

**Author(s):** Nicholas James Ruffini, Andrew R Casey,  
**Institution(s):** Monash University, Cambridge University, University of South Florida

**456.04 - Deep Late-Time Observations of the Supernova Impostors SN 1954J and SN 1961V(Rachel Patton)**

SN 1954J in NGC 2403 and SN 1961V in NGC 1058 were two luminous transients whose definitive classification as either non-terminal eruptions or supernovae remains elusive. A critical question is whether a surviving star can be significantly obscured by dust formed from material ejected during the transient. We use three lines of argument to show that the candidate surviving stars are not significantly optically extincted ( $\bar{I}_\lambda \approx 1$ ) by dust formed in the transients. First, we use SED fits to new HST optical and near-IR photometry. Second, neither source is becoming brighter as required by absorption from an expanding shell of ejected material. Third, the ejecta masses implied by the  $H\beta$  luminosities are too low to produce significant dust absorption. The latter two arguments hold independent of the dust properties. The  $H\beta$  fluxes should also be declining with time as  $t^{-3}$ , and this seems not to be observed.

**Author(s):** Rachel Patton, Scott Adams, Christopher Kochanek

**Institution(s):** The Ohio State University, California Institute of Technology

**456.05 - Swift observations of AT 2018cow(Liliana Rivera Sandoval)**

AT2018cow was an energetic transient discovered on 16 June 2018 in the galaxy CGCG 137-068, at 60 Mpc. In this work, I will present observations of the object carried out with the Neil Gehrels Swift Observatory in X-rays and UV, during the first 27 days after detection. The good coverage in these bands revealed a very blue transient with an unusual, highly variable X-ray behavior. I will discuss the implications of these results.

**Author(s):** Liliana Rivera Sandoval, Thomas J. Maccarone, Craig Wheeler, David Pooley, Peter Brown, Alessandra Corsi

**Institution(s):** Texas Tech University, Trinity University, Texas A&M., University of Texas at Austin

**456.06 - Photometric Analysis of SN2018bgz.(Sebastian Gonzalez)**

Over the past few decades, Type Ia Supernovae (SN Ia) have proven to be very useful tools in Extragalactic Astronomy and Cosmology due to the fact that they behave as "Standardizable Candles," objects that adhere to observable relations that allow for methods to calculate their intrinsic brightness. With the knowledge of a Supernova's (SN's) intrinsic brightness, a great deal of further information can be inferred through photometric



analysis. Here, we present an illustrative example of how that analysis can be done and what can be learned from it. Specifically, we present the result of our photometry of images taken over the course of about 3 weeks with CCD detectors on the 1-m Swope telescope at the Las Campanas Observatory and various other nodes of the Las Cumbres Observatory Global Telescope\footnote{The nodes used are located in Sutherland, South Africa; CTIO in Chile; Fort Davis, Texas; Siding Spring, Australia; as well as 100 km northeast of La Serena, Chile} of SN 2018bgz, a SN Ia located in the outskirts of UGC 9544. The most notable results from our photometric analysis include an inferred distance to the SN of  $d = 142.4 \pm 5.4$  Mpc which corresponds to a redshift of  $z = 0.034$ , a Burns stretch-BV value of  $s_{\text{BV}} = 1.089$ , and a Hubble constant of  $H_0 = 71.4 \pm 3.4$  km s<sup>-1</sup> Mpc<sup>-1</sup>. Evidently, our analysis indicates that SN 2018bgz is close to a normally declining SN Ia, a conclusion that is made more sound by the fact that our value for the Hubble constant is consistent with other more robust measurements.

**Author(s):** Sebastian Gonzalez, Kevin Krisciunas

**Institution(s):** University of Pennsylvania, Texas A&M University

#### 456.07 - Detonation Initiation in Type Ia Supernovae(Gabriel Casabona)

Type Ia supernovae play a crucial role as standardizable candles for cosmology, but their stellar progenitors remain mysterious. Underlying this mystery is a crucial physical process: the mechanism of detonation initiation in Type Ia supernovae. Early suggestions for detonation initiation, based upon a detonation initiation mechanism originally proposed by Zel'dovich, cannot apply in the highly-turbulent conditions prevalent in major Type Ia supernova channels, in which the burning is disrupted into the distributed burning regime. We demonstrate, for the first time, using both analytic estimates and three-dimensional numerical simulations, how a carbon detonation may arise in a realistic three-dimensional turbulent electron-degenerate flow. We term this new mechanism turbulently-driven detonation. The turbulently-driven detonation initiation mechanism leads to a wider range of conditions for the onset of carbon detonation than previously thought possible, with important ramifications for SNe Ia models.

**Author(s):** Pritom Mozumdar, Gabriel Casabona, Robert Fisher

**Institution(s):** University of Massachusetts Dartmouth, University of California Davis

#### 456.08 - Deterministic Telescope Scheduling for Synoptic Surveys: An Alternative for LSST(Daniel Rothchild)

Telescope scheduling is the task of determining the best sequence of observations (pointings and filter choices) for a survey system. The definition of "best" typically comprises a weighted combination of performance metrics, such as cadence, uniformity of coverage, and image depth. A local greedy optimizer rank-orders candidate fields and picks the sequence of  $N$  upcoming observations so as to maximize a composite merit function. One point of this paper is to stress that a local greedy optimizer does not typically produce a global optimum for a multi-year survey such as LSST. We show here that a deterministic scheduler that forces LSST to observe fields close to the meridian, alternating between sky regions N and S of the observatory latitude on alternate nights, outperforms the LSST baseline scheduler in essentially all quantitative performance metrics. This is due to a number of factors, including our forcing dual visits to a field to occur in different filters. We find it easier to use a deterministic algorithm than to adjust weights and penalties to persuade a greedy optimizer to produce a desired outcome. A prototype implementation of this deterministic alternative scheduler has been used to produce observing sequences that can be compared directly with the LSST baseline plan, with an execution time that is considerably faster than the OpSim, the simulated greedy optimizer currently used by the LSST project. A full ten year survey can be simulated in 4 minutes as opposed to tens of hours for OpSim. We also describe a dithering strategy that achieves uniform spatial coverage at the sub-field level, that is superior to a fixed-field-center framework.

**Author(s):** Daniel Rothchild, Chris Stubbs, Peter Yoachim

**Institution(s):** UC Berkeley, University of Washington, Harvard University

#### 456.09 - An X-ray source shines through AT2018cow: the birth of a compact object(Raffaella Margutti)

I present the first extensive radio to gamma-ray observations of a fast-rising blue optical transient (FBOT) AT2018cow in the first 100 days of evolution. Over a rise-time of a few days, AT2018cow reached a luminosity of  $4 \times 10^{44}$  erg/s larger than super-luminous SNe, and later declined as  $\sim t^{-2}$ . Initial spectra at  $\leq 15$  days were mostly featureless and indicated large expansion velocities  $v \sim 0.1c$  and temperatures reaching  $T \sim 30000$  K. Later spectra showed a persistent optically thick photosphere and the emergence of He and H emission features with  $v \sim 4000$  km/s with no evidence for cooling of the ejecta. Our broad-band monitoring revealed a hard X-ray spectral component at  $E \sim 10$  keV, in addition to luminous and highly variable soft X-rays, with properties that are unprecedented among astronomical transients. AT2018cow showed bright radio emission consistent with the interaction of a blastwave with  $v \sim 0.1c$  with a dense environment (mass-loss of  $M \sim 10^{-3} - 10^{-4}$  Msun/yr). Taken together, these properties exclude traditional models of Nickel-powered transients. From our

multi-wavelength analysis we conclude that AT2018cow harbored a central engine, possibly in the form of a compact object (magnetar or black-hole). With AT2018cow we might have witnessed for the first time, the formation of a compact object in real time.

**Author(s):** Raffaella Margutti

**Institution(s):** Northwestern University

#### **456.10 - Swift spectra of AT2018cow: A White Dwarf Tidal Disruption Event?(Amy Lien)**

A bright transient AT2018cow was discovered on June 16, 2018 by the ATLAS wide-field survey. Its large UV brightness, rapid rise in 1-2 days, fast decay, and an initially nearly featureless spectrum are unprecedented and difficult to explain as compared to other transient sources. Here, we present analysis of the multi-wavelength observations from the Neil Gehrels Swift Observatory. The Swift observations show evidence of faint gamma-ray emission that lasts for at least 8 days. The X-ray light curve decays with a break around day 21 and has large amplitude variability. The UV-optical spectrum can be well-described by a blackbody and shows no evidence for C, N, O emission lines in the UV. We model the observations by a tidal disruption event where a small,  $0.1 \hat{=} 0.4$  solar mass, Helium White Dwarf undergoes a fast disruption by a  $10^5 - 10^6$  solar mass Black Hole. In addition to a 30,000K cooling black body, a non-thermal jet is present which is responsible for the high-energy gamma-ray and X-ray emission.

**Author(s):** Amy Lien

**Institution(s):** University of Maryland, Baltimore County  
**Contributing Team(s):** NPaul MKuin, Kinwah Wu, Samantha Oates, Sam Emery, Jamie Kennea, Massimiliano de Pasquale, Qin Han, Peter JBrown, Aaron Tohuvavohu, Alice Breeveld, David NBurrows, SBradley Cenko, Sergio Campana,

### **457 - Catalogs, Surveys & Computation: Late Posters**

#### **457.02 - The Stak Notebooks: Transitioning From IRAF to Python(Sara Ogaz)**

The community-workhorse Image Reduction and Analysis Facility (IRAF) has served astronomy for three productive and fruitful decades and is appreciated by many. But as with many things in the software realm, the landscape has changed significantly since the inception of IRAF. Most modern astronomy analysis tools are built in languages like Python, IDL, and C/C++. As the tide has turned towards these newer languages, IRAF has become more and more difficult to build and maintain on current 64-bit architectures. A large portion of the IRAF tasks cannot be compiled as a 64-bit executable, and must be built as a 32-bit program. For these reasons the Space Telescope Science Institute (STScI) has been working towards IRAF independence for all our instrumentation and calibration work. This effort has included the development of transition resources, re-writes of older IRAF scripts, and some additions to Astropy (the current community-supported Python

Astronomy package) when needed. We showcase here the transition resources we have provided, the stak notebooks.

**Author(s):** Erik Tollerud, Sara Ogaz

**Institution(s):** Space Telescope Science Institute

#### **457.03 - Classification of Extragalactic X-Ray Sources Using Machine Learning Methods(Mehrdad Rostami Osanloo)**

Currently, only a small fraction of extragalactic X-ray sources have reliable classifications. For example, out of the ~2,000 X-ray sources in M31 and M33, only ~25% have been classified. Typically, the X-ray data alone are not enough to reveal the nature of the X-ray source. Therefore, creating an automated machine learning (ML) tool for classification of extragalactic X-ray sources with multi-wavelength data will enable us to understand X-ray source populations in a plethora of nearby galaxies. Modern ML methods can be used to quickly analyze the vast amount of multi-wavelength data for these unclassified sources providing both the classifications and their confidences. We are using data from the Hubble Space Telescope and Chandra X-ray Observatory, to build and test an automated ML classification pipeline. The pipeline makes use of supervised ML methods and relies on a large training dataset. We present the testing and preliminary results of the ML pipeline and discuss the challenges associated with building an automated ML tool for extragalactic purposes.

**Author(s):** Oleg Kargaltsev, Jeremy Hare, Blagoy Rangelov, Mehrdad Rostami Osanloo

**Institution(s):** Texas Stat University, University of California, Berkeley, George Washington University

#### **457.04 - Narrow-Band Filters for LSST(Bet Steven)**

The Large Synoptic Survey Telescope will be capable of observing objects of 25+ magnitude across the u, g, r, i, z, y broad-band filters. At these magnitudes the survey will turn up a large number of unresolvable red point-like sources. With some variation depending on the filter, beyond roughly 25 magnitude these filters will lose the ability to provide data accurate enough for an observer to reconstruct the parameters of the objects being detected. In other words, past that point, it will become difficult to tell whether an object is a nearby low mass main sequence star, a far away giant, or a high-redshift galaxy. The simplest possible solution to this problem is to add some more filters, specifically ones with narrower band width. If these narrow-band filters allow for accurate data to be collected at higher magnitudes than their broad-band counterparts can, it would not only solve the problem, but do so without requiring a longer survey or requiring any great feat of engineering to implement. This is being tested using simulated LSST data on a field of 127,000 stars. The (simulated) observed magnitudes and colors of each star are fed into a model consisting of a catalog of comparison stars, with a nearest-neighbor algorithm applied in an attempt to recover that star's

true effective temperature, surface gravity, and metallicity. It is through this method that we already determined the limits of the broad-band filters (that 'limit' being defined as the magnitude at which the standard deviation of the true minus the predicted parameter increases immensely). Our next step is to repeat the same process using narrow-band filters and magnitudes/colors, with a simulated set of test narrow-bands borrowed from the SPLUS survey. If the point at which the standard deviation spikes is at a noticeably higher magnitude than for the corresponding broad-band filter, it may be that narrow-band filters are a viable solution to the problem of identifying faint survey objects.

**Author(s):** Bet Steven, Peter Yoachim

**Institution(s):** University of Washington

#### **457.05 - Visualizing Nuclear Reaction Rates and Constructing Networks with pynucastro(Donald Willcox)**

We present pynucastro, a python code for interacting with parameterized nuclear reaction rates and constructing custom reaction networks for astrophysical applications. The goals of pynucastro are to make reaction rates and networks more accessible by providing easy to use interfaces and visualization and to assist users in writing reaction network code by providing code generation for the right hand side and Jacobian of the underlying system of differential equations. pynucastro interfaces with the reaction rate libraries published by the JINA ReacLib project and provides a set of Python classes and functions for extracting rates from a ReacLib library file, storing reaction rate data, and assembling rates into a network. pynucastro also provides similar functionality for working with tabulated rates, as is common for weak reaction rate libraries tabulated in density and temperature. This programmatic approach makes it possible to construct a reaction network and easily visualize the flows between nuclei at specified thermodynamic conditions so rates can be added or removed as needed within a Jupyter notebook. Once the desired network object is constructed, pynucastro can generate a standalone python right hand side for integration with Scipy. Alternately, pynucastro can use SymPy to generate Fortran network code for the StarKiller Microphysics repository using its realistic stellar equation of state, reaction rate screening, and thermal neutrino losses. StarKiller Microphysics networks generated with pynucastro can be used with hydrodynamics codes such as Castro or Maestro for astrophysical simulations and we highlight ongoing research using pynucastro networks. We intend for pynucastro to be both pedagogical and a useful research tool and we discuss ongoing development to implement new features and meet the needs of the broader astrophysical community.

**Author(s):** Adam Jacobs, Michael Zingale, Donald Willcox, Xinlong Li

**Institution(s):** Lawrence Berkeley National Laboratory, Michigan State University, Stony Brook University, Joint Institute for Nuclear Astrophysics - Center for the Evolution of

the Elements

#### **457.06 - Hubble in the Cloud(Ivelina Momcheva)**

The Hubble Space Telescope has undeniably expanded our understanding of the universe during its 28 years in space so far, but this is not just due to its superior view from space: One of the major advantages to Hubble is that every single image it takes becomes public within six months (and in many cases immediately) after it is beamed back to Earth. The treasure trove that is the Hubble archive has produced just as many discoveries by scientists using the data "second hand" as it has from the original teams who requested the observations. In May, 2018 we announced that ~110 TB of Hubble's archival observations are available in cloud storage on Amazon Web Services which provides unlimited access to the data right next to a wide variety of computing resources. These data consist of all raw and processed observations from the currently active instruments: the Advanced Camera for Surveys (ACS), the Wide Field Camera 3 (WFC3), the Cosmic Origins Spectrograph (COS), the Space Telescope Imaging Spectrograph (STIS) and the Fine Guidance Sensors (FGS). The data on AWS (available at <https://registry.opendata.aws/hst/>) are kept up to date with the data held in MAST and new and reprocessed data are updated on AWS within 20 minutes of them being updated at MAST. The combination of cloud computing with one of the highest value dataset in astronomy has the potential to yield new scientific discoveries. In this poster we report on the process of uploading the data and the technical decisions we made. We discuss the use of the data in the first six months since the upload and present example use cases for archival exploration leveraging the wide range of AWS services.

**Author(s):** Mike Fox, Ivelina Momcheva, Arfon M Smith

**Institution(s):** Space Telescope Science Institute

#### **458 - Dark Matter, Dark Energy, Etc.: Late Posters**

##### **458.01 - Using generalized dark matter to characterize the dynamics of the dark sector(David Robinson)**

Estimates of the expansion history of the universe have allowed us to build the current standard cosmological model. From the late 1970s to the 1990s, progress in physical cosmology gave us our first handle on the expansion rate of the universe at three epochs: the first minute, when the light elements were generated, recombination, when neutral hydrogen was first generated, and the more recent epoch of accelerated expansion. These observations have helped establish the standard model of cosmology, which includes ordinary baryonic matter, dark (non-relativistic but weakly interacting) matter, and poorly understood dark energy. Today, precise measurements of the cosmic microwave background (CMB) and large-scale structure (LSS) of the matter distribution give us far more information, shedding light not only on the cosmic expansion history, but also the energy budget and perhaps even interactions between the different species composing the universe. In the future this

inventory will dramatically expand with the advent of 21-cm cosmology and intensity mapping at higher redshifts. At much higher redshifts, new measurements of spectral distortions of the CMB monopole away from a perfect blackbody will also provide new probes of the cosmic expansion history. Utilizing the generalized dark matter framework provides tools which systematically characterize, in a data-driven way, the power of these efforts to probe the cosmic expansion history at range of different epochs. From this analysis it may be possible to determine which novel particle interaction models we may learn about from these experiments as well as identify the best-measured epochs. This may yield new insight on the origin of neutrino mass, the physics of dark matter, and the nature of dark energy.

**Author(s):** David Robinson, Daniel Grin, Maxwell Aifer, Tristan Smith

**Institution(s):** Swarthmore College, Haverford College

#### **458.02 - Correlation Function and Redshift Distortion of the Matter Power Spectrum(Kayla Nowak)**

The density fluctuations of the universe can be analyzed through the matter power spectrum and correlation function. For this project, matter power spectrum data from the simulation, Code for Anisotropies in the Microwave Background, was both converted to the correlation function, and analyzed in the Fisher matrix. Code was written in python to convert the matter power spectrum data into its correlation function. We were also able to work with the matter power spectrum data in working with python code already written to produce various Fisher matrices by adding redshift distortion dependence. Previously, this dependence was ignored because it complicated the code and was assumed to be minimal. Our research involved verifying whether or not it should be considered in future research, such as with data received from the Large Synoptic Survey Telescope. To further verify the result of this addition, an additional parameter, bias term  $b$ , was added to the Fisher matrix. This parameter is used in the matter power spectrum equation dependent on redshift distortion, meaning that it allowed us to test if redshift distortion dependence was being added correctly. We did conclude that redshift distortion dependence should be considered, however more analysis beyond adding the bias term is required to fully understand our results.

**Author(s):** Kayla Nowak,

**Institution(s):** Lycoming College, Haverford Contributing Team(s): Daniel Grin

#### **458.03 - Simulating Deficient Dark Matter Galaxies(Mike P Ortiz)**

Most matter in the cosmos is in a mysterious form known as dark matter, which does not interact with light and thus cannot be observed directly. Only 4% of the total matter in the universe can be seen directly; namely, in planets, stars, and galaxies.

Even though we cannot see dark matter, we can measure and simulate its gravitational effects on the rest of the universe. In order to form galaxies that will evolve properly and remain stable, a large amount of dark matter is required. NGC 1052-DF2, an elliptical galaxy, has 400 times less dark matter than expected, sparking a debate in leading scientific principles. This means that re-examining dark matter's role in galaxy composition is imperative. The goal of this project is to demonstrate that it is plausible to generate simulations of dark matter deficient galaxies that can remain gravitationally-bound. Our recreation of NGC 1052-DF2 showed that a galaxy with remarkably low content of dark matter can still be stable. Furthermore, we constrained limits for the central mass and size of our modeled galaxies. We then developed a mathematical expression that predicts a galaxy's stability based on its dark matter content, central mass, and size. Our results show that galaxies with 3000 times less dark matter than expected can still be stable in a scenario where the leading principles on galactic formation theory suggest they would fail.

**Author(s):** Benjamin Pieczynski, Mike P Ortiz, Justin

Castaneda, Edgar Marrufo, Lisa L.-H. Chien

**Institution(s):** Northern Arizona University

#### **458.04 - Perturbations of Gravitational Lenses by Low-Mass Dark Matter Halos(Emily Simon)**

The cold dark matter paradigm predicts that a galaxy the size of the Milky Way should be surrounded by thousands of low-mass dark matter halos, many of which are expected to be devoid of stars and gas. The presence of these invisible halos can be inferred with strong gravitational lensing, since dark matter halos can produce visible distortions in gravitationally lensed images. Our team generated and modeled simulated gravitational lenses to address the following questions: how does the redshift of perturbing dark matter halos affect their inferred mass and what is the relationship between concentration and inferred enclosed mass? To address these questions, we generated mock data for perturbations in different redshifts and concentrations to test them against known gravitational lenses to see their effects on the inferred mass. By generating a mass scaling for dark matter halos with different redshifts and concentrations, we are paving the way for a comparison between the dark matter halos detected in real lenses to the expectation from cold dark matter simulations.

**Author(s):** Anthony Chan, Emily Simon

**Institution(s):** Columbia University, City College of New York

#### **458.05 - Detecting and constraining low mass dark matter halos by their perturbations of gravitationally lensed images(Gregory Peck)**

The cold dark matter paradigm predicts that a Milky Way-like galaxy should be surrounded by thousands of low-mass dark matter halos, many of which are expected to be devoid of stars and gas. The presence of these invisible halos can be inferred

using strong gravitational lensing, since dark matter substructure can produce visible perturbations in gravitationally lensed images. The mass we infer for these perturbing halos depends on the halo's assumed redshift, which is often unknown. However, we have shown there is a characteristic radius at which the halo's enclosed mass can be measured robustly. By modeling simulated gravitational lensed data, we address the questions: What range of halo masses and redshifts can we expect to be detectable for a given telescope resolution? For detected perturbations, how well can we reproduce the robust mass? This characteristic scaling may help to reduce bias when detecting and modeling dark matter halos in real world gravitational lenses.

**Author(s):** Gregory Peck, James De La Torre

**Institution(s):** Borough of Manhattan Community College, Hunter College

#### **458.06 - Calibration Error of Advanced LIGO (Laser Interferometer Gravitational-Wave Observatory) and its Effect on Parameter Estimation(Madeline Stover)**

Gravitational waves are ripples in spacetime that the LIGO Scientific Collaboration works to detect. We improve the calibration of the LIGO detectors by tracking time dependent parameters. The cavity pole frequency is a time dependent parameter that characterizes a critical component in the detector and changes due to drift in the alignment and thermal state of the interferometer optics. We studied how calibration error from the drifting cavity pole frequency affects our ability to extract information about how colliding neutron stars deform. The process of extracting the physics of the source from its gravitational waves is called parameter estimation (PE). To see how calibration affects PE we modified the PE software to mimic the presence of calibration errors due to a drifting cavity pole frequency. We found that cavity pole error did not bias PE. The threshold at which parameters are biased is around four times the observed cavity pole error. In addition, we investigated the effect of the total calibration error, which expands beyond the error due to the drifting cavity pole frequency, on PE and found no significant bias in measured parameters. The threshold at which parameters are biased is around four times the observed total calibration error.

**Author(s):** Madeline Wade, Madeline Stover

**Institution(s):** Kenyon College

#### **458.07 - Frequency Dependent Squeezed Light in Optomechanical Systems for Future Gravitational Wave Detection(Ana Lam)**

With the detection of GW150914 and subsequent gravitational wave (GW) signals, the LIGO-Virgo scientific collaboration has become more dedicated to expanding detection range to increase observations. GW detection faces sensitivity limitations due to the presence of noise from different sources. One of these types of noise, quantum noise, limits the future

sensitivity of the LIGO and Virgo gravitational wave detectors. Squeezed states of light have been implemented to improve detector performance in the mid to high frequency range. Quantum noise, specifically radiation pressure noise, still limits the lower frequency range. To overcome this quantum noise limit and increase sensitivity across the entire frequency range of the detectors, the injection of frequency dependent squeezed light must be implemented to maximize the performance of these interferometers. The optics of gravitational wave detectors are very similar to the ones present in the high precision measurement experiments at Laboratoire Kastler Brossel. At Laboratoire Kastler Brossel, a frequency dependent squeezed light source is being coupled to an optomechanical resonator to saturate measurement sensitivity in the quantum regime and surpass the standard quantum limit. We present here the results a preliminary characterization of resonance frequency and Q factor of a microresonator for the high precision measurement experiment. In addition, we propose a three mirror filter cavity to achieve frequency dependent squeezing through tunable line width.

**Author(s):** Ana Lam

**Institution(s):** Barnard College Contributing Team(s): Laboratoire Kastler Brossel, CNRS, Sorbonne Universite, ENS

#### **458.08 - Fully Global 3D-GRMHD Simulations of Accreting Supermassive Black Hole Binaries(Mark Avara)**

We present the first 3D-GRMHD simulations of accreting supermassive black hole binaries that evolve for 10s of orbits using a new code PatchworkMHD. We detail the construction of this tool, and demonstrate the usefulness of this new multi-mesh/multi-physics code in its first scientific application, enabling simulations otherwise not possible with modern computational resources. A detailed comparison of these new simulations of accreting binary black hole binaries with prior simulations performed on a single mesh allows us to quantify the relevance of 'sloshing' of material between each black hole for the first time in a system self-consistently evolving turbulence driven by the magnetic field. These are the first simulations to achieve acceptable resolution to capture magneto-rotational instability behavior in the mini-disk regions. These types of many-orbit and self-consistent simulations, from which one can post-process to produce reliable models for light curves and spectra, are key in identifying binary supermassive black holes in near-term and future time-domain observations.

**Author(s):** Scott Noble, Mark Avara, Manuela Campanelli, Dennis Bowen, Vassilios Mewes, Julian Krolik

**Institution(s):** RIT, NASA - Goddard, LANL, JHU

## **459 - Education & Public Outreach: Late Posters**

### **459.01 - Engaging undergraduate non-science majors and high school students in multi-messenger astronomy with the Karl G. Jansky Very Large Array(Rachel Smith)**

As the new field of multi-messenger astronomy - learning from the combined signals of gravitational and electromagnetic waves from the same astronomical source - takes off, we present an in-class activity designed to engage undergraduate non-science majors and high school students in the field. We use images collected with the Karl G. Jansky Very Large Array during the follow-up of GW170817, the first binary neutron star merger detected by the LIGO and Virgo gravitational wave detectors. We demonstrate to our target students how the radio sky appears and the need for interferometry in radio astronomy, as well as provide an opportunity for the students to develop data analysis and research skills, numeracy, and problem-solving. A first round of testing of this newly developed in-class activity at Texas Tech University and local high schools in rural Lubbock, TX clearly shows enthusiasm and engagement of non-science majors and high school students in the topic. These tests also highlight the effectiveness of including undergraduate science majors in the development of the activity itself. Observed challenges include unexpected student weakness in mathematics, student difficulty grasping the distance scale of the universe, and student difficulty adjusting to a hands-on activity in a primarily lecture-based course. Formal assessment of student learning and additional testing with new groups of students represent our next steps. Our ultimate goal is to distribute this activity broadly to the general public and teachers of West Texas.

**Author(s):** Anthony Rushing, Heather Harbin, Eric Garcia, Priyadarshini Rajkumar, Alessandra Corsi, Rachel Smith  
**Institution(s):** Texas Tech University

### **459.02 - Twelve iconic women in astronomy(Lucie Leboulleux)**

Role models often play a critical part in the self-determination of a child's or teenager's career, especially for professions that appear both very attractive and initially extremely hard to access, like the ones in space sciences. These models can not only initiate a decision regarding a child's future career, they also influence their vision and interest for astronomy and science in general. Therefore, it is important that the diversity of children is represented in the models they project themselves into. However, well-known models in present and past astronomy do not answer this need for diversity: from Galileo Galilei and Isaac Newton to Carl Sagan and Stephen Hawking, the huge majority of them are Caucasian men. We designed a biographic poster and a booklet designed to be accessible to school and university teachers, to put forward a diverse set of under-recognized women that can constitute role models for girls and boys and to widen their vision of astronomy. For this outreach project, we organized a consultative poll among the

Space telescope Science Institute employees. From its results, twelve women have been selected: Hypatia, Caroline Herschel, Wang Zhenyi, Annie Jump Cannon, Katherine Johnson, Mary Jackson, Vera Rubin, Beatrice Tinsley, Jocelyn Bell Burnell, Sally Kristen Ride, Mae Jemison, and Ellen Ochoa. They show an interesting range of profiles in terms of life era, race, nationality, job, sexual orientation and science field. The poster has been custom made by the artist Luna Picoli-Truffaut. Her illustrations and animated visuals related to feminism, anti-racism, and pro-LGBTQ+ groups have been featured on her website "Draw The Line" and various platforms: social medias, TV series, and magazines. In an additional to the poster booklet, short biographies of these twelve iconic women have been added to the portraits. Both the poster and the booklet will be soon accessible for free online in order to be printed, and we do hope that introducing the poster at the AAS conference will enable to spread it as largely as possible, in both laboratories and schools.

**Author(s):** Emmanuel Hugot, Johan Mazoyer, Luna Picoli-Truffaut, Lucie Leboulleux,

**Institution(s):** ONERA, Draw The Line, Space telescope Science Institute, Jet Propulsion Laboratory

### **459.03 - Christenberry Planetarium - Space Science Mentorship Program 2018(A. David Weigel)**

The Christenberry Planetarium Space Science Mentorship Program purpose is to encourage a greater interest in science in the younger generation, specifically in the Birmingham area. After an application process, we enrolled 21 students into our summer program. Each mentee chose one of four STEM projects and was assigned a specific planetarium intern to teach and guide them. At the end of the summer, they presented their final projects to an audience of family, friends, and the public. The four offered projects were 1) Virtual Reality Tour Creation using AAS WorldWide Telescope, 2) Paint the Universe - teaching data visualization through art, 3) Rockets - 3D modeling, printing and launching, and 4) Robot Building. Students created WorldWide Telescope tours for both our 40 foot dome and our Oculus Rift virtual reality headset. After quick software introductions, we assisted them in the tour-making process. Upon completion, we uploaded their work to YouTube, and each of them presented his or her video during our project presentation. Students painted their own renditions of various features in space. They learned how to conduct accurate research about their chosen sites and studied the distinctions between true and false color images. Each student produced 2 acrylic paintings, one emphasizing true color and the other, false color. Students made 3D models of their own rocket designs using Autodesk Fusion 360. Working alongside them, we taught rocket science, orbital mechanics, and aerodynamics. All of the rockets were printed using the 3D printer in our physics department and launched on campus to test their aerodynamics. Students took on an ambitious robot project. In ten sessions, they learned how to write code via the Arduino IDE, wire circuits, solder, 3D model in Fusion 360 and 3D print. By the end of the program, they each had their very

own robots that they had designed and understood.

**Author(s):** Regan Green, A. David Weigel,

**Institution(s):** Samford University, AAS WorldWide Telescope

#### **459.04 - The League of Astronomers(Adriana Gomez-Buckley)**

The League of Astronomers (LoA) is an undergraduate student-run organization at the University of Washington (UW). We seek to make astronomy accessible to a variety of audiences within the UW and around the Seattle area, focusing on underprivileged and underrepresented communities. We host pre-colloquium and tea time seminars to make upper level astronomy topics and research available to other undergraduate students on a more direct and personal level. Our work with our on-campus and mobile planetariums allows us to connect with younger students and their teachers. Additionally, while open during the spring and summer, our volunteer work at the UW's Theodor Jacobsen Observatory (TJO) gives us an outlet to reach the general public and families. These opportunities connect us to many different communities through a common passion for astronomy.

**Author(s):** Aislynn Wallach, Bayu J Wilson, George Schafer, Aleezah Ali, Adriana Gomez-Buckley

**Institution(s):** University of Washington

#### **459.05 - Bridging the Gap: Empowering Girls with Scientific Research Experiences(Colleen Cleary)**

BridgeUP: STEM is an innovative program developed to nurture interests of science and technology in young women, ultimately improving the representation of women in STEM fields. BridgeUP: STEM's Brown Scholars program is a two-year after school program that actively recruits and prepares high-school girls for computational research at the American Museum of Natural History in New York City. During their first year of the program, Brown Scholars receive hands on training in programming, data science, and data visualization and participate in an internship during their second year. A tiered mentorship model gives five postbaccalaureate Helen Fellows the opportunity to mentor teams of six Brown Scholar interns in a computationally-based research project related to their own research. This poster presents the curriculum and ongoing work of one team of Brown Scholars known as SpectreCell. Combining their knowledge of Python with SQL, SpectreCell is developing code for ingesting new data into the BDNYC (Brown Dwarfs in New York City) SQLite database of observable brown dwarf information. Further work throughout the school year will include the creation of additional scripts for maintaining the database, as well as mapping the entirety of the BDNYC catalogue of brown dwarfs with OpenSpace, an open source interactive visualization program developed at the American Museum of Natural History. Throughout the project, students will advance their analytic and programming abilities, learn to

apply these abilities to a scientific problem, and effectively collaborate on code built as a team.

**Author(s):** Vithya Srikumar, Veronika Ragozina, Colleen Cleary, Jacqueline K Faherty, Oniva Husain, Zoe Tremitiere, Kelle Cruz, Indira Lopez, Ashley Jagai

**Institution(s):** CUNY Hunter College, American Museum of Natural History Contributing Team(s): BridgeUP: STEM

#### **459.06 - In a galaxy far, far away: teaching astronomy from a distance at Athabasca University(Christy Bredeson)**

Athabasca University, Canada's foremost distance education university, has been educating students in astronomy from a distance for the past 30 years, currently offering two freshman astronomy courses and two senior-level planetary science courses. These have been taken by thousands of students, many obtaining science option transfer credit at other universities. There has been an evolution in distance education astronomy courses; what once was done by correspondence has now transitioned into fully web-based courses that are available online. With a rise in interest in new and innovative methods for teaching astronomy online, it must be asked, how can we effectively teach students when we are no longer in a classroom setting? How can we engage students in astronomy from home when it can seem like they are far, far away? This poster will discuss the particulars of how we teach astronomy from a distance to nearly 200 students per year; including an overview of the courses we offer and Athabasca University's unique education model. It will also cover the challenges of teaching astronomy from a distance and possible resolutions.

**Author(s):** Christy Bredeson, Martin Connors

**Institution(s):** Athabasca University

#### **459.07 - An Intuitive Spectral Calibration Program for Undergraduate Laboratories(Wei Li)**

We developed an intuitive spectral calibration program for data collected with compact grism spectrometers similar to those developed by Ludovici & Mutel (2017). The calibration program receives raw data from the spectrometer and determines the wavelength and gain calibration for the spectrometer. The calibration program requires an A type star for wavelength calibration, and several stars with catalogued spectra to determine the gain calibration. Behind the simple graphical user interface is a semi-automated script that interacts with the user, granting hands on experience with basic calibration techniques. The program is simple enough that students can be taught how to calibrate a spectrometer within half an hour. This makes the program more viable than older calibration programs in both a majors and non-majors astronomy course setting. We plan to incorporate the spectrometer and calibration program into astronomy classes and laboratories at Rose-Hulman, allowing undergraduates to gain first-hand experience in the field of spectroscopy.

**Author(s):** Wei Li, Dominic Ludovici  
**Institution(s):** Rose-Hulman Institute of Technology

#### **459.08 - Instrumentation as a Teaching Tool for Undergraduate Students(Dominic Ludovici)**

Small telescopes (D~20-50 cm) are common on college and university campuses. While these telescopes are typically used for undergraduate observing laboratories and public outreach, they also offer excellent opportunities for student lead instrumentation projects. Upper level students in an advanced physics laboratory or similar courses can design instruments for these small telescopes to enable new observing modes not previously available on campus, such as spectroscopy. For the students, these projects introduce them to experimental design principles, as well as helping to solidify their knowledge of optics and the nature of light. Additionally, these instruments can then be incorporated into other astronomy classes, allowing students firsthand experience in observing techniques that are typically neglected at the undergraduate level.

**Author(s):** Dominic Ludovici  
**Institution(s):** Rose-Hulman Institute of Technology

#### **459.09 - The Physics Bachelor of Science Program at the University of the Virgin Islands: Enabling Careers in Science and Engineering Through Astrophysics(David C Morris)**

The University of the Virgin Islands (UVI) is a minority serving institution (MSI) with campuses on the islands of St. Thomas and St. Croix in the US Virgin Islands (USVI) with a 2018 enrollment of approximately 2000 students. Though traditionally a liberal arts university, UVI has responded to an increase in demand for course offerings in the physical sciences and engineering by establishing a bachelor of science in physics program with a concentration in astronomy. This B.S. program is a first of its kind for UVI. Students enrolled as physics majors are engaged from the earliest possible point in their academic career in research activities. The program was established in 2017 and is preparing to graduate UVI's first-ever class of physics majors in spring of 2019. Prior to development of the UVI physics degree program, students interested in physics, astronomy, or engineering could begin their education at UVI but were required to transfer to a partner school in the mainland US to complete upper-division courses and finish their degree. The UVI physics program was developed as an alternative degree that can be completed entirely at UVI at a greatly reduced financial cost and in a familiar environment. The UVI physics program also develops a highly trained undergraduate research workforce that supports faculty research and improves UVI's research capacity and competitiveness in future research proposals. A key component of the UVI physics program is UVI's Etelman Observatory which serves as a primary research instrument and student training center. The Etelman Observatory is home to UVI's

Virgin Islands Robotic Telescope (VIRT), an 0.5m robotic telescope. Together with a detector development and cubesat laboratory, these hands-on research facilities offer UVI physics and engineering students unusual levels of hands-on engineering and research activities throughout their academic careers at UVI. We detail the development of the UVI Physics program, highlight successes from the first 2 years, and look forward to potential areas of growth and collaboration between UVI and its research and education partners.

**Author(s):** Jan Staff, David C Morris, Antonino Cucchiara  
**Institution(s):** University of the Virgin Islands

#### **459.10 - Visuals and Captions for Proposals(Rolf Danner)**

Your task as a proposal writer is to demonstrate to the reviewers that your research is compelling, feasible, and achieves the goals of the sponsor. In this task, visuals are an effective way to capture and maintain the attention of the reader. In fact, developing the flow of your figures first will clarify your message and strengthen the case for your research. Like sign posts, good visuals guide the reviewers through a document and increase your chance of winning. Here, we review how scientific and technical writing for papers and reports differs from persuasive writing for proposals. We show how persuasive visuals and captions go beyond reporting facts and support your proposal. We review how action captions, a tool commonly used in commercial proposals, tie a proposal feature to an evaluation criteria. We introduce the "undiscovered country chart" to illustrate how your research expands beyond current knowledge. We conclude with a summary of how these elements work together in a proposal. Over the years, we have worked hard to put these ideas into practice. Today, we are delighted when we see visuals make a proposal shine and would like to see more writers take advantage of these tools. Danner previously led instrument and mission proposals in response to NASA AOs. He now manages JPL's proposal office. Richey previously worked with NASA Headquarters and now leads Proposal Writing Workshops from NASA's Science Mission Directorate through the ROSES TWSC Program.

**Author(s):** Christina Richey, Rolf Danner  
**Institution(s):** JPL/Caltech

#### **459.11 - Hackathons for Science, How and Why?(Ei Pa Pa Pe-Than)**

Based on our empirical studies of 14 hackathons held by a corporation (Microsoft OneWeek Hackathon), universities, and scientific communities including three hack days at Space Telescope Science Institute (STScI), we will present how hackathons can be designed to achieve specific goals in a semi-academic environment like STScI. Our recommendations are derived from the analysis of data collected through ethnographic observations, interviews, and questionnaires. Hackathons are not only a good way to foster



innovation but also to provide learning and knowledge exchange opportunities, to create new and enhance existing social connections, to exercise new technical and leadership opportunities, and to get the needed work done or to make a quick progress on technical work. However, designing a hackathon involves careful upfront planning, project selection, team formation, goal setting, and follow-up activities. Before the hackathon, the organizers should ask potential participants to propose project ideas (e.g., highest priority needed work in the case of STScI), and elicit their skills, expertise, and project preference. The organizers should form teams by matching participants' skills to required skills for the projects. The resulting teams consist of a mix of members with varying levels of expertise. It is advisable for teams to perform preparatory work which includes appointing a team lead and having pre-event meetings where they discuss their plan for the event, break the projects into small individual tasks, assign tasks to team members, and familiarize themselves with the environment, project, and task. The organizers should advise teams to set realistic goals for the event and keep track of their progress toward these goals. At the end of the event, the organizers should advise teams to present their accomplishment and future plans, and encourage them to plan for future collaboration and designate a person to keep track of the progress. Examples include using the common free time to work side-by-side and self-organizing mini-hackathons (e.g., lunch hacks). With careful consideration of activities mentioned above, hackathons may provide a fruitful avenue of collaboration between astronomers and software experts.

**Author(s):** Erik Tollerud, James D. Herbsleb, I. Momcheva, E. Pa Pa Pe-Than

**Institution(s):** Carnegie Mellon University, Space Telescope Science Institute

#### **459.12 - When Diversity is a Necessity - The Evolution Toward Accessibility by Design (Kate Meredith)**

Over the past fifteen years, Yerkes Education Outreach (now Geneva Lake Astrophysics and STEAM or GLAS) has been involved with projects and partnerships focused on equity, accessibility, and inclusion in astronomy and STEM+C (Science, Technology, Engineering, and Mathematics plus Computing Science) experiences. The National Science Foundation award, Innovators Developing Accessible Tools for Astronomy (IDATA), seeks to engage blind and visually impaired (BVI) students in the user-centered design of accessible data processing software. As GLAS Education carries out its mission to sustain and preserve former Yerkes programs and complete the goals of IDATA, we look carefully at the process of community building that has grown the capacity of underrepresented groups to contribute meaningfully to a product that is accessible by design.

**Author(s):** Kate Meredith, Katya Gozman

**Institution(s):** Geneva Lake Astrophysics and STEAM, University of Chicago

#### **460 - Galaxies Big & Small: Late Posters**

##### **460.01 - A Deeper Look at the New Milky Way Satellites (Burcin Mutlu Pakdil)**

We present deep Magellan/Megacam stellar photometry of four recently discovered faint Milky Way satellites: Sagittarius II (Sgr II), Reticulum II (Ret II), Phoenix II (Phe II), and Tucana III (Tuc III). Our photometry reaches ~2-3 magnitudes deeper than the discovery data, allowing us to revisit the properties of these new objects (e.g., distance, structural properties, luminosity measurements, and signs of tidal disturbance). Sgr II is particularly interesting as it sits in an intermediate position between the loci of dwarf galaxies and globular clusters in the size-luminosity plane. The ensemble of its structural parameters is more consistent with a globular cluster classification, indicating that Sgr II is the most extended globular cluster in its luminosity range. The other three satellites land directly on the locus defined by Milky Way ultra-faint dwarf galaxies of similar luminosity. Ret II is the most elongated nearby dwarf galaxy currently known for its luminosity range. Our structural parameters for Phe II and Tuc III suggest that they are both dwarf galaxies. Tuc III is known to be associated with a stellar stream, which is clearly visible in our stellar density map. The other satellites do not show any clear evidence of tidal stripping in the form of extensions or distortions.

**Author(s):** Burcin Mutlu Pakdil, Jeff Carlin, Dennis Zaritsky, Nelson Caldwell, Allison K. Hughes, Beth Willman, David Sand, Kristine Spekkens, Denija Crnojević

**Institution(s):** University of Arizona, Harvard-Smithsonian Center for Astrophysics, Texas Tech University, Queen's University

##### **460.02 - Mapping the Warped H<sub>2</sub>O Maser Disk in the Dwarf Galaxy IC 750 (Michael Rosenthal)**

We present the first map of H<sub>2</sub>O megamasers in the dwarf galaxy IC 750. Very Long Baseline Array (VLBA) K-band images detect maser emission at 22.235 GHz in the central parsec of the galaxy, redshifted 595-835 km s<sup>-1</sup>. We extracted and mapped maser positions to reveal a nearly edge-on, warped disk structure of diameter 0.20 pc, roughly aligned with the galaxy disk. The disk contains two high-velocity regions, one blueshifted and one redshifted from the optical galaxy recession velocity of 701 km s<sup>-1</sup>, with masers in Keplerian orbits around the black hole. We iterated a Keplerian fit over possible center locations in a 5 mas x 5 mas region around which the map was nearly symmetric, and for BH recession velocities of 697-705 km s<sup>-1</sup>. Fitting the red and blue Keplerian regions separately for each point, we accepted masses for which red and blue mass values agreed within 5%. We find a best-fit BH mass range of  $7.1-8.1 \times 10^4 M_{\odot}$ . Fitting only the highest-velocity points yields an upper limit for the BH mass of  $9.4-11.8 \times 10^4 M_{\odot}$ . Our image of IC 750 from archival Chandra data shows three hard, compact sources along the galaxy, and soft extended emission along the galaxy and perpendicular to it. The Chandra 0.3-10.0 keV centroid position

of the central source is offset from the maser location by  $0''.76$ .  
**Author(s):** Michael Rosenthal, Ingyin Zaw, Lincoln Greenhill, Hind Al Noori, Walter Briske  
**Institution(s):** New York University Abu Dhabi, National Radio Astronomy Observatory, Harvard-Smithsonian Center for Astrophysics

#### **460.03 - Modeling Cosmic Rays in Starburst Galaxies(Molly Kaplan)**

In starburst galaxies, cosmic rays accelerated by supernova interact with the interstellar medium, creating a unique gamma-ray source population. Through their interactions with the medium, they undergo energy losses, and are assumed to then escape the medium according to the "leaky box" model. By considering cosmic ray injection, energy loss, secondary electron/positron creation, and escape, we model the steady state energy spectra of cosmic ray protons, electrons and positrons. For protons, our model incorporated energy losses from ionization and pion production. For electrons and positrons, we considered energy losses from ionization, Bremsstrahlung radiation, synchrotron radiation, and inverse Compton scattering. Using the astropy package Naima, these models can in turn be used to generate observables, such as the expected gamma-ray and radio emission from a starburst galaxy. The ambient gas density, escape timescale, injection spectrum power law index, and magnetic field strength are left as free parameters. These free parameters can be constrained for a particular galaxy by comparing its Fermi gamma-ray and radio spectra to expected spectra generated from the steady state models.

**Author(s):** Timothy Paglione, Molly Kaplan  
**Institution(s):** Massachusetts Institute of Technology, American Museum of Natural History, CUNY York College

#### **460.04 - Cosmic ray transport in the halo of NGC 3556 from radio continuum observations(Ralf-Juergen Dettmar)**

Using JVLA 1.5- and 6-GHz observations from the CHANG-ES project and LOFAR 144-MHz data from the LoTTS survey, we mapped the total intensity, the radio spectral index as well as the magnetic field strength and orientation of the edge-on galaxy NGC 3556. In order to identify the prevailing mode of transport for cosmic ray electrons into the halo we fitted 1D cosmic-ray propagation models. We find that the spectral index in the galactic midplane is, as expected for young CRe,  $1 \pm 0.05$  and steepens towards the halo of the galaxy as a consequence of spectral ageing. The intensity scale heights are about 1.4 and 1.9 kpc for the thin and 3.3 and 5.9 kpc for the thick disk at 1.5 GHz and 144 MHz, respectively. While pure diffusion cannot explain our data, advection can, particularly if we assume a linearly accelerating wind. Our best-fitting model has an initial speed of 123 km/s in the galactic midplane and reaches the escape velocity at a heights between 5 kpc and 15

kpc above the disk, depending on the assumed dark matter halo of the galaxy. This galactic wind scenario is corroborated by the existence of vertical filaments seen both in the radio continuum and in  $\text{H I}$  in the disc-halo interface, and of a large-scale reservoir of hot, X-ray emitting gas in the halo.

**Author(s):** Ralf-Juergen Dettmar, Arpad Miskolczi, Volker Heesen  
**Institution(s):** Ruhr-University Bochum, University Hamburg  
Contributing Team(s): CHANG-ES, LOFAR MKSP

#### **460.05 - HI Holes, Shells and Star Formation in LITTLE THINGS Galaxies(Nau Raj Pokhrel)**

We present the physical properties of atomic hydrogen (HI) gas distribution in nearby dwarf galaxies as part of the LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes, The HI Nearby Galaxy Survey). We use high spatial and velocity resolution HI data from the survey to identify and analyze the HI holes and calculate the surface and the volume porosity in each galaxy. We find some LITTLE THINGS galaxies with no star formation regions have high porosities. This result is consistent with the idea that these galaxies are too porous to continue star formation. The sample galaxies with the lowest porosities and no star formation may suggest the necessity of recent star formation to form the holes. We estimate the star formation rate from the energy required to create a hole which is consistent with the star formation rates measured from visible and far ultraviolet spectral data, suggesting that the stellar feedback can be considered as a factor in creating HI holes.

**Author(s):** Caroline Simpson, Nau Raj Pokhrel  
**Institution(s):** South Texas College, Florida International University

#### **461 - Galaxies: Late Posters**

##### **461.01 - Simulating Reionization in the Illustris Universe: the Effect of Photoheating Feedback(Xiaohan Wu)**

We present the first self-consistent radiation hydrodynamic simulations of hydrogen reionization with AREPO-RT using the Illustris galaxy formation model and examine how photoheating feedback shapes the properties of galaxies. Our fiducial model finishes reionization at about  $z=6$  and matches the observed volume-averaged neutral hydrogen fraction, electron scattering optical depth of the cosmic microwave background (CMB) photons, the high redshift ultraviolet (UV) continuum luminosity functions and stellar mass functions. However, contrary to previous works, photoheating only generates larger than 50% suppression in star formation rate in halos less massive than  $108.4 M_{\odot}$  at  $z=6$ , though at  $z=5$  this mass threshold reaches  $108.8 M_{\odot}$ . Assuming a uniform UV background to mimic reionization instead yields an earlier onset of suppression, indicating such an approximating scheme acts like an early reionization. Meanwhile, turning off stellar wind results in a much larger suppression by photoheating at

such redshifts, quenching a large fraction of halos less massive than 109 Msun. This indicates that stellar feedback is the most important mechanism governing star formation, and photoheating only plays a sub-dominant role in suppressing star formation of low mass halos. Moreover, by reducing the amount of stellar sources, stellar feedback also suppresses the strength of photoheating feedback. Most importantly, we find no observable change in the faint end slope of the UV luminosity function for  $M_{1500} < -15$  mag, the stellar mass function at  $M^* > 106$  Msun, or a dip in the cosmic star formation rate density caused by reionization. Using these observables to detect imprints of reionization is therefore questionable.

**Author(s):** Federico Marinacci, Mark Vogelsberger, Rahul Kannan, Xiaohan Wu, Lars Hernquist

**Institution(s):** Harvard Smithsonian Center for Astrophysics, Kavli Institute for Astrophysics & Space Research, Massachusetts Institute of Technology

#### **461.02 - Simulating Outflows in the Circumgalactic Medium with Non-equilibrium Chemistry and Variations in Metallicity(Gabriela Huckabee)**

Using the FLASH code from the University of Chicago, we simulate outflows in the circumgalactic medium (CGM) with hydrodynamic simulations of hot (107 K), diffuse (10-27 g/cm<sup>3</sup>) gas flowing over a cold (104 K), dense (10-24 g/cm<sup>3</sup>) cloud. We account for contributions from radiative cooling, thermal conduction, and non-equilibrium chemistry in addition to the base physics of the FLASH v4.3. We aim to refine the modeled physics in these simulations in order to produce ion abundances which reflect the CGM ion abundances seen in surveys such as COS-HALOS, with a mysterious lack of NV. In order to make these simulations more realistic, we are currently working to run simulations with more accurate initial metallicity values for the hot gas and cold blobs. In future work, we will account for the impact of magnetic fields as well.

**Author(s):** Gabriela Huckabee, Evan Scannapieco, J'Neil Cottle

**Institution(s):** Arizona State University Contributing Team(s): The DOE NNSA-ASC OASCR Flash Center at the University of Chicago

#### **461.03 - Nature vs Nurture: Cosmological Implications for Bar Formation and Galactoseismology(Jacob S Bauer)**

We present twelve high resolution cosmological simulations of stellar disks. Stellar disks are inserted into zoom-in simulations of cosmological halos by first treating the disks as rigid bodies and slowly growing them to their present day masses and sizes. The rigid disks are allowed to respond to their dark matter halos, and their orientations are evolved per a comoving representation of Euler's equations of rigid body dynamics. After a rigid disk finishes growing, it is replaced with a live

stellar disk and evolved to present day. We explore the impact that a live stellar disk has on halo substructure and adiabatic contraction, the effect that live disk and halo properties have on bar formation, and the evolution of vertical structure in the thin disk. In particular, we focus on the evolution of stars which are stripped from a disk's outer regions to form stream-like structures at a variety of latitudes. We show that global tidal fields can generate these populations, and invoke them as a means to explain observations of low-latitude Milky Way structures like the Monoceros Ring, A13, and TriAnd.

**Author(s):** Larry Widrow, Jacob S Bauer

**Institution(s):** Queen's University

#### **461.04 - Central Galaxy Clustering at Intermediate Redshift with PRIMUS(Angela Berti)**

It has been shown that at a given stellar mass quiescent galaxies are more strongly clustered than star-forming galaxies. It is not known, however, whether this signal is due to clustering differences in central versus satellite galaxies, which has strong implications for galaxy evolution models. To understand the contribution to this signal from central galaxies, we present measurements of the clustering amplitude of isolated primary (IP) galaxies, used as a proxy for central galaxies, at  $0.2 < z < 0.9$  using the PRIMUS galaxy redshift survey. Using spectroscopic redshifts for ~60,000 galaxies in four separate fields covering 5 square degrees on the sky, we find that quiescent IP galaxies are more strongly clustered than star-forming IP galaxies at fixed stellar mass. We use PRIMUS-like mock galaxy catalogs, based on the UniverseMachine model of Behroozi et al., to quantify the clustering of true central and IP galaxies, to understand how contamination from satellite galaxies can impact the observed clustering of IP galaxies. We find that central galaxies contribute to the observed difference in the clustering amplitude of quiescent and star-forming galaxies at fixed stellar mass. Finally we quantify the completeness and contamination of galaxy isolation criteria and demonstrate how using isolation criteria produces biased subsamples of central galaxies, preferentially selecting central galaxies in low density, less clustered environments.

**Author(s):** Andrew Hearin, Angela Berti, Alison Coil

**Institution(s):** University of California, San Diego, Argonne National Laboratory Contributing Team(s): PRIMUS Team

#### **461.05 - How Superbubble-powered, Entropy-driven Outflows Regulate Star Formation and Bulge Growth in Disc Galaxies(Benjamin Walter Keller)**

L/M\* galaxies are an important class of objects. Not only are they the "turnover" in the galaxy mass Schechter function, they also have the highest stellar mass (and baryon) fraction, very low bulge-to-disk ratios, and dominate the star formation efficiency of every epoch they live in. In this talk I will present the results of a sample of 18 cosmological M\* galaxies, simulated using the state-of-the-art superbubble method for

handling feedback from Type II Supernovae. I will show that the key to obtaining a realistic stellar mass to halo mass relation (SMHMR) is preventing the runaway growth of a massive bulge by driving outflows with large mass-loadings. These how outflows can flow through the CGM, driven by local entropy gradients & buoyancy until the halo reaches a critical mass, and they no longer effectively transport gas away from the star forming disc.

**Author(s):** Benjamin Walter Keller

**Institution(s):** University of Heidelberg

#### **461.07 - Simulated Observations of Multiphase Galactic Winds(Lita de La Cruz)**

Galactic winds are streams of gas that are often observed flowing at high speed out of star-forming galaxies. Supernova-driven winds are particularly important to model because of their role in regulating the star formation rates and gas supply of galaxies over time. In this study, we are using simulations of multiphase galactic winds modeled with the hydrodynamics code Cholla to create mock observables, such as the optical depth of absorption lines in different ions. The simulations include high density turbulent clouds with a median density of  $n=0.5 \text{ cm}^{-3}$  embedded in a low density, hot wind. By comparing our mock observables to observations of the nearest galactic wind systems, we will be able to better constrain theoretical models of the density, velocity, and temperature structure of these winds.

**Author(s):** Eve C Ostriker, Lita de La Cruz, Evan Schneider

**Institution(s):** Princeton University

#### **461.08 - The South Pole Telescope Strong Lensing Cluster Sample(Lindsey Bleem)**

The strong gravitational lensing regime, observable via the lensing of background galaxies into highly magnified and often multiple images by foreground gravitational potentials, provides a unique probe of structure formation in the Universe. Amongst other applications observations of such systems can be used to probe the mass-concentration relation (an important test of the predictions of cosmological simulations), arc abundances (which test models of both the background source population as well as the cores of massive systems), and the highly magnified sources themselves (which can be used to explore the evolution of galaxies at high redshifts). There has been significant effort to identify and characterize strong lensing clusters selected in the X-ray and optical wavelengths; here we extend such studies to a large sample of strong lensing clusters identified by the Sunyaev Zel'dovich (SZ) effect in  $>5,000$  square degrees of South Pole Telescope (SPT) data. In this poster I will describe (i) the construction of the SPT cluster sample and the identification of the strong lensing subset using imaging observations from the new PISCO imager on the Magellan/Clay telescope and an ongoing HST SNAP program, (ii) the spectroscopic campaign to characterize the background

source population, and (iii) simulation efforts using large N-body (and soon hydrodynamic) simulations to both generate predictions for the abundances of strong lenses in the SPT sample as well as to extract constraints from the observational data.

**Author(s):** Guillaume Mahler, Katrin Heitmann, Nan Li, Salman Habib, Juan David Remolina, Michael Gladders, Anthony Stark, Keren Sharon, Lindsey Bleem, Brian Stalder

**Institution(s):** Argonne National Laboratory, University of Michigan, University of Chicago, LSST, University of Nottingham, Harvard Smithsonian, KICP, University of Chicago

#### **462 - Instrumentation Space & Ground: Late Posters**

##### **462.02 - US Contributions to the Athena WFI(David Burrows)**

The US is contributing to the Athena Wide Field Imager (WFI) in three areas: development of a secondary computer board (the Science Products Module, or SPM) for on-board transient analysis and background rejection; assistance with the design and testing of the VERITAS-2 ASIC that is part of the detector front-end electronics; and fabrication of heat pipes. We will present the preliminary design of the SPM software algorithms under development at Penn State, MIT, and SAO.

**Author(s):** David Burrows

**Institution(s):** Penn State University Contributing Team(s): The US Wide Field Imager team

##### **462.03 - Habitable Exoplanet Observatory (HabEx) Exposure Time Calculator Tools(Dawn Gelino)**

The Habitable Exoplanet Observatory (HabEx) is a concept for a mission to directly image planetary systems around Sun-like stars. HabEx also will enable a broad range of general astrophysics, from studying the earliest epochs of the Universe, to understanding the life cycle and deaths of the most massive stars. In this poster, we describe the exposure time calculator (ETC) tools for the mission's suite of four instruments. The HabEx Workhorse Camera ETC computes the signal to noise ratio (SNR), exposure time, limiting magnitude, and SED for general astrophysics. The UV Spectrograph ETC plots the Flux and SNR for a range of input targets for general astrophysics. The Coronagraph and Starshade ETC computes the integration time needed to achieve a SNR specified by the user on an input exoplanet albedo model. This tool is currently designed for exoplanet applications, but we plan to expand model capabilities to also include general astrophysics. All ETCs output data and plot results in plotly for interactive manipulation by the user. The ETCs are provided as tools for the whole astrophysics community to discover the broad science potential of the HabEx mission concept.

**Author(s):** Tyler Robinson, Keith Warfield, Paul Scowen, Dawn Gelino, Tiffany Meshkat, Bertrand Mennesson, Patrick W. Morris

**Institution(s):** Caltech/IPAC-NExSci, Caltech/IPAC, Jet Propulsion Laboratory, Arizona State University, Northern Arizona University

**462.04 - E-Beam Generated Plasma Etching for High-Reflectance FUV Astronomical Instruments(Manuel Alberto Quijada)**

The Naval Research Laboratory (NRL) has developed a processing system based on an electron beam-generated plasma that provides for controlled fluorination and/or etching of both the surface morphology and chemistry of 2-dimensional materials with monolayer precision. In this poster, we combined the expertise at GSFC to produce advanced PVD coatings of bare and protected Al and treat those samples at the NRL Laboratory's Large Area Plasma Processing System (LAPPS) where restoration of the high intrinsic reflectance in the FUV spectral range have been observed of aluminum (Al) mirrors protected with a magnesium di-fluoride (MgF<sub>2</sub>) overcoat. This paper will also extend these studies to other Al mirrors protected with metal-fluoride overcoats in order to realize the high intrinsic reflectance Al down to FUV wavelengths (100-200 nm), while still maintaining the high reflectance in the optical and NIR spectral regions.

**Author(s):** Scott Walton, Javier del Hoyo, Manuel Alberto Quijada, Vivek Dwivedi, David Boris, Edward Wollack

**Institution(s):** NASA-GSFC, Naval Research Laboratory

**462.05 - MoonBEAM: A Beyond Earth-orbit Gamma-ray Burst Detector for Multi-Messenger Astronomy(Chiumun Michelle Hui)**

Moon Burst Energetics All-sky Monitor (MoonBEAM) is a CubeSat concept of deploying gamma-ray detectors in cislunar space to increase gamma-ray burst detections and improve localization precision with the timing triangulation technique. A gamma-ray instrument in cislunar orbit will have greatly reduced sky blockage compared to instruments in low Earth orbit. Working in conjunction with another instrument in low Earth orbit, MoonBEAM can also help constrain the arrival direction of the wavefront to an annulus on the sky by utilizing the light arrival times between the different orbits. This method has been demonstrated by the Interplanetary Gamma-Ray Burst Timing Network. However, delays in data downlink for instruments outside the Tracking and Data Relay Satellite network prevent rapid follow-up observations. We present here a gamma-ray CubeSat concept in Earth-Moon L3 halo orbit that is capable of faster response and provide a timing baseline for localization improvement. Such an instrument would aid in the gravitational wave follow-up observations in other wavelengths to identify the gamma-ray burst afterglow and kilonova emission. Reducing the region of interest makes identifying afterglows much faster, allowing for rapid on-source observations and monitoring of the rise and decay times. It will also prevent source confusion between two transients and

enable robust association. A gamma-ray detection could also increase the confidence of a simultaneous but marginal gravitational wave signal, extending the detection horizon.

**Author(s):** Colleen A. Wilson-Hodge, Daniel Kocevski, Adam Goldstein, Chiumun Michelle Hui, Eric Burns, Peter Jenke, Michael S. Briggs

**Institution(s):** NASA/MSFC, Universities Space Research Association, University of Alabama in Huntsville, NASA/GSFC

**462.06 - HaloSat: Early results on the mass of the Milkyway halo(Keith Jahoda)**

HaloSat is the first NASA SMD CubeSat funded through the ROSES Astrophysics Research and Analysis Program. HaloSat's goal is test the hypothesis that the "missing baryons" reside in hot dilute halos of visible galaxies. This is performed by performing an all-sky survey and measuring Oxygen line emission from the halo of the Milkyway. Halo gas is predicted to have temperatures near a million degrees and is can be separated and traced by an experiment with large grasp and energy resolution < 100 eV in the vicinity of the emission lines of O VII and O VIII. HaloSat was deployed from the International Space Station in mid-July and began routine science operations in October. We present initial scientific results, including observations of the Cygnus loop and Crab Nebula, which demonstrate instrument performance and contribute to the in-orbit energy scale calibration, and selected high latitude regions.

**Author(s):** Hannah Gulick, William Fuelberth, Keith Jahoda, Dimitra Koutroumpa, K. D. Kuntz, Emily Silich, Philip Kaaret, Daniel LaRocca, Anna Zajczyk, Thomas Johnson, Jesse Bleum

**Institution(s):** NASA Goddard Space Flight Center, LATMOS, UIowa, Johns Hopkins University

**462.07 - Developing Low-Cost Adaptive Optics Telescopes for Long Baseline Optical Interferometry(Micha Heilman)**

Our research examines the use of adaptive optics (AO) in tandem with low-quality optics to determine if diffraction limited results can be achieved using active corrective optics. The 1 $\frac{1}{4}$ m scale of wavefront corrections provided by AO systems are substantially greater than the ~50nm construction specifications of typical telescopes. Thus, this pairing of optics and software could increase image quality while decreasing cost by significantly (~20x) relaxing mechanical requirements. As a baseline, we measured a 6in lab-quality flat with a Zygo interferometer, an instrument built for surface inspection of diffraction-limited optics. To contrast this result, we similarly inspected a low-quality mirror. We found roughly 2 full waves, about 1 $\frac{1}{4}$ m, of smoothly varying static wavefront distortion across the ~5in Zygo inspection aperture. Our lab setup consisted of a Thorlabs AO Kit (model 7) with light source, deformable mirror (DM), and Shack-Hartman wavefront sensor (WFS). A 2.5cm beam expanded from a 0.34mW laser diode hit

the low-quality mirror, which retroreflected into the AO system and was re-collimated to 5mm to match the sensor diameter of the WFS. Fifteen data sets were collected to find the Peak-to-Valley (PV) and root-mean-square (rms) of the wavefront measured from the low-quality mirror and the reconstructed wavefront corrected by the DM. This second data set was used to calculate the difference between the measured and reconstructed wavefronts. The process was repeated by replacing the low-quality mirror with a lab-quality mirror rated to  $\lambda/20$ . The PV measurement for the low-quality mirror was  $55\lambda/4$  m with a rms of  $12.7\lambda/4$  m, compared to the lab-quality mirror whose PV was  $53\lambda/4$  m with a rms of  $10.8\lambda/4$  m. The difference between the low-quality mirror's wavefront and the DM reconstructed wavefront was a PV of  $0.21\lambda/4$  m with a rms of  $0.04\lambda/4$  m. The resultant wavefront corrected 80% past its predicted outcome of  $1\lambda/4$  m. Our results indicate it would be advantageous to use a telescope design that assumes integral AO from the outset; further benefits come from tailoring the telescopes to the narrow set of specifications that emphasize use in a narrow-angle long-baseline optical interferometry system.

**Author(s):** Gerard van Belle, Jon Depinet, Jim Clark, Micha Heilman,

**Institution(s):** Mount Holyoke College, Navy Precision Optical Interferometer, Lowell Observatory

#### **462.08 - Wavelength Calibration Test for LAMOST MRS Commissioning (Jianjun Chen)**

After 6 years survey, LAMOST has published more than 9 million low resolution spectra, and catalogs of 6 million stars. In 2017, LAMOST upgraded its spectrographs to be able to switch between low and medium resolution modes. During 2017/2018 observing year, the commission observation was conducted for LAMOST MRS survey. In this poster, we represent the wavelength calibration test results of two sets of lamps, ThAr HCL and Sc MHL, which we tested during this commissioning.

**Author(s):** Yihan Song, Jianrong Shi, Jianjun Chen, Zhongrui Bai, Yonghui Hou

**Institution(s):** National Astronomical Observatories of China, Nanjing Institute of Astronomical Optics and Technology

#### **462.09 - Polarization Commissioning of the Five hundred meter Aperture Spherical Telescope (Tao-Chung Ching)**

As the world's largest filled-aperture radio telescope, the Five hundred meter Aperture Spherical Telescope (FAST) offers polarization capabilities. In the current commissioning stage of FAST, we have been working on the polarization calibration of the ultrawide receiver (270 MHz-1.62 GHz) and the 19-beam receiver (1.05-1.45 GHz). Here we present the polarization calibration strategy of FAST and the calibration results using the RHSTK (Robshaw/Heiles STOKes) software package. The current results accurate the polarization degrees of

astronomical sources to better than 1 degree, and higher accuracy will be achieved in the future. The polarization commissioning of FAST will enable many scientific studies such as Zeeman observations of HI and OH lines, pulsar profiles, and gravitational waves.

**Author(s):** Tao-Chung Ching, Di Li, Carl Heiles, Jing Tang

**Institution(s):** National Astronomical Observatories, China, University of California

#### **462.10 - Assessment of throughput variations for the SDSS APOGEE South flat field (Emily Farr)**

APOGEE is a high resolution near infrared spectrograph survey and is one of several ongoing Sloan Digital Sky Survey projects. The APOGEE survey is conducted at two separate locations, in the Northern hemisphere at Apache Point Observatory in New Mexico and in the Southern hemisphere at Las Campanas Observatory in Chile. The purpose of this study is to better understand and assess the flat field images taken at the APOGEE South site. This will supply needed parameters for data reduction in upcoming SDSS V projects. We began by obtaining flat field images from the APOGEE South survey and mapping the throughput variations to the field positions. The image data being used is from flat field images taken throughout the survey. Each image part is then appropriately correlated to the exact fiber and variations over time are assessed. This will allow the survey to establish better defined parameters for acceptable flat field images in preparation for the addition of new instrumentation to the Irénée du Pont Telescope. A full accounting of the throughput loss associated with the APOGEE fiber systems in both North and South surveys would be a beneficial next step which could be compared to the original throughput loss measurements of the fiber system to evaluate any change.

**Author(s):** Emily Farr

**Institution(s):** University of Washington

#### **462.11 - The Limits on Exoplanet Detection of Axicon-Lens Coronagraphs (Jaeho Choi)**

A coronagraph one of the high-contrast imaging of faint object that can be suppressed the bright stellar light or active galactic nuclei during the direct detection of astrophysical activities. It became one of the essential instruments to image exoplanets. Since the first coronagraph using an opaque amplitude mask at the focus was introduced by Lyot to observe solar protuberances, various concepts of stellar coronagraph have developed. Although direct imaging of younger, high mass and large separated exoplanets are made. For imaging small angular separation, older and less massive object are required spectroscopic and achromatic high contrast imaging. Moreover, broadband imaging is extreme challenging in visible and near-infrared. The theoretical limit of the proposed the axicon-lens coronagraph is derived. In this simulation, three configurations are examined; the first case is that the

separation limitation is calculated using two simulated stars set within the resolution limitation ( $1.22\lambda/D$ ) and the second case is that two planets are added in the first case in order to verify the multiple planet system. Then simulation also was carried out for the solar system at a distance of 10pc with 4m diameter telescope. In this presentation, the simulation results as well as laboratory based detection results are presented. The results shown that the proposed coronagraph can be implemented small IWA and high contrast imaging with large broadband imaging in visible to near-infrared. Furthermore it is insensitive to the stellar angular size, simple and robust.

**Author(s):** Jaeho Choi

**Institution(s):** Dankook University

## **463 - Large Scale Structure and Cosmology: Late Posters**

### **463.01 - Searching for the BAO signal in the density field of the 2MRS survey(Lingyu Wang)**

A density field, providing the matter density at positions in a regular three-dimensional grid, has recently been created from a catalog of galaxy clusters in the 2MASS redshift survey. This provides us with the opportunity to characterize the large-scale structure of the local volume by applying mathematical tools directly to this density field rather than using galaxy counts. We first calculate the density correlation function; our results show a significant bump at  $r = 105 h^{-1} \text{ Mpc}$  corresponding to the Baryon Acoustic Oscillation signal, previously seen only in data from much deeper surveys. Secondly, we apply the Fourier transform to the density field giving us an estimate of the power spectrum. Finally, we apply a void finding algorithm to the density field in order to characterize the void distribution.

**Author(s):** Lingyu Wang, Brent Tully, Richard Watkins

**Institution(s):** Willamette University, Institute for Astronomy

### **463.02 - Measuring the Baryonic Content of the Circumgalactic Medium(Olivia Petry)**

Throughout a galaxy's billion-year lifetime, its baryonic material will cycle through many different phases on scales of hundreds of kpc. This cosmic baryon cycle occurs primarily in the Circumgalactic Medium (CGM) which surrounds and stretches far beyond the luminous centers of galaxies. Characterized by rich dynamics and complex ionization states, the CGM regulates and recycles the galaxy's gas supply, playing a vital role in galaxy evolution. Using high-resolution quasar spectroscopic data collected by the Cosmic Origins Spectrograph on the Hubble Space Telescope (HST-COS), I identify CGM absorption features and tie them to galaxy properties. I describe a python-GUI that helps the process of determining the species, redshifts, velocity dispersions, and column densities of the many absorption lines along  $z \sim 1$  QSOs. My work, part of the larger efforts of the Werk SQuAD: a group of undergraduate "Student Quasar Absorption Diagnosticians," will serve a major role in characterizing the rich, multiphase

cosmic baryon cycle that drives galaxy evolution.

**Author(s):** Olivia Petry

**Institution(s):** University of Washington

### **463.03 - Schwinger Effect in De Sitter Space-Time(Syed Jibran Haider)**

Electric fields as well as gravitational fields can create pairs of particles via quantum tunneling (the Schwinger mechanism). These processes are usually studied using quantum field theory on Minkowski or curved space-times. There is an alternative to Feynman diagram loop calculations - the worldline formalism -, which can offer insights into the space-time evolution of the produced particles. When the solutions of the classical equations of motion are known, the path integral in the quantum mechanical propagator is reduced to an ordinary integral over the internal time of the particle. We can then study the semiclassical limit using Picard-Lefschetz theory, a set of mathematical tools for oscillatory integrals, which has given exciting new results in recent years (in quantum cosmology, QCD lattice computation, non-perturbative quantum field theory). The goal of the project is to apply Picard-Lefschetz theory to pair production in de Sitter space-time (with or without a constant electric field). The process, besides being interesting in itself, could help model pair production in black holes, bubble nucleation, or the production of universes.

**Author(s):** Beatrice Bonga, Syed Jibran Haider, Angelika Fertig

**Institution(s):** University of Richmond, Perimeter Institute for Theoretical Physics

### **463.04 - Redshift Space Distortion of the 21cm Background from the Epoch of Reionization II: Effect of Finite Optical Depth(Jiachuan Xu)**

The redshift space distortion (RSD) of the 21cm brightness temperature is a promising tool to extract the cosmological information from the nonlinear astrophysics process during the epoch of reionization (EoR). Optically thin approximation is widely assumed during this extraction. However, the optical depth of intergalactic medium could be finite at turnaround and virialized stages of the dark matter halo, which may impair the extraction of cosmological information. In this work, we propose a numerical scheme, tau-MMRRM, to include these nonlinearities, and implement it on top of simulation data. We find that: (1) The number of optically thick cells is increasing as time evolve, peaks before the X-ray heating from the first generation of galaxies is turned on, then decreases due to the shrinking neutral hydrogen (HI) region. (2) The maximum optically thick cells fraction depends on the resolution of simulation. For a  $256^3 100 \text{ Mpc}^3$  simulation, this fraction could reach 1%. (3) The break of optically thin approximation would introduce an overall decrease in 21cm power spectrum, at all scales, both in real and redshift space. The maximum correction could reach 20%. Also, the break would also modify the profile

of probability distribution function (PDF) of 21cm signal. To understand the RSD, we present a semi-analytical formula, the extended quasi-linear scheme, to calculate the power spectrum in redshift space. Compared with the numerical results: (4) The semi-analytical formula's result agrees with the numerical ones within 10% accuracy during and before EoR. (5) Using  $\hat{1}/4$ -decomposition, we find that the extracted dark matter power spectrum deviates from the real one, which could be on account of the coupling between neutral fraction, velocity field and spin temperature fluctuation.

**Author(s):** Jiachuan Xu

**Institution(s):** Tsinghua University Contributing Team(s): YMao

#### **463.05 - How to Proceed in the Face of Finetuning and Bayesian Confirmation Problems Present in the Eternal Inflation Scenario.(Daniel David Sega)**

Results from the Planck Collaboration published in 2013 and 2016 have discarded some models of inflation and favor others. Nevertheless, Ijjas, Steinhart and Loeb (2013 Phys.Lett.B, 723, 261-266) have put into question the empirical testability of the slow-roll models of cosmic inflation. These concerns were quickly met by a reply by Alan Guth (2014, Physical Letters B, 112, 119), and the debate hasn't progress since then. In this poster presentation, we'll analyze the current controversy and describe the opposing arguments of the that favor and reject inflation as a verified hypothesis. The conclusion will be drawn in Ijjas, Steinhart and Loeb favor, albeit we'll briefly suggests paths towards solutions to the problems they presented. In particular, we analyze the finetuning problems that steams from this plateau potentials that generate the infation, and compare them to the flatness and the horizon problem of the Hot Big Bang Theory (without inflation). We find these problems similar and conclude that, if one finds the horizon and flatness problem a hindrance to the big bang theory, then the plateau models should be found equally problematic. Finally, we go over the "eternal inflation' scenario produced by slow-roll models. We find that under a Bayesian framework of hypothesis confirmation, the CMB observations do support slow-roll inflation, but only provided that we have an acceptable measure for the probability of the CMB occurring. The issues surrounding these measures will be briefly discussed. Overall, we find (1) slow-roll inflationary models to be untestable under the Bayesian framework, at least in its current form, and (2) that the solution of finetuning problems shouldn't be our basis to believe that inflation is true. This poster is aimed to be a clear presentation of the foundational issues surrounding the current inflationary paradigm.

**Author(s):** Daniel David Sega,

**Institution(s):** University of Colorado, Boulder, APS, University of Oxford, Faculty of Philosophy

#### **463.06 - Constraints on primordial gravational waves using BICEP2/Keck Array up to the 2015 season with WMAP and Planck(Justin Willmert)**

The BICEP2/Keck Array telescopes are small aperture, polarization sensitive, on-axis refractors designed for study of the degree-scale microwave sky. They observe an  $\sim 400$  square degree patch from Amundsen-Scott South Pole Station and are optimized for detecting cosmological B-modes within the cosmic microwave background. In this poster we present the analysis results for all data up to and including the 2015 observing season. The 2015 season adds new data at 95, 150, and 220GHz, complementing the already very deep 150GHz map, approximately doubling the map depth at 95GHz, and adding a 220GHz map for the first time. We supplement these maps with WMAP and Planck maps spanning 23 to 353GHz and form all auto- and cross-spectra. The spectra are used to evaluate a likelihood in an 8-parameter model of lensed- $\Lambda$ CDM + r + dust + synchrotron + noise. We find  $r < 0.07$  at 95% confidence with  $\tilde{l}f(r) = 0.020$ , the strongest constraints on primordial gravitational waves to date.

**Author(s):** Justin Willmert

**Institution(s):** University of Minnesota Contributing Team(s): BICEP/Keck Array Collaboration

#### **463.07 - Thermometry Integration & Calibration for the Simons Observatory(Sanah Bhimani)**

The Simons Observatory experiment is a next-generation CMB experiment, fielding arrays with up to  $\sim 30,000$  detectors. Amongst goals like measuring neutrino masses and discovering dark matter via gravitational lensing, the Simons Observatory will also search for direct evidence of inflation in the B-mode polarization pattern. In order to make sensitive measurements, the Simons Observatory detectors must be cooled down to 100mK with dilution refrigerators, with intermediate cold stages of 80K, 40K, 4K, and 1K. In addition, it is crucial that we map any temperature fluctuations at the 100mK stage that cools the detectors. This requires the construction of temperature sensors that can be placed at different stages of the cooling process, ranging from 80K down to 100mK. At Yale University, approximately 250 temperature sensors are currently being constructed, where the data from these sensors are analyzed using readout systems in development for the Simons Observatory.

**Author(s):** Sanah Bhimani

**Institution(s):** Yale University

#### **463.08 - Data Acquisition and Control Systems for the Simons Observatory(Lauren J Saunders)**

The Simons Observatory will be a system of four new Cosmic Microwave Background (CMB) telescopes designed to improve constraints on inflation, measure the sum of the neutrino masses, probe dark energy, and usher in an era of using the CMB to search for new particles and axion dark matter. To



achieve these science goals, the Simons Observatory will deploy a total of 60,000 detectors among four separate telescopes: 30,000 on a single high-resolution Large Aperture Telescope, and 10,000 on each of three smaller, refracting Small Aperture Telescopes. The observatory will utilize a new Observatory Control System (OCS) data acquisition and control system, which will be implemented across all four telescopes to control, monitor, and collect data from a wide range of housekeeping and detector readout systems. OCS is currently in development, with functionality for temperature monitoring and control purposes. It will soon be expanded to facilitate other telescope subsystems, including half-wave plate encoder readout and detector readout. While OCS is currently being developed specifically for the Simons Observatory, it is designed with scalability in mind, making it applicable to future CMB experiments, such as CMB-S4.

**Author(s):** Lauren J Saunders

**Institution(s):** Yale University **Contributing Team(s):** Simons Observatory Collaboration

#### **463.09 - Disentangling Dark Physics with Cosmic Microwave Background Experiments(Zack Li)**

We forecast constraints on dark matter (DM) scattering with baryons in the early Universe with upcoming and future cosmic microwave background (CMB) experiments, for DM particle masses down to 15 keV. In terms of the upper limit on the interaction cross section for a velocity-independent spin-independent elastic scattering, compared to current Planck results, we find a factor of  $\sim 1/46$  improvement with CMB-Stage 3, a factor of  $\sim 1/26$  with CMB-Stage 4, and a factor of  $\sim 1/200$  with a cosmic-variance limited experiment. Once the instrumental noise reaches the proximity of  $1 \text{ } \mu\text{K-arcmin}$ , the constraints are entirely driven by the lensing measurements. The constraints benefit from a wide survey, and show gradual improvement for instrumental noise levels from  $10 \text{ } \mu\text{K-arcmin}$  to  $1 \text{ } \mu\text{K-arcmin}$  and resolution from  $5 \text{ arcmin}$  to  $1 \text{ arcmin}$ . We further study degeneracies between DM interactions and various other signatures of new physics targeted by the CMB experiments. In the primary temperature and polarization only, we find moderate degeneracy between the effects of DM scattering, signals from massive neutrinos, and from the effective number of relativistic degrees of freedom. The degeneracy is almost entirely broken once the lensing convergence spectrum is included into the analyses. We discuss the implications of our findings in context of planned and upcoming CMB measurements and other cosmological probes of dark-sector and neutrino physics.

**Author(s):** Zack Li

**Institution(s):** Princeton University

#### **464 - Stars In All Their Glory: Late Posters** **464.01 - The old and new ULXs of NGC 6946(Hannah Penn Earnshaw)**

Two recent observations of the nearby galaxy NGC 6946 with NuSTAR, the second simultaneous with an XMM-Newton observation, provide an opportunity to examine its population of bright accreting sources from a broadband perspective. We study the three known ultraluminous X-ray sources (ULXs) in the galaxy, as well as a new appearance in the second, simultaneous observation which we call ULX-4. ULX-1 and ULX-2 have very steep power-law spectra with  $\Gamma \sim 3.6$  in both cases and luminosities  $L_X \sim 5 \times 10^{38} \text{ erg s}^{-1}$ . While not technically ULXs in this observation, their properties are consistent with being ultraluminous supersoft sources - super-Eddington accreting sources with the majority of their hard emission obscured and down-scattered. ULX-3 (also known as NGC 6946 X-1) is significantly detected by both XMM-Newton and NuSTAR, and has a power-law spectrum with  $\Gamma = 2.46 \pm 0.07$ . Using the NuSTAR data we are tentatively able to prefer a ULX spectral model that turns over around  $\sim 10 \text{ keV}$  to a straight power-law for this source. We also characterise the new source ULX-4, which is detected for the first time in the joint XMM-Newton and NuSTAR observation and is absent in a Chandra observation ten days later. It has a very hard spectrum, equally well described as a cut-off power-law with  $\Gamma = 0.7 \pm 0.2$  and  $E = 12^{+14}_{-4} \text{ keV}$ , or a hot multicolour disc blackbody with  $T = 4.5 \pm 0.5 \text{ keV}$ . We do not detect any pulsations from ULX-4, however its unusually hard spectrum and transient nature can be explained either as a neutron star ULX briefly leaving the propeller regime or as a micro-tidal disruption event induced by a stellar-mass compact object.

**Author(s):** Felix Fuerst, Dominic Walton, Marianne Heida, Fiona Harrison, Murray Brightman, Brian Grefenstette, Daniel Stern, Hannah Penn Earnshaw

**Institution(s):** Caltech, Insitute of Astronomy, ESAC

#### **464.02 - Effects of Metallicity on High Mass X-ray Binary Formation(Sam Ponnada)**

The heating of the intergalactic medium in the early, metal-poor Universe may have been partly due to radiation from high mass X-ray binaries (HMXBs). Previous investigations on the effect of metallicity have used galaxies of different types. To isolate the effects of metallicity on the X-ray properties of galaxies, we study a sample consisting only of blue compact dwarf galaxies (BCDs) covering metallicity in the range  $12 + \log(\text{O}/\text{H})$  of 7.15 to 9.1. We use a Bayesian method to constrain the dependence of the X-ray luminosity function (XLF) on the star formation rate for three different metallicity ranges in our sample. We find the X-ray luminosity-SFR normalization at low, intermediate, and high metallicity, and find an increase by a factor of  $7.19 \pm 3.13$  in the normalization between the metallicity ranges 7.1-7.7 and 8.2-9.1 at a statistical significance of 99.4 per cent. Additionally, we find an increase in the number of HMXBs normalized to SFR over the metallicity range and a decrease in the total resolved X-ray

luminosity normalized to SFR at high metallicity. Our results suggest that metallicity is an important factor in the formation of HMXBs, and consequently that HMXBs may have contributed significantly to the heating of the Universe during the epoch of reionization.

**Author(s):** Matthew Brorby, Sam Ponnada, Philip Kaaret

**Institution(s):** University of Iowa

#### **464.03 - Evryscope Photometry of the New Hot Subdwarf Reflection Effect Binary EC 01578-1743(Stephen Walser)**

EC 01578-1743 is a new hot subdwarf binary discovered by the “wide-seer” Evryscope array on Cerro Tololo. Its light curve reveals an orbital period around six hours and a strong reflection effect, implying a low-mass stellar or substellar companion. Hot subdwarfs are commonly found in these types of post-common envelope binaries, referred to as “HW Vir” systems when they eclipse. Determining the companions’ masses and other properties can help shed light on the formation scenarios that lead to hot subdwarf stars. Our analysis of three years of Evryscope photometry finds no primary or secondary eclipses and a ~14% reflection effect, fairly high for HW Vir-type binaries with this orbital period. Spectroscopy was obtained with the CHIRON spectrograph on the CTIO 1.5-m telescope and reveals the radial velocity semi-amplitude of the hot subdwarf to be  $86 \pm 1$  km/s. Here we present our photometric and spectroscopic analyses and argue that the companion is a red dwarf, and one with higher mass than usual for HW Vir-type binaries. This material is based in part upon work supported by the National Science Foundation under Grant No. AST-1812874.

**Author(s):** Sam Mycroft, Stephen Walser, Ward S Howard, Henry T Corbett, Nicholas Law, Brad Barlow, Octavi Fors, Kyle A Corcoran, John Aube, Jeff Ratzloff

**Institution(s):** High Point University, UNC Chapel Hill, University of Notre Dame, University of Barcelona

#### **464.04 - Detecting a Third Body in KIC9832227(Riley Jordan)**

KIC 9832227 is a well-studied contact binary system with a recently disproved merger prediction. We explore the existence of a third body to elucidate the formation of contact binaries. Since KIC 9832227 is a well-observed system, there is an abundance of optical data, both spectroscopic and photometric, which indicate that a third companion must be smaller and dimmer than the observed G dwarf stars. We use IR spectra from Apache Point Observatory, to look for the spectral signature of a dim third star. A broadening function code was used to search for any spectral signatures of a third companion. We present our results which constrain the mass of the hypothetical third body. Furthermore, we tested our broadening function pipeline on our IR data with an injected third body signal. These tests demonstrate the sensitivity of the

data to a faint third star.

**Author(s):** Henry Kobulnicky, Riley Jordan, Lawrence A Molnar, Jacob McLane

**Institution(s):** University of Wyoming, Calvin College

#### **464.05 - The Nature of X-Ray Sources in the Starburst Galaxy NGC1569(Michael Sanchez)**

Images of nearby starburst galaxies taken with the Chandra X-Ray Observatory reveal bright X-ray sources, many of which are believed to be high mass X-ray binaries (HMXBs), formed during recent star formation. We use archival optical (Hubble Space Telescope) and X-ray (Chandra X-ray Observatory) data to study the X-ray source population in the nearby starburst galaxy NGC 1569. We determine count rates, luminosities and X-ray colors for each X-ray source. We identify optical counterparts for a number of HMXB candidates. Combining the X-ray and optical data, we investigate the nature of the X-ray sources in NGC 1569.

**Author(s):** Blagoy Rangelov, Michael Sanchez

**Institution(s):** Texas State University

#### **464.06 - The iPTF high cadence survey in the Galactic Plane(Alison Dugas)**

Ultracompact hot subdwarf binaries are short period binaries of a white dwarf with a hot subdwarf, a helium star with a high effective temperature and a low mass. Their orbital periods are so short that the subdwarf will fill its Roche Lobe before the end of helium burning, and the binary will engage in mass transfer as it continues to shrink via gravitational wave emission. Helium-rich material accreted to the white dwarf is predicted to possibly ignite unstably which could in turn trigger carbon ignition, so the study of these systems is important for our understanding of supernova Ia progenitors in addition to binary evolution. Some of them may also be detectable as Galactic gravitational wave sources with eLISA, but the number of known systems is currently limited. We conducted a high cadence r-band survey using the intermediate Palomar Transient Factory (iPTF) to identify detached white dwarf/hot subdwarf binaries with periods well below two hours. Two hundred square degrees were surveyed at low Galactic latitudes ( $|b| < 5^\circ$ ), and each field was imaged a median of 67 times over a two-hour period with a 115-second cadence. We extracted 17.6 million individual sources within the crowded region of the survey, and used a random forest classifier based on light curve features to differentiate true variables from the many blended sources in this field. Simulated light curves were generated using the elc binary star model to detect eclipsing sources, and the results from several period-finding algorithms were used in combination in order to reveal other periodic systems. In addition to the survey’s photometric data, colors were cross-matched from PanSTARRS DR1 in order to identify systems with high effective temperatures. In this poster we present results of the survey.

**Author(s):** Jan van Roestel, Kevin Burdge, Thomas Prince, Thomas Kupfer, Frank Masci, Alison Dugas, Eric Bellm, Russ Laher

**Institution(s):** California Institute of Technology, University of Washington, University of California, Santa Barbara  
Contributing Team(s): iPTF collaboration

#### **464.07 - Analyzing white dwarf + main sequence binaries with Gaia trigonometric parallaxes(Adam Moss)**

White dwarfs have been used as chronometers to age date the solar neighborhood, open clusters, globular clusters, and even the Galactic halo field population. The availability of highly accurate and precise Gaia trigonometric parallaxes along with nearly all-sky, homogenous photometric (SDSS, Pan-STARRS) and spectroscopic (GALAH, LAMOST, RAVE) surveys now allows us to improve the precision in white dwarf ages. We report on the leverage brought to age dating WDs based on the measured metallicities in 136 WD+MS pairs.

**Author(s):** Dr. David Stenning, Adam Moss, Elliot Robinson, Dr. Areem El-Badry, Dr. Ted Von Hippel, Isabelle Kloc, Dr. David van Dyk, Natalie Moticska, Jimmy Sargent, Dr. Elizabeth Jeffery, Dr. William Jefferys

**Institution(s):** Embry-Riddle Aeronautical University, California Polytechnic State, Imperial College, University of California, Berkeley, University of Texas

#### **464.08 - Analyzing white dwarf + white dwarf binaries with Gaia trigonometric parallaxes(Isabelle Kloc)**

White dwarfs (WDs) have been used as chronometers to age date the solar neighborhood, open clusters, globular clusters, and even the Galactic halo field population. The availability of highly accurate and precise Gaia trigonometric parallaxes along with nearly all-sky, homogenous photometric surveys (SDSS, Pan-STARRS) now allows us to improve the precision in white dwarf ages. We report on the consistency of ages among 379 WD+WD pairs with both known and unknown spectral types. In this sample, we study 100 pairs with one known spectral type (74 DA, 1 DB, 17 DC, 7 DQ, 1 DZ) and 18 pairs with known spectral types for both objects.

**Author(s):** Dr. David Stenning, Adam Moss, Elliot Robinson, Dr. Areem El-Badry, Isabelle Kloc, Ted von Hippel, Dr. David van Dyk, Natalie Moticska, Jimmy Sargent, Dr. Elizabeth Jeffery, Dr. William Jefferys

**Institution(s):** Embry-Riddle Aeronautical Univ., California Polytechnic State Univ., Imperial College, Univ of Texas, Univ of California

#### **464.09 - Impacts of Nuclear Reaction Rate Uncertainties on Nucleosynthesis in sub-Chandrasekhar-mass White Dwarf Detonations(Thomas Cy Fitzpatrick)**

The precise nature of Type Ia supernovae (SN Ia) progenitors remains a mystery, but the detonation of a sub-Chandrasekhar-mass white dwarf (WD) has become one of the most promising scenarios. There is a growing body of work suggesting that a carbon core detonation of a sub-Chandrasekhar-mass WD can be triggered by the detonation of a helium shell ignited by the rapid accretion of a small amount of helium from a companion WD. This "dynamically driven double-degenerate double-detonation" SN Ia is well modeled by the detonation of a bare carbon-oxygen white dwarf (C/O WD). The effects of nuclear reaction rate uncertainties on nucleosynthesis in detonations of sub-Chandrasekhar-mass WDs have not yet been comprehensively studied. We investigate the sensitivity of our hydrodynamic simulation of a bare C/O WD detonation to these uncertainties in order to better constrain the reaction rates which most significantly impact nucleosynthesis. We vary the standard nuclear reaction rates in the detonation of a 1.0  $M_{\odot}$  spherically symmetric bare C/O WD by a factor of 10 up and down and compare the resulting nuclear abundances to those generated by our model using standard rates. From our nuclear physics network of 1884 nuclear reactions and 205 isotopes, we find that 45 reactions have a significant impact on the final abundance yields of at least one species. Uncertainties in the rates of  $^{20}\text{Ne}(\alpha, n)^{24}\text{Mg}$ ,  $^{23}\text{Na}(\alpha, p)^{26}\text{Mg}$ , and the triple- $\alpha$  process have the most pronounced effects on nuclear yields in our model. The chemical abundances, in particular those of the Fe-group elements, are relatively insensitive to uncertainties in the rates of nuclear reactions.

**Author(s):** Thomas Cy Fitzpatrick, Ken Shen, Dan Kasen

**Institution(s):** University of California, Berkeley

#### **464.10 - Pulsar Observation Group at UVA(Nick Anderson)**

The Pulsar Observation Group at UVA, which currently consists of approximately 15 undergraduate students, uses the Long Wavelength Array to observe and construct timing solutions for a number of pulsars over the course of the academic year. Each pulsar observed has either no previously published timing solution or a solution which was published over thirty years ago. Our group, which was recently recognized as an official student organization at UVA, consists of members with varying levels of research experience, providing an opportunity for younger students to familiarize themselves with valuable techniques and engage with useful scientific material. The timing solutions we produce are uploaded to a public database, and our methodology is published on our website for any interested parties to easily access.

**Author(s):** Nick Anderson, Kevin Stovall, Nicholas Clifford, Robin Leichtnam

**Institution(s):** University of Virginia, National Radio Astronomy Observatory  
Contributing Team(s): Pulsar Observation Group at UVA

## **465 - Stars, Stellar Evolution & Circumstellar Disks : Late Posters**

### **465.01 - Exploring the Brown Dwarf Desert: Short-period substellar companions from the Kepler and K2 missions(Theron Carmichael)**

The brown dwarf desert describes the lack of observed brown dwarfs orbiting in short periods (less than on the order of 30 days) around main sequence stars. Using data from the Kepler spacecraft, we have found two new short-period companions to main sequence stars. The light curves from the Kepler and K2 missions indicate Jupiter-sized, short-period companions that were followed up with radial velocity measurements using the Tillinghast Reflector Echelle Spectrograph (TRES) in 2014 and 2018. In addition to the spectra and light curves, we use parallaxes from the Gaia mission to constrain the parameters of the host star. The first object is a low-mass star of approximately 90 Jupiter masses orbiting a solar twin. The second object is a brown dwarf of approximately 50 Jupiter masses orbiting a late F-type star. Both of these stellar companions have 5 day periods and are eccentric. The brown dwarf is interesting as it occupies the sparsest region of the brown dwarf desert. The low-mass star is right on the mass boundary separating brown dwarfs from stars.

**Author(s):** Theron Carmichael

**Institution(s):** Harvard University Contributing Team(s): Kepler team, K team

### **465.03 - Investigating the Slow Neutron-Capture Process in the Early Universe(Tiger Lu)**

Carbon Enhanced Metal Poor (CEMP) stars show unusually large enhancements in carbon and low concentrations of iron. A subset of these also show enhancements in elements created in the slow neutron-capture process (s-process), called CEMP-s stars. The prevailing theory for how these stars gained such peculiar elemental abundances is via mass transfer from a partner star. However, radial velocity monitoring of 22 CEMP-s stars have identified 4 as single stars. For these stars, enhancement of s-process elements cannot be explained via mass transfer, hence their abnormal abundance is likely the result of nucleosynthesis events in the early universe. We measure abundances of C, N, alpha and iron peak elements, and 15 s-process elements in these stars using high resolution spectra, and compare them to abundances predicted from progenitor models of the s-process. We observe that no current theory completely explains the abundances measured in this experiment.

**Author(s):** Terese Hansen, Tiger Lu

**Institution(s):** California Institute of Technology, Carnegie Observatories

### **465.04 - A Large X-ray Stellar Flare from the RS CVn type Star GT Mus Observed with MAXI and NICER(Ryo Sasaki)**

We report on the properties of a huge X-ray flare from the RS CVn type star GT Mus observed with MAXI and NICER. MAXI detected a flare from GT Mus at 2017-07-17UT03:55. After 1.5 days from that, NICER started to observe the flare intermittently for three days with a total exposure time of 1.6 ksec. The count rate was 140 - 300 count s<sup>-1</sup>. The flare duration was estimated to be 2.4 days from the MAXI and NICER light curves. The total flare energy was  $5 \times 10^{38}$  erg. This flare was one of the longest and the largest flare ever. We analyzed a peak spectrum obtained with MAXI and a time-resolved spectrum obtained with NICER. The peak spectrum was reproduced by an absorbed one temperature optically thin thermal plasma model. The time-resolved spectrum was reproduced by an absorbed two-temperature optically thin thermal plasma model. The emission measure (EM) at the flare peak was  $20 (10 - 30) \times 10^{55} \text{ cm}^{-3}$ . The EM of the hot component of the NICER spectrum decreased from  $10 \times 10^{55} \text{ cm}^{-3}$  to  $2 \times 10^{55} \text{ cm}^{-3}$ . The EM decreased by one order of magnitude from the flare peak to the end. On the other hand, the temperature (kT) did not show a significant change during the flare. The peak kT was 6 (4 - 12) keV. The kT of the hot component distributed from 4 keV to 6 keV, randomly. We compared this with the NICER spectrum for the three days data from 2017-11-18. The count rate was 43 count s<sup>-1</sup> on average. The spectrum was reproduced by the same model as the time-resolved spectrum. The kT of the hot component was 3.1 (3.0 - 3.2) keV. It was suggested the over 4 keV plasma constantly exist from the flare peak to the end.

**Author(s):** Yohko Tsuboi, Kenji Hamaguchi, o, Tatsuki Sato, Motoko Serino, Teruaki Enoto, Tatehiro Mihara, Hiroki Kawai, Zaven Arzumanyan, Ryo Sasaki, Keith C Gendreau, Yoshitomo Maeda, Hitoshi Negoro, Wataru Iwakiri, Stephen A. Drake, Craig Markwardt, Michael F

**Institution(s):** The Catholic University of America, OUMBC, Chuo University, NASA/GSFC, RIKEN, JAXA, USRA, Nihon University, Aoyama Gakuin University, Ehime University, Kyoto University Contributing Team(s): MAXI team, NICER team

### **465.05 - Radio detection of ultracool dwarfs with FAST(Jing Tang)**

Ultracool dwarfs (UCDs) are a new class of radio emitters. In the past two decades, more than 20 UCDs have been detected ~GHz radio emissions, indicating they have ~kG magnetic fields. How such strong fields generate and sustain in fully convective objects is a big challenge to current dynamo theory. The physical conditions associated with these radio-active objects have been investigated, but the understanding is still limited due to the small sample. As the world's largest single dish radio telescope, the Five-hundred-meter Aperture Spherical Telescope (FAST) has high sensitivity. It can observe from 70MHz to 3GHz, with full polarization measurement, very suitable to detect highly circularly polarized radio emission from UCDs, and even giant exoplanets. Here we will estimate possible radio emissions from UCDs and check if they can be detected by FAST.

**Author(s):** Jing Tang

**Institution(s):** NAOC

#### **465.06 - Orbital decay in binaries containing post-main-sequence stars(Meng Sun)**

The tide raised by the companion in the red giant branch (RGB) star leads to an exchange of angular momentum between the orbit and the stellar spin, causing the orbit to contract. Two mechanisms are often invoked to explain tidal friction in binary systems. The “dynamical tide” is the resonant excitation of internal gravity waves by the tide, and their subsequent damping by nonlinear fluid processes or thermal diffusion. The “equilibrium tide” refers to non-resonant excitation of fluid motion in the star’s convection zone, with damping by interaction with the turbulent eddies. There have been numerous studies of these processes in main sequence stars, but less so on the subgiant and RGBs. Motivated by the newly discovered close binary systems in the Apache Point Observatory Galactic Evolution Experiment (APOGEE-1), we have performed calculations of both the dynamical and equilibrium tide processes for stars over a range of mass as the star’s cease core hydrogen burning and evolve to shell burning. Even for stars which had a radiative core on the main sequence, the dynamical tide may have a very large amplitude in the newly radiative core in post-main sequence, giving rise to wave breaking. The resulting large dynamical tide dissipation rate is compared to the equilibrium tide, and the range of secondary masses and orbital periods over which rapid orbital decay may occur will be discussed, as well as applications to close APOGEE binaries and data from exoplanets.org.

**Author(s):** Steve Majewski, Nevin N Weinberg, Phil Arras, Meng Sun, Nicholas Troup,

**Institution(s):** University of Virginia, MIT, UW Madison, Salisbury University

#### **465.07 - Distribution of stellar rotation periods using light curve analysis of second phase Kepler data(Zoe Bell)**

Analysis of the first phase of Kepler data found an unexpected bimodal distribution of star rotation periods (McQuillan, Mazeh & Aigrain, 2014). We sought to perform a similar analysis with the larger sample of stars offered by the second phase of Kepler data (K2). We explored lightcurves from 80,000 stars and looked for trends in the star rotation periods using a subset of K2 data campaigns. Two algorithms were developed-using the Lomb-Scargle and autocorrelation methods-and applied to the data set. Using the GAIA data for these stars, only stars with  $MG \geq 4$  and other quality cuts were analyzed. A subset of periods were selected when the two algorithms agreed within a specific percentage threshold. We found evidence of a bimodal distribution of periods in the resulting period vs. BP-RP plots. There was some evidence that the bimodality was more pronounced in stars within 300 parsecs. Our analysis provides additional evidence for the unexpected bimodal distribution of

star rotation periods.

**Author(s):** Zoe Bell, James Davenport

**Institution(s):** Harvey Mudd College, University of Washington, Seattle

#### **465.08 - Multi-wavelength Flare Observations of Wolf 359 from Earth and Space(Dennis Afanasev)**

Wolf 359 is a nearby red dwarf that produces frequent flares, which are unpredictable increases in stellar brightness caused by the sudden release of magnetic energy. Kepler’s extended mission, K2, observed Wolf 359 for over 80 days with high-precision 1-minute photometry in 2017. Wolf 359 exhibited hundreds of flares in the K2 data, each more energetic than the Sun’s Carrington flare, the largest recorded geomagnetic storm on Earth. To understand this flare activity with the underlying physical processes, we obtained simultaneous observations of Wolf 359 in the UV, X-ray, and radio using Swift, HST, and ground-based radio observatories. I will present results from our multiwavelength campaign of Wolf 359, and discuss our plans to observe a large sample of low-mass stars that span a wide range of masses and ages with TESS and other multiwavelength facilities. Low-mass stars like Wolf 359 are the most common stars in the galaxy and are the most common type of exoplanet host star. Our long-term goal of this program is to understand the impact of flares on the potential habitability of exoplanets.

**Author(s):** Thomas Barclay, Dennis Afanasev, Elisa Quintana

**Institution(s):** NASA Goddard, George Washington University

#### **465.09 - Properties of Protoplanetary Disks in Chamaeleon I: An SED Modeling Study(Tyler Baines)**

Protoplanetary disks, where planets form, are a natural consequence of star formation. Thermal emission from dust in protoplanetary disks is observed from near-IR through mm wavelengths. Observations at these wavelengths allow disk structure to be constrained and properties such as mass to be measured. Measuring the properties of protoplanetary disks is essential for understanding planet formation, as the mass and size of a disk determine the number and types of planets that can form. I fit an analytic disk model to the spectral energy distributions (SEDs) of 60 disks in the Chamaeleon I star-forming region located approximately 160 pc from the Sun. I used available data from catalogs and the literature to compile flux density measurements covering the SED. I modeled the radial variations in surface density and temperature with power laws and applied dust opacity models based on a realistic distribution of grain sizes. In addition, I constrained the disk’s geometric properties: inner radius, critical radius, and inclination. Using an MCMC fitting routine, I determined the parameters and measured uncertainties. Here I present the derived disk parameters and discuss the planet-forming potential of these disks.

**Author(s):** Tyler Baines  
**Institution(s):** University of Arizona

**465.10 - Simulating the Streaming Instability in Planetesimal Formation: Understanding the Effect of Radial Pressure Gradient(Charles Abod)**

The streaming instability is a mechanism that produces regions of particle overdensity in protoplanetary disks. These overdensities gravitationally collapse to form planetesimals. Although it is well known that the extent of particle clumping is dependent on the radial gas pressure gradient, the relationship between pressure gradient and planetesimal properties is not known. We carry out very high resolution local, shearing box simulations (i.e., a small co-rotating patch) of a protoplanetary disk to study the effect of the radial pressure gradient on the streaming instability and resulting planetesimal properties. We find that the pre-collapse structure of particles grows increasingly axisymmetric with increasing pressure gradient, and for relatively small radial pressure gradients, smaller filaments form with a non-axisymmetric web-like structure. The initial mass distribution can be fit to a single power-law, where we measure a power-law index of  $p = 1.6$  for every non-zero pressure gradient. An exponentially truncated power law provides a better fit; here, we find a power-law index of  $p = 1.3$ . We also find that the largest planetesimal masses have a weak, and possibly negligible, dependence on pressure gradient. This result rules out a cubic scaling of planetesimal mass with the pressure gradient, as suggested by linear theory. A simulation initialized with zero pressure gradient, which is not subject to the streaming instability, also yields a top-heavy mass function but with a noticeably different shape. These results point towards a initial planetesimal mass distribution that is at best very weakly dependent on the properties of the disk.

**Author(s):** Charles Abod, Jacob Simon  
**Institution(s):** University of Colorado, Boulder

**465.11 - Resolving the late planet formation stages around young M-stars in Upper Sco with STIS(Maxwell Millar-Blanchaer)**

Recent discoveries of earth-like planets around M-stars have highlighted the importance of understanding planet formation around late-type stars. However, this effort has been hampered by the lack of resolved observations of protoplanetary disks. In particular, scattered light images of M-star disks near the age of dispersal are critical to making further progress. The Upper Sco region provides a promising venue to remedy this situation, as it is the closest region with an age of 5-11 Myrs, commensurate with dispersal timescales. We present results from an HST/STIS program to resolve protoplanetary disks around M-stars in the Upper Sco association, leveraging the smaller inner working angle of the BAR5 focal plane mask and STIS's sensitivity to low surface brightness disks. Two of the three disks in our program have been observed and here we present

initial PSF-subtracted images and preliminary analysis of the disk morphologies.

**Author(s):** Maxwell Millar-Blanchaer, Paul Kalas, James Graham, Marshall Perrin, Karl Stapelfeldt, Anneila Sargent, John M. Carpenter, Scott A. Barenfeld

**Institution(s):** NASA-JPL, ALMA, UC Berkeley, STScI, California Institute of Technology

**466 - The ISM, Dust & Star Formation: Late Posters**

**466.01 - The Radio Ammonia Mid-Plane Survey (RAMPS)(Taylor Hogge)**

The Radio Ammonia Mid-Plane Survey (RAMPS) is a molecular line survey that aims to map 20 square degrees in the 1st Quadrant of the Galactic midplane. The purpose of RAMPS is to provide a large sample of dense molecular clumps to help us better understand the formation of high-mass stars. We used the 100 m Green Bank Telescope (GBT) to map several  $\text{NH}_3$  inversion lines,  $\text{NH}_3(1,1)$ -(5,5), the  $\text{H}_2\text{O}$  61,6-52,3 maser line, two  $\text{CH}_3\text{OH}$  maser lines, and several other lines that trace higher density gas. We have analyzed the  $\text{NH}_3(1,1)$  and (2,2) data from the RAMPS pilot survey to create maps of the  $\text{NH}_3$  rotational temperature, the  $\text{NH}_3$  column density, the  $\text{NH}_3$  line width and velocity. We have also created a catalog of all  $\text{H}_2\text{O}$  masers detected in the pilot survey, which includes their positions and positional error, the velocity and brightness temperature of their peak channel, and whether the masers are associated with a star-forming region, an Asymptotic Giant Branch star, or an unknown environment. These data, as well as the data cubes and moment maps, are available at the RAMPS website (<http://sites.bu.edu/ramps/>).

**Author(s):** Andrew Walsh, Ian William Stephens, Toby Moore, Patricio Sanhueza, Robert Loughnane, Matthew Camarata, James M. Jackson, Jonathan Foster, Steven Longmore, James Di Francesco, D. Anish Roshi, J. Scott Whitaker, Jill Rathborneo, Taylor Hogge

**Institution(s):** National Astronomical Observatory of Japan, oCSIRO Astronomy and Space Science, Curtin University, Boston University, Center for Astrophysics, SOFIA, National Radio Astronomy Observatory, Yale Center for Astronomy and Astrophysics, University of Leed

**466.02 - Which Galactic dust map should I use? Insights from extragalactic tomography(Yi-Kuan Chiang)**

Extragalactic astronomy relies on the accurate estimation of source photometry corrected for Milky Way dust extinction. This has motivated the creation of a number of "Galactic" dust maps. We investigate whether these maps are contaminated by extragalactic signals using the so-called clustering redshift technique, i.e., by measuring a set of angular cross-correlations with spectroscopic galaxies and quasars as a function of redshift. Our tomographic analysis reveals imprints of extragalactic large-scale structure patterns in 9 (out of 10)

Galactic dust maps, including all infrared-based maps as well as ``stellar'' reddening maps. When such maps are used for extinction corrections, this extragalactic contamination introduces redshift- and scale-dependent biases in photometric estimates at the milli-magnitude level. It can affect both object-based analyses such as the estimation of the Hubble diagram with supernovae as well as spatial statistics. The bias can be appreciable when measuring angular correlation functions with low amplitudes such as lensing-induced correlations or angular correlations for sources distributed over a broad redshift range. As expected, we do not detect any extragalactic contamination for the dust map inferred from the distribution of HI from 21cm observations. Such a map provides an alternative to widely used infrared-based maps but relies on the assumption of a constant dust-to-gas ratio. We note that using the WISE 12 micron map sensitive to Polycyclic Aromatic Hydrocarbons (PAH), an indirect dust tracer, we detect the diffuse extragalactic PAH background up to  $z \sim 2$ . For precision cosmology experiments using optical photometry, we recommend to test the robustness of the final results against different dust maps used. Finally, we provide a procedure to correct for or decrease the level of biased magnitude corrections in maps with extragalactic imprints.

**Author(s):** Yi-Kuan Chiang, Brice Ménard,  
**Institution(s):** Johns Hopkins University, IPMU

#### 466.03 - Whipping IC63/IC59(Els Peeters)

The mid-IR spectra of photodissociation regions (PDRs) are dominated by the well-known emission features at 3.3, 6.2, 7.7, 11.3, and 12.7  $\mu\text{m}$ , generally attributed to polycyclic aromatic hydrocarbon molecules (PAHs). PAHs drive much of the physics and the chemistry in these PDRs, e.g. by heating the gas and as a catalyst in the formation of molecular hydrogen on their surfaces. Thus, PAHs and PDRs are intimately connected, and a complete knowledge of PDRs requires a good understanding of the properties of the PAH population and vice-versa, a complete knowledge of the PAH population requires a good understanding of the local physical conditions. IC63 and IC59 are a pair of cometary-shaped PDRs in the vicinity of the star  $\hat{1}^3$  Cas (also known as Tsih, "the Whip"). We use available data on both nebulae taken with Spitzer, Herschel and SOFIA to study the infrared emission at the tip of both clouds, and derive the intensity of the UV radiation field, the density and the gas temperature. We find that the PAH emission is very similar at the tip of both nebulae. Their PAH ratios are similar to those found in the more shielded regions of other nebulae. While in IC63 the intensity of the UV field,  $G_0$ , is a factor of  $\sim 10$  higher than in IC59, the density  $n$  at the tip of IC59 is lower than in IC63 by a similar factor. We derive  $G_0$  values significantly lower than reported in previous works. Comparison with other PDRs and known correlations support our claim that both IC63 and IC59 are low-UV irradiated environments. We conclude that the tips of IC63 and IC59 are about 3 and 5 times farther away from the star than their respective projected distances. The similarity of the MIR emission between the two nebulae is consistent not only with both objects being overdensities within the same region around

$\hat{1}^3$  Cas, but it is also consistent with the similar  $G_0/n$  ratio and ionization parameters, which altogether rule the evolution of the hydrogenation and ionization level of the emitting population of PAHs. Finally, regarding the kinematics of the material in IC59, we find evidence of photo-evaporation due to the incident radiation from  $\hat{1}^3$  Cas.

**Author(s):** Alexander G.G.M. Tielens, Heather Andrews, Yoko Okada, Els Peeters,

**Institution(s):** University of Western Ontario, Leiden Observatory, SETI Institute, Physikalisches Institut der Universität zu Köln

#### 466.04 - Disruption of the Orion Molecular Core 1 by the stellar wind of the massive star $\hat{1}_1$ Ori C (Alexander Tielens)

Mechanical and radiative energy input by massive stars stir up the environment, heat the gas, produce cloud & intercloud phases in the interstellar medium and disrupt molecular clouds, the birthsites of new stars. Ionization by UV photons, stellar wind action and supernova explosions control molecular clouds lifetimes. Theoretical studies predict that momentum injection by radiation dominates by far over momentum injected by a stellar wind, but this has hitherto been difficult to assess observationally. Velocity-resolved large-scale images in the fine structure line of ionized carbon ([CII]) provide an observational diagnostic of the radiative energetics and the dynamics of the ISM in the immediate vicinity of massive stars. Here, we present the [CII] 1.9 THz (158  $\mu\text{m}$ ) study of  $\sim 1$  square degree region ( $\sim 7\text{pc}$  in diameter) at a resolution of  $16''$  ( $0.03\text{pc}$ ) of the nearest region of massive star formation, Orion. The results reveal that the stellar wind originating from the star,  $\hat{1}_1$  Ori C, has created a  $\sim 2\text{pc}$  sized bubble by sweeping up a 2600  $M_{\text{sun}}$  shell expanding at 13 km/s. This shows that the stellar wind mechanical energy is coupled very efficiently to the molecular core and its action dominates over photo-ionization/evaporation or future supernova explosions.

**Author(s):** Cornelia Pabst, Alexander Tielens

**Institution(s):** Leiden University Contributing Team(s): C+Squad

#### 466.05 - Illuminating the Complex Environment of Outbursting Protostars with SPHERE Scattered Light Observations (David Principe)

FU Ori (FUor) and EX Lup (EXor) objects represent a short-lived stage of protostellar evolution characterized by intense mass accretion causing extreme variability in the form of outbursts. It is likely such rapid accretion events constitute the means by which most newborn stars gain their initial mass. However, the mechanism(s) causing such intense outbursts are poorly understood due in large part to their level of difficulty to observe in detail. We present SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch) optical and near-IR scattered light observations of several nearby outbursting

protostars which spatially resolve the circumstellar environment at radii  $> 10$  au. These images reveal complex morphological features in the dust surrounding these young stars which likely hint at their highly variable origins.

**Author(s):** Nicolas Cuello, Henning Avenhaus, Joel H Kastner, David Principe, Alice Zurlo, Lucas Cieza, Simon Casassus, Sebastian Perez, Zhaohuan Zhu

**Institution(s):** Massachusetts Institute of Technology, Max Planck Institute for Astronomy, Universidad Diego Portales, Pontificia Universidad Católica de Chile, Universidad de Chile, University of Nevada, Rochester Institute of Technology

#### **466.06 - Environmental Impact on the Presence of Star Formation in the Rings of Galaxies from ARRAKIS(Nicholas Duong)**

The presence of star formation (SF) in the rings of galaxies is currently thought to be independent from the effects of the surrounding environment. We use ARRAKIS (Atlas of Resonance Rings As Known In the S4G) and the 2MASS environmental catalog to examine this. ARRAKIS is a galaxy morphology catalog of nearby galaxies observed with Spitzer (up to a redshift of  $z=0.01$ ) and 2MASS provides environmental measures such as distance to 4th nearest neighbor (4NN), group membership, and size. We first cross-correlate the RA and DEC between the two catalogs so that the environmental parameters we obtain from 2MASS are accurate. If the ARRAKIS entry's RA and DEC are within 5 arcseconds of the RA and DEC in the 2MASS catalog, that is a successful cross-correlation. Out of 1324 entries listed in ARRAKIS, 1168 were successfully cross-correlated. Group mass and 4NN are our primary environmental parameters for this research. Out of 2MASS, the ARRAKIS entries' group masses appear to mainly lie within  $10^{12}$  to  $10^{14}$  solar masses and the distances to the 4NN mainly lie within 1 and 10 Mpc. We conducted a series of Kolmogorov-Smirnov (K-S) statistical tests on each subset with their respective parent set. We say that a p-value  $< 0.05$  is enough to reject the null hypothesis that the two samples come from the same distribution. From our K-S test on ARRAKIS with 2MASS, we find that they are not from the same distribution but this is not surprising due to the fact that 2MASS has 43533 entries while ARRAKIS (after cross-correlation) only has 1168. Also, it doesn't appear that the environment has an effect on the presence of outer/inner rings or bars/no bars. Furthermore, we tested where SF occurred in this environmental space. We find that SF rings seem to come from the same distribution as ARRAKIS. But SF does seem to occur slightly more often in central galaxies and barred galaxies. From two separate runs of our data, 33 of the 53 SF rings came from central galaxies and 40 of the 53 SF rings came from barred galaxies. However, with such a small sample size, our preliminary conclusion is that there is an extremely subtle, if any at all, environmental impact on the presence of SF in the rings of galaxies.

**Author(s):** Nicholas Duong, Benne Holwerda

**Institution(s):** University of Louisville

#### **466.07 - Dust dynamics on adaptive-mesh refinement grids.(Ugo Lebreuilly)**

The universe is essentially composed with gas and a small amount of dust. In the interstellar medium, the average dust-to-gas ratio has an estimated value of 1% and the distribution of dust grain sizes well approximated by a power law distribution. In denser medium, such as the molecular clouds or the protostellar cores, these properties could not be true because dust dynamics is particularly affected pressure and density gradients. Most of modern studies do not consider a possible variation of dust-to-gas in these objects supposing that dust is frozen in the gas, but it is not satisfactory if its dynamics shows a complex behaviour since dust plays an important role for their thermal evolution. For that reason, I introduce an algorithm that I implemented in the adaptive mesh refinement code RAMSES that allows to treat gas and dust mixture as a monofluid in the diffusion approximation. I present my algorithm with the usual tests for dust and gas mixtures and an application to protostellar collapse and disk evolution.

**Author(s):** Ugo Lebreuilly

**Institution(s):** Ecole normale supérieure de Lyon

Contributing Team(s): CRAL ens Lyon

#### **467 - The Solar System & Extrasolar Planets: Late Posters**

##### **467.01 - Ultima Thule: a prediction for bulk chemical composition and physical structure, just in time for the New Horizons encounter(Andrew J Prentice)**

The 2019\_01\_01 encounter of the New Horizons spacecraft with the cold classical Kuiper Belt object 2014 MU69 (alias Ultima Thule, hereafter MU69) provides a new test for the author's gas ring model of planetary origin (Prentice 1978, Moon Planets 19 341; 2015, 46th LPSC #2664; 2018, 50th DPS #113.03). This model proposes that the planets condensed from a concentric family of orbiting gas rings. The rings were shed by the protosolar cloud (PSC) as a means of ridding excess spin angular momentum during gravitational contraction. I propose that MU69 and proto-Pluto condensed from the outermost gas ring shed by the PSC at the same initial orbital distance as that of Quaoar, namely  $\sim 36$  AU. The temperature and mean orbit pressure of that ring are 26.3 K and  $1.27 \times 10^{-9}$  bar. The bulk chemical composition of the homogeneous condensate mix is nearly-dry rock (mass fraction 0.5269), graphite (0.0163), H<sub>2</sub>O ice (0.1845), CO<sub>2</sub> ice (0.2210) and CH<sub>4</sub> ice (0.0513). I assume that heat released by the decay of <sup>26</sup>Al causes all CH<sub>4</sub> ice to melt, rise up and then refreeze at the surface. As MU69 is so tiny, CO<sub>2</sub> ice can only sublime, unlike the situation for proto-Pluto where it forms a melt. I propose that  $\sim 60\%$  (by mass) of the CO<sub>2</sub> vapour escapes into space and  $\sim 40\%$  refreezes in the outer CH<sub>4</sub> shell. Melting of H<sub>2</sub>O ice allows the rock & graphite to form a core of mass fraction  $\sim 0.622$ . The predicted zero-porosity mean density of MU69 at 35 K is  $\sim 1.73$  g/cm<sup>3</sup>, irrespective of how much CO<sub>2</sub> is lost. MU69's surface should show signs of (1) early upward migration of liquid CH<sub>4</sub>, and (2) large-scale loss of the original store of CO<sub>2</sub> ice. Actions (1) & (2)



may completely obliterate the primordial surface, so rendering it globally smooth and crater free, regardless of whether MU69 is a single- or double-lobed body. If double-lobed, its waist profile should match the equipotential surface defined by local gravity and rotational forces, just as has been suggested for comet Hartley 2 (A'Hearn et al. 2015, Sci 332 1396). The ~60% loss of CO<sub>2</sub> results in a ~5% reduction in fractional radius of both lobes. Pure CH<sub>4</sub>-CO<sub>2</sub> ice makes up ~11% of the outer radius of each lobe. The top CH<sub>4</sub> is damaged by radiation, making MU69 appear dark. CO<sub>2</sub> remains prevalent.

**Author(s):** Andrew J Prentice

**Institution(s):** School of Physics & Astronomy, Monash University

#### **467.02 - Extracting cloud properties from Keck OSIRIS observations of Neptune(Heather G Bradley)**

Near-infrared wavelength observations of Neptune can be used to determine the properties of Neptune's clouds and provide insight into the underlying atmospheric motions. In particular, the near-infrared imaging spectrometer OSIRIS on the Keck II telescope on Mauna Kea provides a three-dimensional view (latitude, longitude, and wavelength) across Neptune, in both the H (1.47-1.80  $\mu$ m) and K (1.97-2.38  $\mu$ m) bands. We present projections of OSIRIS data onto a latitude and longitude grid, which allow us to view the cloud features that are on the same latitudes and visualize differences in the properties of these clouds. Because there was an hour between the data collection for H and K broad bands, factors such as planetary rotation and winds cause the position of clouds to change. This makes it difficult to correctly extract the spectrum for the same cloud from both bands and properly account for changes in viewing geometry. To address this challenge, we generate simulated cloud observations, test different methods of re-extracting spectra for the simulated clouds, and compare the retrieved cloud parameters to the input parameters. These simulations will allow us to determine the most effective way to extract a full (H+K) spectrum from the OSIRIS data, in order to understand how Neptune's clouds vary within and across latitudes. The implications for Neptune's global circulation will be discussed.

**Author(s):** MÃitÃ© ÃdÃimkovics, Katherine de Kleer, Statia Luszcz-Cook, Heidi Hammel, Heather G Bradley, Imke de Pater

**Institution(s):** Pennsylvania State University, American Museum of Natural History, Columbia University, Clemson University, California Institute of Technology, Association of Universities for Research in Astronomy, University of California, Berkeley

#### **467.03 - Mis-aligned Circumbinary Planets: A Two-Front Attack(Zhanbo Zhang)**

~10 circumbinary transiting planets (CBPs) have been discovered around eclipsing binaries (EBs), and for all of them, the planetary and binary orbits are well aligned. Are there any

mis-aligned CBPs? Although seemingly against the expectation from simple one-disk formation scenario, people have long raised the possibility that they may form and remain on stable orbits. However, no detection has been made so far. We have carried out two independent projects to attack this problem on two fronts: 1. With Subo Dong, Simon Albrecht, Tsevi Mazeh, Simchon Faigler et al., we look for transiting planets around non-eclipsing binaries. First, we identify binary hosts with significant Radial Velocity (RV) variations using repeated LAMOST spectroscopic observations in the Kepler field. Then we search for transits using Kepler light curves of ~300 such objects. We find one event with a single transit signal induced by a Saturn-size planet. The BEaming, Ellipsoidal and Reflecting (BEER) effects from the Kepler light curves and following-up RV observations with Nordic Optical Telescope confirm the binary nature of the host, which is composed of an F star (~1.8 M<sub>Sun</sub>) and an M dwarf (0.6 M<sub>Sun</sub>). Our discovery suggests that the occurrence rate of mis-aligned CBPs is likely ~10%, which is similar to that of the aligned CBP population. 2. With Daniel Fabrycky, another way was explored to detect misaligned CBPs using the Eclipsing Timing Variations (ETVs). We analyzed the ETVs of Kepler-34 system and found the primary-secondary eclipsing period divergence, the Eclipsing Duration Variations, as well as morphological features of the ETVs such as primary and secondary ETV amplitude ratios and phase shifts are good indicators that Kepler-34 is not on a polar orbit. We extended our simulation on grids of the system parameters and confirmed the features could all serve as planet inclination indicators. Analytically we explained all the phenomenal distinctions, and we expect our research to avail in detecting more misaligned CBPs in Kepler and TESS data without seeing their transits.

**Author(s):** Simon Albrecht, Daniel Fabrycky, Subo Dong, Zhanbo Zhang, Tsevi Mazeh, Simchon Faigler

**Institution(s):** The Department of Astronomy and Astrophysics, University of Chicago, School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Department of Physics and Astronomy, Aarhus University, The Kavli Institut

#### **467.04 - A Small Transiting Planet Discovered by Citizen Scientists(Geert Barentsen)**

The Kepler and K2 missions have provided the astronomical community with unprecedented amounts of data to search for transiting exoplanets and other astrophysical phenomena. Here, we present a low-mass binary system hosting a small transiting planet observed in K2 Campaign 4. The candidate was identified by citizen scientists using the Exoplanet Explorers project hosted on the Zooniverse. Follow-up observations and subsequent analyses validate the planet and indicate that it likely orbits the lower-mass companion star on a 31.34 day period. This orbit places it near the habitable zone of its host star. The planet resides in a system with a unique architecture and further follow-up may provide insight into its formation and evolution. Additionally, its estimated size straddles the observed gap in the planet radius distribution.

Planets of this size occur less frequently and may be in a transient phase of radius evolution. This planet is the third identified by citizen scientists using Exoplanet Explorers and its discovery exemplifies the value of citizen science in the era of Kepler, K2, and TESS.

**Author(s):** Geert Barentsen, Erik Petigura, Ian Crossfield, Makennah Bristow, Lauren Arnold, Molly Kosiarek, Joshua Schlieder, John Livingston, Jessie Christiansen, Grant Miller, Beverly Thackeray, Courtney Dressing, Erica Jasmine Gonzales, David Ciardi, Andrew Ho

**Institution(s):** University of California at Berkeley, Massachusetts Institute of Technology, University of Oxford, University of California, Santa Cruz, Moorpark College, Jet Propulsion Laboratory, California Institute of Technology, University of Maryland College

#### **467.05 - WFIRST: The strategies of muLAn Team for the Microlensing Data Challenge(Stela Ishitani Silva)**

The Wide Field Infrared Survey Telescope (WFIRST) is the top-priority large space mission of 2010 Astronomy and Astrophysics Decadal Survey. This is a wavefront controlled technology program and has three targeted science programs, which goals are to study the dark energy, to perform a statistical census of exoplanets with a microlensing survey, and to provide a guest observer program. The WFIRST microlensing survey will complement Kepler's discoveries of exoplanets. Previous data challenges (CoRoT analyses challenge, Extremely Precise Radial Velocities 3: Evidence Challenge, Exoplanet Data Challenge) were positively helpful for the demanding upgrade of analysis techniques due to the new generation of space telescopes. Therefore, the Microlensing Source resource center has organized a data challenge with synthetic datasets, whose goal is to identify the phenomenon causing the variability in each light-curve and to characterize the lensing systems, including exoplanetary systems. In this poster, I will present the methods I have developed and the result of the light-curve classification I have performed, as a member of the muLAn Team. I will also present the overall modeling strategy of the team by discussing shortly all the different stages of the analysis. It includes the light-curve fitting process of single-lens and planetary events, using the Microlensing Search Map (MiSMap), a new python library to find initial conditions to be used with the MICROLensing Analysis software (muLAn) to find the best-fit models and the error bars. This first data challenge enabled me to test several classification approaches and to learn how to model a microlensing event with an open-source modeling code.

**Author(s):** Stela Ishitani Silva, Yiannis Tsapras, Esther Euteneuer, Clement Ranc, Richard Barry, Arnaud Cassan

**Institution(s):** Catholic University of America, Universities Space Research Association, NASA Goddard Space Flight Center, Zentrum für Astronomie der Universität Heidelberg, Institut d'Astrophysique de Paris, Astronomisches Rechen-Institut

#### **467.06 - Follow-up Transit Photometry of K2 and TESS Exoplanet Candidates With a Rooftop, On-Campus 0.4-Meter Telescope(Loren Stephens)**

We present the results of an ongoing photometry campaign conducting follow-up observations of exoplanet candidates. We use a Meade 16-inch telescope, a cooled SBIG CCD, and an autoguider at the McConnell Rooftop Observatory at Smith College in Northampton, MA. For 12th-magnitude stars, we typically achieve light curves with RMS  $\sim 2$  mmag. Targets are observed through a 400-700 nm broadband filter at a 1 minute cadence. Whenever possible, we observe the complete duration of a transit plus a 1 hour baseline before and after the transit. Candidates are selected to have a transit depth of around 10 mmag, a host star magnitude between 10 and 13, a duration that is observable over the span of a night, and a period shorter than 30 days. For candidates from Kepler and K2, these criteria shortened the list of several hundred unconfirmed candidates to around 20 candidates for possible observation. We have been successful at evaluating K2 candidates by discriminating between true exoplanets and eclipsing binary stars based on the shape and depth of the resulting transit light curve. We are now fine-tuning our observing and analysis procedures in preparation for follow-up of TESS candidates. We have joined Science Group 1 in the TESS Follow-Up Observing Program and plan to observe TESS candidate exoplanets when northern TESS fields become available.

**Author(s):** Sally Robson, Lilia Pronin, Kerry Walker, James D. Lowenthal, Lilah Mercadante, Anne Peck, Olivia Cooper, Loren Stephens

**Institution(s):** Smith College Contributing Team(s): Smith College Exoplanet Transit Team

#### **467.07 - Pyramid Wavefront Sensing for Direct Imaging of Exoplanets(Richard Frazin)**

The scientific objective of direct imaging of exoplanets with GMT and TMT demands the highest performance possible from the adaptive optics (AO) system. Due to its high sensitivity and minimal aliasing, the pyramid wavefront sensor (PyWFS) has become the WFS of choice for many AO systems, including those planned for TMT and GMT. Obtaining the highest possible performance will require model-based estimation of the wavefront, since standard model-free implementations can only work in the linear regime, which requires degradation of the sensitivity of the PyWFS. Model-based estimation will allow treatment of nonlinearities, as well as the "island effect" and phasing of segmented mirrors.

**Author(s):** Richard Frazin

**Institution(s):** University of Michigan

#### **467.08 - Photometric performance of the MIT Quick Look Pipeline for the TESS full frame data(Lizhou Sha)**

MIT developed the Quick Look Pipeline (QLP) as a lightweight image reduction, planet search, and planet validation suite for the TESS (Transiting Exoplanet Survey Satellite) long-cadence full frame data, complementing NASA Ames's SPOC pipeline for the short-cadence sparse frame data. We perform a full reduction of the TESS full frame data from Sectors 1 and 2. To better understand the photometric characteristics and performance of the QLP, we compare the measured photometric scatter to the theoretical best-case predicted by Sullivan et al. (2015). We also present the full ensemble of known planets and new planet candidates detected by the QLP to showcase the scientific achievements of the TESS mission in its first two months of operation.

**Author(s):** Andrew Vanderburg, Lizhou Sha, Xu Huang

**Institution(s):** Massachusetts Institute of Technology, University of Texas at Austin

#### **467.09 - The Measured Impact of Chromatic Atmospheric Effects on Barycentric Corrections: Results from the EXPRES Exoplanet Search(Ryan Blackman)**

One source of error in high-precision radial velocity measurements of exoplanet host stars is caused by chromatic changes in Earth's atmospheric transmission during observations. The impact of this effect is that the photon-weighted barycentric correction should be applied as a function of wavelength across the stellar spectrum. We present results on the strength of this effect from the commissioning and early science periods of the EXtreme PREcision Spectrograph (EXPRES) exoplanet search, which amounts to over 1,000 observations and 700,000 individual low-resolution stellar spectra from an exposure meter spectrograph. We find that the standard deviation of the chromatic error in visible wavelengths is of order 10 cm/s, but depends on the distribution of absorption lines used in the cross-correlation mask, the nightly atmospheric conditions, and the observation lengths. This error is mitigated almost entirely by frequent flux sampling of the observed star with the low-resolution exposure meter spectrograph of EXPRES.

**Author(s):** Ryan Blackman, Joel Ong, Debra Fischer

**Institution(s):** Yale University

#### **467.10 - Volume-Limited Stellar Samples for TESS Exoplanet Demographics(Matthew Penny)**

Full-frame images captured at high cadence by TESS will enable millions of stars to be searched for transiting planets. TESS will therefore be a boon for exoplanet demographics studies, with an order of magnitude larger input sample than Kepler, and no human-induced bias in the target sample. Despite this, great care will still be necessary to assemble input stellar samples for demographic studies. Gaia parallaxes for all the stars TESS can

see enable the selection of highly complete volume-limited input stellar samples. However, I show that because the detectability of transits is a strong function of stellar and planet properties, volume limits must be selected extremely carefully in order to avoid biasing exoplanet demographic results.

**Author(s):** Matthew Penny

**Institution(s):** Ohio State University

#### **467.11 - X-ray, UV, Optical Irradiances and Age of Barnard's Star's new Super-earth Planet:-"Can Life Find a Way" on such cold Planet?(Edward Francis Guinan)**

Barnard's Star (GJ 699) is a dim old red dwarf M4 V star. At 6 LY it is the 2nd nearest star system. Until recently Barnard Star's claim to stardom is having the largest proper motion ( $\mu = 10.4''$  /yr). Adding to its fame, Ribas et al. (2018 Nature 563, 365) recently found that Barnard's Star hosts a super-Earth exoplanet (Mp sini = 3.2 Me). Barnard b has an orbital period of 233-d and semi-major axis of  $a = 0.40$  au- i.e. at the same distance of Mercury from the Sun. However Barnard's Star is very dim ( $L_{bol} = 0.0033L_{\odot}$ ) thus Barnard b with an irradiance (relative to the Earth) of  $S/Se \sim 0.020$  and thus it is cold (-170 C). So that there is little chance of liquid water and life on its frigid surface. Barnard's Star is a founding member of the Villanova Living with a Red Dwarf program (Engle & Guinan 2011, ASPCS 451) From photometry started in 2003 we determined a rotation period of  $Prot = 142 \pm 8$  days. Utilizing our Period-Age relation for red dwarfs (Engle & Guinan 2018 RNAAS 2, 34) indicates an age of  $8.5 \pm 0.9$  Ga. This gyro-chronological age agrees well with other age indicators that include large UVW space motions and low chromospheric Ca II HK and coronal X-ray emissions. From the available X-ray and UV data, we compute the X-ray and UV irradiances of the planet. All hope for life on Barnard b may not be lost. As a super-earth, if not too massive, Barnard b could have a large hot (iron?) core and possibly enhanced geothermal activity. Geothermal heating could support "life zones" under its surface. We note that the surface temperature on Jupiter's icy moon Europa is similar to Barnard b but because of tidal heating Europa probably has liquid oceans under its icy surface. However, if the actual mass of the Barnard b is much higher than  $\sim 5$  Me, its higher gravity could result in a thick H-He atmosphere and thus be a dwarf gas giant / mini-Neptune. The angular separation of the Barnard b from its star is  $\sim 220$  mas. Although very faint, it may be possible for the planet to be imaged by future very large telescopes. Such observations will shed light on the nature of the planet's atmosphere/surface and potential habitability. This research is supported by grants from NASA that we gratefully acknowledge.

**Author(s):** Ignasi Ribas, Edward Francis Guinan, Scott Engle

**Institution(s):** Villanova University, Institut de Ci ncies de l'Espai (ICE, CSIC),

#### **467.12 - K2 and Spitzer Joint Analysis of 4 Transiting Exoplanets(Alison Emily Duck)**

We present new Spitzer transit observations of four K2 transiting exoplanets: K2-36c, K2-79b, K2-167b, and K2-212b. We derive updated orbital ephemerides and radii for these planets based on a joint analysis of the Spitzer and K2 data. The EVEREST pipeline provided improved K2 photometry, by detrending instrumental noise and K2's pointing error. We used a pixel level decorrelation method to reduce instrumental noise in the Spitzer observations. The BATMAN transit model provided transit shapes that we fit to the data using a Markov Chain Monte Carlo (MCMC) method to find best fit transit times, transit depths, and precision on those parameters for each observation. We began by fitting the K2 and Spitzer observations separately. Those independent best fit parameters served as the priors for a simultaneous fit to the K2 and Spitzer observations using an MCMC to produce the final planet radii, orbital ephemerides, and error bars.

**Author(s):** Michael Werner, Caleb Harada, Ian Crossfield, Drake Deming, Alison Emily Duck, Ryan Morris, Edward Williams, Justin Harrell

**Institution(s):** University of Maryland, Massachusetts Institute of Technology, Jet Propulsion Laboratory

#### **467.13 - Exoplanet Mass Determination Using Transit Data Only: Machine Learning(Casey Kowalski)**

Current methods of determining exoplanet mass require radial velocity observations. However, the majority of the current exoplanet catalog has been initially detected photometrically (e.g., Kepler). This research investigates the presence of natural patterns in photometric transit data using machine learning techniques. A regression based approach uses feed-forward multi-layer neural networks to predict exoplanet mass as a function of known data available from transit observations. Results are compared with true radial velocity based mass measurements, with an average  $R^2$  value of -1.142 across a five-fold cross validation technique. Classification schemes are also implemented using the decision tree and k-nearest neighbor algorithms, with comparison of predictive capability between all techniques. For KNN classification, the highest accuracy value obtained was 36.8%. The decision tree classification algorithm was found to be 55.65% accurate. The data set we used was selected from the Exoplanet Orbit Database.

**Author(s):** Steven Novotny, Casey Kowalski, Samantha Howard, Devin J Della-Rose, Drew Gibson

**Institution(s):** USAFA

#### **467.14 - Exoplanet Mass Determination Using Transit Data Only: Analytic Equation Solutions(Jeneke Heerema)**

Determination of the mass of an extrasolar planet is a vital step towards understanding its basic properties. Currently, an

exoplanet's mass can be determined through analysis of combined transit and radial velocity measurements or transit data and transmission spectra (De Wit, 2013). As an extension of Seager and Mallén-Ornelas's 2003 method of determining numerous exoplanet system parameters through purely transit data, we examine possible methods of determining the mass of an exoplanet in a circular orbit using transit data alone. We present results for two such methods of determining exoplanetary mass: i) a back-substitution method using the full version of Kepler's Third Law, and ii) Newton's Method, a numerical method using a set of five nonlinear equations. The datasets used in both methods were constructed from the Exoplanet Orbit Database <exoplanets.org>.

**Author(s):** Jeneke Heerema, Devin J Della-Rose, Sequoia Chun

**Institution(s):** USAFA

#### **467.15 - Finding Exoplanets by Assessing the Dynamical Packing of Kepler Multi-Candidate Systems(Ana Humphrey)**

Barnes' and Raymond's Packed Planetary System (PPS) hypothesis postulates that planetary formation is efficient and creates dynamically-packed planetary systems that cannot contain additional planets. Here I look for unpacked spaces in Kepler multi-candidate systems that should, according to a PPS corollary, contain planets. In doing so, a "roadmap" was created to find potential unidentified planets. Previous research suggests that a system's dynamical packing can be quantified using the dynamical spacing  $\hat{I}$ : the number of mutual Hill radii between adjacent planets (a "planet pair"). Using previously proposed values for minimum  $\hat{I}$  (10, 12.3, and 21.7) required for planet pair orbital stability, I determine whether planet pairs in Kepler multi-candidate systems could host an intermediate body (an "unpacked pair"). For each Kepler unpacked pair, the maximum mass of an intermediate body that the pair could host while remaining in stable orbits ("mass capacity") and the semimajor axis at which this mass could be hosted were calculated. Next, the probable masses were determined. Known packed planet triplets were surveyed to determine the mass capacity each middle planet uses. It was found that 95% of middle planets have a semimajor axis that fall within a 12.45% semimajor axis deviation of the ideal semimajor axis. Furthermore, the results suggest that Kepler multicandidate systems have space for as many as 559 unidentified intermediate planets assuming a minimum  $\hat{I} = 12.3$ . Median mass efficiencies suggest that of these planets exist, 28% could be Earth or Super Earth-sized. If the unpacked pairs are due to missing planets as suggested by PPS, the predicted mass and semimajor axis for these potential planets may facilitate detection by characterizing expected transit and radial velocity signals. However, the large number of unpacked pairs might also be explained by variations of PPS (for example, systems that start packed and become unstable over time) or alternate system architecture hypotheses.

**Author(s):** Ana Humphrey

**Institution(s):** Student Researcher

#### **467.16 - Properties of Planets Formed in a Transitional Disk(Rory Bowens)**

Planets form in disks of gas and dust, known as protoplanetary disks, which are found orbiting young stars. Transitional disks are a type of protoplanetary disk that have large and deep central holes in the gas, possibly carved by young planets. The properties of these young planetary systems are set by the need to carve the gaps in the disk, which requires 3 to 6 Jupiter-like planets from 3 to 30 AU. We simulate long term evolution of these planetary systems for 10 billion years in order to compare their expected properties with that of observed radial-velocity exoplanets. We find that the systems that begin with 5 or 6 planets produce a range of eccentricities consistent with observed exoplanet systems. We found the overall stability of a system decreased with higher number of planets and increased in the presence of 2:1 mean motion resonances between the planets. We found that the 2:1 MMRs usually broke within several million years from the end of the gas disk phase or remained stable throughout the lifetime. Finally, the resemblance of eccentricity ranges between simulations that ejected several planets to observed exoplanet systems suggests that most real transitional disk systems may produce systems that lose planets during their lifetime. This research was funded by NASA XRP 80NSSC18K0355.

**Author(s):** Andrew Shannon, Rory Bowens, Rebekah Dawson,

**Institution(s):** Penn State Department of Astronomy and Astrophysics, Center for Exoplanets and Habitable Worlds

#### **468 - Late iPosters**

##### **468.01 - Chemical Abundances of M-dwarfs from the APOGEE Survey(Katia Cunha)**

We present a detailed study into the chemical make-up of the most numerous type of star in the Milky Way - the M-dwarfs. These low-mass, cool stars account for some 70% of the stars in our Galaxy, and interest in them has increased in the last decade due to the discovery of many small exoplanets, including a few very nearby Earth-sized exoplanets, orbiting such stars. Using the near-infrared (1.5--1.7 microns) APOGEE / SDSS-IV high-resolution spectrograph, we derived chemical abundances of 14 elements (C, O, Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Fe, and Ni) in 24 M-dwarfs, three of which are known to host small exoplanets (Kepler 138, Kepler 186, and Ross 128). The metallicity scale of the sample ranges from  $[\text{Fe}/\text{H}] \sim -1.00$  --  $+0.25$  dex. This study represents the most substantial multi-dimensional elemental abundance analysis of M dwarfs presented to date. Implications for galactic chemical evolution will be discussed.

**Author(s):** Johanna Teske, Olga Zamora, Anibal Garcia Hernandez, Verne Smith, Katia Cunha, Steve Majewskio, Suvrath Mahadevan, Carlos Allende Prietro, Ryan Terrien, Diogo Souto, Henrik Jonsson, Thomas Masseron, Kevin Covey  
**Institution(s):** oUniversity of Virginia, University of Arizona,

NOAO, Observatorio Nacional, Western Washington University, Carnegie Observatories, Pennsylvania State, Carleton College, Lund Observatory, IAC Contributing Team(s): APOGEE team

##### **468.02 - New X-ray observations of Hercules X-1 with AstroSat(Denis Leahy)**

The X-ray binary system Hercules X-1 has been observed by X-ray instruments on the AstroSat multiwavelength satellite. The 35-day phases of the observations were determined using Swift BAT monitoring. One AstroSat observation was taken during Low State and early Turn-On to Main High State. A second observations was taken during the peak of Main High State. X-ray lightcurves and spectra from the different system states are compared. The Main High spectrum shows a power-law continuum, a soft (0.1 keV) black-body component, a 1 keV emission broad line feature and a 6.5 keV iron emission line. The parameters of these components are consistent with previous Main High broad-band X-ray spectral observations. In Main High State, evidence is found, in the spectrum, for a new feature: a highly-ionized absorber. This is consistent with the recently-detected corona in Her X-1. Comparing different X-ray states of Hercules X-1, the strengths of the spectral components varies greatly. This is consistent with previous multi-state studies, such as carried out by RXTE. The physical origin of the spectrum variations is discussed in terms of the precessing accretion disk in the binary system.

**Author(s):** Yuyang Chen, Denis Leahy

**Institution(s):** University of Calgary

##### **468.03 - Wind accretion in high mass X-ray binaries: stability and disk formation(Wenrui Xu)**

The neutron star (NS) in a high mass X-ray binary (HMXB) commonly accretes from the stellar wind of its companion. Observations suggest that the accretion flow around some sources (e.g. OAO 1657-415) should be highly structured, which may indicate the existence of accretion disks. The NS accretion flow in a HMXB can be simplified as a Bondi-Hoyle-Lyttleton (BHL) accretion flow with imposed transverse upstream gradient. We use 2D axisymmetric and 3D simulations to investigate the problem of BHL accretion with and without upstream gradient, focusing on the regime of high (upstream) Mach number, small accretor size and weak upstream gradient, which is relevant to many observed HMXB systems but has not been explored with simulations before. When there is no upstream gradient, we find the accretion flow to be always stable. However, when the upstream gradient is small but nonzero, the flow is significantly more prone to instability than previously expected. For small accretor size, the unstable flow is highly turbulent, reducing accretion rate and preventing disk formation. The instability we observe is different from the "flip-flop" instability of 2D planar BHL accretion, and the physical origin of the instability is discussed. We also investigate the

contribution of orbital effects not captured in the BHL model (e.g. Coriolis force), and find that they tend to increase stability. Comparing our results with previous studies, we discuss the stability of the flow and the possibility of disk formation in different regimes of the parameter space. In general, a highly structured flow can develop when the upstream gradient is sufficiently large, but forming an accretion disk is difficult.

**Author(s):** James Stone, Wenrui Xu

**Institution(s):** Princeton University

#### **468.04 - Characterizing the sensitivity of realfast at the Very Large Array to fast radio bursts(Sabrina Berger)**

realfast is a real-time commensal Fast Radio Burst (FRB) instrument on the Very Large Array (VLA) telescope in Socorro, New Mexico. FRBs are powerful millisecond radio bursts of extragalactic origin. We need to discover more FRBs to better understand their origins and how they enable us to probe the universe. The VLA is an ideal instrument to look for FRBs because it can localize and detect faint radio transients. The pipeline uses millisecond visibility data to dedisperse and generate 100 million images per hour. We use simulated data to test the FRB search pipeline and characterize its sensitivity and completeness. We vary mock transient parameters such as dispersion measure, galactic coordinates, and SNR and inject these simulated transients into the pipeline. We hope to validate the pipeline is working as expected and constrain a limit on the rate of FRB detections given system sensitivities to ensure thousands of hours of successful commensal observing at the VLA.

**Author(s):** Casey Law, Sabrina Berger

**Institution(s):** UC Berkeley

#### **468.05 - 3D Optical Spectroscopic Study of NGC3344 with SITELLE: I. Identification and Confirmation of Supernova Remnants(Daniel Devost)**

In this poster, we present a SITELLE optical identification and confirmation of a large sample of Supernova Remnants (SNR) candidates in the nearby spiral galaxy NGC 3344 and its impact on the measurement of the Star Formation Rate (SFR). SITELLE, the imaging Fourier transform spectrograph of the Canada-France-Hawaii Telescope (CFHT), provides spectroscopic capabilities in the visible (350 to 900 nm, with filters) with a large field of view (11'x11'), complete spectral coverage, and a high spatial resolution (0.32" limited by the seeing), which are ideal to cover the whole disk of NGC 3344. Using 3 filters, we measured the strong emission lines [OII]  $\lambda$  3727, H $\beta$ , [OIII]  $\lambda$  4959, 5007, H $\gamma$ , [NII]  $\lambda$  6548, 6583, and [SII]  $\lambda$  6717, 6731. A sample of SNR candidates have been identified based on the emission line criteria [SII]/H $\beta$  > 0.4. The whole set of emission lines have been used to describe the SNR properties and to confirm the shock-excited nature of these sources. We find that the contribution of the SNRs flux to the total H $\beta$  flux is ~8 %. This

contribution decreases the global SFR estimated in NGC 3344 from 0.148 to 0.126  $M_{\odot} \text{ yr}^{-1}$ .

**Author(s):** Phillipe Amram, René Pierre Martin, Laurent Drissen, Thomas Martin, Ismaël Moumen, Carmelle Robert, Daniel Devost

**Institution(s):** Canada-France-Hawaii Telescope, University of Hawaii, Université Laval, Laboratoire Astrophysique de Marseille

#### **468.06 - Poseidon: A relativistic gravity solver for core collapse supernova simulations(James Nick Roberts)**

The Conformally Flat Approximation (CFA) to the 3+1 formalism of General Relativity reduces the complexity of the Einstein equations by placing constraints on the dynamic degrees of freedom and restricting the spatial metric to be conformally flat. This results in a system of non-linear elliptic equations, describing the metric variables; the conformal factor,  $\tilde{\gamma}$ ; the lapse function,  $\tilde{\alpha}$ ; and the shift vector,  $\tilde{\beta}^i$ . The CFA is an exact representation of General Relativity in spherically symmetric spacetimes and in tests comparing CFA to full General Relativity, it has been shown to be very accurate for axisymmetric rotating neutron stars and gravitational core collapse of supernovas. Solving elliptic equations requires approximating continuous differential equations in a discrete form, and specifying appropriate boundary conditions. The Poseidon code solves the CFA system of equations on a spherical polar grid using a mixed spectral/finite element method. The CFA equations are decomposed angularly using spherical harmonic functions, resulting in a system of radial differential equations. These are discretized using the continuous finite element method, resulting in a nonlinear system of equations that is then solved using a Newton-Raphson scheme. This combination of methods gives the user access to several parameters with which they can control the degree to which the solution is approximated. Poseidon is being developed to run within the CHIMERA core collapse supernova (CCSN) simulation code. Therefore, it has been designed to run on shared and distributed memory systems. This is achieved using MPI and OpenMP directives to parallelize the creation of the linear system, which is then solved distributively using the PETSc library. Results will be presented showing comparisons between Poseidon's CFA treatment and the so called "effective" potential currently used in CHIMERA, which is a modified Newtonian potential whose monopole moment is corrected using the Tolman-Oppenheimer-Volkoff (TOV) potential. Additionally, the performance characteristics of the Poseidon code will be presented.

**Author(s):** James Nick Roberts, Eric Lentz, Anthony Mezzacappa, Eirik Endeve,

**Institution(s):** Department of Physics and Astronomy, Univ of Tennessee, Knoxville, Oak Ridge National Laboratory

## 468.07 - HST Imaging of Globular Cluster System of the Virgo Cluster Ultra-Diffuse Galaxy VLSB-B(Yunhao Zhang)

Ultra-diffuse galaxies (UDGs) are low surface brightness galaxies that appear to be outliers in traditional galaxy scaling relations, with low stellar masses similar to quenched dwarf galaxies, but sizes comparable to more massive galaxies. The extremely high total mass to light ratio of some UDGs suggest that they could be “failed galaxies” that have been extremely inefficient in their star formation, and thus extremely dark matter dominated. The galaxy VLSB-B in the nearby Virgo cluster as one of the lowest surface brightness UDGs, with central surface brightness of  $\hat{I}_{1/4V,0}=26.7$  mag/arcsec<sup>2</sup>, and it also has a high specific frequency of globular clusters (GCs). We have used HST/WFC3 to image VLSB-B and spatially resolve its globular clusters (GCs), eliminating contamination from foreground stars. Based on this clean GC catalog, we will present the full GC luminosity function and size distribution of this unique UDG. Coupled with our ground-based spectroscopy, we will also present a clean measurement of the VLSB-B dynamical mass. This research is funded in part by NASA/STScI. Yunhao Zhang’s visiting scholarship at University of California Santa Cruz is sponsored by the China Scholarship Council.

**Author(s):** Patrick R. Durrell, Elisa Toloba, Yunhao Zhang, Sungsoon Lim, Puragra Guhathakurta, Christopher Mihos, Patrick CÃ´t , Eric W. Peng, Laura Sales

**Institution(s):** University of California, Santa Cruz, Kavli Institute of Astronomy and Astrophysics, Peking University, National Research Council of Canada, University of the Pacific, University of California Riverside, Youngstown State University, Case Western R

## 468.08 - Dynamics of Merging Galaxy Clusters: What Can Simulated Analogs Tell Us?(David Wittman)

Post-pericenter mergers of galaxy clusters may provide a unique window into the behavior of dark matter by acting as "dark matter colliders." Mergers may also play a role in the evolution of cluster member galaxies and other astrophysical processes such as cosmic ray acceleration. To quantify these connections, we need reliable estimates of the basic dynamics of each observed merger: the time since pericenter, the maximum relative speed of the merging subclusters, pericenter distance, the merger phase (outbound vs returning for second pericenter), and the viewing angle (which is critical for determining the 3-d velocity and separation today, given that we measure only line-of-sight velocities and projected separations). We describe a new technique: finding analog systems in cosmological n-body simulations and extracting these parameters from the simulation. This eliminates many of the approximations used in the classic "timing argument" approach for estimating these parameters: assuming purely radial trajectories, assuming a specific mass profile or even point masses, neglecting substructure and surrounding large-scale structure, etc. We find analogs for 10 observed systems

and show that we can distinguish between old and young systems, fast and slow, outbound and returning.

**Author(s):** David Wittman

**Institution(s):** UC Davis

## 468.09 - Northern Galactic Calibration of the Red Giant Branch Tip(Jeremy Mould)

Indications from the Gaia data release 2 (DR2) are that the tip of the red giant branch (TRGB, a population II standard candle related to the helium flash in low mass stars) is close to  $-4$  in absolute I magnitude on the Cousins photometric system. Our first sample was high latitude southern stars from the thick disk and inner halo with SkyMapper photometry, and our result was consistent with longstanding findings from globular clusters, whose distances were calibrated with RR Lyrae stars. The way forward in this work isâ—□ detailed simulations of parallax uncertainty luminosity biasâ—□ adding PanSTARRS photometry of high northern latitudesâ—□ reducing the uncertainty in parallaxes and the parallax offset in future Gaia data releases (of which the next DR3, is currently scheduled for early 2021)â—□ extending the wavelength range through infrared photometry of stars with  $M_I < -3.8$  mag. Here we present the northern galactic latitude color magnitude diagram. Its TRGB is consistent with our published southern latitude data. As the Gaia mission proceeds (with a recently approved extension to end of 2020 and a further indicative extension for up to end of 2022), there is every reason to think that an accurate Galactic geometric calibration of the TRGB will be a significant outcome.

**Author(s):** Gisella Clementini, Gary Da Costa, Jeremy Mould

**Institution(s):** Swinburne University, RSAA, ANU, INAF, Osservatorio di Astrofisica e Scienza dello Spazio

## 468.10 - PhoSim: A Comprehensive Observational Simulation Tool for Precision Astronomy(John Peterson)

We describe the Photon Simulator (PhoSim), an ab initio physics-based simulation tool for use in precision astronomy. PhoSim follows the trajectory of photons from astronomical objects and through the atmosphere, telescope, sensor, and readout systems. We employ photon and electron physics for all interactions, and use the relevant hydrodynamic solutions for the atmosphere, elasticity theory for the deformation of optics, and electrostatics for the electric field in the sensor. The result is simulated astronomical images with unprecedented detail that can be analyzed in parallel with real observations. This can be used for a variety of applications that involve precision astrometry, precision photometry, or precision PSF characterization. We describe a number of current and future telescopes that have been implemented. PhoSim is multi-threaded numerically efficient code, and large images can be generated in minutes. We also have recently implemented a graphical user interface. New versions of PhoSim are released

periodically and are publicly available.

**Author(s):** Garrett Jernigan, Caleb Remocaldo, John Peterson, Anirban Dutta, Glenn Sembroski, Colin Burke  
**Institution(s):** Purdue University, Eureka Scientific

#### **468.11 - Stability of Nitrogen in Exoplanetary Atmospheres in Contact with Liquid Water(Héctor Emanuel Delgado DÃ-az)**

Kepler, K2, and ground-based telescopes have detected around 3,750 exoplanets of which about 10 are temperate and rocky, making them potential candidates for further studies on habitability. An important gas that maintains habitability is nitrogen N<sub>2</sub>; it is one of the common building blocks of planetary atmosphere, and it is a greenhouse gas that maintains a planet's temperature above the freezing point of water. The main sink of nitrogen in the atmosphere is the production of NO from lightning; furthermore, NO drives synthesis of HNO<sub>2</sub>, HNO<sub>3</sub>, and HNO<sub>4</sub> in the atmosphere. If bodies of liquid water (e.g. oceans) are present, these nitrogen-bearing species would be sequestered due to their high solubility and depleted from the atmosphere. Therefore, it is important to study the efficiency of the conversion from N<sub>2</sub> to soluble nitrogen species which can represent a limit to the lifetime of nitrogen in the atmosphere. Using EPACRIS, an advanced atmospheric chemistry and radiative transfer code, we determine the lifetimes of N<sub>2</sub> in N<sub>2</sub>-CO<sub>2</sub> atmospheres by varying the flux of NO produced by lightning by three orders of magnitude based on Earth's NO flux. We study an Earth-sized exoplanet with a 1-bar N<sub>2</sub>-dominated atmosphere, a CO<sub>2</sub> mixing ratio of 5%, and in the habitable zone of an M dwarf star and a Sun-like star. Results for the M dwarf star's planet show a non-linear behavior of nitrogen lifetime when changing the NO flux: it decreases non-linearly up to a minimum followed by a slow increase for an increasing NO flux, with a minimum lifetime reached at the Earth-like NO flux. In other words, a higher lightning rate does not drive faster deposition of soluble nitrogen species. The minimum lifetime found in this study is >1 billion years, indicating that the N<sub>2</sub> in an N<sub>2</sub>-CO<sub>2</sub> atmosphere on terrestrial exoplanets is kinetically stable over geologically long periods of time.

**Author(s):** Héctor Emanuel Delgado DÃ-az, Renyu Hu  
**Institution(s):** California State University Los Angeles, Jet Propulsion Laboratory

#### **468.12 - Astronomy Education With Puerto Rico: Restoring Education Capacity After Hurricane Maria(Joanne D Hughes)**

Astronomy Education with Puerto Rico is a new non-profit, organized by astronomy educators to restore astronomy education capacity in Puerto Rico after Hurricane Maria. Partnered with the Puerto Rico Astronomy Society (PRAS), we have identified 2 specific immediate projects: refurbishment of the Ferre Planetarium projection equipment, and the

completion of the Greg Garcia Optical Observatory (GGOO) at Ana Mendez University. The time is now appropriate to fundraise for these, as more crucial infrastructure problems are mostly addressed, and the US mainland response to the devastation wrought by Maria is under renewed scrutiny. The Ferre planetarium was the only public planetarium in Puerto Rico (population 4 million), and in the month before Maria, hosted, with PRAS, a solar eclipse viewing event that drew 1000 participants. In that same month, the planetarium enjoyed ticket sales of over \$180,000. It has been out of operation since that time. The GGOO was in planning stages before Maria, but it was impossible to advance in the year afterwards, as basic services were being restored. An excellent site has been identified in partnership with Ana Mendez University staff, and much equipment lies in storage awaiting the construction of a small building. PRAS anticipates the observatory, the first and only of its kind in Puerto Rico, will become the focal site of much of their outreach work in San Juan, the 35th largest metropolitan area in the US.

**Author(s):** Gabriella Gutierrez y Muhs, Eric Muhs, Joanne D Hughes

**Institution(s):** Seattle University, IceCube Neutrino Observatory, University of Wisconsin-Madison, PolarTREC