National Aeronautics and Space Administration

NASA Space Science and Astrobiology

Fifth Annual Jamboree
March 7, 2017

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Welcome to the Fifth Annual Ames Space Sciences and Astrobiology Jamboree!

The Space Science and Astrobiology Division at NASA Ames Research Center consists of over 60 civil servants and more than 120 contractors, co-ops, post-docs, visiting scientists, and associates. Researchers in the division are pursuing investigations in a variety of fields including exoplanets, planetary science, astrobiology and astrophysics. In addition, division personnel support a wide variety of NASA missions including (but not limited to) Kepler, K2, SOFIA, JWST, and New Horizons. With such a wide variety of interesting research going on, distributed among three branches in at least 5 different buildings, it can be difficult to stay abreast of what one's fellow researchers are doing. Our goal in organizing this symposium is to facilitate communication and collaboration among the scientists within the division, and to give center management and other ARC researchers and engineers an opportunity to see what scientific research and science mission work is being done in the division.

We are also continuing the tradition within the Space Science and Astrobiology Division to honor one senior and one early career scientist with the Pollack Lecture and the Early Career Lecture, respectively. With the Pollack Lecture, our intent is to select a senior researcher who has made significant contributions to any area of research within the space sciences, and we are pleased to honor Dr. Robert Haberle this year. With the Early Career Lecture, our intent is to select a young researcher within the division who, by their published scientific papers, shows great promise for the future in any area of space science research, and we are pleased to honor Dr. Thomas Bristow this year.

We hope you can take advantage of the day to learn something new and meet some new faces!

Sincerely,

Science Organizing Committee

Tim Lee
Steve Howell
Mark Fonda
Jeff Hollingsworth
Chris Dateo

FIFTH ANNUAL SPACE SCIENCES JAMBOREE MARCH 7, 2017	
8:00 am	Registration & Poster Setup
Session Chair: Tim Lee	
8:30 am	Welcome & Announcements
8:45 am	***Outstanding Early Career Space Scientist Lecture:*** Tom Bristow: Mineralogy and Models of Ancient Mars
9:45 am	Christopher Burke: Terrestrial Planet Occurrence Rates From The Final Kepler Pipeline Search
10:05 am	Kathryn Bywaters: IN SITU Life Detection and Characterization using Nanopore Sequencing in the Hyper Arid Region of the Atacama Desert, Chile
10:25 am	Poster Session (odd number posters) & Coffee Break
Session Chair: Steve Howell	
11:10 am	Anthony Colaprete: Resource Prospector: An Update on the Lunar Volatiles Prospecting and ISRU Demonstration Mission
11:30 am	Cristina Dalle Ore: Ices on Charon: Distribution of H2O and NH3 from New Horizons LEISA Observations
11:50 am	Craig Everroad: Fine-scale niche partitioning and cooperation in co-existing cyanobacteria may promote systems-level fitness across environmental conditions
12:10 pm	Poster Session / Lunch
Session Chair: Chris Dateo	
1:15 pm	Mark Marley: Preparing for the Next Decade of Exoplanet Discovery and Characterization
1:35 pm	Milena Popovich: Modularity and Evolution of RNA Function
1:55 pm	Richard Quinn: Microfluidic Approaches to Searching for Extant Life
2:15 pm	Nasseem Rangwala: SOFIA/EXES 13 Micron High Spectral Resolution Observations of Orion IRc2
2:35 pm	Lynn Rothschild: Stanford-Brown iGEM 2016: Bioballoon
2:55 pm	Poster Session (even number posters) & Coffee Break
Session Chair: Jeff Hollingsworth	
3:40 pm	Andrew Rushby: Long Term Planetary Habitability and the Carbonate-Silicate Cycle
4:00 pm	David Wilson: Catching Life from the Icy Ocean World Plumes: Applications to Europa & Enceladus
4:20 pm	***Pollack Lecture:*** Bob Haberle: The Early Mars Climate System
5:20 pm	Remove Posters

ID	Title	Corresponding Author
Astrobiology Posters		
AB.1	Biological Production of a Novel Polymer for Space Industry	Nils Averesch
AB.2	Methane at the Aqua De Ney Hyperalkaline Spring (N. California USA), A Site of Active Serpentinization	Jennifer Blank
AB.3	Life Detection in Briny Environments: Mitigating False Negatives	Rosalba Bonaccorsi
AB.4	A Continuous Production of Fragile Proto-Metabolites in the Early Solar System: Evidence from Carbonaceous Chondrites?	Andro Rios & George Cooper
AB.5	The Lassen Astrobiology Intern Program	Dave Des Marais
AB.6	Direct observation of coevolution at the RNA-protein interface	Mark Ditzler
AB.7	Volumetric Distinction Between Gully Types on Mars; Volatile Implications	Natalie Glines
AB.8	Determining The Magnitude and Duration of Potentially Habitable Aqueous Environments on Mars	Ginny Gulick
AB.9	Building a Biosignature Imaging, Spectral and Thin Section Library to Support Upcoming Mars Surface Missions	Ginny Gulick
AB.10	Navua Valles – Hadriacus Mons – Ausonia Montes: Channels, Paleolakes, Knobby Terrains and Mound Fields	Henrick Hargitai
AB.11	Biosignatures in the Context of Low Energy Flux	Tori Hoehler
AB.12	Eukaryotic Sterol Biomarkers: Production and Fate in a Laminated Microbial Mat	Linda Jahnke
AB.13	Production and Preservation of Lipid Biomarkers by Iron-Oxidizing Chemolithotrophs in Circumneutral Iron Deposits	Taylor Kelly
AB.14	Data Sharing In Astrobiology: The Astrobiology Habitable Environments Database (AHED) and the Chemin Database	Barbara Lafuente
AB.15	The Formation Of Nucleobases from the Irradiation of Astrophysical Ices	Christopher Materese
AB.16	Rock Sample Analysis and Raman Spectroscopy in the Development of Automatic Classifiers	Paige Morkner
AB.17	Sugars and Sugar Derivatives in Residues Produced from the UV Irradiation of Astrophysical Ice Analogs	Michel Nuevo
AB.18	Powercell 2° Payload on Eucropis: A Cyanobacterial Fuel Source for In Situ Biological Production	Ivan Paulino-Lima
AB.19	Influence of Galactic arm scale dynamic on the molecular composition of dense clouds	Maxime Ruaud
AB.20	Ocean Biomolecule Explorer for Astrobiology	Heather Smith
AB.21	The University Rover Challenge: An international rover competiton under simulated Mars Operational Conditions	Heather Smith
AB.22	The Icebreaker Life Mission Plan	Carol Stoker
AB.23	Mid-IR Spectroscopy of Perchlorates	David Summers
AB.24	Ionizing Radiation in the Subsurfaces of Enceladus and Europa: Implications for the Search for Evidence of Life	Luis Teodoro
AB.25	Mars Drill Bio-barrier Study: Design and Surface Coatings	Seamus Thomson

AB.26	Critical Assessment of Biosignature Detection with Raman Spectroscopy on Biologically Lean Soils	Mary Beth Wilhelm
AB.27	Development of a new chiral-sensitive photothermal microscope: Towards a search for biosignatures in extraterrestrial environments	Hiroharu Yui
AB.28	Gully Distribution and the Analysis of Two Gullies in Hale Crater, Mars Using HiRise DTMs	Sean Corrigan
AB.29	Geomorphic Analysis of Integrated Gully Systems on Mars	Ginny Gulick
Astrophysics Posters		
AP.1	Photochemistry of the PAHs Coronene and Ovalene in Cosmic Water Ice	Ana Lucia Ferreria de Barros
AP.2	Nucleobase Synthesis via UV-induced Oxidation of their Precursors in Astrophysical Ices: A Quantum Chemical Perspective	Partha Bera
AP.3	Polycyclic Aromatic Hydrocarbon Charge and Size Across a Reflection Nebula, H II-region and Planetary Nebul	Christiaan Boresma
AP.4	Laboratory Approach to Astrophysical Catalysis and the Interaction of Cosmic Ray and UV Photons with IVA	Gustavo Cruz Diaz
AP.5	The Anharmonic Quartic Force Field Infrared Spectra of Five Non Linear Polycyclic Aromatic Hydrocarbons: Benz[a]anthracene, Chrysene, Phenanthrene, Pyrene, and Triphenylene	Tim Lee
AP.6	Molecular Identification Tool for High-Resolution Astronomical Line Surveys	Naseem Rangwala
AP.7	Spectroscopy of Cryogenic Thin Films Containing PAHs: PAH Clusters, Binary PAH Mixtures, and the Effect of Water Ice	Joseph Roser
AP.8	Recent Progress in Laboratory Astrophysics achieved with the COSmIC Facility	Farid Salama
AP.9	Opacities and Turbulence in Cold Planet Forming Accretion Disks	Orkan Umurhan
AP.10	UV-Visible Spectroscopy of PAHs and PANHs in Supersonic Jet	Salma Bejaoui
AP.11	IR Intensity Prediction of CO2 Isotopologues: New Ames Line Lists vs. Existing Databases	Xinchuan Huang
Exoplanet Posters		
EP.1	Creating the Final Kepler Catalog for an Accurate Exoplanet Census	Susan Elizabeth Mullally
EP.2	Reaching the Diffraction Limit: High-Resolution Imaging for Exoplanet & Stellar Studies	Steve Howell
EP.3	Global Surface Photosynthetic Biosignatures of Anoxic Biospheres	Niki Parenteau
EP.4	Direct Imaging of Circumstellar Dust and Debris Environments with EXCEDE	Dan Sirbu
Planetary Atmosphere and Climate		
PA.1	The Impact of Planetary-Scale Waves Upon Venus' Thermal Structure In The Thermosphere Based Upon VTGCM Simulations	Amanda Brecht

PA.2	Effects of radiatively active clouds on wind stress dust lifting during Northern Hemisphere Summer on Mars	Vandana Jha
PA.3	The South Residual CO2 Cap on Mars: Investigations with a Mars Global Climate Model	Melinda Kahre
PA.4	The Antarctic analogy for ancient lakes at Gale Crater, Mars	Alexandre Kling
PA.5	The Mars AutoRotating Science StationS (MARS3)	Alexandre Kling
PA.6	Temperature-Dependent Radiative Transfer Modeling of Martian Water Ice Clouds	Delia Santiago-Materese
PA.7	Significance of topography-driven vertical transport on the global water cycle on Mars	Richard Urata
PA.8	Investigating Titan's Atmospheric Chemistry with the Titan Haze Simulation Experiment	Ella Sciamma-O' Brien
PA.9	Modeling N2/CH4 Plasma Chemistry in the Titan Haze Simulation Experiment	Alexander Raymond
PA.10	Synoptic Traveling Weather Systems on Mars: Effects of Radiatively-Active Water Ice Clouds	Jeff Hollingsworth
Planetary Surfaces & Interiors		
PS.1	Testing A Sample Delivery System for Planetary Surface Missions	Elliot Steel
PS.2	Adhesion, and Adfreezing of Sticky Mars Dirt to Various Scoop Materials	David Wilson
PS.3	A Framework for Inferring Taxonomic Class of Asteroids	Jessie Dotson
PS.4	The Ames Vertical Gun Range	John Karcz
PS.5	Fluid Flow and Tholin Transport on Pluto, an Analysis of New Horizons Data	Dale Cruikshank
PS.6	Resource Prospector Landing Site and Traverse Plan Development	Richard Elphic
PS.7	Advanced Optical Characterization of Simulated Complex Organic Matter for Solar System Objects and Beyond	Hiroshi Imanaka
PS.8	Science Return of a Hydrophone On-Board an Ocean World Lander	Heather Smith
PS.9	Low Velocity Impacts on Phobos	Heather Smith
PS.10	Urban Biomining: Biological Extraction of Metals and Materials from Electronics Waste Using a Synthetic Biology Approach	Jessica Urbina-Nvarrete

Outstanding Early Career Space Science Lecture

Mineralogy and Models of Ancient Mars

Thomas. F. Bristow

The mineralogy of sedimentary rocks provides a record of aqueous interactions that can span billions of years in a single sample. Minerals may preserve information ranging from their original near-surface depositional environments to subsequent overprinting during burial, diagenesis and hydrothermal activity. Recovery of mineralogical signatures of ancient near-surface conditions are particularly valued as markers of the evolution of planetary surfaces and indicators of habitable environments. These primary signatures have the potential to constrain and track broad changes in planetary redox state, atmospheric composition, ocean chemistry and climate conditions through time. At smaller scales, mineral derived bounds on local chemical conditions give indications of potential chemical energy sources for organisms, while specific minerals and mineral species diversity as a whole are proposed as biosignatures.

In this talk I will discuss approaches to paleoenvironmental interpretation of sedimentary minerals with a focus on inferring conditions on Hesperian Mars. This work draws on recent findings of the Mars Science Laboratory from Gale Crater examined in the context of Earth-based analogue studies. The emerging picture from Gale Crater is of a dynamic, long-lived, Hesperian lake and river system that had the potential to host life. However, Gale lake sediments also indicate low atmospheric carbon dioxide levels, deepening the puzzle of the lakes very existence, a topic Bob Haberle will explore more fully in the Pollack Lecture.

TITLE: **Terrestrial Planet Occurrence Rates From The Final Kepler Pipeline Search**

AUTHORS: **Christopher J. Burke**, Jessie Christiansen, Joseph Catanzarite, Susan E. Thompson, Jeffrey L. Coughlin, Fergal Mullally, Jie Lie, Bruce Clarke, Kelsey Hoffman, Steve Bryson, Michael Haas, Natalie Batalha, Christian Clanton, Geert Barentsen, & Jason Rowe

ABSTRACT:
I discuss latest results in measuring terrestrial planet occurrence rates using the planet candidates discovered by the Kepler pipeline. The final Kepler pipeline search results are publicly available, and the automated planet candidate assessments which are critical for an accurate measurement of habitable zone planet population statistics are underway. I discuss how to go from the biased set of Kepler planet candidate discoveries to measuring the underlying planet population. The Kepler data points to a sharp contrast between the planets hosted by G and M dwarfs with potential implications for understanding the planet formation process and providing guidance for planning future NASA missions to directly image Earth analogues.

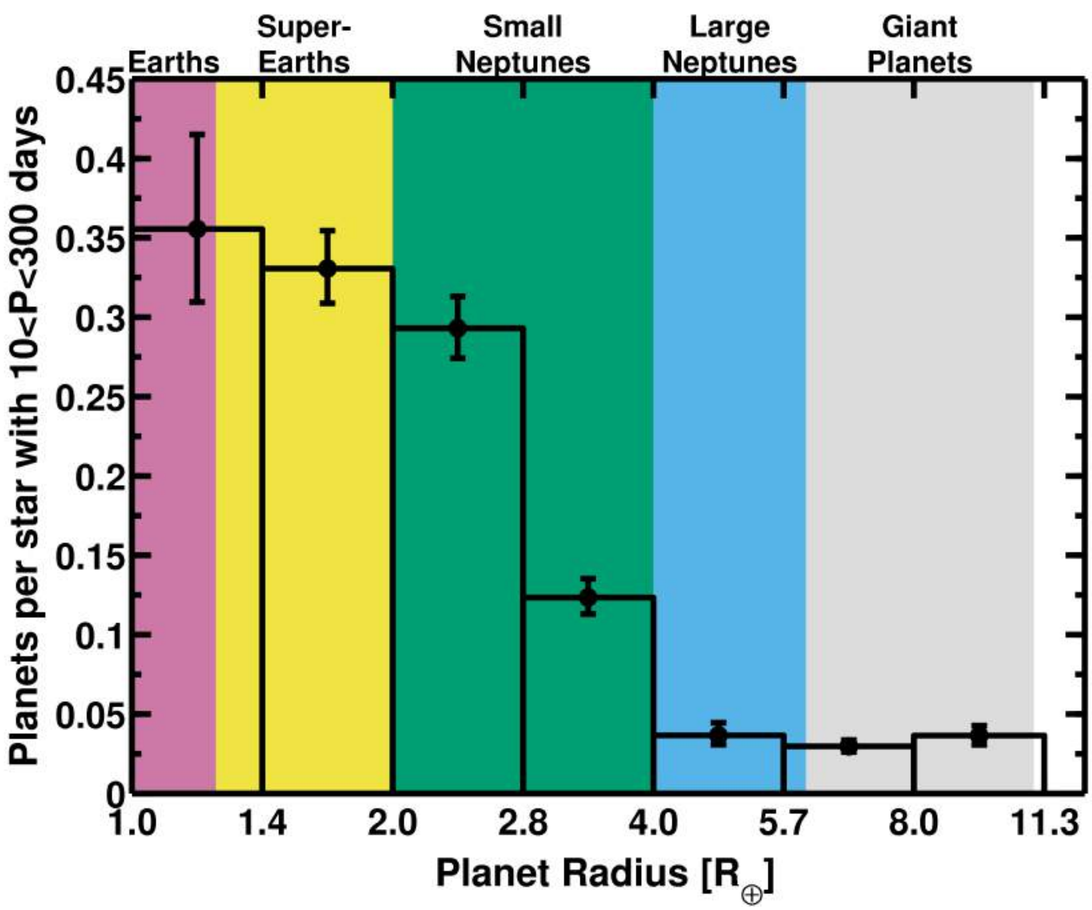

Fig. 1.— Average number of planets per star over the orbital period range 10$<P_{\rm orb}<$ 100 days from analysis of the Q1-Q16 Kepler planet catalog Burke et al. (2015). Color shaded regions correspond to the qualitative planet sizes as labeled along the top.

IN SITU LIFE DETECTION AND CHARACTERIZATION USING NANOPORE SEQUENCING IN THE HYPER ARID REGION OF THE ATACAMA DESERT, CHILE. Kathryn F. Bywaters (SSX/NPP), Chris P. McKay (SST), David Deamer (UCSC), Brian Glass (TI), Alfonso Davila (SSX) and Richard C. Quinn (SSX)

Introduction: Biomolecules are the most unambiguous and information-rich of all known biosignatures. For a successful life detection experiment, a search for biomolecules is the superior strategy, but few technological solutions exist for *in situ* identification.

Nanopore-based technology is one of the few technologies that has the potential for *in situ* detection and characterization of molecular biosignatures. The advantage of nanopore technology is that it can search for biomolecular qualities thought to be universal in life, rather than realized biochemical solutions that might be intrinsic only to Earth life, such as DNA. Nanopore technology could be used for the detection of biosignatures that are linear charged polymers, similar to DNA or RNA, but with chemical variations in the backbone or nucleobases.

The Oxford Nanopore MinION is a novel, miniature, off-the-shelf instrument capable of detecting nucleic acids without the need for amplification (i.e. the use of primers) and/or bulky sequencing equipment. These attributes make the MinION a superior solution for biosignature detection on planetary missions, such as Mars landers and icy world flybys.

The MinION Experiment: A proof-of-concept study was conducted that investigated *in situ* field analysis to determine the detection capabilities of nanopore sequencing technologies in the hyperarid Atacama Desert at Yungay.

Figure 1. MinION in a halite field at the Yungay site in the Atacama Desert, Chile.

By evaluating nanopore technology, as a method for sequencing DNA *in situ* and detecting microbial community composition in an extreme environment on Earth, we can validated the feasibility of nanopore technology as a tool for exploration and characterization of analog environments. Real-time *in situ* analysis and results will expedite the testing of hypothesis and enable more flexible and adaptive strategy techniques when in the field.

Results: The MinION was successful at *in situ* sequencing of DNA present in the Atacama halite sample. Results from the analysis were comparable to sequencing done by traditional methods (PCR amplification of 16S rRNA genes) [1-3]. Our analysis showed that the halite sample was dominated by archaea at 78% (using standard sequencing techniques archaea population represents 81-89%; [3].). Within the archaea population the relative abundance was primarily comprised of *Halococcus* sp (53%) and the cyanobacteria group *Halothece* (93%), the sole photosynthetic member inside the halite nodules, also consistent with previous studies [2,3].

Out of the three MinION trials conducted one was successful. Also, the number of viable pores was greatly reduced in all flow cells by the time of use. While the decreased number of viable pores is not detrimental for the use of nanopore sequencing at analog sites here on Earth it does limit nanopore sequencing for long duration space flight missions.

Discussion: This field trial was successful at demonstrating the feasibility and application of *in situ* sequencing methods capable of characterizing the microorganisms present in an extreme environment. However, we find that the robustness of the current nanopore membrane is limited and this has important implication for future development needs. Long duration space mission, involving life/biosignature detection, will need hardier technology to be developed, such as solid-state nanopores. This field trial not only has implications for work here on Earth but possibly for future life and biosignature detection missions to other planetary bodies as well.

References: [1] Wierzchos J. et al. (2006) *Astrobiology., 6,* 415-422. [2] de los Rios et al. (2010) *Int. Microbiol.,* 12, 79-89. [3]Robinson et al. (2015) Environ. Microbiol. 17, 299-315.

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Resource Prospector: An Update on the Lunar Volatiles Prospecting and ISRU Demonstration Mission A. Colaprete[1], R. C. Elphic[1], T. Roush[1], A. Cook[1], D. Andrews[1], J. Trimble[1], B. Bluethmann[2], J. Quinn[3], G. Chavers[4], [1]NASA Ames Research Center, Moffett Field, CA, [2]NASA Johnson Space Center, Houston, TX, [3]NASA Kennedy Space Center, FL, [4]NASA Marshall Space Flight Center, Hunstville, AL.

Over the last two decades a wealth of new observations of the moon have demonstrated a lunar water system dramatically more complex and rich than was deduced following the Apollo era. Lunar water, and other volatiles, have the potential to be a valuable or enabling resource for future exploration. The NASA Human Exploration and Operations Mission Directorate (HEOMD) has selected a lunar volatiles prospecting mission for a concept study and potential flight in 2021. The mission includes a rover-borne payload that can (1) locate surface and near-subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials.

To address the viability / economics of lunar ISRU, the volatile distribution (concentration, including lateral and vertical extent and variability), volatile form (H_2, OH, H_2O, CO_2, ice vs. bound, etc.), and accessibility, including overburden, soil mechanics, and trafficability, must be understood. To this end RP will assess the hydrogen and water distribution across several relevant environments that can be extended to a more regional and global assessment

Given the relatively short planned duration of this lunar mission, prospecting for sites of interest needs to occur in near real-time. The two prospecting instruments are the Neutron Spectrometer System (NSS) and the NIR Volatile Spectrometer System (NIRVSS). NSS will be used to sense hydrogen at concentrations as low as 0.5WT% to a depth of approximately 80-100 cm. NIRVSS, which includes its own calibrated light source, radiometer (for thermal correction) and context camera, will look at surface reflectance for signatures of bound H_2O/OH and general mineralogy. Once an area of interest is identified by the prospecting instruments the option to map the area in more detail and/or subsurface extraction via drilling is considered. The RP drill can sample from discrete depths using "biting" flutes, deep flutes with shallow pitch which hold material as the drill is extracted. As the drill is extracted a brush can deposit cuttings from the biting flutes to the surface in view of NIRVSS for a "quick assay" of the materials for the presence of water or other volatiles. If this quick assay shows indications of water or other volatiles, a regolith sample may be extracted for processing. Processing of the sample is performed by the Oxygen and Volatile Extraction Node (OVEN). OVEN will heat the sample to first 150C, pause, then to 450C. Any gases evolved from the sample are analyzed by the Lunar Advanced Volatile Analysis (LAVA) system which includes a Gas Chromatograph / Mass Spectrometer system.

As part of efforts to mature mission design and reduce technical risk during fiscal year 2015, RP designed, built and tested a RP rover/payload prototype, referred to as "RP15". This effort resembled a "mission in a year" in that initial RP15 requirements were defined at the start of the fiscal year, with interface control documents and initial design review occurring a couple of months later. The effort culminated in a demonstration of multi-center distributed operations of the prototype rover/payload as it performed mission related tasks. These efforts worked to reduce a great number of technical risks as well as inform mission design going forward. Additional design efforts and hardware testing have been taking place over the last year, including using the RP15 rover at NASA JSC and the K-Rex Rover at NASA Ames for specific operations/rover simulation tests..In parallel to these hardware and operational developments, continued effort has been made in lunar surface operation concepts, including detailed analysis of candidate traverse sites, which required development of new analysis and planning tools. Payload design maturation and testing has also continued, with evaluation of the mass spectrometer performance and testing of the drill, NIRVSS and mass spectrometer in lunar-like conditions.

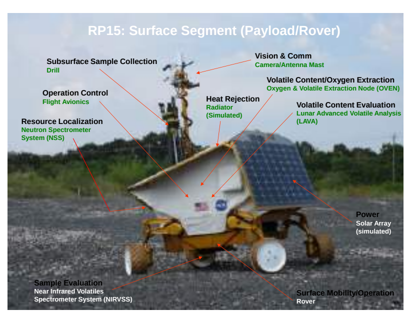

Figure 1. The RP15 rover and payload propotype was designed, built, and operated remotely with distributed operations network.

Ices on Charon: Distribution of H2O and NH3 from New Horizons LEISA Observations

C.M. Dalle Ore[1,2], Silvia Protopapa[3], J.C. Cook[4], D.P. Cruikshank[1]

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Charon, the largest moon of Pluto, appeared as a fairly homogeneous, grey, icy world to New Horizons during closest approach on July 14th, 2015. Charon's sub-Pluto hemisphere was scanned by the Ralph/LEISA near-IR spectrograph providing us with an unprecedented opportunity to obtain its surface composition and achieve a better understanding on the moon's history and evolution. We focus on the variations of the 2.0 µm H_2O ice band to map the distribution of the ices previously reported to be present on Charon's surface, namely H_2O and the products of NH_3 in H_2O. We find that H_2O ice is mostly crystalline, confirming previous studies, with the pixels with the most amorphous ice coinciding with areas that are dark in the albedo map. We also find that the brighter regions, often corresponding to the ejecta blankets of Charon, are characterized by larger H_2O grains, possibly an indication of a younger age. The behavior of the NH_3 products in H_2O seems, however, more complicated. We map two distinct behaviors for two of the NH_3 in H_2O ice bands. The 2.21 µm band tends to cluster more in the northern areas than the ~2.01 µm band. Both bands are present in correspondence of bright crater rays, but not all craters present both bands. The 2.21 µm band is also clearly present on the smaller moons Hydra and Nix. The picture hints at two kinds of NH_3 in H_2O with possibly different physical qualities.

Fine-scale niche partitioning and cooperation in co-existing cyanobacteria promote systems-level fitness across environmental conditions

R Craig Everroad, Anne K McHugh, Angela M Detweiler, Leslie Prufert-Bebout, Brad M Bebout

Cyanobacteria-dominated microbial mats played a key role in the evolution of the early Earth and provide a model for exploring the relationships between function, diversity and ecology. Understanding how functional and genetic diversity is maintained in such microbial systems is a central question in microbial ecology. Six distinct lineages of cyanobacteria were isolated from the intertidal microbial mat system at Elkhorn Slough, CA, USA and assayed to assess phenotypic and physiological differences between them. Using newly designed approaches to measure growth rate in filamentous cyanobacteria, these isolates were grown separately, and in pairs, across a matrix of environmentally-relevant light intensities and salinities. These isolates, including ones closely related to the typical hypersaline and intertidal mat cyanobacteria, *Coleofasciculus chthonoplastes* and *Lyngbya aestuarii*, showed clear differences in their photophysiology, specifically in the spectral properties of their phycobilisomes, and their photosynthesis-irradiance response curves. These differences translated into clear fitness effects, as measured by changes in growth rate, in response to the light environment. Similarly, individual isolates displayed different fitness optima with respect to salinity. Each isolate displayed a unique ‘peak fitness’ within the experimental matrix. When grown together, the cyanobacterial growth rates largely followed that as could be predicted by simple averaging of their individual growth rates, but it some cases, the cyanobacteria grown in combination showed higher fitness, as measured by growth rate, photosynthetic efficiency and peak biomass, than if grown in isolation. This suggests that a community-level fitness can exist that facilitates the co-existence of organisms expected to share the same niche or guild. This work contributes new techniques for studying filamentous cyanobacteria, and reveals how cooperation and fine-scale partitioning of phenotypic traits can promote the overall diversity of a microbial ecosystem.

Preparing for the Next Decade of Exoplanet Discovery and Characterization

Mark Marley and Roxana Lupu

Twenty years after the discovery of extrasolar planets we now know of thousands of new worlds. Almost all of these these planets were discovered by indirect means, primarily by transit and radial velocity methods. NASA is now constructing the WFIRST space telescope which is slated to launch in the mid-2020s. Using high contrast imaging, WFIRST will image and obtain spectra of about a dozen known radial velocity planets and search for worlds too small to have been discovered by radial velocity methods. This will provide the first opportunity to characterize temperate to cool gas and ice giant planets in reflected light. To prepare for this opportunity we are supporting the mission by producing forward models for a variety of likely WFIRST targets and are conducting retrieval studies to understand what sorts of information can be extracted from exoplanet reflected light spectra of various spectral resolutions, spectral ranges, and signal to noise ratios. We find that clouds, hazes, observing geometry, and available constraints on planetary mass all play a role in determining the fidelity of the retrievals. Efforts such as these also pave the way towards the interpretation of data from future space telescopes, such as HabEx or LUVOIR, that aim to find and characterize habitable extrasolar planets.

MODULARITY AND EVOLUTION OF RNA FUNCTION

Milena Popović[1,2], Andrew Pohorille[1,3], Chenyu Wei[1,3], and Mark Ditzler[1];

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Abstract: The emergence of first information polymers marks a defining point in the early evolution of life. Ribonucleic acids (RNA) are widely considered to be early, if not earliest molecules of heredity and catalysis. In order to study the mechanisms of evolution of such systems, we used *in vitro* evolution of RNA molecules that catalyze ligation of two RNA oligomers - ligase ribozymes, coupled with high-throughput sequencing. The impact of genome length on evolution of functional structures is examined. We find the evolution of identical recurring sequences among the populations of short and long RNA ligases. Moreover, both short and long ligase ribozymes prefer the same ligation junction and form identical structural scaffolds surrounding it, suggesting a role for modularity in evolution of RNA structure.

Modularity is considered a characteristic of biological organization, and an important source of evolutionary innovation[1]. Origin of modularity has been suggested to stem from a reduction in plasticity of molecules by stabilization of their shapes through natural selection[2]. Modular evolution (through the use of multiple smaller components of structure) has been suggested to increases overall functional complexity of populations of replicating RNA molecules[3].

RNA World theories[4] are widely accepted scenarios for the evolution prior to the emergence of translation, where RNA molecules transmitted heritable information and acted as dominant biocatalysts[5-7]. However, the size of the nascent information polymers was necessarily limited by the accuracy of replication during the time when error-prone replication would have been more widespread. The size-limit would have restricted the amount of heritable information that could be transferred, and is thought to have limited the functional capacity of early biopolymers[3]. This brings to question the impact of sequence length on evolution of RNA catalysis, and generally, how common function is in sequence space. Another important question is whether length impacts on evolutionary mechanisms available to a polymer of a given size. To answer these questions we evolved ligase ribozymes *in vitro* using large combinatorial libraries of short (20N random region) and long (80N) RNA molecules of random sequence. Evolved populations were sequenced through high-throughput sequencing and analyzed for recurring sequence and structural motifs. We find evidence for the role of modularity in evolution of catalytic RNA structures. The effects of length on the possible evolutionary mechanisms of RNA catalysis will be discussed.

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Microfluidic Approaches to Searching for Extant Life. R.C. Quinn[1], A.J. Ricco[1], T.D. Boone[1], N. Bramall[2], K. Bywaters[1], T.N. Chinn[1], A. Davila[1], D.M. Gentry[1], J. Forgione[1], M.F. Horne[1], J.E. Koehne[1], A.K.-S. Lee[1], G.C. McCutcheon[1], C.P. McKay[1], M.R. Padgen[1], M.N. Parenteau[1], M.X. Tan[1], L. Timucin[1], [1] NASA Ames Research Center, Moffett Field, CA 94035 [Richard.C.Quinn@nasa.gov], [2]Leiden Measurement Technology, Sunnyvale CA, 94089

Introduction: While no definitive definition of life exists, a living organism can be described as a “self-sustained and self-enclosed chemical entity capable of undergoing Darwinian evolution” [1]. Within this context, We are developing a multi-dimensional science and technology approach to the search for extant life that places biochemistry at the center, and focuses on aspects of life that are likely to be universal across the entire biochemical space.

In a biochemical context, self-sustenance requires the use of catalytic molecules to transform energy and drive the metabolic processes responsible for growth, reproduction, maintenance of cellular structures, and response to the environment. Earth life uses amino acids to build catalytic polymers (i.e. enzymes, a subset of proteins). In order to contain their metabolic machinery, organisms must be self-enclosed, and on earth this requires the use of membranes that separate the intracellular space from the exterior environment, regulating the traffic of chemical substances in and out of the cell. When faced with environmental challenges, populations must be capable of undergoing Darwinian evolution, and this requires that genetic information be encoded and stored in a manner that is reliable, stable, and transducible, but at the same time mutable. Lovelock [2] first pointed out that biochemistry at its most fundamental level occupies a relatively narrow chemical space, because life only utilizes a selected set of organic compounds to build larger, more complex molecules.

Methods: Mission constraints will inevitably limit searches for evidence of life to a few selected measurements. Our approach includes the search for simple building blocks, more complex biomolecules involved in basic biochemical functions and information storage, and structures that are required for cellular life to exist. This strategy allows us to cover a broad biochemical space and maximize the chances of a (true) positive result, even as the chances of a false positive result are minimized. This approach not only offers complementarity, but also reinforces the interpretation of the data and minimizes ambiguity.

Key to enabling this approach are ARC advances in the development of automated microfluidic handling and manipulation technologies for use in microgravity. These technologies have been successfully demonstrated through a series of small-sat NASA missions including GeneSat (3U cubesat), PharmaSat (3U), O/OREOS (3U), SporeSat (3U), and the upcoming EcAMSat (6U) and BioSentinel (6U). Currently, fluidic processing technologies derived from these systems (including fluid storage and metering, particle filtration, mixing, de-bubbling, gas expulsion, dry reagent storage and preparation, labeling, and sample concentration) are being coupled with measurement technologies to enable the search for extant life in the solar system. Microfluidic measurement technologies in development at ARC, among others, include luminescent imaging for identification of microscopic biological structures (Fig. 1) and chemical sensors for the detection of molecular biological building blocks and complex biomolecules. Our approach leverages ARC nanosatellite technology development and fabrication capabilities including stringent sterility and cleanliness assembly approaches, as well as microfluidic design, development, fabrication, integration, and test approaches.

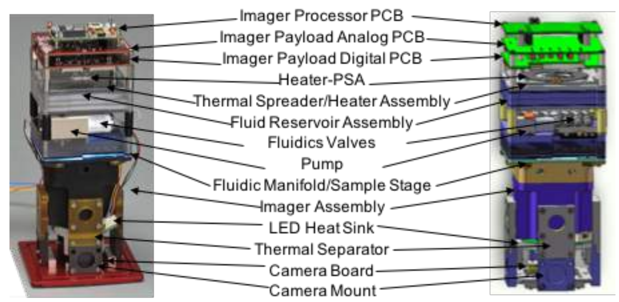

Fig. 1. Picture (left) and CAD model (right) of a TRL6 ARC microfluidic fluorescence microscope developed under the NASA Innovative Partnerships Program. The instrument is hermetically contained in a 2-liter volume (20x10x10 cm) and is an integrated payload system comprised of a fluorescence imager, LED light sources, a fluidics manifold with microorganism manipulation and sample stage, a valve-and-pump manifold, fluid reservoirs, associated peripheral components, and electronics. Leveraging this technology, the Luminescence Imager for Exploration (LIfE) instrument is currently being developed for the detection of filter-captured, cellular structures and sub-cellular fragments and the identification of key structural biomarkers contained in samples collected during Icy World missions.

Acknowledgements: The authors acknowledge support from the NASA Science Mission Directorate Concepts for Ocean worlds Life Detection Technology (COLDTech) program.

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Title: SOFIA/EXES 13 Micron High Spectral Resolution Observations of Orion IRc2

Authors: Naseem Rangwala (NASA Ames/NPP USRA), Xinchuan Huang (NASA Ames/SETI), Sean Colgan (NASA Ames), Timothy J. Lee (NASA Ames)

We present results from high resolution SOFIA/EXES spectra of Orion IRc2. Ten ro-vibrational transitions of C_2H_2 were detected - 5 each in the ortho and para states. Their rotational diagrams are shown below for covering fractions (f_C) of 1.0, 0.5 and 0.3. The line fits become increasingly poor below f_C = 0.5, as illustrated by f_C = 0.3. We find that the ortho and para ladders trace different temperatures even at f_C = 0.5, suggesting that this difference is real and not an optical depth effect. This difference could not be measured from previous ground based instruments. Additionally, we obtain a robust measurement of the ortho to para ratio and find that its unusually low, ~0.6 compared to the standard values of 3. Such a low ratio might indicate a different formation path for C_2H_2 that in turn may have significant impact on the formation of other molecules in the ISM since C_2H_2 is considered to be the most common precursor in the formation of bigger hydrocarbons, ring molecules and PAHs in the interstellar medium. Preliminary analysis of $^{13}CCH_2$ gives an isotopic $^{12}C/^{13}C$ ratio of only ~30, consistent with lower than expected optical depths of C_2H_2 lines.

This project began as a search for c-$C_3H_3^+$, the most important precursor in the formation of c-C_3H_2 - an interstellar organic ring molecule widespread in the ISM. There has been interest in detecting c-$C_3H_3^+$ in astrophysical environments for more than 25 years. Using these EXES observations along with *ab initio* calculations from the Ames quantum chemistry group, we report for the first time an observed 3σ upper limit on the column density of c-$C_3H_3^+$ ~2 x10^{13} cm^{-2}. This will help with the future searches for this molecule using ALMA and JWST.

We have an accepted SOFIA Cycle-5 impact program to use EXES to conduct an unbiased molecular line survey towards Orion IRc2 from 12.5 - 28.5 microns with a S/N of better than 70 over 90% of the proposed bandpass. The survey (due to its higher resolving power; R = 50,000) will do 5 - 50 times better than ISO in detecting isolated, narrow lines. This will allow us to (a) resolve the ro-vibrational structure of the gas phase molecules in order to identify them, (b) resolve their kinematics, (c) detect new gas phase molecules that were missed by ISO, and (d) provide useful constraints on Orion's hot core chemistry as sampled by IRc2. The proposed observations 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.

Stanford-Brown iGEM 2016: Bioballoon

Stanford University:	Michael Becich, Anna Le, Eric Liu, Theresa Sievert, Taylor Sihavong, Gordon Sun, Amy Weissenbach, **Kara Rogers**
Brown University:	Charles Gleason, Julia Gross, Cynthia Hale-Phillips, Taylor Pullinger, Elias Robinson, **James Head, Gary Wessel**
NASA Ames Research Center:	Mark Ditzler, **Lynn J. Rothschild** (CS), Trevor! Kalkus, Kosuke Fujishima, Jesica Navarrete, Griffin McCutcheon (Coops & Contractors)

The iGEM (international Genetically Engineer Machine) competition facilitates teams to create DNA constructs that can contribute to research and the bioengineering toolbox. Since 2011 the Rothschild Lab has hosted students from Stanford and Brown University for the iGEM competition, adding Spelman in 2014. Biological materials have a variety of advantages over traditional building materials; most significantly, they are cheap, light, and self-replicating. These characteristics make biomaterials ideally suited for space exploration. One possible application for these materials is a biosensing balloon, which could be sent up into both terrestrial and extraterrestrial atmospheres to detect both temperature and molecules of interest.

The 2016 Stanford-Brown team worked towards using synthetic biology to produce a balloon for planetary exploration and monitoring.[1] Traditionally balloons have been ideal tools for atmospheric research: they can track weather patterns and monitor atmospheric composition. Our bioballoon could be used to traverse long distances and collect data in hard-to-reach places on other planets, complementing a rover's capabilities. The bioballoon could be “grown” and re-grown with the same bacteria, dramatically reducing the cost of transport and production.

Over the course of a summer, the iGEM team successfully produced latex as a biomaterial to use for the balloon, used algae to produce biological hydrogen to inflate the balloon with oxygen an option for denser atmospheres such as Titan, utilized melanin as a radiation resistant material for the surface of the balloon, and pioneered the use of chromoproteins for use as biological thermometers. Together, these projects could create a novel scientific instrument: cheap, light, durable, and useful to planetary scientists. For this work, they received a blue ribbon at the Bay Area Maker Faire, were gold medalists at the iGEM competition, were runner up for the Best Manufacturing prize at the iGEM competition, and won the distinction of having the Best Measurement award at the iGEM competition.[2]

[1] http://2016.igem.org/Team:Stanford-Brown
[2] https://news.brown.edu/articles/2016/10/igem

Long Term Planetary Habitability and the Carbonate-Silicate Cycle.
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Introduction: The potential habitability of exoplanets is traditionally assessed by determining whether or not its orbit falls within the circumstellar 'habitable zone' of its star (Kopparapu *et al*., 2013). However, this metric does not readily account readily for changes in the abundance of greenhouse gases and their associated radiative forcing as a result of the action of the carbonate-silicate cycle.

Methods: We develop a model of the carbon cycle on Earth, coupled with a a 1-D radiative-convective climate model with an Earth-like atmospheric water vapour profile [1], to explore the potential changes in the CO_2 greenhouse under conditions of varying planet size (0.5 – 2 $R_\oplus$) and stellar flux (0.75 to 1.25 $S_\oplus$).

Results: We find that likely changes in global topography, tectonic outgassing and uplift, and the hydrological cycle on larger planets results in proportionally greater surface temperatures and pCO_2 for a given incident flux. For planets between 0.5 and 2 $R_\oplus$ the effect of these changes results in average global surface temperature deviations of up to 15 K, which suggests that these relationships be considered in future studies of planetary habitability.

Furthermore, by coupling this model with the stellar evolution scheme presented in [2] and setting an upper temperature limit of 343 K, the habitable period of the Earth-sized world around the Sun can be quantified. For a 1 $R_\oplus$ planet, this limit is approximately 6.35 Gyr after planet formation, or 1.81 Gyr from present day.

Additionally, atmospheric CO_2 falls below the limit at which C3 and C4 plants can effectively photosynthesize after ~5.38 Gyr and ~6.1 Gyr respectively, which may initiatiate a significant reorganization of the biosphere of the planet well before average surface temperatures render it un-inhabitable.

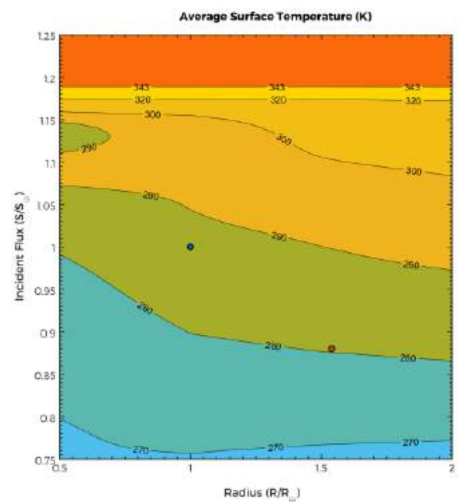

Fig. 1: Surface temperature as a function of planet radius and incident flux, both normalized to present Earth values. Also shown are the present day Earth (blue-filled marker) and GJ 667 Cc (red-filled marker).

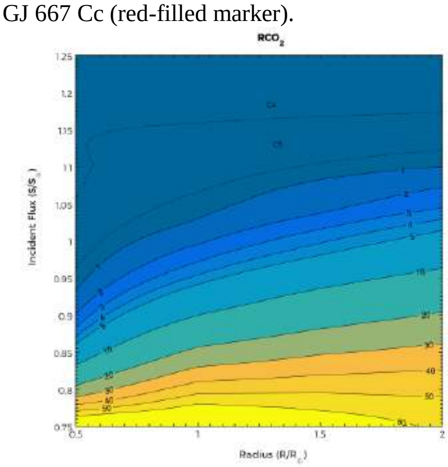

Fig. 2: pCO_2 as a function of planet radius and incident flux, both normalized to pre-industrial levels (280 ppm). Also shown are contours showing the photosynthesis limit for C3 and C4 plants.

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Catching Life from the Icy Ocean World Plumes: Applications to Europa & Enceladus

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Introduction: Icy plumes at Europa and Enceladus provide an opportunity to determine their habitability and presence of life by collecting ice particles in a pristine condition and transferring to on-board instruments.

The Cassini spacecraft has undertaken flythroughs of the Enceladus geyser plumes at speeds > 7 km/sec [1] where instruments such as the Cosmic Dust Analyser [2] and the Ion Neutral mass spectrometer [3] instruments detected spectrums from plasma generated by impacting plume ice particles. Cassini's measurements provided remarkable evidence of a salty ocean and hydrothermal vents under the ice, but these measurements were limited by the high flythrough speeds, where large organic compounds impacting the instruments were destroyed or altered [4].

A solution is to flythrough the plumes at slower speeds (e.g., speeds < ice melt speed at impact) collecting ice particles in pristine condition where cell structures or large biomolecules are intact for analysis. The Applied Physics Laboratory (APL) and NASA Ames Research Center (ARC) are undertaking studies to determine the feasibility of collecting ice in the plumes during 1.5 km/sec fly-throughs speeds.

Methods: (1) *Apparatus:* Plumes of 140° K ice

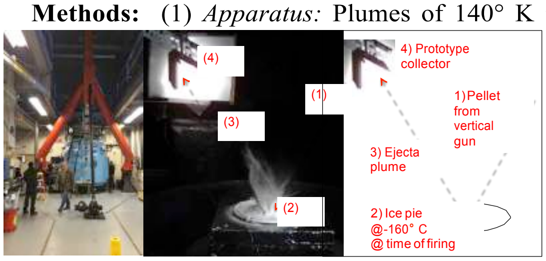
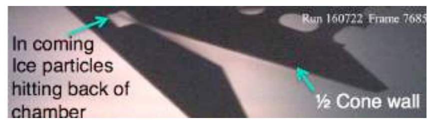


Figure 1: (*Left*) *ARC Vertical Gun. (Middle & Right) Prototype cone collector & ice pie setup.*

particles travelling up to 2.3 Km/sec, were created by firing 3 mm hollow aluminium pellets (up to 6 Km/sec) at liquid nitrogen cooled ice pies. The experiments were at the NASA ARC Vertical Gun (Fig 1).

Prototype Collectors (30° wall angled cone cross-sections) were positioned to catch the plume particles (Fig 1). Particles were filmed as small as 150 µm, impacting the cone and funnelled into a collection chamber (Fig 2). *(2) Cells Survival (A trial simulating the organics journey from Eceladus ocean to Collection):* Seawater form the Pacific ocean was used and frozen in the ice pie. Adenosine triphosphate (ATP), a lable biomarker was used as a proxy to estimate the amount of viable and/or intact cells in the: (1) sea water, (2) ice pie before pellet firing, (3) Ice pie after pellet firing, and (4) Sample chamber after collection (Fig 4).

(3) Computer simulation modelling: Simulation impacts were modelled of a 100µm particle impacting an aluminium surface at 30°, from 20 to 1500 m/sec, using ALE3D hydrocode from LLNL. Material modelling involved a simple equation of state using bulk modulus and stress/strain based failure criteria (Fig 3)



Left Figure 2: *Particle clouds entering sample chamber* @ 1.5 Km/sec.

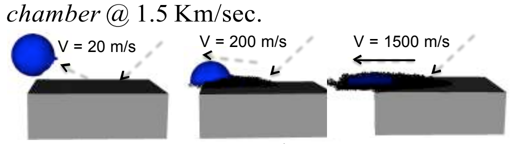


Figure 3: *Computer simulation at various speeds*

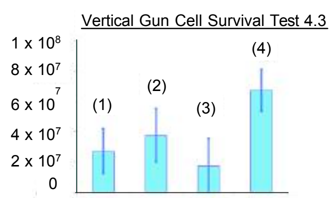


Figure 4: *Tentative Cell survival results. (1) Sea water, (2) Ice, (3) Ice post pellet shoot,(4) Collection*

Results: The Vertical Gun tests showed >95% particles at speed > 250 m/sec smashed at impact and flowed down the cone walls into the sample chamber. Clouds of particles of size < 150 µm diameter size were filmed flowing into the sample chamber at ~1.5 Km/sec (Fig 2). The cell survival trial showed significant survival and/or ATP preservation at ~1.2 km/sec impact. Some contamination may have occurred. The computer simulation correlated with the Vertical Gun results.

Conclusion: All results are tentative requiring further work and stricter contamination controls. However the Vertical Gun and computer simulation results show particles smash upon impact and flow into the sample chamber with >>95% efficiency. Cellular survival is significant suggesting large molecular biomarkers may remain intact for mass spectrometer measurement.

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Pollack Lecture
March 7, 2017

The Early Mars Climate System

Robert M. Haberle

Today Mars is a cold, dry, desert planet. The atmosphere is thin and liquid water is not stable at the surface. But there is evidence that very early in its history it was warmer and wetter. Since Mariner 9 first detected fluvial features on its ancient terrains researchers have been trying to understand what climatic conditions could have permitted liquid water to flow on the surface. The main issue is coping with the faint young sun. During the period when warmer conditions prevailed ~3.7-4.1 Ga the sun's luminosity was ~25% less than it is today. How can we explain the presence of liquid water on the surface of Mars under such conditions? A similar problem exists for Earth, which would have frozen over under a faint sun even though the evidence suggests otherwise.

Most attempts to solve the "Faint Young Sun Paradox" rely on greenhouse warming from an atmosphere with a different mass and composition than we see today. This is true for both Mars and Earth. However, it is not a straightforward solution. Any greenhouse theory must (a) produce the warming and rainfall needed, (b) have a plausible source for the gases required, (c) be sustainable, and (d) explain how the atmosphere evolved to its present state. These are challenging requirements and judging from the literature they have yet to be met.

In this talk I will review the large and growing body of work on the early Mars climate system. This was a topic of great interest to Jim Pollack who believed that a thick carbon dioxide atmosphere maintained by a novel recycling mechanism could be the solution to the early Mars dilemma. However with time, support for this idea dwindled and to this day a long-lived sustainable greenhouse atmosphere remains illusive. Reducing greenhouse atmospheres have been getting some attention recently, but they require background carbon dioxide levels much greater than suggested by Tom Bristow's recent analysis of the sediments in Gale Crater.

The difficulty in finding long-lived greenhouse atmospheres has focused attention on alternative explanations. Impact-generated climate change, an idea suggested years ago, is undergoing a revival with a number of groups employing sophisticated general circulation models to attack the problem. And new work aimed at understanding how fluvial features and lakes could be produced in cold environments is progressing. But, not surprisingly, these alternative ideas have significant challenges and it remains to be seen just how far they will take us towards a solution.

So where are we now? Well, in spite of the nearly 50 years of research on the topic a robust solution is not yet in hand and the nature of the early Mars climate system remains uncertain. To be sure, we have eliminated some possibilities and have therefore narrowed the search. But a full solution will take more time.

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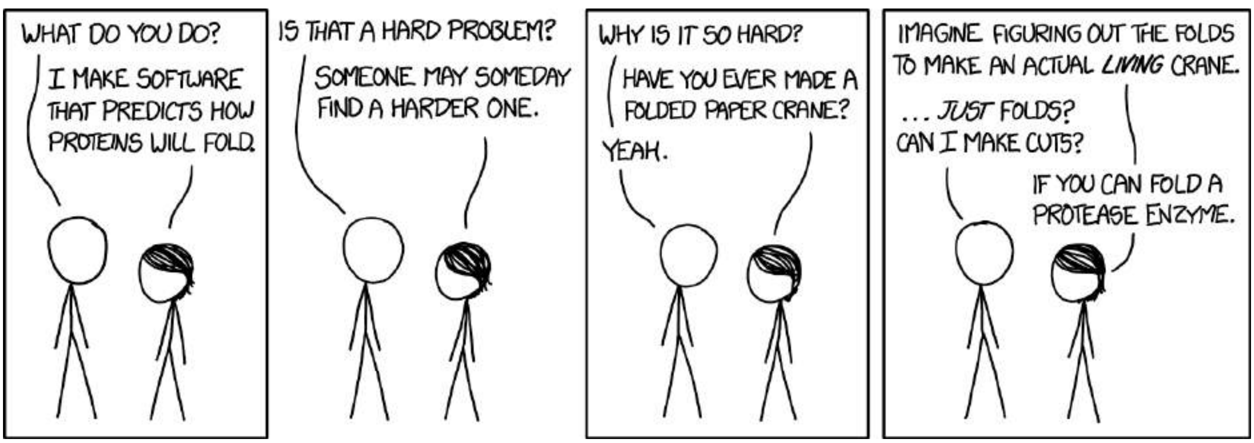

http://xkcd.com/

Astrobiology

Biological production of a novel polymer for space industry

Nils Averesch, Universities Space Research Association at NASA Ames Research Center;
Lynn J. Rothschild, NASA Ames Research Center, Moffett Field, CA 94035

Aramids, namely Kevlar, Vectran, Nomex but also other fabric or sheet materials are described as materials useable for (inflatable) space and surface habitat modules. In particular, open cell elastomers, are layered and compressed prior to launch. On site, for example in orbit or on the Mars surface, the elastomeric layers could be expanded or stretched over a structure, deploying the module into its designated configuration. The polymer layers act as insulation while also serving structural purposes, providing stability, rigidity and ballistic protection. Current plans designate a composite of different polymers, as high rigidity and high elasticity are rarely mutual properties of a single material.

This project explores production of a novel aramid-fiber. The so far undescribed material is expected to combine high strength with flexibility and may even be varied to also feature elasticity. This not only simplifies the construction of the modules: because the compounds for production of the polymer are fully bio-accessible, autonomous production is feasible, enabling onsite repair and potentially even construction of new modules.

The core compound is *para*-aminobenzoic acid, which can be polymerized to form a material analogous to Kevlar. Kevlar, or the analogue "poly(pABA)", derive their strength from a high degree of crystallinity on the molecular level. However, this crystallinity is also the reason for very low elasticity and a difficult production process with harsh reaction conditions. The plan to overcome this issue is to introduce blocks of amorphous regions in the polymer that break the structure. If amorphous and crystalline regions are balanced correctly, as in spider-silk, a reasonable level of stability should be retained, while also granting some elasticity. Potential compounds for the co-polymerisation include *meta*- and *ortho*-aminobenzoic acid (oABA), the latter of which is also bio-accessible.

In metabolism the shikimate pathway is the foremost metabolic route leading to formation of aromatic compounds, including tryptophan, phenylalanine and tyrosine. Using an approach that combines metabolic modelling with genetic engineering a microbial production system for pABA has successfully been established. This yeast-based cell factory for aromatics may easily be modified to also enable production of oABA. The established system also serves as a basis to explore possibilities for enhanced production of the target compounds as well as biological polymerisation of pABA.

In parallel, production is being moved into *Bacillus subtilis*, which is more suited for application in space synthetic biology and may as well open unexplored opportunities to enhance production. In industry, *B. subtilis* is valued as a protein producer, which may be beneficial for production of poly(pABA): pABA is chemically an amino acid (just commonly not proteinogenic) and in poly(pABA) the individual residues are joined together by peptide bounds, analogous to spider-silk, which is a natural protein. This imposes the angle on biological polymerisation of pABA: by hijacking (non-ribosomal) cellular protein synthesis a method for biological formation of poly(pABA) as a non-natural protein may be developed.

METHANE AT THE AQUA DE NEY HYPERALKALINE SPRING (N. CALIFORNIA USA), A SITE OF ACTIVE SERPENTINIZATION. J. G. Blank[1,2], G. Etiope[3], V. Stamenković[4], A. R. Rowe[5], I. Kohl[6], S. Li[6], and E. D. Young [1]NASA Ames Research Center (Moffett Field, CA, USA; Jennifer.g.blank@nasa.gov), [2]Blue Marble Space Institute of Science (Seattle WA, USA), [3]Istituto Nazionale di Geofisica e Vulcanologia (Rome, IT) [4]California Institute of Technology/Jet Propulsion Laboratory (Pasadena CA, USA), [5]University of Southern California (Los Angels CA, USA), [6]Universify of Californa Los Angeles (UCLA) (Los Angeles CA, USA).

Introduction: Insight in to the processes controlling the origins and forms of methane (CH_4) on Earth, especially in sites of active continental serpentinization, contributes to the understanding of biomarkers in the search for life on other planets. Here, we present new results of stable C and H isotope and isotopologue composition of CH_4 and water chemistry from the Aqua de Ney (California), a site where methane gas is actively bubbling through spring water. We use our measurements of $\delta^{13}C_{CH4}$, $\delta^{2}H_{CH4}$, $^{12}CH_2D_2$ and $^{13}CH_3D$ to constrain an origin for the methane, through comparison with the same parameters in other serpentinization sites [1]. We will discuss our results in the context of the regional geologic setting of the site and a preliminary 16S rRNA study of the microbiological community thriving at the spring.

The Field Site: Aqua de Ney is an hyperalkaline (pH~12) mineral spring located in Siskiyou County, Northern California, known for its high CH_4 content [2]. Stable isotope compositions of O and H, reported for the waters of Aqua de Ney [3], reveal a signature that is much enriched in heavier isotopes than local meteoric water and support a connate origin for the spring waters. Such an origin is consistent with the emplacement setting of ophiolites in the California Coast Range, which are juxtaposed with cherts and deep-marine sedimentary rocks [4]. The Ney spring has unusual chemistry, including extreme dissolved silica content, high boron, sulfide, sodium bicarbonate, and ammonium [5]. The spring also supports unusual microbial ecology and/or microbes extracting energy from fluids of deep origin.

Sample Collection: On-site methane detection was conducted using a portable sensor, and T and pH measurements were determined using portable digital sensors and cross-checked with hand-held thermometers and pH papers. Water and gas samples were collected using sampling techniques employed in prior studies (e.g., [6],[7]), with special treatment for the high-pH water samples [2]. Water samples were passed through 0.2 µm filters and collected in borosilicate and Nalgene bottles. Gas samples were collected in two vessel types: evacuated glass bottles with rubber septa and Giggenbach-style gas bottles.

Laboratory Analyses: Stable C and H isotopes and resolved $^{12}CH_2D_2$ and $^{13}CH_3D$ isotopologues of CH_4 were determined using the novel large-radius high-mass resolution multiple-collector isotope ratio mass spectrometer, *Panorama*, at UCLA. Water aliquots were processed in a commercial laboratory (Thermochem, Santa Rosa CA) for anion and cations and total dissolved solids. Gas samples were analyzed for gas speciation and concentrations by GCMS by Thermochem and UCLA.

Results & Discussion: The measured effluent gas from the spring consisted of >73 vol.% of CH_4. Stable C and H isotope and clumped isotope compositions of CH_4 are similar to those of abiotic methane, rather than microbial methane, typically occurring in other continental serpentinization sites. Isotopologues are in near-equilibrium, suggesting a CH_4 formation temperature of approximately 50°C. Not excluding possible minor microbial components, CH_4 seems to be dominantly abiotic, likely generated by Fischer-Tropsch type reactions at depth [9]. We will compare the microbiology population counts and metabolic activies between the springs, both of which are hosted in the same ophiolite provence. Our reporting on the water and gas chemistry of this unusual site may trigger future detailed microbiological, geochemical and mineralogical studies at Ney.

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Life Detection in Briny Evironments: Mitigating False Negatives. R. Bonaccorsi[1,2], A. Davila[1,2], C.R. Stoker[2], D. Willson[2,3], C.P McKay[2]. [(1)]SETI Institute, Mountain View, CA 94043 (rosalba.bonaccorsi-1@nasa.gov); [(2)]NASA Ames Research Center, Moffett Field, CA 94035; [(3)] KIPR Institute, Norman, OK 73069.

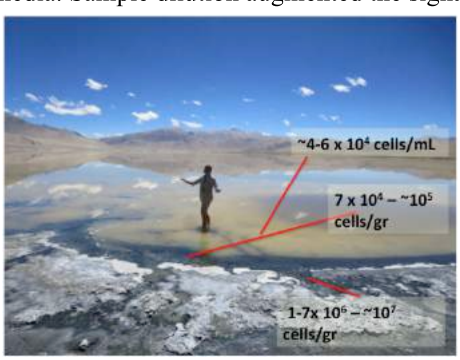
Understanding if Mars is currently inhabited by dormant microorganisms – that may become an active an active biohazard under transient conditions - is a key priority in the context of the NASA vision for Space Exploration preparing for humans safely living and working on the Martian surface. On the surface of Mars the Recurrent Slope Lineae [1] and other brine-rich deposits [2] represent promising candidate environments for this search. Investigations on terrestrial briny environments demonstrated that they are inhabited by life. For instance, the deliquescence of hygroscopic salts in the hyperarid core of the Atacama Desert (Chile) provides a shallow surface habitat for active halophylic prokaryotes [2-3]. Furthermore, hypersaline ponds, lakes, shorelines and salt flats can also shelter complex microbial communities as well as eukaryotic life [4]. However, life detection in these environments is complicated by their physico-chemical features.

Life detection and analytical gaps: The detection of molecular proxies for life, or metabolically active life (as we know it) in planetary environments depends on four conditions: (1) their initial presence due to current and past biological production; (2) their concentration in measurable amount in target environments; (3) their long-term preservation within the geological material; and (4) the analytical ability of payload instruments to detect and identify them. One key aspect of this search involves mitigation strategies to address recurring life detection issues such as false negatives, low signal to noise ratio, etc. False negatives (null or incomplete recovery) can result from the analysis of both biologically lean and biologically rich materials, which is a chief concern for our ability to detect life on Earth and other planets. We present here an example of successful detection of metabolically active life in terrestrial briny extreme environments.

Approach & Results: Briny water and clay-rich sediments were collected from high-altitude hypersaline evaporitic lakes (Figure 1) in the Leh-Ladakh region (Himalayas, India) [5]. Samples were analyzed for both the Adenosin Triphosphate (ATP) biomarker and the lipopolysaccaride (LPS) Lipid A using lab-on-the chip / wet chemistry assays. Water samples were diluted x10, x100, and x1000 to mitigate chemistry-related interfering factors; up to 10-12 100-μL subaliquots were analyzed to asses the frequency of false negatives. The highest concentrations of ATP were measured in water samples from a hypersaline lake, e.g., ~5 x 10^5 fmoles of ATP/gram, or mL (Figure 2).

Results and Discussion: Overall, the LPS- and ATP-based biomass of freshwater, saline, and hypersaline samples range from 10^2 cells/gram to 10^9 cells/gram and cells/mL. The most common issues related to the analysis of briny samples are: 1. False negatives; 2. Poor yields in non-diluted briny samples; 3. quenching effects (for nanophase clay- and pigment-rich brines); and 4. Large intra sample variability.

In geological and water samples the detection of LPS and ATP biomarkers can be affected by the mineralogical (i.e. clay minerals, nanophase iron oxyhydroxides) and physico-chemical composition (salts, pH, T, organics) of the media. Sample dilution augmented the signal to noise/ratio up to 3 orders of magnitude.



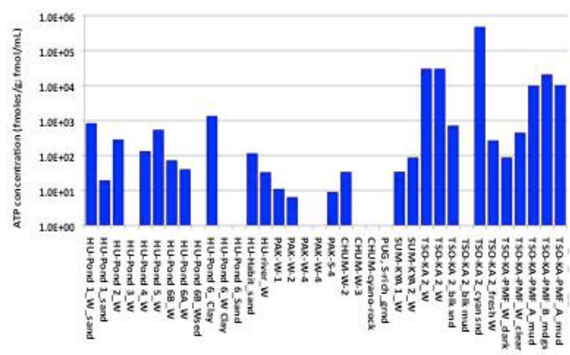


Figure 1. Briny environments sampled from an hypersaline lake. ***Figure 2.*** Biomarker in periglacial/briny settings.

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A CONTINUOUS PRODUCTION OF FRAGILE PROTO-METABOLITES IN THE EARLY SOLAR SYSTEM: EVIDENCE FROM CARBONACEOUS CHONDRITES?

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Introduction: Carbonaceous chondrite meteorites (CC) provide evidence of organic compounds that were present in the Solar System before the origin of life. Amino acids, purines, pyrimidines and short monocarboxylic acids are some of the classes of prebiotically relevant compounds that have been detected in a variety of meteorites [1]. The survival of these compound classes in meteorite parent bodies, and presumably in the prebiotic Earth environment, is generally expected based on their known low spontaneous degradation rates (Figure 1) [2]. Recently, however, alpha and beta keto acids have been reported in CC [3]. These molecules are vital to life's carbon metabolism but notorious for their high chemical reactivity and fast degradation rates [4,5]. How did organic compounds such as these survive in early, and uncontrolled, prebiotic environments? Cold temperatures and perhaps minimal exposure to aqueous alteration on meteorite parent bodies might offer an explanation of what aided in the survival of these labile compounds. However we have been pursuing an additional hypothesis that can also explain the long-term persistence of these compounds in meteorites as well as possibly in various warmer and aqueous abiotic settings. This scenario takes advantage of the natural chemistry of pyruvic acid, the smallest and most abundant alpha keto acid detected in CC [3]. **Results and Discussion:** We have found that pyruvate can serve as a single-source reactant to continuously generate some of the most labile compounds such as oxaloacetate . The production of these metabolites appears to result from the isomerization, hydration and decarboxylation reactions of subsequent pyruvate aldol condensation products. Importantly, compounds such as oxaloacetate and other (larger) products replenish the starting material as they readily degrade to pyruvate. We have begun to search for pyruvate aldol polymers in meteorite samples to support this scenario of pyruvate chemistry being the source of meteoritic metabolites. Thus the chemical instability of alpha and beta keto acids does not limit their persistence in abiotic environments as long as a pyruvate source is maintained. Additional results from these studies, proposed mechanistic pathways, and implications for prebiotic chemistry will be presented.

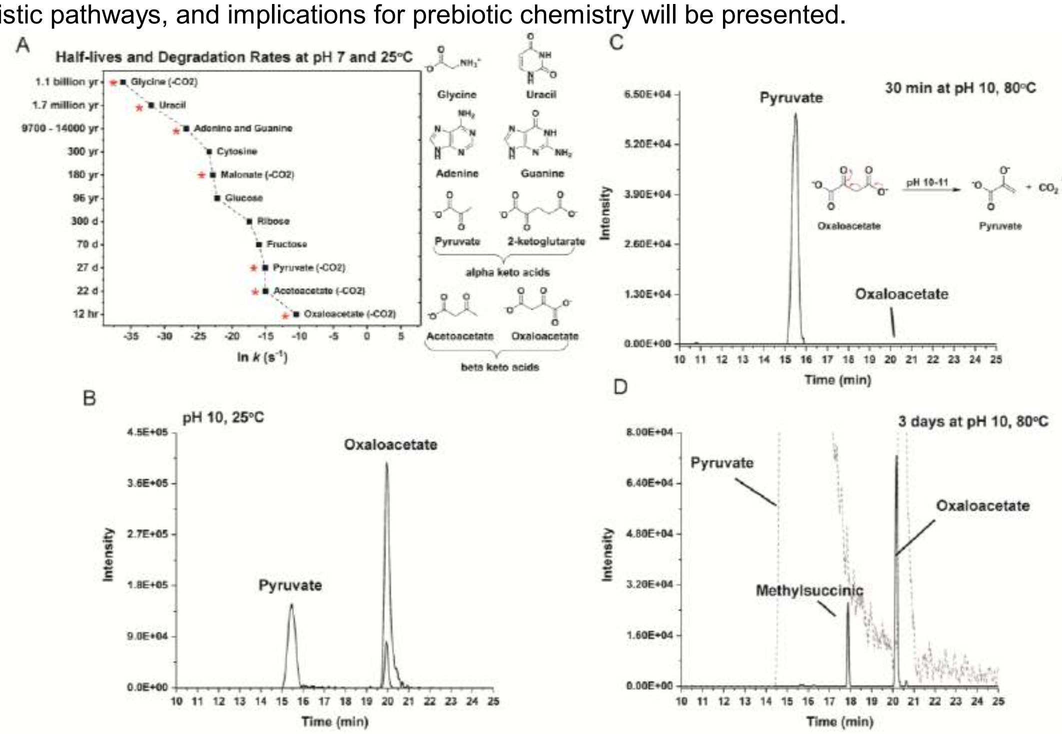

Figure 1.**A.** Organic compounds found in biology exhibit a wide range of spontaneous degradation rates. Of the biologically relevant organics detected in meteorites (denoted by an asterisk above) the alpha and beta keto acids are among the most labile known. **B**. Chromatogram of a standard solution of oxaloacetate under alkaline conditions. **C.** Chromatogram of the heated oxaloacetate standard under alkaline conditions shows the complete degradation of oxaloacetate to pyruvate occurs within minutes. **D**. Chromatogram showing that a heated reaction mixture of pyruvate under alkaline conditions will generate oxaloacetate and maintain a low-level steady state abundance of oxaloacetate. **References:** [1] Pizzarello S. and Shock E. (2010). Cold Spring Harbor Perspectives in Biology. 2: a002105. [2] Wolfenden R. (2011). Annual Review of Biochemistry. 80:645–667. [3] Cooper G. et al. (2011). Proceedings of the National Academy of Sciences of the United States of America. 108:14015–14020. [4] Cooper A.J.L, et al. (1983). Chemical Reviews. 83:321-358. [5] Wolfenden R., et al. (2011). Journal of the American Chemical Society. 133:5683–5685.

THE LASSEN ASTROBIOLOGY INTERN PROGRAM. David J. Des Marais[1], Mary N. Parenteau[3] and Michael D. Kubo[1,3], [1]Exobiology Branch, NASA Ames Research Center, Moffett Field, CA, [2]Technology for Learning, North Kingston, RI, [3]SETI Institute, Mountain View, CA (Mail Stop 239-4, NASA Ames Research Center, Moffett Field, CA 94035; david.j.desmarais@nasa.gov)

Since 2009 scientists on the Ames Team of the NASA Astrobiology Institute have collaborated with staff at Lassen Volcanic National park and Red Bluff High School, CA to offer this program to junior and senior students. The program provided an authentic place-based hand-on educational opportunity for students to interact directly with research scientists as they learned concepts in astrobiology, conducted field and laboratory research and prepared technical reports.

Concepts: Students learned about the following key concepts in astrobiology: 1) Geological processes interact with solar radiation to shape planetary climates. Such interactions can create and sustain habitable environments where diverse life forms can persist, forming a biosphere. 2) Our biosphere consisted solely of microbial life for more than 80% of its documented 3.7 billion year history. 3) Certain key resources and clement conditions must be available simultaneously to create habitable environments. These requirements can be met in diverse ways that, in turn, can sustain diverse life forms. 4) Volcanic hydrothermal processes create habitable environments. Hydrothermal activity has occurred on Mars. Thus Lassen Volcanic National Park (LVNP) enables research on environments that also occurred on other planets and are key targets to search for life.

Implementation: The curriculum followed the progression of a scientific investigation, starting with literature review and fieldwork and ending with written reports and oral presentations. Each part provided opportunities for students to acquire skills that they would need in a science or technology career.

Online lectures on astrobiology. Recorded online lectures provides the students with basic background about astrobiology (geology, microbiology, water chemistry, etc.). This allowed us to focus on hands-on activities and discussions when we met with the students weekly either in person or via videoconference.

Fieldwork. Three research teams, each consisting of juniors led by a senior, documented volcanic rocks, mineral deposits, hot spring waters and microbial life in Warner Valley, LVNP. They investigated and compared these features at three sites – a near-neutral pH stream and an alkaline and an acidic hot spring.

Laboratory exercises. Students conducted laboratory experiments to analyze minerals in rocks, investigate reactions between rock and simulated spring waters, and culture microorganisms collected in the field.

Examples of student findings. 1) Relative abundances of elements in spring water solutes correlated with the relative elemental abundances in the rocks hosting the springs. 2) Volcanic gases and their oxidation products can greatly enhance rates of rock weathering relative to rates that occur in surface waters. 3) The pH of spring waters reflected the effects of volcanic gases and their reactions with volcanic rocks. 4) Solutes in hot spring waters provided key nutrients for microbes. 5) The abundance and diversity of microbes decreased from neutral pH streams to alkaline hot spring waters to highly acidic hot spring waters. 6) The abundance and nature of microbes were affected by a combination of geological and hydrological processes. 7) Thoughtfully designed laboratory experiments can help to interpret field data but these experiments also have limitations in simulating natural processes.

Written and oral reports. Each student prepared a report to present data and discuss relationships between volcanic rocks and gases, spring waters and microbial communities. The students critiqued each other's draft reports during several states of their preparation during the program. The class presented its findings orally to the school, parents and public at their final evening "graduation" event.

Evaluation: Surveys were administered to students before and after their lectures, labs, fieldwork and discussions with scientists. Students' work was scored using rubrics (labs, progress reports, final report, oral presentation). Parents, teachers, rangers, Ames staff and students completed end-of-year surveys on program impact. Students had a unique and highly valued learning experience with NASA scientists. They understood what scientists do through authentic research and by observing what scientists are like as individuals. Students became familiar with astrobiology and how it can be pursued in the lab and in the field. Student interest increased markedly in astrobiology, interdisciplinary studies and science generally. Testimonials from several graduates revealed that their program participation influenced their decisions regarding college majors in science, technology and education.

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Direct observation of coevolution at the RNA-protein interface

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Functional RNA-protein complexes (RNPs) are ubiquitous in biology. They represent the most conserved molecular assemblies in cells, including the ribosome and ribonuclease P that carry out critical cellular functions. Their conservation and variation provide a record of life's shared ancestry and evolved diversity, respectively. For several RNPs this record has been interpreted as supporting a gradual transition from RNA-only or RNA-dominated complexes to RNP complexes increasingly dominated by their protein components. In some cases, it has been suggested that RNPs transitioned completely to protein-only enzymes. One proposed scenario for such a transition is illustrated in **Figure 1**. Alternative interpretations have also been suggested, in which protein and RNA played equal roles in biology from the very beginning. A major challenge for the various interpretations is identifying which features of the RNA-protein interface are reproducible features of their coevolution and which are historical.

In vitro evolution provides a means of understanding fundamental properties of molecular evolution independent of biology. It provides insight into which features of evolution are historical, and which are fundamental to the evolutionary process. For example, multiple experiments in which RNA populations were subjected to *in vitro* evolution revealed that a specific catalytically active RNA structure (the Hammerhead ribozyme) that is observed in contemporary biology is common among RNA sequences and likely evolved independently multiple times, while another catalytic, biological, RNA structure (the Hairpin ribozyme) is rare among RNA sequences and therefore less likely to have multiple origins.

Our experimental system allows us to coevolve RNA and proteins with the potential to evolve functional RNPs. The system also allows for the parallel evolution of RNA-only and protein-only catalysts under the same conditions as the coevolution experiments. By comparing these parallel evolution experiments, we can determine the degree to which the populations resulting from the RNA-protein coevolution differ from the RNA-only and protein-only populations subjected to the same selection pressures.

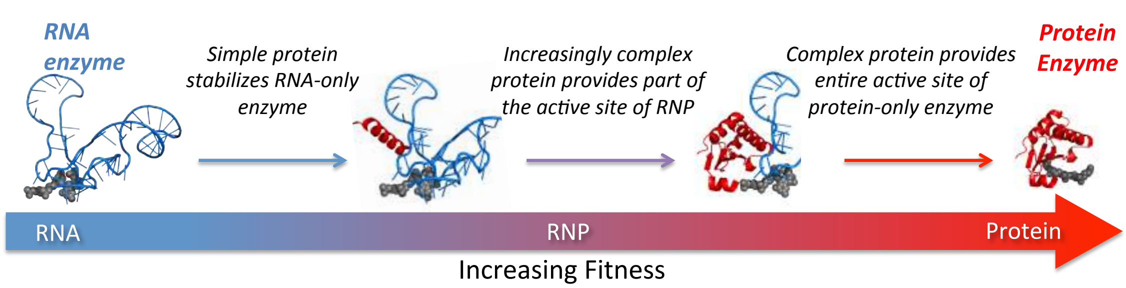

Figure 1 *One potential scenario in which a catalytic function involving a conserved substrate (grey) transitions from an RNA (blue) catalyzed reaction to a protein (red) catalyzed reaction by passing through multiple RNP intermediates.*

VOLUMETRIC DISTINCTION BETWEEN GULLY TYPES ON MARS; VOLATILE IMPLICATIONS

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Introduction*:* Loss discrepancies between the eroded volumes from classic alcove-chute-apron (ACA) crater wall/peak gullies and their depositional aprons have been linked to evidence of a significant **volatile role** in Martian gully formation [1,2,3,4]. Of the wall and peak gullies previously studied, volume loss averages ~60% [1,2,4]. Most volumes remain a loss when including assumptions about the pre-depositional surface. What remains is an adjustment for compression of the deposit.

Trends in volume loss may be used to infer a relative volatile content; as water in pore space sublimates, the ground compresses. Using the High Resolution Imaging Science Experiment (HiRISE) multitemporal and Digital Terrain Model (DTM) data of an ACA-type dune gully in Matara Crater (49.5˚S, 34.8˚E), we have mapped the gully at the highest resolution, tracked changes, and measured volumes. We have found several results that differ from our previus results for classic type gullies.

Given the connections between global gully distribution [5], climate and obliquity changes, and required melt conditions, in addition to morphologic observations, water as liquid, snow, or ice can best explain early gully formation on Mars. Classic ACA gullies on crater walls or peaks have been distinguished from dune gullies by morphology and formation mechanisms, particularly the role of liquid water. Dune gully formation is linked to CO_2-based processes [6,7,8], although water may still play a role [9]. Classic gullies are also active today [6,7]; however, this is likely due to modification processes. Linear dune gullies and terminal pit gullies have been shown to form from dry ice blockslides during early spring [6,8,10]. We have detected 'snowballs' appearing and disappearing on the Matara dune gully apron, forming linear trails. Seasonal frost activities appear to trigger channel changes within this Matara dune gully [9,11,12,13,14,15,16]. Vincendon 2015 derived equal probabilities for both H_20 and CO_2 being present at the Matara site associated with alcove and channel changes [15].

If ACA dune gullies form by wind-driven surface frost-supported oversteepening and in springtime a sublimation-driven collapse, we might not expect to find a volatile component to volume shifts downslope; However, if volatiles exist throughout the dune, a newly unearthed deposit could be expected to have a volatile loss component. Recent evidence predicts dunes on Mars may contain up to 40-50% water by mass [17].

Dune Gully Volume Results: We have measured the volumes removed and deposited of the ACA dune gully on the Matara Crater Megadune. When comparing the alcoves and upper channel to the apron deposit, the gully has under a 15% volume loss, which would be the lowest for any ACA-type gully we've previously measured on Mars. This apron volume is 1000% greater than the volume directly removed from the small surficial gully channels.

Conclusions & Considerations: The ~15% volume loss could mean several things, the most significant being indication of a volatile component throughout the dune. These results suggest that the Matara Megadune Gully initially formed by significant mass-movement, likely a destabilization triggered by wind, dune movement, and frost actions. The alcove channels visible today are surficial frost modifications and may not necessarily be attributed to dune gully initiation. A newly shadowed alcove and channel in the dune would provide a shelter or sink for frost activities. Ice exploiting such alcoves has been seen on Earth, in the analog sand dunes of the Victoria Valley, Antarctica [18,19]. While major channel changes downslope on the gully might at first glance appear fluvial, detailed examination using network diagraming in HiRISE images shows they instead resemble a mass movement with both gravity-formed alcove 'channels' and surficial discontinuous 'channels' where frost blocks or 'snowballs' slide. Compressionary volume is a factor when measuring gully and deposit volumes in geomorphometric studies, and there is likely a volatile component for both dune and classic ACA-type gullies; preliminary results indicate that either there is less volatile content to the original dune compared to traditional gullies, or that there are additional factors to be considered, such as our understanding of material densities, or exploitation of pre-existing hollows.

Acknowledgments: Research support was provided by SETI Institute's NAI Grant No. NNX15BB01, MRO HiRSE Co-I funds

References: [1] Gulick et al., (2014), *8th Int. Conf. on Mars,* Abstract #1490. [2] Gulick & Glines (2016), *DPS/EPSC,* Abstract #513.06. [3] Glines et al., (2016), *47th LPSC,* Abstract #2464. [4] Gulick et al., 2016, *GSA Rocky Mt.,* Abstract #276281. [5] Harrison et al., (2015), *Icarus 252*. [6] Dundas et al., (2012), *Icarus 220*. [7] Dundas et al., (2015), *Icarus 251*. [8] Diniega et al., (2013) *Icarus, 225*. [9] Vincendon et al., (2014), *8th Int. Conf. on Mars,* Abstract #1237. [10] Reiss et al., (2010), *Geophys. Res. Lett. 37,* L06203. [11] Diniega et al., (2010) *Geology, 38,* 1047-1050. [12] Dundas et al., (2016), *47th LPSC,* Abstract #2327. [13] Jouannic et al., (2014), *Geomorph. 231*. [14] Pasquon et al., (2016), *6th Mars Polar Sci. Conf.,* Abstract #6049. [15] Vincendon (2015), *J. Geophys. Res. Planets 120,* 1859-1879. [16] Núñez et al., (2014), *8th Int. Conf. on Mars,* Abstract #1486. [17] Bourke, (2005), *The Halstead Lecture, British Assoc. for the Adv. of Sci., Trinity College*. [18] Morris et al., (1972), *Astrogeol. 52.* [19] McGowan & Neil, (2005), *AGU,* Abstract #P13B-0145.

DETERMINING THE MAGNITUDE AND DURATION OF POTENTIALLY HABITABLE AQUEOUS ENVIRONMENTS ON MARS.
Virginia C. Gulick[1], Henrik I. Hargitai[2], Natalie H. Glines[1], J. Alexis Palmero Rodriguez[3], NASA Ames-SST/ SETI Institute, MS 239-20, *virginia.c.gulick@nasa.gov*, [2]NASA Ames-SST/NPP, MS 239-20, [3]Planetary Sciences Institute, Tucson, AZ

Introduction: Each new mission continues to erode the Viking era conventional wisdom that although Mars had an early earth-like climate, it has maintained the current cold desert climate that we see today for much of its history. Higher resolution imagers, imaging spectrometers, and other instruments have revealed a much more dynamic planet that has experienced aqueous activity periodically throughout its history, perhaps even into the modern day. Determining the timing, duration, and volumes of individual aqueous events is crucial to understanding whether any habitable environments could have persisted either in the past or until more recently.

To address these issues, we have undertaken detailed geomorphic and hydrologic studies of several sites where water processes were active early on, and continued to be active periodically throughout Mars history, with evidence that some sites remain potentially active today.

Navua Valles: Navua Valles are located on the inner NE slopes of Hellas basin and are adjacent to Dao Valles (located just to the SE) and to the SW of Hadriacus Montes and Tyrrhenus Montes. These drainages have eroded into volcanic plains that were likely emplaced during the formation of Tyrrhenus and Hadriacus Montes, and terminate in Hellas basin.

We [1,2,3,4] have mapped, in detail, the drainages and surface terrains in this region and have documented at least five major episodes of fluvial activity at a confluence of channels within the Navua B system which intersect and erode into previous channels suggesting that significant periods had elapsed between each event [3]. Initial discharges in episode 1 were ~10^4 m^3/s and steadily increased through episodes 2-4 to a maximum ~5 x 10^5 m^3 /s before declining to several 10^4 m^3/s by episode 5. The terrains on which these channels episodically formed, range in age from the Noachian (3.7Ga) to the late Amazonian (~0.1Ga) [4].

Navua drainages formed discontinuous morphologic patterns similar to terrestrial fluvial systems in volcanic terrains. These patterns form a repetitive sequence from source to sink of V-shaped valleys eroding into bedrock, followed by broad channels and valleys in alluvial material. Drainages then transition into alluvial deposits where the flow presumably infiltrated into the subsurface only to reappear again downstream in a steeply sloping segment consisting of a narrow v-shaped shaped channel eroding into bedrock. This sequence repeats until the drainages terminate on the basin floor of Hellas. We have also identified several locations within the Navua Valles where water likely ponded forming possible paleolakes. We have identified at least13 paleolake locations within the Navau Valles with volumes ranging from 1.5 to 1356.5 km^3 and depths ranging from several 10s of meters to over 1 kilometer [5]. Given the long time span over which fluvial activity was periodically active, and the possible association of this activity to volcanic/magmatic hydrothermal systems, these paleolakes may have provided localized areas of habitable environments that may have been connected by shallow subsurface aquifers throughout the Navua Valles drainage system.

Mars Tsunamis deposits: Using detailed geomorphic and thermal image mapping in the circum-Chryse and NW Arabia Terra regions of the northern plains, we have identified deposits that are consistent with formation by tsunami waves early in Mars geological history [5]. We have documented evidence for two enormous tsunami events possibly triggered by bolide impacts, perhaps a few million years apart. The tsunamis produced widespread littoral landforms, including run-up water-ice-rich and bouldery lobes, which extended tens to hundreds of kilometers southwards over gently sloping plains of the cratered highlands. Additionally, we identified evidence for wave retreat in the form of backwash channels on highland-boundary surfaces. As with terrestrial tsunamis, fossil and microbial communities potentially living in this northern ocean would have been swept up, transported landwards, incorporated, and preserved in the fine grained and icy lobes of the tsunami deposits. The preservation potential for near-surface evidence for ancient life makes these deposits a prime target for future astrobiological investigation.

Gullies and RSL: We have also been carrying out detailed mapping, morphologic and morphometric studies of integrated gully systems and spatially associated RSL using HiRISE DTMs (e.g., [7,8,9,10,11]). We find that these gullies are largely consistent with fluvial processes and that the spatially associated RSL may reflect either the last vestiges of water activity or could have played an integral role in gully formation.

Acknowledgments: Research support was provided by SETI Institute's NAI Grant No. NNX15BB01, MRO HiRSE Co-I funds, NASA's NPP and OSSI internship program.

References: [1] Hargitai & Gulick 2015, AGU Fall Mtg, EP51A-0900. [2] Hargitai & Gulick 2016, LPSC #1670. [3] Hargitai et al. 2016a & [4] 2016b, Icarus, submitted. [5] Hargitai et al 2017, ABSciCon. [6] Rodriguez et al., 2016. Sci. Rep. 6, 25106; doi: 10.1038/srep25106. [7] Gulick et al 2017, LPSC #1970, [8] Gulick et al 2014, 8th Mars Conf. #1490. [9] Glines & Gulick 2016, DPS/EPSC #513.06. [10],Hart et al 2010, LPSC, #2662, [11] Narlesky & Gulick 2014, LPSC #2870.

BUILDING A BIOSIGNATURE IMAGING, SPECTRAL AND THIN SECTION LIBRARY TO SUPPORT UPCOMING MARS SURFACE MISSIONS. Virginia C. Gulick[1], Paige Morkner[2], Jason Angell[1], Timothy Johnsen[1,3], Patrick M. Freeman[1,3], and Job Bello[4]. [1]NASA Ames/SETI Institute (NASA Ames Research Center, MS 239-20, Moffett Field, CA 94035, *Virginia.C.Gulick@nasa.gov*, [2]NASA ARC/OSSI, [3]UC-Irvine, , [4]UC- Santa Cruz, [5]EIC Laboratories, MA.

Introduction: Identifying minerals, organics, and potential biosignatures within individual rock and sediment samples is an important part of both terrestrial field and planetary surface exploration studies. To help with this effort, we are building a library of spectra, images, and thin sections of the biosignatures and the rocks and minerals with which they are associated. We have been characterizing the samples in the lab using Raman spectroscopy at two different laser excitations, 532nm and 785nm, close up imaging with constrained lighting conditions, and hand sample and thin section analysis. Samples are generally characterized as is, without grinding to powders, to retain the critical spatial and geologic context and alteration history of of the rock sample.

Locating Biosignatures in Rock: An important component of sample analysis on future missions will be location selection on the sample. Prepared samples are mostly homogeneous, but natural rock samples are more heterogeneous and non-uniform. Analysis of the travertine sample shown in Figure 1 revealed ß-carotene peaks in the more protected locations on the rock, while large flatter areas appeared devoid of spectral signatures pointing to life.

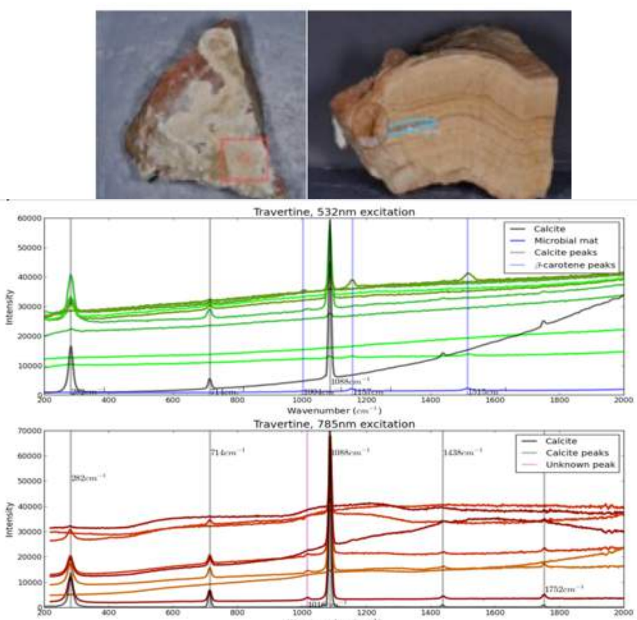
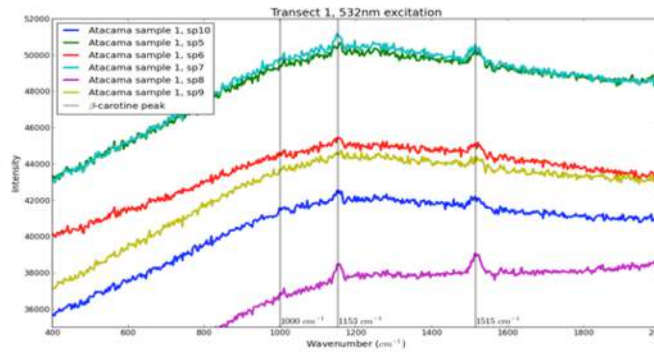


Figure 1: Travertine sample from Travertine Springs, CA. Image on left shows region where no biosignatures were identified. Image on right contained beta-carotene peaks in two protected regions circled. Plot shows several Raman spectra of the sample compared with β-carotene from a microbial mat *(blue) and calcite (gray) spectra. Distinct calcite peaks as well as distinct peaks in the sample demonstrate the ability to detect both minerals and biosignatures in the same spectra. Microbial mats provided by Lee Bebout (ARC-SSX).*



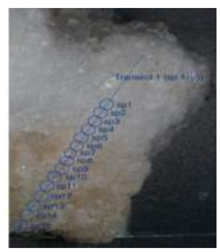


Figure 2: Spectra sp5-10 and sample showing transect 1, from which spectra were taken. Rock sample provided with β-carotene peaks highlighted, of Atacama salt rock by Alfonso Davila (SETI Institute).

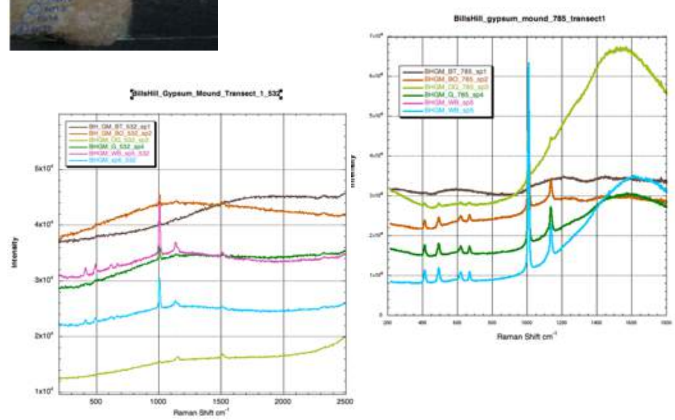


Figure 3: Vertical transect of Raman spectra through sample taken at Raman laser excitation 532nm (left) and 785nm (right). Spectra 5 and 6 show prominent gypsum peaks as well as beta carotene peaks (left). Spectra 3 shows distinct Spectra 3 shows distinct beta carotene peaks while those in spectra 2 and 4 are subtle. Spectral plot on right shows strong gypsum peaks. Image below shows transect of spectra; locations. Sample from Nancy Hinman, University of Montana.

The end result will be an online library of samples containing Raman spectral transects, close-up images, and hand and thin section analysis for the community's use. Ultimately, we plan to develop image and spectral analysis algorithms that can automatically classify the minerals and biosignatures in samples to support upcoming Mars missions.

NAVUA VALLES – HADRIACUS MONS – AUSONIA MONTES: CHANNELS, PALEOLAKES, KNOBBY TERRAINS AND MOUND FIELDS. H. I. Hargitai[1], V. C. Gulick[2], and N. H. Glines[2], [1] ARC-SST/ NPP, MS 239-20, henrik.i.hargitai@nasa.gov) [2]ARC-SST/SETI Institute, MS239-20; virginia.c.gulick@nasa.gov

Introduction: The Eastern rim of Hellas Basin contains dense drainage networks. The main system of Navua Valles is a precipitation-fed discontinuous channel that transported water from its source over long distances without additional sources, which is consistent with flood origin. [1] This is also analogous to ephemeral streams on Earth. The main Navua drainage system begins with valleys that cut into Noachian highlands and continues in channels that cut Hesperian volcanic terrains. In South Hadriacus Mons, sinuous pit chains may be surface manifestations of subsurface fluid pathways.

Lakes: We have catalogued 34 depressions and identified 19 potential open basin lakes, and 14 closed basin lakes. The identification criteria for these paleolakes included: inlet channels, terminal deposits (potential deltas), outlet channels, a bench, and a closed depression. We measured paleolake volumes in ArcGIS with MOLA in the method of Cooley [2] and determined the ages of the floors of the basins.

Knobby terrain: 10s to 100s m diameter knobs occur in the source areas of the drainage systems. Knobs are very rare at lower reaches. This setting suggests that the knobs and the channels are related, however, the knobs postdate the channel's formation because they are typically located on the erosional channel floors. Some of the knobby areas are crescent shaped on mountain slopes and are associated with arcuate ridges. Among the potential interpretations are pingos and spring mounds. Mud volcanoes and fumarolic mounds have similar shapes, however, despite the proximity to Hadriaca Patera, many of these features are located on nonvolcanic mountains or crater rims which make a glacial or spring origin more plausible.

Mound fields: Fields of closely spaced mounds occur in one, small region in several patches, at the lower reaches of the Navua Valles. The main area is within a large, degraded crater that is crossed by a channel and likely also hosted paleolakes, but similar mounds also occur on a nearby lobate impact ejecta. Similar mounds are common at higher southern latitudes zonally and are interpreted as patterned ground.

Summary. The Navua Valles likely formed in a paleo-climate episodically and locally rich in liquid surface water and ground water, possibly hydrothermal, consistent with other models of persistent or repeated effects of water throughout the geologic history in Eastern Hellas [3], Reull Vallis [4] and elsewhere on Mars [5-8].

Conditions here at the eastern rim of Hellas Basin locally enabled the formation of knobby terrain and mound fields, after the active phases of the channel and lake systems. These landscapes –channels-and-lakes, knobs, mounds – were active at different times and may represent different episodes in the history of East Hellas that have provided habitable environments in the same areas.

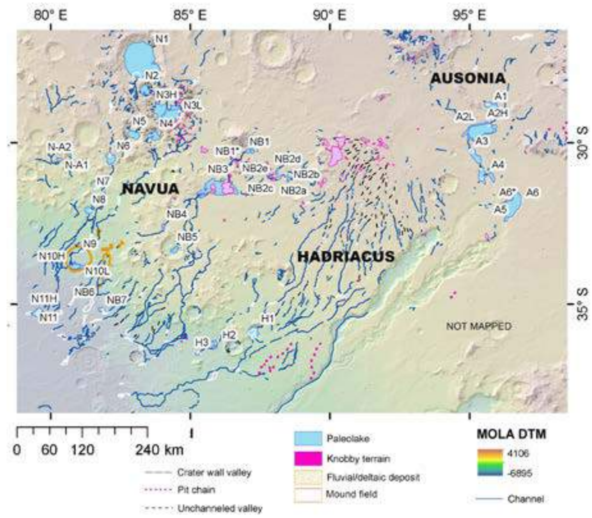


Fig. 1. Map of the Navua–Hadriacus–Ausonia area East of Hellas Basin. N: Navua Valles, H: Hadriaca Patera, A: Ausonia Montes.

Acknowledgement: This research was supported by a postdoctoral research fellowship awarded to H. Hargitai by the NASA Postdoctoral Program (NPP) at the Ames Research Center, administered by ORAU and USRA through a contract with NASA. V. Gulick and N. Glines are supported by MRO HiRISE Co-I funds and also by SETI Institute's NAI Co-I funds.

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BIOSIGNATURES IN THE CONTEXT OF LOW ENERGY FLUX. T. M. Hoehler, SSX

Many of the features that are thought of as biosignatures – including the mediation of chemical and physical processes with speed, specificity, and selectivity – result directly or indirectly from life's unique capability to mediate and direct energy flux. As such, it is important to consider the impact that differences in energy flux may have on the quantity and quality of evidence for life.

Earth differs from every other body in our solar system in the magnitude of biologically-usable energy flux into a liquid water environment. On a global basis, the capture of light energy into photosynthesis and the flux of chemical energy represented in the products of that photosynthesis (organic material + O_2) are about six and four orders of magnitude larger, respectively, than the flux of energy represented in geochemical sources. Our conception of what an inhabited world "looks like" and our intuition about how to search for life are based in this high-energy context.

Energy fluxes on worlds beyond Earth may be better approximated by the million-fold smaller flux provided to Earth's biosphere by geochemical sources. As a result, the nature, abundance, and quality of evidence for life that could be expected on an inhabited extraterrestrial world within our solar system may differ profoundly from that found on Earth. Understanding this potential difference in quantitative terms provides important context for the formulation of life detection strategies.

The influence of energy flux on biosignatures can be evaluated through reference to the two basic purposes into which life partitions energy flux:

(1) Life expends energy to sustain existing biomass in a metabolic steady state (metabolically functional but non-growing). The formal representation of this relationship in the traditional microbiology literature equates biomass directly with energy flux. The direct implication is that worlds having lower energy flux will have correspondingly lower potential to support biomass. Life detection strategies that directly target extant organisms should therefore be prepared to encounter average biomass densities that may be many orders of magnitude smaller than those found in most of Earth's surface environments

(2) Life expends energy to synthesize new biomass. An end-member case in which new biomass is created at the energy-limited rate and the corresponding cells are immediately destroyed (so that the energy partitioned to cell maintenance is minimized) establishes an upper bound on the rate at which biological material can enter a bulk global pool. For a specified bulk concentration $[i]$ of any particular biological compound, i, or for biologically produced matter overall, this synthesis rate, R_i, defines a characteristic time scale $\tau_i = [i]/R_i$. τ_i can be thought of as (a) the minimum time required for biosynthesis to yield a specific bulk concentration (e.g., a detection threshold) of i, and (b) the average residence time of i within a bulk pool when $[i]$ is held in steady state through a balance between biosyntheseis and attrition by physical, chemical, or biological consumption. τ_i becomes an important quantity in considering the potential utility of enantiomeric excess (as a product of homochiral biosynthesis) as a biosignature. Spontaneous racemization of amino acids acts to "erase" the signature of homochiral synthesis over time scales that may range from hundreds to hundreds of thousands of years, depending on temperature. For environments in which low energy flux translates to low rates of biosynthesis, including the synthesis of homochiral amino acids, amino acid residence times in pools having detectable concentrations may compare to or significantly exceed the time scale for racemization. This and similar consequences of long residence times should be considered in the formulation of life detection strategies based on detection of biologically-produced species.

Fluxes of biologically-useful energy on potentially habitable worlds within our solar system are, at present, not well constrained. Improving such constraint has the potential to inform priorities in the formulation and targeting of search-for-life strategies, based on the implications of energy flux for the abundance and quality of biosignatures overall, and in specific categories.

EUKARYOTIC STEROL BIOMARKERS: PRODUCTION AND FATE IN A LAMINATED MICROBIAL MAT

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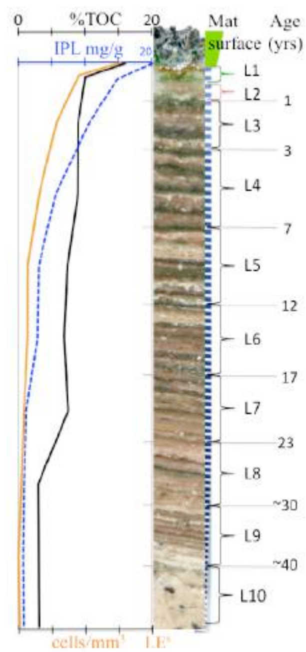
Introduction. The products of isoprenoid biosynthesis are numerous and serve as important biomarkers for many groups of organisms. Cyclic triterpenoids are particularly well preserved in sediments and provide an organic molecular record, which spans more than two billon years. Sterols and hopanoids are of central importance to the evolution of cellular membrane function [1]. Sterols are synthesized almost exclusively by eukaryotes and therefore are important chemical fossils for this lineage. The hopanoids are equally important as biomarkers for bacteria. Both the hopane and sterol carbon skeleton share a common biosynthetic source, squalene. This C30, acyclic, tail-to-tail triterpene is directly cyclized to hopane (an anaerobic process) in bacteria. However in eukaryotes squalene is first converted to an epoxide (oxygen-requiring) and then cyclized to a C30 proto-sterol, either lanosterol or cycloartenol. Further structural modifications require a total of eleven molecules of oxygen for synthesis of a C27 (cholesterol), C28 (ergosterol) or C29 (sitosterol) molecule [2]. The sterol biosynthetic pathway is well documented, and is a useful tool to understand the emergence and evolution of eukaryotes. Phylogenomic reconstructions from completed eukaryotic and bacterial genomes are now possible [3, 4] and continue to shed light on this evolutionary process. Understanding the role of micro-eukaryotes in sterol synthesis in microbial ecosystems provides a guide to bringing these two records together.

Photosynthetic microbial mats played important roles in the early biosphere. Cyanobacterial oxygenic photosynthesis has dominated global biological productivity for billions of years and had profound consequences for the trajectory of planetary evolution, particularly the evolution of higher plants and animals. Phototrophic mats have probably hosted and recorded many key evolutionary advances in the physiologies of mat-inhabiting microorganisms. Modern microbial mats are dynamic ecosystems. A challenge to interpreting the organic record is to understand the processes of synthesis, modification and deposition of organic biomarkers such as hopanoids and sterols in these microbial ecosystems.

Results. The flat-laminated microbial mats from Pond 4 of the Guerrero Negro saltworks are a well-studied ecosystem [5a,b], but limited information on the eukaryotic population or the expected sterol contribution is available. These mats are primarily composed of prokaryotic microbes and eukaryotes are relatively minor populations. Pennate diatoms of the *Nitzchia* and *Navicula* genera in the water column form a flocculent layer on the mat surface particularly in the summer months. Phylogenetic analysis of eukaryotic sequences have identified abundant nematodes of the *Monhysteridae* and *Rhabdolaimidae* families to a depth of 3.7 cm with some arthropods at the very surface (1-2 mm) [6]. The only photosynthetic group identified was a stramenopile *Nannochloropsis gaditana*.

We have collected a mat with underlying core from Pond 4 for lipid biomarker analysis over the full 8 cm depth. Initial analyses have demonstrated that lipid biomarkers sustained substantial diagenetic alteration throughout a major anoxic portion of the core. In the surface sample (1-2 mm depth), the major sterol was a fully saturated C27 molecule (cholestanol). Other major sterols in this layer are cholesterol (Δ5 monoene), 24-methylcholestanol, 24-methylcholesterol, 24-ethylcholestanol and 24-ethylcholesterol. The relative abundances of the three saturated sterols (C27, C28, C29) increased with depth. Small amounts of cycloartenol and several 4-methylsterols were also present in the surface. However, below the uppermost 4 mm of depth, the abundance of cycloartenol and methylated sterols increased dramatically. The 4-10 mm depth sample (anoxic) contained the highest level of proto-like sterol (4,4,14-trimethylsterols) normally associated with de novo sterol synthesis. Increased levels of sterones and other sterol diagenetic products with depth were also documented.



Guerrero Negro Pond 4 mat and core over 80 mm depth, showing analyzed sample intervals and approximate age. Black line total organic carbon (TOC), Blue total membrane acyl/alkyl lipid, Red calculated cell density derived from cell membrane lipid.

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PRODUCTION AND PRESERVATION OF LIPID BIOMARKERS BY IRON-OXIDIZING CHEMOLITHOTROPHS IN CIRCUMNEUTRAL IRON DEPOSITS. E. T. Kelly[1], M. N. Parenteau[2], M. B. Wilhelm[2], A. F. Davila[2],R. C. Quinn[2], L. L. Jahnke[2], F. Rull[3], J.A. Sanz-Arranz[3], A. Sansano[3], [1]SETI Institute, Mountain View, CA 94043 (Erin.T.Kelly@nasa.gov); [2]Space Science and Astrobiology Division, NASA Ames Research Center, Moffett Field, CA 94035; [3]Unidad Asociada UVA-CSIC CAB, Paseo de Belén 5, Universidad de Valladolid, 47011 VALLADOLID (Spain).

Introduction: Data collected by the Mars Science Laboratory (MSL) and Mars Exploration Rover (MER) missions from the surface of Mars have provided (and continue to provide) mineralogical insights regarding the redox cycling of iron. Recent observations made by the MSL *Curiosity* rover have revealed ancient martian sedimentary deposits that experienced a small degree of Fe(II) oxidation (and thus, less acidity generated), allowing more benign – low salinity and circumneutral pH conditions to persist [1, 2, 3, 4].

We are studying circumneutral iron springs in Yellowstone National Park as an analog for circumneutral iron settings on Mars. We are examining the production and preservation of lipid biomarkers by chemolithoautotrophs, which oxidize Fe(II) to power their metabolism. Microbial communities such as these could have been operating on early Mars.

Results: We analyzed the lipid composition of two samples of flocculent biofilm containing chemolithoautotrophs such as *Leptothrix* and *Gallionella* collected from iron seeps at Chocolate Pots Hot Springs in Yellowstone. We extracted the lipids using solvents, separated them using thin layer chromatography, and analyzed them on a gas chromatograph-mass spectrometer (GC-MS). The dried biofilms were also analyzed using Raman spectroscopy. The samples were analyzed with a European Space Agency ExoMars flight prototype (the RLS Simulator) at UVa-CSIC-CAB Associated Unit. The aim was to compare the types of information revealed by GC-MS and the Raman ExoMars instrument**.**

Fatty acids. The chemolithoautotrophs grew in temperature ranges of 10 to 37^{o}C. The major fatty acids found in the higher temperature sample indicated the sample was dominated by chemotrophic iron-oxidizers such as *Leptothrix* [5]. Diagnostic biomarkers of these sheathed bacteria included hexadecanoic acid, cis-9-hexadecanoic acid, and oxadecanoic acid, all of which were dominant in the sample [5]. While present in lower abundance, unsaturated heptadecanoic acids and iso-heptadecanoic acid were also present in the higher temperature sample, indicating the presence of sulfate reducing bacteria. Wax esters, a diagnostic lipid biomarkers for green nonsulfur filamentous anoxygenic phototrophs (FAPs) (*Chloroflexus* and *Roseiflexus* spp.), were absent from both samples. However, the diversity of unsaturated heptadecanoic acid and high relative abundance of cis-9-octadecanoic acid and 9,12 octadecanoic acid implicate the presence of cyanobacteria in both samples, with a stronger relative presence in the cooler sample. Poly-unsaturated eicosanoic acid and docosanoic indicate possible contamination of the sample with detrital plant material.

Alkanes. Both samples were dominated by straight chain hydrocarbons, with midchain branched alkanes present. Monomethyl alkanes and heptadecanes were present in both samples, though in higher relative abundance in the cooler sample. These compounds are considered biomarkers for cyanobacteria [6,7].

Surprisingly, the lipid biomarkers resisted the earliest stages of microbial degradation and diagenesis to survive in the Fe oxides beneath the mats, though hydrocarbon signatures did show signs of degradation. Understanding the potential of particular sedimentary environments to capture and preserve fossil biosignatures is of vital importance in the selection of the best landing sites for future astrobiological missions to Mars. This study explores the nature of organic degradation processes in Fe(II)-rich groundwater springs— environmental conditions that have been identified as highly relevant for Mars exploration.

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DATA SHARING IN ASTROBIOLOGY: THE ASTROBIOLOGY HABITABLE ENVIRONMENTS DATABASE (AHED) AND THE CHEMIN DATABASE. B. Lafuente[1], T. Bristow[1], N. Stone[2], A. Pires[3], R. M. Keller[1], R. T. Downs[3], D. Blake[1], C. Dateo[1] and M. Fonda[1]. [1]NASA Ames Research Center, Moffett Field, CA (barbara@sarrazin.org), [2]Open Data Repository, Gray, ME [3]University of Arizona, Tucson, AZ.

Introduction: Astrobiology is a multidisciplinary area of scientific research focused on studying the origins of life on Earth and the conditions under which life might have emerged elsewhere in the universe. NASA uses the results of astrobiology research to (1) understand and interpret planetary geology; (2) identify and characterize habitable environments and prebiotic/biotic processes; (3) interpret returned data from present and past missions; (4) develop spacecraft instrument concepts and evaluate science value; (5) evaluate future mission and instrument concepts prior to selection for flight. The Astrobiology Habitable Environments Database (AHED) is a central, high-quality, long-term data repository that aims to promote the field of astrobiology and increase scientific returns from NASA funded research by enabling data sharing, collaboration and exposure of non-NASA scientists to NASA research initiatives and missions.

Objectives: The main goal of AHED is the creation of a single repository that has the flexibility to deal with the diversity of astrobiology datasets, while allowing a degree of standardization necessary for more rapid database creation, fulfillment of data archiving mandates, as well as facilitating data discovery and mining through efficient search.

Characteristics: AHED is a collection of databases storing information about samples, measurements, analyses and contextual information about field collection sites, the instruments or equipment used for analysis, and the people and institutions involved in their collection. To tie these databases together AHED will be structured based on framework of templates. A published AHED master template will sit at the highest level of this scheme, defining metadata requirements of AHED subscribing databases. Curation groups and users will contribute to a library of AHED database templates that allow other scientists and researchers to make compatible, but flexible, database designs tailored to their datasets (Fig. 1). By conforming to the AHED master template, databases will be visible for data mining and search through the AHED web portal.

Infrastructure: AHED will provide public and open access to astrobiology-related research data through a user-managed web portal implemented using open-source software created by the Open Data Repository (ODR) [1]. At the same time, publication of the metadata associated with the AHED master template will allow other platforms and software to create datasets in a way that makes them discoverable and searchable by the AHED web portal.

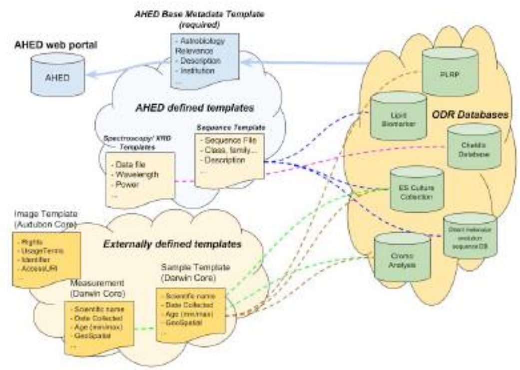

Figure 1. AHED framework of metadata templates.

AHED pilot - The CheMin Database: As a proof of concept, a database containing the raw and derived data products from the CheMin instrument [2] on the MSL rover *Curiosity* has been built (http://odr.io/CheMin). The database benefits from the capabilities of the ODR software to provide a very user-friendly interface (Fig. 2), where the data is easy to access using search tools, to visualize with a versatile graphing system, and to download in different formats. In the future, the database will also include online analytical tools to create high-level data products.

Figure 2. The CheMin database built in the ODR platform as part of AHED.

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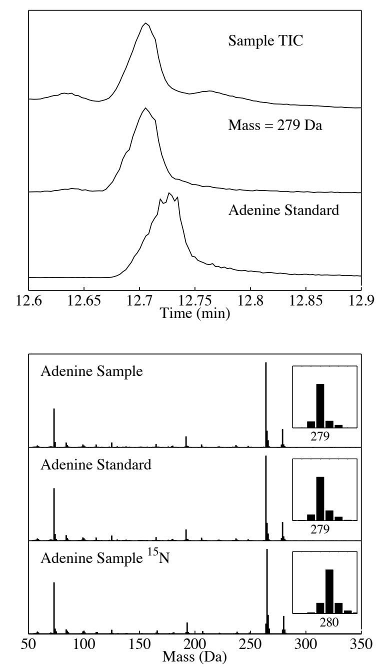
THE FORMATION OF NUCLEOBASES FROM THE IRRADIATION OF ASTROPHYSICAL ICES. C. K. Materese[1,2], M. Nuevo[1,2], and S. A. Sandford[1], [1]NASA Ames Research Center, Moffett Field, CA, USA, [2]BAER Institute, Petaluma, CA, USA

Introduction: Nucleobases are the informational subunits of both RNA and DNA, are central to all known terrestrial life, and they are generally conserved between species. The nucleobases can be divided into two groups based on the *N*-heterocyclic molecules pyrimidine (uracil, cytosine, and thymine) and purine (adenine and guanine) respectively. Importantly, to date, no experimental conditions have been determined that could produce pyrimidines and purines together, abiotically, in a terrestrial environment or an early terrestrial analog.

It has been proposed that organic materials produced in extraterrestrial environments may have been delivered to the primitive earth by comets and meteorites and may have contributed to the emergence of life [1]. Some nucleobases have been detected in meteorites [2-4] and their isotopic signatures may be consistent with an extraterrestrial origin [5]. Earlier work in our lab showed that it is possible to produce all of the pyrimidine group nucleobases from the UV-irradiation of pyrimidine in astrophysically relevant ice analogs [6-9]. Here we present our most recent work, which studied the formation of the purine group nucleobases under similar conditions [10].

Experimental: Gas mixtures of H_2O and/or NH_2 were premixed in ~2L bulbs. Because of its low volatility, purine was prepared separately in an evacuated sample tube that was attached directly to the vacuum chamber, and wrapped with heat tape and a thermocouple to control and monitor the temperature and deposition rate. The gas/purine deposition rates were calibrated to establish a mixing ratio of $1.0{:}0.1{:}10^{-3}$ for 3 component $H_2O{:}NH_3$:purine ices or $1.0{:}10^{-3}$ for 2 component H_2O:purine or NH_3:purine ices. Throughout the deposition, the ice mixtures were simultaneously irradiated with an H_2-discharge lamp emitting UV photons (Lyman α at 121.6 nm and a continuum at ~160 nm). After irradiation, samples are warmed to room temperature, and refractory residues are recovered for derivatization and analysis using gas chromatography coupled with mass spectroscopy.

Results: The UV irradiation of our ice mixtures resulted in the formation of refractory residues containing numerous functionalized purines. This included the nucleobases adenine (shown in the figure) and guanine, in addition to hypoxanthine, isoguanine, several aminopurines, and 2,6-diaminopurine. Overall, in both the most recent work, and in previous work, the relative abundance of photoproducts seems to be controlled by three factors in roughly decreasing order of importance: 1) the number of functional group additions required to form the product; 2) the type of functional group added; and 3) the position where the addition takes place. Finally, our results demonstrate that all biological nucleobases can be produced under the same astrophysical conditions.



Top panel: *(Top trace)* Total-ion chromatogram (TIC) of the residue produced from a UV-irradiated $H_2O{:}NH_3$:purine ice. *(Middle trace)* Single-ion chromatogram (SIC) of the same residue for mass 279 Da. *(Bottom trace)* SIC of the adenine standard (mass 279 Da). ***Bottom panel:*** *(Top trace)* Mass spectrum of the peak identified as adenine in the residue produced from a UV-irradiated $H_2O{:}NH_3$:purine ice. *(Middle trace)* Mass spectrum of the adenine standard. *(Bottom trace)* Mass spectrum of the peak identified as adenine in the residue produced from an irradiated ice containing $^{15}NH_3$.

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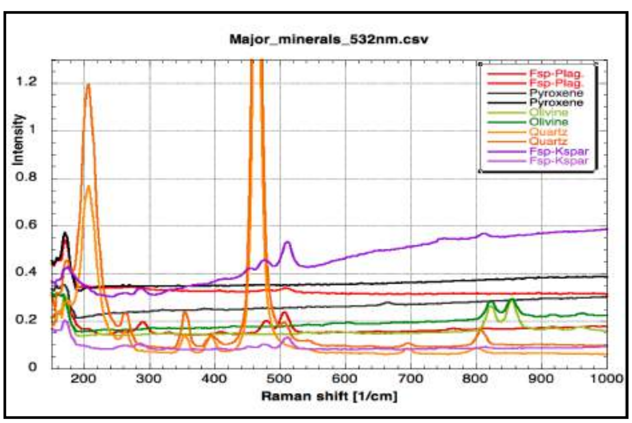
ROCK SAMPLE ANALYSIS AND RAMAN SPECTROSCOPY IN THE DEVELOPMENT OF AUTOMATIC CLASSIFIERS

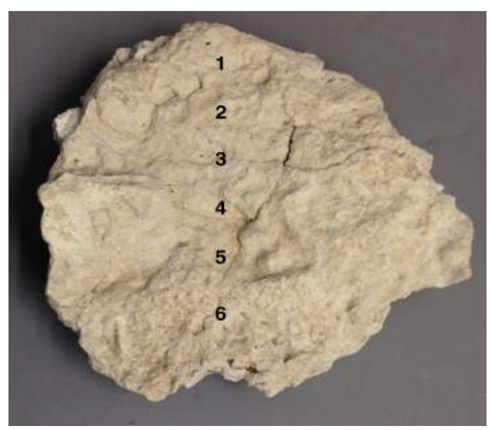
Paige Morkner (ARC-SST/OSSI), Virginia Gulick (ARC-SST/SETI), Patrick Freeman (ARC-SST/SETI/UCSC), and Timothy Johnson (ARC-SST/SETI/UC-Irvine)

Development of automated science analysis software to support the future exploration of the surface of Mars and other rocky solar system bodies is essential to minimize data retrieval times and enhance the science return of upcoming missions. We are using a variety of techniques to both analyze our samples and to obtain data for use as input into our algorithms. These include hand sample and thin section analysis of the rocks, sediments and minerals in our collection to use as ground truth, and Raman spectra, contextual and close-up imaging of each sample to obtain the data needed as input for our Raman spectral and imaging analysis (e.g., color, texture, grain size, etc.) algorithms. This data forms the basis for the continued development of autonomous rock and biosignature identification and classification software for future rover missions.

Dr. Gulick's team has collected well over 1200 rocks and more samples are added each year. Hand sample and thin section analysis of each specimen provides information such as the presence of biosignatures, mineral content and percentages, color, texture, grain size and any other identifying characteristics. We take Raman spectral transects of these samples along with a close-up imaging both of which can then be utilized within the algorithms developed by Dr. Gulick's team. The continual addition of rock samples, particularly those containing biosignatures provides a greater wealth of data necessary to continue developing and refining our algorithms. Thus, hand sample and thin section analysis are compared with our spectral data to identify and classify these samples and used as ground truth to algorithmic results to see how well the software is developing.



Raman spectra of major igneous rock minerals



Transect of spectra taken along rock

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Sugars and Sugar Derivatives in Residues Produced from the UV Irradiation of Astrophysical Ice Analogs

Michel Nuevo,[1,2,*] George W. Cooper,[1] and Scott A. Sandford[1]
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Carbonaceous chondrites contain a large variety of organic compounds of prebiotic interest, which include amino acids, amphiphiles, nucleobases, as well as sugar derivatives.**[1]** The presence of these compounds strongly suggests that molecules essential to life can form abiotically under astrophysical conditions. Among the sugar derivatives reported in the Murchison and Murray meteorites,**[1]** only one sugar (dihydroxyacetone) was found, together with a variety of sugar alcohols and sugar acids containing up to 6 carbon atoms, including sugar acid derivatives of the biological sugars ribose and glucose.

On the other hand, laboratory studies on the formation of complex organic molecules from the ultraviolet (UV) irradiation of simulated astrophysical ice mixtures consisting of H_2O, CO, CO_2, CH_3OH, CH_4, NH_3, etc., have shown that the resulting organic residues recovered at room temperature also contain amino acids, amphiphiles, nucleobases, as well as other organics of astrobiological interest such as urea. However, until very recently, no search for the presence of sugars and sugar derivatives in laboratory residues had been carried out. Several sugar alcohols, sugars, and sugar acids were first detected in residues produced from the UV irradiation of H_2O:CH_3OH ice mixtures.**[2,3]** Then ribose (the sugar of RNA) as well as several other sugars and sugar derivatives were identified in one residue produced from an H_2O:CH_3OH:NH_3 ice mixture.**[4]** In this work, we carried out a full, systematic search for sugars and sugar-related compounds in 15 organic residues produced from the UV irradiation of several H_2O:CH_3OH (2:1 and 5:1) ice mixtures. The resulting residues contain sugar alcohols, sugars, and sugar acids, with up to 5 carbon atoms, including ribose and several of its isomers.**[5]** Our results suggest that sugar alcohols are formed before sugars, which are themselves formed before sugar acids.**[5]** This is different from the formose reaction pathway proposed for the formation of ribose and other sugar derivatives in a residue produced from an H_2O:CH_3OH:NH_3 ice mixture.**[4]** Finally, the distribution of photoproducts in our residues appears to be different from that in meteorites, in which only the smallest sugar (dihydroxyacetone) was identified, while several sugar alcohols and sugar acids with up to 6 carbon atoms are present.**[1]** This suggests that the processes leading to the formation of the sugar derivatives in meteorites may be different from those in laboratory experiments.

References:

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POWERCELL 2° PAYLOAD ON EUCROPIS: A CYANOBACTERIAL FUEL SOURCE FOR IN SITU BIOLOGICAL PRODUCTION. Ivan Paulino-Lima; Griffin McCutcheon; Ryan Kent; Evlyn Pless; Antonio Ricco; Edward Mazmanian; Steven Hu; Bruce White; Dzung Hoang; Elizabeth Hyde; Earl Daley; Greenfield Trinh; Brett Pugh; Eric Tapio; Karolyn Ronzano; Charles Scott Richey; Lynn J. Rothschild; PowerCell team, Team Brown-Stanford, 2011; EuCROPIS team, Team Stanford-Brown, 2012.

Problem

Using synthetic biology, there are literally millions of biologically-produced capabilities in nature that could be accessed ranging from enhanced radiation tolerance to biological glues and production of drugs, but these microbial systems will need food to survive.

Concept

The use of photosynthetic microbes to feed a non-photosynthetic "production cell", as such co-cultures will ultimately provide the "power" for a synthetic-biology enabled mission.

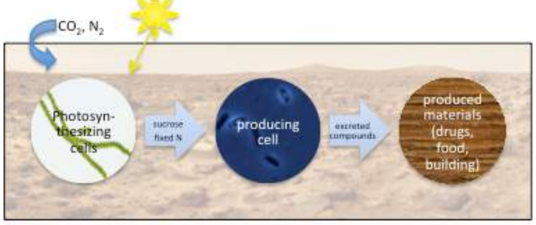
• In situ Resource Utilization photosynthetic organisms will only require sunlight, N_2, and CO_2

• The cyanobacterium, *Anabaena* sp., was engineered to secrete sucrose, to fuel "producing cells"

Benefits

The development of self-sustaining biologically-produced fuel source would have a fundamental effect on the development of facilities and infrastructure for synthetic biology in space.

The impact from this research will be paramount in opening the door for the use of synthetic biology off planet.



Payload

NASA's PowerCell payload, as part of the German Space Agency's (DLR's) Eu:CROPIS (Euglena Combined Regenerative Organic-food Production In Space) mission, will compare the effect of multiple simulated gravity regimes on basic processes required for synthetic biology in space including growth, protein production, and genetic transformation of the bacterium *Bacillus subtilis*. In addition, it will pioneer the use of a cyanobacterially-produced feedstock for microbial growth in space, a concept we call "PowerCell."

Satellite

The PowerCell experiment system will be integrated on the DLR's compact satellite as a secondary payload to be launched during the summer of 2017. In order to simulate the gravitational range of different celestial bodies, the satellite will establish an artificial gravity level in the 1.4% – 52% of terrestrial gravity range prior to conducting each set of biological experiments, with experimental results compared to ground controls.

Experiments

Experiments will be carried out in microfluidics cards with experimental progress measured through absorbance as detected by the LED-based optical system. Here we describe the ground studies that led to these experiments, along with a description of the experiment system hardware and its performance. The mission results will provide foundational data for the use and production of genetically engineered organisms for extraterrestrial missions.

Influence of Galactic arm scale dynamic on the molecular composition of dense clouds

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We study the effect of large-scale dynamic during the transition between diffuse to dense clouds on the molecular composition of the dense ISM. To do so, we follow the formation of dense clouds (on sub-parsec scales) through the dynamics of the interstellar medium at galactic scales. We use results from SPH simulations [1] from which we extract physical parameters that are used as inputs for our full gas-grain chemical model [2]. In these simulations, the evolution of the interstellar matter is followed for ~50Myr. The warm low-density interstellar medium gas flows into spiral arms where orbit crowding produces the shock formation of dense clouds, held together temporarily by the external pressure. We will show that depending on the physical history of each SPH particles, the molecular composition shows a high dispersion in the computed abundances even if the local physical properties are similar. This could account for the molecular diversity observed in the dense cores of the interstellar medium.

Références

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[2] Ruaud M., Wakelam V., Hersant F. MNRAS, 459, 3756-3767 (2016)

Ocean Biomolecule Explorer for Astrobiology. H.D. Smith[1] A. G. Duncan[2], C.R. Lloyd[2], L. Merrill[2], and J. Li[3]. [1]Space Science and Astrobiology Division, NASA Ames Research Center, Moffett Field, Ca 94035, 2.Retego Labs, Salt Lake City, Utah, 84341 and 3.Technology Division, NASA Ames Research Center, Moffett Field, Ca 94035

Introduction: The Ocean Biomolecule Explorer for Astrobiology is a life detection instrument suite designed towards an Ocean Worlds surface mission. The instrument suite relies on the modification of commercial off-the-shelf (COTS) instruments combined with newly developed biochemical analysis methods to paint a picture of the biological realm on Europa's Ocean World. This search for extant life relies on our understanding and assumptions of Europa, Enceladus, and Titan within the context of Earths biochemistry and known metabolic process. To gain an initial picture of Europa life, if present, the instrument suite is designed to detect a range of targets associated with life on Earth including basic biomolecules as well as the yield from complex metabolic process. The instrument suite will both detect the presence of extant life and provide insight into evolutionary process on the Ocean World.

The Instrument Suite utilizes fluorescence ,spectroscopy and colormetric enzyme assays to determine the habitability potiental in liquid samples. Combined with a nanotubes detection system to asses the environment in the gas phase. The Goal of the instrument is:

1. **Determine the chemistry of the Ocean.** – determine constituents within the brine. i.e. Salts, oxidants, CHNOPS to asses for habitability. Retego Labs Advanced Spectrometer and New Nose instrument.

2. Detect Amino Acids and determine chirality (enantiomer) – detect amino acids if present

3. Detect Biomarkers - Determine presence of biomolecules that are ubiquitous and unique indicating life and metabolic activity. For example nucleic acids (ubiquitous), and F420 (unique to methanogens), S reducers, etc.. Photosynthesis, chemosynthesis, Kreb cycle byproducts metabolism.

The engineering design of the instrument suite will be designed to fit within a portion of the resource allocation of the current best estimates of the Europa lander payload (26.6 Kg, 24,900 cm^3, 2,500 W-hrs and 2700 Mbits). The instrument package prototype proposed here will aim to achieve the following engineering parameters: 5 kg mass, $50cm^3$, 5 watts, and 4Mbits for suitability to propose as a Europa Lander payload instrument. The instrument package will be designed to ensure planetary protection is maintained and will function under the current Europa lander mission operations scenario of a two-year cruise phase, and 30-day surface operational phase on Europa.

The University Rover Challenge: An international rover competiton under simulated Mars Operational Conditions.

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Introduction: Since 2006, the Mars Society has sponsored the University Rover Challenge at MDRS in Hanksville, Utah. Each year undergraduate university teams design and build the next generation of Mars Rovers to compete in both science and engineering tasks by remotely operating a rover across the desert terrain. In the 10 years the competition has grown from 3 teams in the United States to more than 80 applicants from over 10 countries. In this presentation we provide an overview of the evolution of the competition, the advantages and limitations of the competition site, and the most common challenges teams face. For the most current information see. http://urc.marssociety.org

The Icebreaker Life Mission Plan. C. Stoker[1], C. McKay[1], A. Davila[1] , B. Glass[2], V. Parro[3], [1] Space Science Division, NASA Ames Research Center, Moffett Field CA, [2]Exploration Technology Division, NASA Ames Research Center, Moffett Field CA, [3]Centro de Astrobiología (INTA-CSIC), Madrid, Spain.

Introduction: The results from the 2008 Phoenix mission that sampled ground ice at 68°N latitude, along with climate modeling studies, indicate that the high N. latitude ice-rich regolith at low elevations is likely to be a recently habitable place on Mars [1].

Habitable Conditions Evidence: Ice was found within 3-5 cm of the surface. If warmer conditions occur, the ice could provide a source of liquid water. Phoenix found evidence for liquid water processes including 1) beneath 3 -5 cm of dry soil, segregated pure ice was discovered in patches covering 10% of the area explored, 2) calcite mineral was detected in the soil, 3) varying perchlorate salt concentrations were observed with higher concentrations seen in soil clods [2]. Carbon dioxide and nitrogen in the atmosphere, and nitrates in the soil along with reduced iron and perchlorate salts in the soil provide carbon and energy sources, and oxidative power to drive chemoautotrophic metabolism. Search for organics was a mission objective but perchlorate, discovered by Phoenix [3], would have oxidized any organic carbon during the heating step in the Thermal Evolved Gas Analysis (TEGA) instrument. Variations in solar insolation associated with changes in the season of perihelion on 25kyr timescales and obliquity variations on 125kyr timescales [4] cause warmer and colder periods in the N. polar region. The current epoch is colder than normal because orbital tilt is low and summer occurs at apehelion. As recently as 17kyr ago, when summer solstice was at perihelion, climate models show temperatures were warm enough to allow pure liquid water to form [5]. At orbital tilts > 35°, insolation is equivalent to levels experienced in Earth's polar regions at the present time. At 45° temperatures above -20°C can persist to 75 cm depth for durations long enough to allow microbial growth [6].

Terrestrial permafrost communities are an example of possible life in the ice-rich regolith. Studies in permafrost have shown that microorganisms can function in ice-soil mixtures at temperatures as low as -20°C, living in the thin films of interfacial water [7]. In addition, it is well established that ground ice preserves living cells, biological material, and organic compounds for long periods of time, and living microorganisms have been preserved under frozen conditions for thousands and sometimes millions of years[8]. Smilar biomolecular evidence of life could have accumulated in the ice-rich regolith on Mars.

The Mars Icebreaker Life mission [9] was proposed to Discovery in 2015 to search for evidence of modern life in northern plains ground ice on Mars, and future proposals are planned. The mission returns to the well-characterized Phoenix landing site with a payload designed to address the following science goals: (1) search for biomolecular evidence of life; (2) search for organic matter from either exogeneous or endogeneous sources using methods that are not spoiled by the presence of perchlorate; (3) characterize oxidative species that produced reactivity of soils seen by Viking; and 4) assess the habitability of the ice bearing soils. The Icebreaker Life payload hosts a 1-m drill that brings cuttings samples to the surface where they are delivered to three instruments. The Signs of Life Detector (SOLID) [10] uses immunoassay to search for up to 300 biomolecules that are universally present and deeply rooted in the tree of Earth life. The Laser Desorption Mass Spectrometer (LDMS) [11] performs broad search for organic compounds of low to moderate molecular weight that may be cosmogenic in origin or degraded biomolecules. The results are not impacted by the presence of perchlorate. The Wet Chemistry Laboratory (WCL) [3] detects soluble species of potential nutrients and reactive oxidants, providing insight into the habitability potential of icy soils.

The Icebreaker payload fits on the same spacecraft/ lander used by Phoenix. The mission plan that fits in a Discovery budget profile proves that a search for modern life on Mars can be performed for modest cost while conforming to planetary protection constraints.

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Mid-IR Spectroscopy of Perchlorates. D. P. Summers, R. C. Quinn, V. C. Gulick, and Jason Angel.

The presence of perchlorates and other oxyhalides on Mars needs to be considered in the context of habitability and the preservation of biomarkers on Mars. Zent and McKay [1], suggested that "activated halides" could play a role in the oxidizing nature of martian soils. More recently, perchlorate was recognized by researchers as one of a number of oxidized salts present in the Atacama Desert [2, 3], but the roles of perchlorate and perchlorate formation as they may relate to the presence and preservation of organics on Mars have not been thoroughly explored. Following the discovery of perchlorate on Mars during the Phoenix Mission [4], products formed by perchlorate radiolysis were shown to reproduce the results of the Viking Biology Experiments [5]. The reactive intermediates and secondary products that are formed in processes that generate and decompose perchlorate may have significant impacts on the chemistry of surface materials, soil habitability, preservation of biomarkers, and the ability to analyze organics.

The recent detection of perchlorate, and likely other oxychlorine species, in the subsurface (~5cm) within ancient sedimentary deposits sampled by MSL [6] indicates that the formation and presence of reactive oxidants on Mars may not be limited to UV-processes in the regolith, as previously suggested [1, 7]. Results suggest that there are major spatial variations in oxidant distributions, even for samples collected in very close proximity (e.g., MSL John Klein and Cumberland samples). Data indicate the presence of different types of perchlorates, other oxychlorine species, and possibly other oxidants including ROS [6]. Suggesting that the chemical alteration of geological materials is more extensive and complex than previously thought.

To support the detection and characterization of perchlorates on Mars, K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, and Al^{3+} perchlorate salts were studied to provide spectral data for detecting and characterizing their possible presence. To extend earlier work to the mid-IR [8], they were characterized by IR microscopy (Figure 1) and Raman spectroscopy (Figure 2). This included anhydrous samples, samples with adsorbed water, and samples exposed to humidity during analysis to observe changes. With divalent cations, changes during hydration of peaks due to water at ~1600 cm^{2-} and ~5100-5200 cm^{2-} showed evidence of different peaks and different states (see Figure 1).

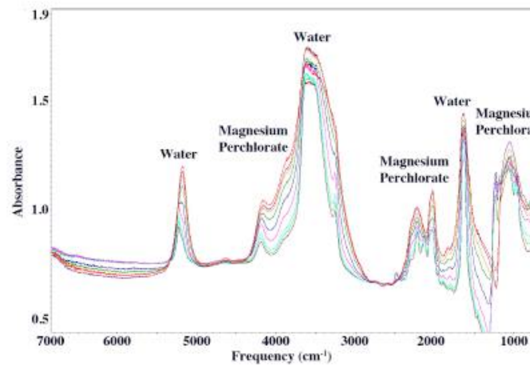

Figure 1. IR spectra of a particle of magnesium perchlorate as it takes up water from the air.

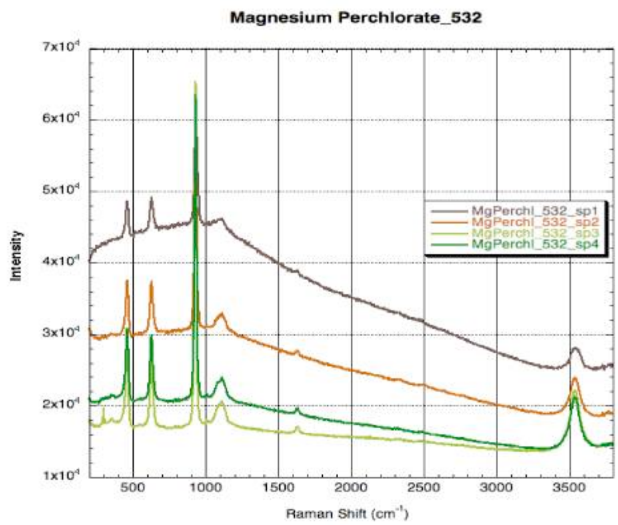

Figure 2. Raman spectra of magnesium perchlorate using a laser excitation of 532nm. Peak near 3500cm^{-1} is due to chemically bound water of hydration.

Acknowledgements: The research described in this abstract was funded by the NASA Astrobiology Institute.

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IONIZING RADIATION IN THE SUBSURFACES OF ENCELADUS AND EUROPA: IMPLICATIONS FOR THE SEARCH FOR EVIDENCE OF LIFE.

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Introduction: _Enceladus_' and _Europa's_ subsurface oceans are possible abodes for life, but they are inaccessible with current technology. At Enceladus, however, icy particles are expelled from the sub-surface by geyser-like jets and are present in the moon's exosphere as well as in the Saturn's E-rings. The particles might provide direct access to materials originated from shallow pockets of liquid water within the ice shell, or even the subsurface ocean itself. These would be ideal locations to search for possible evidence of life, such as organic biomarkers. In Europa, the best-case environment for such evidence would be the orbital "upstream" hemisphere, shielded from much of host Jupiter's electron radiation belt flux, but where galactic cosmic rays (GCRs) still interact with surface materials. GCRs that strike icy moons' surface produce ionizing radiation in the form of high-energy electrons, protons, gamma rays, neutrons and muons. The effects of ionizing radiation in matter always involve the breaking of chemical bonds and the creation of free radicals. Both can alter organic biomarkers over time. Using ionizing radiation transport codes, we recreated the most-favorable radiation environment on the surface of Europa and Enceladus, and evaluated its possible effects on organic biomarkers within the ice shell.

We performed a full Monte-Carlo simulation of the nuclear reactions induced by the GCRs hitting the icy moon's surface using the GEANT-4 toolkit for the transport of particles through matter using a computational domain comprising 20 m of water ice. We have also simulated the radiation environment within icy particles, which are a few microns across.

Results: Our preliminary results show that the flux of ionizing radiation caused by GCR in a large ice volume as a function of depth in Europa's and Enceladus's ice shell is similar in magnitude to that estimated for the surface on Mars for pure ice. The flux of ionizing radiation can be converted into dosage at the molecular level using a "biologically-weighted" scheme. The derived radiation dose at 1 meter depth is ~0.3 Gy/year. Further work will take into account the Jovian and Saturnian radiation environments. However, previous work has shown that this radiation environment is less penetrating (decimeters). Finally, the nuclear cascade radiation environment in micron ice particles is very minimal. This is due to the small physical size of the ice particles and high kinetic energy per nucleon carried by the GCR. The effects of radiation belt electrons and ions is likely to be greater.

Discussion: Our results indicate that dormant microorganisms within the top 1 meter of regolith of the most *favorable hemispheres of the icy moons* would likely be killed in less than 150 kyr due to cumulative radiation damage. This survival time applies to radiation-resistant organisms such as *Deinoccocus radiodurans*. More importantly, organic biomarkers such as complex biomolecules (i.e. proteins) would be severely damaged by ionizing radiation within the top 1 meter in time scales of 1-2 million years. For example, the immunoresponse (an indicator of molecular integrity) of several biological polymers, including proteins and exopolyssacharides, diminishes by >90% after exposure to 500 kGy of electron radiation, equivalent to 1.6 Myr exposure at 1 meter depth in Europa's and Enceladus' ice-shell. Smaller organic molecules of astrobiological interest, such as amino acids, would also be affected by ionizing radiation. The D_{10} value for the radiolytic decomposition of glycine and alanine is reached after exposure to 20-30 MGy, equivalent to 60-90 Myr exposure at 1 meter depth in Europa's ice shell.

Our results indicate that even the best-case Europan and Enceladus radiation environment, created by GCRs alone, biomolecules would be heavily damaged quickly. Complex organic molecules, including biomarkers, could become heavily processed in the top 1 meter in time scales >1 million years, and smaller organic molecules such as amino acids could be severely damaged in time scales <100 million years. Model age estimates of Europa's surface range between 60 and 100 million years, which would place serious constraints on the preservation of organic biomarkers near the surface. However, age estimates of Chaos regions are lacking, and might be critical to the success of life detection missions. Hence, a better constraint on the surface age of Chaos regions on Europa might be critical to the success of life detection missions. If surface ice deposits are fresh and young, biomarkers may be preserved. For this reason it is important to confirm the existence of putative plumes of icy particles at Europa, such as exist at Enceladus. Such fresh particles, very recently erupted from deep liquid reservoirs, might be relatively undamaged and more likely to bear intact biomarkers. On the other hand, such particles are exposed to the full brunt of the Jovian and Saturnian radiation environment.

Mars Drill Bio-barrier Study: Design and Surface Coatings

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Introduction: The proposed Icebreaker Discovery Class Mission [1] plans to land and drill one meter below the Martian surface near the Phoenix Lander, a site that has shown evidence of previous habitability [2]. Icebreaker (Fig 1) will search for life by collecting and analyzing for biosignatures, markers of prior or present life. A mission science risk, is earthly organic material on the drill (or the sample handling system) may render a false-positive result or uncertain results. Icebreaker is a category IVb & IVc mission (NASA's Planetary Protection Policy NPR 8020 12D), where elements contacting the subsurface (e.g. the drill string) must be sterilized to prevent forward contamination, and elements contacting samples must be cleaned to mitigate false-positive results. Thus, prior to launch, the drill is cleaned, placed in a bio-barrier box, sterilized, and fixed on the Lander deck for the journey to Mars. Upon landing, the box is opened and drill extended.

Objective: A study was undertaken in mid-2016 of the Drill Bio-barrier design, and in particular surface coatings that limit microbial growth. Modifications to the drill were also investigated to decrease contamination risks. This abstract will focus on surface treatment evaluation.

Method: Independent Bio-barrier designs were compared and ranked in terms of: design complexity, fit to drill and Lander, mass, and volume. Surface treatments that limit microbial growth in the bio-barrier and on the drill were evaluated. Drill prototypes were inspected to evaluate modifications to decrease contamination risk.

Results and Discussion: A rigid/isometric design of metal constituent was chosen as the best design fit for the bio-barrier. Issues arose when considering polymer and ceramic-based options due to their respective mechanical properties that imposed risk factors that could prevent the bio-barrier from opening, as well as their options for surface modifications. Three features were identified as desirable for the surface modification of the chosen material: anti-adhesive, anti-microbial, and anti-abrasive. Anti-adhesive would prevent the attachment of microbes, anti-microbial would prevent their growth, and anti-abrasive properties would decrease the spread of microbes and biofilms (extracellular polymeric substances). Current research leans towards the use of anti-microbial, abrasion-resistant coatings that incorporate metal nanoparticles – in particular silver and copper - into different substrates [3]. Copper electroplating poses issues for adhesion to metal alloys of titanium or stainless steel, however research into the use of plasma when applying these anti-microbial materials to relatively strong metals has been demonstrated [4].

Conclusion: Anti-microbial metals being incorporated into the surface of the design material should impact microbial growth and contamination on structures inside a bio-barrier. The research in this field is pressing towards introducing these ions into polymer substrates to allow an anti-adhesive and anti-abrasive properties.

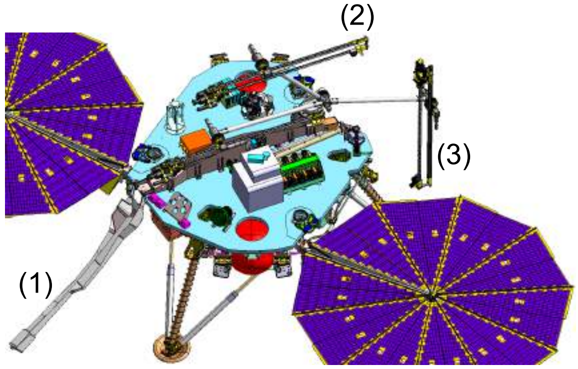

Figure 1: Lockheed Lander with: (1) Drill bio-barrier (opened), (2) Drill being deployed, (3) Deployed (Honeybee Robotics) Drill [5],

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CRITICAL ASSESSMENT OF BIOSIGNATURE DETECTION WITH RAMAN SPECTROSCOPY ON BIOLOGICALLY LEAN SOILS. M.B. Wilhelm[1,2], A. Sansano[3], J.A. Sanz-Arranz[3], P. Sobron[4], F. Rull[3], A.F. Davila[1], [1]Space Science & Astrobiology Division, NASA Ames Research Center, Moffett Field CA 94035 (marybeth.wilhelm@nasa.gov), [2]Georgia Institute of Technology, [3]Unidad Asociada UVA-CSIC Centro de Astrobiología, [4]SETI Institute

Introduction: The Mars2020 and ExoMars rovers will each carry a Raman Spectrometer to Mars to identify and characterize minerals, organic compounds and biomarkers. The Raman Spectrometer was selected in part due to its operational simplicity—it analyzes samples at a distance, non-destructively and with minimal or no sample handling. However, operational simplicity comes at a performance cost, and the limit of detection (LOD) of the Raman Spectrometer will be lower than other analytical systems such as GC/MS. We undertook a project to critically evaluate the capability of the Raman Spectrometer to detect organic compounds and biomarkers in organically and biologically lean natural samples from the Atacama Desert.

Raman library and natural samples: First, we built a Raman spectral library of hydrocarbons and lipid biomarkers using analytical standards. Analytical standards were analyzed with three different Raman Spectrometers (532nm, and 1064nm-FT-Raman) to get the best spectra as possible. Analyzed standards included short-chain and cyclic hydrocarbons expected on Mars from abiotic sources, as well as the main classes of lipids biomarkers found in Atacama soils and other natural samples. We also selected a suite of Atacama soils samples with one of the lowest biomass contents anywhere on Earth, assumed to be a "best case scenario" for samples containing evidence of life on Mars. Lipid biomarkers (~ppb concentrations), amino acids (ppb), and proteins/peptides (ppm) have been thoroughly characterized in these samples in the laboratory [1], and as such, these samples provide an excellent baseline to test flight unit performance.

Analyses with the ExoMars flight prototype: To be as mission relevant as possible, Atacama soil samples were be analyzed using the same protocols planned for the ExoMars mission. We used the ExoMars RLS Simulator at UVa-CSIC-CAB Associated Unit. This Simulator allows to perform several scientific key experiments under conditions similar to those of the RLS on the ExoMars rover. It also provides the means for the definition and development of the necessary algorithms for the automation of the instrument measurements [2]. Powdered soil samples were placed on a refillable container similar to ExoMars' sample distribution carousel serving the RLS, which can be emptied and reused for new analyses just as during mission operations. The RLS, in its automatic mode, then analyzed a set of at least 10 points in each sample, with a 50 microns spot size and an irradiance level of 0.6–1.2 kW cm–2 with a 532 nm continuous wave (CW) laser [3].

Results: Biomarker standards of interest for astrobiology, such as lipid and hydrocarbon biomarkers, have distinct Raman spectra that can be used as diagnostic for the presence of these compounds in natural samples. The ExoMars RLS Simulator instrument detected organic carbon (only C-C bonds) in soil samples from the hyperarid core of the Atacama Desert (Fig. 1), including a stratigraphic sequence that reflects a change in environmental conditions from wet-to-dry. However, the Raman instrument failed to identify the most abundant lipid and hydrocarbon biomarkers (e.g. C16:0 and C18:0 fatty acids) known to be present in the same soil samples at ppb concentrations

Preliminary conclusion: Raman spectroscopy could be a suitable (relatively simple operations, no sample contact, no sample prep…) diagnostic tool for the presence of organic compounds in natural samples. However, current prototypes might not be capable of detecting biomarkers present in complex natural samples (soils, sediments, regolith…) if present at concentrations equivalent or lower to the biologically leanest environments on Earth.

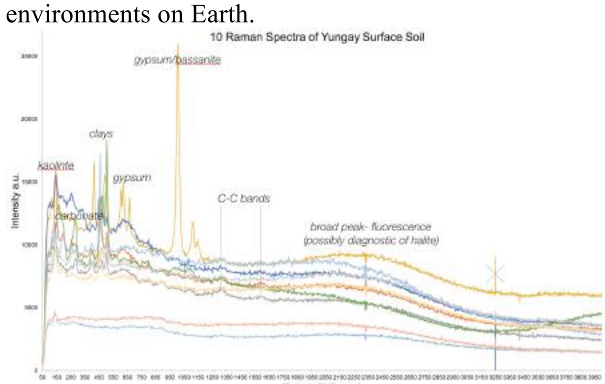

Figure 1. Data from ExoMars RLS Simulator, 10 random points on bulk soil from the Atacama Desert. Spectra yielded a good mineralogical snapshot. Organic carbon (C-C bonds only) was detected in about half of the spectra collected. No specific biomarkers were observed.

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Development of a new chiral-sensitive photothermal microscope: Towards a search for biosignatures in extraterrestrial environments

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Search for life in the extraterrestrial environments, such as on Mars, Europa, and Enceladus, has gained much more attention and importance. For detecting signatures for living or past life forms, homochirality in organic molecules, such as amino acids and sugars, is one of the promising biosignature. For detections of the enantiometric excesses of target biomolecules, the techniques of chiral separation (i.e., chromatography, electrophoresis) have been commonly used. However, chromatographic separation techniques usually require complicated sample preparations, and the specific target molecules have to be kept in mind to optimize the measurements. For the detection of unexpected biosignatures in the extraterrestrial samples, a robust chiral detection method with ultrahigh-sensitivity is badly desired.

Here, we have constructed a prototype of circular dichroism–thermal lens microscope (CD-TLM). This CD-TLM method is based on the photothermal lens effect combined with circular polarized light excitation. It is a non-destructive analytical method with ultra-high-sensitivity upto sub ato-mol level. It requires only small amount of samples around nano/pico liter levels. This CD-TLM method would provide a new complementally tool to the search for homo-chiral biosignatures from trace amount of samples in future solar system explorations.

GULLY DISTRIBUTION AND THE ANALYSIS OF TWO GULLIES IN HALE CRATER, MARS USING HiRISE DTMs.
Sean Corrigan[1,2], Virginia Gulick[2], Natalie Glines[2] and Patrick Freeman[2]. [1]Colgate University, [2]NASA Ames Research Center/SETI Institute, MS 239-20, Moffett Field, CA 94035. *Virginia.C.Gulick@nasa.gov*.

Introduction: Gullies are erosional slope features characterized by their morphology - consisting of an erosional alcove on top, an apron of deposited material on the bottom, and a channel in between - as described by [1]. They appear to be originally formed by flowing water processes, rather than dry mass wasting [1, 2].

Here, we report the general characteristics of Hale Crater gullies and a detailed study of two gully systems using HiRISE Digital Terrain Models (DTMs). One is on its central peak and the other on its SW crater slope. Our findings support the formation of gullies on Mars depends at least partially on the presence and flow of liquid water.

Individual Gully Measurements: We used HiRISE DTMs DTEEC_012241_1440_012663_1440 and DTEEC_014153_1430_14008_1430 to measure in detail two gully systems. We produced longitudinal and cross-sectional profiles of gullies A and B. These profiles are used to calculate various morphometric parameters that provide clues to the processes involved in gully formation and modification. We determined both gully and apron deposit volumes using two methods.

Hale Crater Gully Mapping. We produced detailed maps of the Gully A system, including tributaries, drainage basin area and apron extents using HiRISE orthoimage ESP_012241_1440_RED_A_01_ORTHO.

We used a CTX image mosaic of Hale Crater to identify and record the locations and aspects of all gully-like forms. Straight lines were drawn from the gully origin to the start of the apron. We recorded MOLA elevation, slope, and aspect values from the midpoints of these lines.

Results: The volumes of Gully Systems A and B were calculated using the two methods.

Volumes	Transect Method	ArcGIS Method
Gully A	7.20 x $10^4 m^3$	6.77 x $10^4 m^3$
Apron A	5.7s7 x $10^4 m^3$	2.51 x $10^4 m^3$
% Missing	19.9 %	62.9%
Gully B	2.80 x $10^6 m^3$	2.89 x $10^6 m^3$
Apron B	5.04 x $10^5 m^3$	4.40 x $10^5 m^3$
% Missing	82.0%	84.8%

Table 1: Gully volumes and associated debris apron volumes of two gully systems in Hale crater. "% missing" is the percentage of the eroded gully volume material that is not present in the apron.

Both gullies have a concave longitudinal profile. Gully A has a complicated, integrated network. The streams along the gully system contain numerous tributaries, and many of the paths are sinuous. The channels on the debris apron form a complicated distributary network.

Hale Crater Gullies: The total number of gully-like slope features in Hale Crater is 1,953. Calculation of the aspects of all the gullies shows that about 83% of them face between 112.5˚ and 247.5˚, clockwise from north. These angles correspond to southeast and southwest, respectively.

These results agree with earlier studies that concluded gullies in this region tend to form on pole-facing slopes [1,4,6,7]. In addition to aspect, we calculated the slopes on which gullies formed. The average slope is 14.2˚ with a standard deviation of 6.5˚, lower than slopes estimated previously [4], which may be the difference between measuring the hillside slope versus only the upper channel and alcove.

Conclusions:

Volume Measurements of Gullies A and B. The differences between the gully volume and the apron volume are significant and require an explanation other than dry gully formation processes. The results of this study point to an explanation where water is important in the formation of these gullies. As with our previous studies, we find a large disparity between the gully and apron volumes and conclude that the missing apron volume may reflect the volume of water and other volatiles involved in the gully formation [10, 11]. These measurements do not say much about fate of the water and volatiles, as water, for example, can infiltrate into the subsurface, can evaporate into the atmosphere, freeze, or flow out of the system.

Longitudinal Profile Measurements. The concave profile of the center streamline is consistent with fluvial processes [7] as dry processes would likely form straight or convex profiles.

Drainage Maps. The complicated, integrated system shown in Gully A's drainage maps indicates that the gully formed at least partially by water. Dry processes tend to form singular, straight paths, rather than such integrated networks [11, 12].

Hale Crater Gullies. As expected [7], 83% of gullies in Hale Crater formed on south-facing pole-ward slopes. During the day, these slopes are more shadowed than north-facing slopes and likely provide a lower-temperature environment in which water ice is more likely to accumulate and be preserved.

Acknowledgements: Research was completed while S.C. was a SETI Inst. REU summer intern under the mentorship of V. Gulick. Gulick, Glines, and Freeman were partially supported by both Gulick's HiRISE Co-I and SETI NAI Co-I funds.

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GEOMORPHIC ANALYSIS OF INTEGRATED GULLY SYSTEMS ON MARS. Virginia C. Gulick[1,2], Natalie H. Glines[1,2], Patrick M. Freeman[1,2], Paige Morkner[4], Carly Narlesky[5], Sean Corrigan[6]. [1]NASA ARC-SST/SETI Inst., MS 239-20, [2]NASA ARC-SST/SETI Inst., [3]UCSC [4]NASA ARC-SST/OSSI [5]MBK Engineers, Sacramento, CA; [6]SETI Inst. REU/Colgate University. Virginia.C.Gulick@nasa.gov.

Introduction: The formation of gullies during Mars' more recent geological history has remained an active topic of debate for nearly the past decade and a half. Several global studies have provided information on their distribution and have inspired numerous hypotheses to explain gully formation (for a recent review see [1]). However, the variety of gully morphologies present on the surface of Mars has led many to conclude that gullies likely formed by multiple processes. Therefore to better understand the relative importance of various gully formation and modification processes, we have been conducting detailed morphologic and morphometric studies of gullies in a variety of environmental settings on Mars using HiRISE images and DTMs. Here we present some of our results from our research of several integrated gully sites as well as two dune gully systems.

Drainage Maps: Using HiRISE and CTX images, we produced detailed drainage maps of gullies on the slopes of Corozal crater, Moni crater (located along the southern floor of Kaiser crater), and Palikir Crater (located on the floor of Newton crater), on the central peak of Lyot crater (Fig. 2b, 3b), a gully system on the central peak of Hale crater (Fig. 3a), and one on the western rim of Hale crater, on the western wall of Sisyphi Cavi, in addition to the large Matara dune gully, and a gully located on the Kaiser dunes for comparison.

The resulting drainage maps reveal that the gully systems on the crater slopes and on the central peaks form complex, highly integrated, tributary systems in the source regions, incised channels in the mid-sections and channels with levees on the aprons when viewed close up at HiRISE resolution (~25cm/px). Such morphology is consistent with water erosional processes operating within a fluvial system. Integrated drainage patterns are characteristic of water erosion and fluvial activity. Additionally, we also note that many of the debris aprons are heavily dissected by channels with levees. This is consistent with fluvial activity where flow transitions from confined to unconfined and is associated with a sudden decrease in slope. As flow spreads out on the apron, water infiltrates and evaporates, sediment concentration increases and flow behaves more like a debris flow.

DTM analysis: In our previous [2-9] and current studies, we find that most gullies that we've studied have concave profiles. Deviations in the longitudinal profiles generally correlate to areas where the gullies have incised through stratigraphic layers.

We also note several interesting correlations/ associations in our study locations. When we compare the individual gully volumes with their associated debris aprons, the gully volumes are significantly larger than the apron volumes. This is a finding that we initially reported in [6] and have attributed the discrepancy in volumes to the potential water, ice, and volatile volumes initially contained in the system and that were lost to the system during gully formation. In comparing the resulting volume discrepancies in the two dune gullies to the crater gullies, we see that the apron volumes are generally similar or larger than their gully volumes.

Gullies associated with RSL? In mapping the gully drainage systems in detail at HiRISE resolution, we also noted a spatial association with RSL in some locations particularly in the Palikir and Hale study sites. RSL are often found either in the tributaries of these integrated systems or in adjacent regions. Therefore, this suggests that RSL may play a role in initiating gully formation and/or mark the last vestiges of water activity in these locations.

Summary and Conclusions: Studying gully systems in a variety of environmental settings at HiRISE resolution and analyzing these systems with DTMs continues to provide additional insights to understanding gully formation. We find that the more highly integrated gullies have eroded volumes significantly larger than their deposited apron volumes, suggesting that the missing volumes may reflect the volatile volumes involved in gully formation. In contrast, the Matara dune gully, and the Kaiser dune gully, which are much less integrated, either have minimal volume discrepancy or larger apron volumes when compared to their gully volumes. Apron volumes that equal or exceed their gully volumes suggest that dry flows, avalanching, gully infill, active dune processes or other dry processes may have been more important in these less integrated systems. These associations suggest that although there are various gully morphologies on Mars that reflect the involvement of multiple processes, we find gully systems in Moni, Corozal, Palikir, Lyot, and Hale craters to be consistent with a primary formation by fluvial processes.

Acknowledgements: Gulick, Glines, and Freeman were partially supported by both Gulick's HiRISE Co-I and SETI NAI Co-I funds. Corrigan was supported by a SETI Inst. REU summer internship under the mentorship of V. Gulick.

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Notes


DEPARTMENT OF ASTROPHYSICS
MOTTO:
YES, EVERYBODY HAS ALREADY HAD THE IDEA, "MAYBE THERE'S NO DARK MATTER—GRAVITY JUST WORKS DIFFERENTLY ON LARGE SCALES!" IT SOUNDS GOOD BUT DOESN'T REALLY FIT THE DATA.
http://xkcd.com/

Photochemistry of the PAHs Coronene and Ovalene in cosmic water ice

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Polycyclic aromatic hydrocarbons (PAHs) are believed to represent a significant reservoir of interstellar carbon widely distributed throughout the interstellar medium (ISM) in both the gas and solid phases. PAHs embedded in water ices can undergo photochemical reactions upon vacuum ultraviolet (VUV) irradiation producing more complex organic species. To date, the photochemistry of PAHs have been extensively studied in inert matrices, but only a few experiments have been conducted with PAHs embedded in a mixture with water molecules. The processes through which these water-rich, oxygen-dominated ices promote the production of complex organic species from simple molecules call for deeper understanding. In this study we performed UV photochemistry processing of Coronene ($C_{24}H_{12}$) and Ovalene ($C_{32}H_{14}$) in water ices. The Mid-infrared Fourier transform absorption spectroscopic measurements ranging from 500 to 6500 cm^{-1} are performed on freshly deposited and vacuum ultraviolet processed cosmic H_2O ices containing PAHs at 15 K at four PAH:H_2O different concentration such as: (1:50), (1:100), (1:200) and (1:300).

Band strengths of the neutral PAH modes in H_2O ice are derived. Additionally, spectra of ultraviolet processed PAH containing H_2O ices are presented. These spectra are compared to spectra measured in VUV processed PAH:argon matrix isolation studies. The two PAHs studied here are found to be readily ionized upon VUV photolysis when trapped in H_2O ice and their photoproducts, mainly more complex PAH derivatives, also exhibit similar rates for ionization at astronomically relevant temperatures. The infrared absorption spectra are presented for these PAHs and their photoproduct species such as oxygenated, cationic and protonated is this assignment definitive trapped in H_2O ice. In addition to product formation, the decay of the two PAH molecules as a function of photolysis time (VUV fluence) has been analyzed. The loss of the parent and growth of PAH photoproducts are measured as a function of VUV dose, yielding solid state reaction constants. Depending on the relative efficiency of H_2O photodesorption and PAH photoionization in H_2O ice, the latter may trigger a charge induced aromatic solid state chemistry, in which PAH cations play a central role.

As a astrophysics implication, the results may suggests that oxygenated, cations and protonated PAHs should be widely observed in regions of the ISM, near the edges of molecular clouds where water molecules begin to form.

Nucleobase Synthesis via UV-induced oxidation of their precursors in astrophysical ices: A Quantum Chemical Perspective.

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Introduction: Identification of nucleobases in extraterrestrial carbonaceous chondrites, such as Murchison, implies their formation in an abiotic condition, and supports their prebiotic role in early Earth. Physicochemical processes by which these complex molecules are synthesized in icy grains are not well understood. The products of UV photo-irradiation of purine and pyrimidine in H_2O, NH_3 and CH_4 ices have been explored using fancy new density functional theory (DFT) methods (ωB97M–V) along with large correlation consistent basis sets, and compared against laboratory experimental results. Mechanisms studied include those starting with neutral pyrimidine and purine, and their cationic counterparts, and then reacting with neutrals and radicals generated by radiation. Reaction mechanisms that involved cations on the purine or pyrimidine proved to be the ones that are most important. The calculations reveal that the formation of nucleobases is energetically and kinetically favorable. The gas phase mechanism of their formation proved ineffective, and the presence of one or several water molecules is necessary in order for the final products to form. Explicit solvent calculations using a polarized continuum model (PCM) established the effect of the ice matrix and product formation preferences. Uracil forms rather easily as oxidation is rather easy in pure H_2O ices. The scope of thymine formation in H_2O:CH_4 mixed molecular ices, however, is limited due to the inefficiency of the methylation of pyrimidine, and its oxidized derivatives. Thymine is a minor component of the products in the experimental samples. Amine group addition to purine leading to adenine and guanine in mixed NH_3 and H_2O ices is facile. Although adenine is the most likely monosubstituted photoproduct in mixed H2O:NH3 ice, isoguanine and xanthine are the bi-substituted products. Many of the photoproducts in UV-irradiated H_2O and pyrimidine ice mixtures are found in an experimental study. The results support the scenario in which prebiotic molecules, such as the nucleobase uracil, can be formed under abiotic processes in astrophysically relevant interstellar environments, and on surfaces of icy grains before being delivered to telluric planets such as Earth. But, it constrains the formation of thymine as well as its role in the origin of life.

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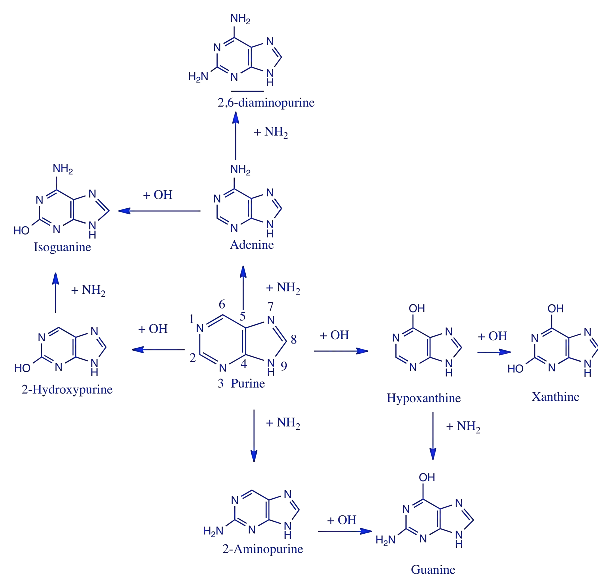

Figure 1. A reaction scheme indicating the amino and hydroxyl group substitutions on the purine ring.

Title : Polycyclic Aromatic Hydrocarbon Charge and Size Across a Reflection Nebula, H II-region and Planetary Nebula

Authors : Dr. Christiaan Boersma, Dr. Louis J. Allamandola, Dr. Jesse Bregman

Polycyclic aromatic hydrocarbons (PAHs) are an important constituent of interstellar dust. Intermediate in size between molecules and particles, PAHs have characteristics of both. This unique property, coupled with their spectroscopic response to changing conditions and the ability to convert ultraviolet to infrared (IR) radiation, makes them powerful probes of astronomical objects at all stages of the stellar life cycle. PAH emission can dominate as much as 20% of the total IR luminosity in the many Galactic and extragalactic objects where they are seen and they are thought to hold up to 10-15% of all cosmic carbon. Due to their omnipresence and stability, PAHs play important roles in many astronomical environments and a defining role in the star- and planet formation process; and perhaps even in the origin of life itself. The *Spitzer*-IRS spectral maps of a reflection nebula (NGC 7023), an H II-region (M17) and a planetary nebula (NGC 40) are analyzed using the data and tools made available through the NASA Ames PAH IR Spectroscopic Database (PAHdb; www.astrochemistry.org/pahdb/).

The PAH emission at each pixel in these maps is broken down, *quantitatively*, into contributing PAH charge state- (neutral and positively charged) and size components (small-large) using a database fitting approach. In this approach the physics of the PAH emission process is taken into account and uses target appropriate parameters, e.g., a model for the irradiating source, etc. Figure 1 presents the three color composite image constructed from the database size breakdown for each of the three objects.

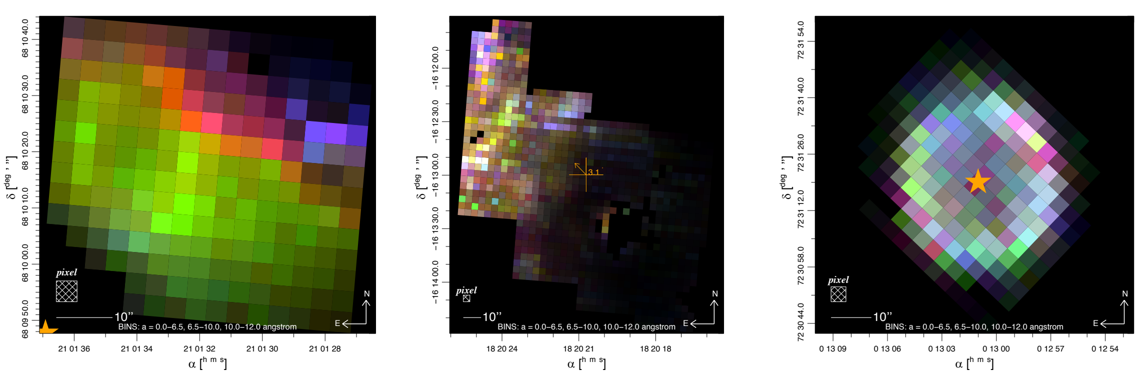

Figure 1: Three color composite image constructed from the PAHdb size breakdown. Here the absolute contribution from PAHs with an effective radius of 0-6.5, 6.5-10 and 10-12 Å are shown in red, green and blue, respectively. Left: The reflection nebula NGC 7023. Middle: The H II-region M17. Right: The planetary nebula NGC 40. The pixel size is indicated by the labeled box and the orange star/arrow shows the position of/points towards the irradiating source.

The *quantitative* breakdown results are used to calibrate the *qualitative* results derived using the traditional PAH band strength approach, which interprets particular PAH band strength ratios as *qualitative* proxies for the PAH charge- and size state. Subsequently, the charge proxies are linked to the PAH ionization parameter, which connects the ionized fraction to the gas temperature, electron density and radiation field strength in the emitting region. Furthermore, the differences between the PAH emission from these objects are linked to evolutionary stages of the star- and planet formation process.

Laboratory Approach to Astrophysical Catalysis and the interaction of cosmic ray and UV photons with IVA

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Abstract: Laboratory research concerning PAHs and ice analogs have been carried out for years. Most of the studies were performed under vacuum conditions and low temperatures trying to mimic the physical the interstellar medium. One aspect we consider is important to address, and so far few people have studied, is the interaction between the molecules, PAHs, ice mantle, etc., with the surface of dust particles. Interstellar dust particles are the primary sites of molecular formation. As such, we have to deal with different and fundamentally less well-understood physics. Many of the physical details involving dust particles are empirical as we do not yet know the precise composition of dust grains, nor do we know their precise physical properties. Catalysts pose a major challenge to characterization techniques. For our studies we use the Harrick's Praying Mantis accessory which allows us to perform Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS). This technique helps to analyze materials under reactive atmosphere, high vacuum, and low/high temperature analyzing the light scattered by the dust sample. As a first approach, we are currently working with the smallest PAHs: Benzene, Naphthalene, and Anthracene, using the simplest dust analogs as the reservoirs: Aluminum Oxide, Hematite, and Silicon Oxide. Once simple experiments have been done we plan to move gradually to more complex compounds like Coronene, Dicoronylene, and dust analogs like Olivines and Pyroxenes.

Past research efforts have accumulated observational, theoretical, and experimental evidence demonstrating that Polycyclic Aromatic Hydrocarbons (PAHs) in the interstellar medium (ISM) may be responsible for infrared emission features observed throughout our galaxy as well as in other galaxies. Argon matrix isolation mid-infrared spectra are measured for Isoviolanthrene (IVA), $C_{34}H_{18}$. IVA was among the chemical samples selected for the Space Environment Viability of Organics (SEVO) experiment aboard the O/OREOS satellite, launched in 2010 to probe the stability of PAHs and other organic compounds in low earth orbit. In this study, the stability of IVA is tested in laboratory simulations under a variety of conditions. A sample was exposed to cryogenic temperatures, high vacuum, a degree of isolation from other chemical species achieved by argon matrix isolation, and photolysis by exposure to varying doses of UV radiation from an H_2 gas discharge lamp, simulating interstellar space. The population of neutral IVA and generation of ionized species was monitored over time by FTIR spectroscopy. This data was analyzed and compared to density functional theory (DFT) calculations to determine which modes of vibration yield the observed IR signal bands. From this information the experimental molar absorptivities of observed bands was determined. A thin film experiment of IVA was also conducted to establish if the UV photolysis effects for the PAH in the thin film state were substantially different than the matrix isolated sample and for direct comparison to the O/OREOS results. A third experiment consisted of IVA in a H2O ice matrix to determine the degradation rate of IVA in ice versus thin film and an argon matrix, as well as to identify chemical products of the UV induced photo-chemistry. IVA thin film samples were sent to Brazil to be bombarded with protons in order to compare the destruction by cosmic ray and UV photon analogs.

The anharmonic quartic force field infrared spectra of five non-linear Polycyclic Aromatic Hydrocarbons: benz[a]anthracene, chrysene, phenanthrene, pyrene, and triphenylene

Cameron J. Mackie, Alessandra Candian, Xinchuan Huang, Elena Maltseva, Annemieke Petrignani, Jos Oomens, Andrew L. Mattioda, Wybren Jan Buma, Timothy J. Lee, and Alexander G. G. M. Tielens

Abtract:

The study of interstellar polycyclic aromatic hydrocarbons (PAHs) rely heavily on theoretically predicted infrared (IR) spectra. These studies currently use scaled harmonic frequencies for band positions and the double harmonic approximation for intensities. However, recent high–resolution gas–phase experimental spectroscopic studies have shown that the harmonic approximation is not sufficient to reproduce experimental results. In our previous work we presented the anharmonic theoretical spectra of three linear PAHs; showing the importance of including anharmonicities into the theoretical calculations. In this paper, we continue this work by extending the study to include five non–linear PAHs: benz[a]anthracene, chrysene, phenanthrene, pyrene, and triphenylene. The theoretical anharmonic spectra is compared to two different experimental spectra presented here: matrix–isolation spectroscopy, and high–resolution low–temperature gas–phase spectroscopy, and shows excellent agreement with each.

Title: Molecular Identification Tool for High-Resolution Astronomical Line Surveys

Authors: Rachel Lim (Mulberry Academy), Naseem Rangwala (NASA Ames/NPP USRA), Sean Colgan (NASA Ames)

Abstract: High resolution astronomical line surveys provide the raw data for a chemical inventory for the interstellar medium — essential for establishing the relative importance of potential chemical networks, understanding organic chemistry associated with star formation, and providing constraints on the supply pathways of key organic molecules in Earth-like planet formation.

We are developing a tool to identify and characterize the line features in the Prebiotic Interstellar Molecular Survey (PRIMOS) — a high spectral resolution molecular line survey done by the Green Bank Telescope covering a frequency range of 1 - 50 GHz. This frequency region is rich in line features belonging to complex organic molecules. About half of the lines in this survey remain unidentified. Our tool will produce a list of line positions, widths and strengths for comparison with molecular line databases such as Splatalogue and theoretical spectra to identify molecules. Even though this tool is currently being developed for PRIMOS, some of the algorithms can be used on other line surveys. Our goals are to (a) identify new molecules in the ISM, (b) determine the physical conditions assuming Local Thermodynamic Equilibrium, (c) refine reference data (line centers and intensities), and (d) propose for follow-up observations.

Title: Spectroscopy of Cryogenic Thin Films Containing PAHs: PAH Clusters, Binary PAH Mixtures, and the Effect of Water Ice

Authors: Joseph Roser & Alessandra Ricca

Affiliations: NASA-Ames Research Center, SETI Institute

Abstract: Polycyclic Aromatic Hydrocarbons (or PAHs) are believed to be abundant in interstellar space and a main contributor to intense infrared emission features seen throughout the interstellar medium. In addition to the well-known gas phase (or "free flying") PAHs, PAH clusters of various compositions may also exist in the interstellar medium. Here we describe experiments using Fourier transform infrared spectroscopy to infer the properties of PAH clusters from transmission spectra of cryogenic thin films containing PAHs along with accompanying quantum chemistry calculations. By varying the concentration of PAH molecules relative to an IR-transparent matrix gas (solid argon ice at 5K) we can observe spectral shifts that we attribute to cluster formation in the matrix. Additional shifts can be observed in binary mixtures of PAHs in the argon ice matrix. We also describe the band shifts observed with PAH molecules in thin films of water ice at 5K.

Recent Progress in Laboratory Astrophysics achieved with the COSmIC Facility

Farid Salama[1], Ella Sciamma-O'Brien[1, 2] and Salma Bejaoui[1]
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We describe the characteristics and the capabilities of the laboratory facility, COSmIC, that was developed at NASA Ames to generate, process and analyze interstellar, circumstellar and planetary analogs in the laboratory[1]. COSmIC stands for "Cosmic Simulation Chamber" and is dedicated to the study of neutral and ionized molecules and nanoparticles under the low temperature and high vacuum conditions that are required to simulate various space environments such as diffuse interstellar clouds, circumstellar outflows and planetary atmospheres. COSmIC integrates a variety of state-of-the-art instruments that allow forming, processing and monitoring simulated space conditions in the laboratory. The COSmIC experimental setup is composed of a Pulsed Discharge Nozzle (PDN) expansion, that generates a plasma in the stream of a free supersonic jet expansion, coupled to two high-sensitivity, complementary *in situ* diagnostics: a Cavity Ring Down Spectroscopy (CRDS[2]) and laser induced fluorescence (LIF[3]) systems for photonic detection, and a Reflectron Time-Of-Flight Mass Spectrometer (ReTOF-MS) for mass detection[4].
Recent results obtained using COSmIC will be highlighted. In particular, the progress that has been achieved in the domain of the diffuse interstellar bands (DIBs) [5] and in monitoring, in the laboratory, the formation of circumstellar dust grains [6] and planetary atmosphere aerosols [7, 8] from their gas-phase molecular precursors. Plans for future laboratory experiments on interstellar and planetary molecules and grains will also be addressed, as well as the implications of the studies underway for astronomical observations and past and future space mission data analysis.

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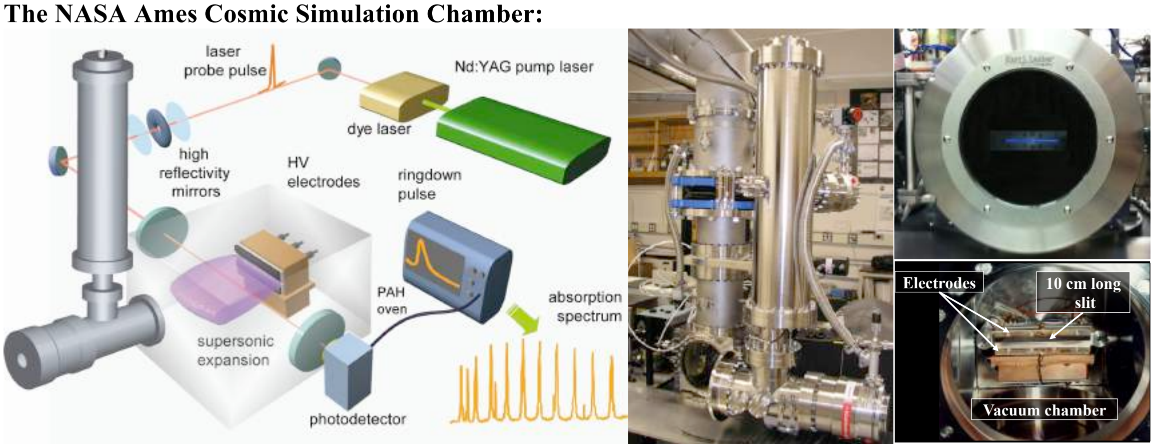
The NASA Ames Cosmic Simulation Chamber:



OPACITIES AND TURBULENCE IN COLD PLANET FORMING ACCRETION DISKS. O. M. Umurhan[1,2,3], P. R. Estrada[1,2], J. N. Cuzzi[1], [1]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, [2]SETI, Carl Sagan Institute, Mountain View, CA 94043,[3]Senior Nasa Postdoctoral Fellow.
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Abstract: The temperature and opacity structure of planet forming accretion disks (PFAD), which is shaped by the local dust content in the disk, is directly influenced by the underlying turbulence present within. The dynamic activity generating this turbulence (arising from several recently identified mechanisms), in turn, is determined by the local thermodynamics which is largely set by the local abundance of dust so that the two processes are intimately linked [1-11]. In this talk we present the results of a study in which the temperature/opacity fields arising from global turbulent disk evolution models [12-13] are used to assess which of the currently considered linear instability mechanisms are likely to be operational in driving hydrodynamic turbulence in stably stratified PFADs. Some preliminary results include (i) currently published global disk models with parametrized turbulent intensities appear to give rise to opacities that are self-consistent with the small-scale linear instabilies driving turbulence, (ii) the vertical shear instability [3-6] and the convective overstability [10-11] appears to operate robustly in the 1-100 AU range in both early and mid epochs of young disks, while the zombie vortex instability [7-9] generally occurs in the outer parts of the disk (>50-100 AU) and becomes prominent during evolved epochs of PFADs.

Aims: The main goals of this study are to take the results of vertically integrated axisymmeric global disk models with assumed values of dust porosity and turbulent intensity, and reconstruct the opacity structure as a function of the PFAD's vertical and radial coordinates using the methodology detailed in [13]. With these opacities in hand we calculate the resulting thermal relaxation times and assess which of the aforementioned instability mechanisms are consistently operating and where in the PFAD.

The fate of the various instabilities over time. Fig. 2 displays a first-pass prediction of which instability may or may not be operating in a given location of a PFAD model at early times (2×10^5 years). Each mechanism considered has unique spatial scales for optimal operation included (not described here). The VSI dominates the turbulence in the range 3-90 AU while the COV occurs generally in the inner disk (<3 AU). The ZVI is prominent in outer solar nebula (>100 AU).

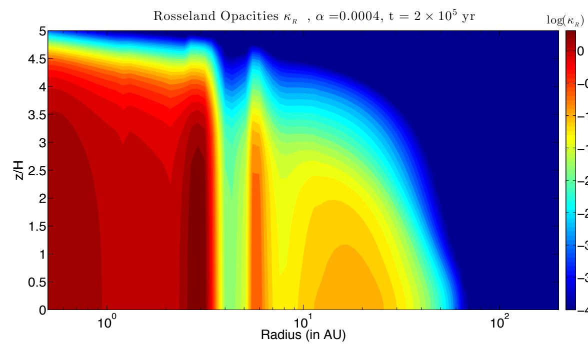

Fig. 1. Rosseland mean opacities after 2×10^5 years. Opacities quoted in units of cm^2/gm. H is the local pressure scale height.

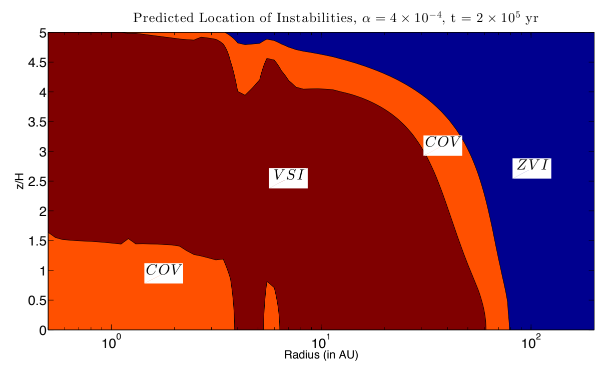

Fig. 2. A PFAD "butcher" diagram indicating locations where various instabilities are operating based on output of [12]: 2×10^5 years, $\alpha = 4\times10^{-4}$ and dust porosities of zero, where α is the inverse turbulent Reynolds number.

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UV-Visible Spectroscopy of PAHs and PANHs in Supersonic Jet. Astrophysical Implications

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Polycyclic Aromatic Hydrocarbon (PAHs) molecules are attracting much attention in the astrophysical and astrochemical communities because of their ubiquitous presence in space due to their ability to survive in the harsh environmental conditions of the interstellar medium (ISM). PAHs have been proposed as plausible carriers of the still unassigned diffuse interstellar bands (DIBs) for more than two decades now. The so-called PAH-DIB proposal has been based on the abundance of PAHs in the ISM and their stability against photo and thermo dissociation. Nitrogen is one of the most abundant elements after hydrogen, helium, and carbon [1]. Nitrogenated PAHs (PANHs) exhibit spectral features similar to PAHs and may also contribute to the unidentified spectral bands.

Laboratory absorption spectra of aromatic measured under astrophysical relevant conditions are of crucial importance to test the PAHs-DIBs hypothesis and compare with the observed DIBs spectra. The most challenging task is to reproduce as closely as technically possible, the physical and chemical conditions that are present in space. Interstellar PAHs are expected to be present as free, cold, neutral molecules and/or charged species [2]. In our laboratory, comparable conditions are achieved using an excellent platform developed at NASA Ames. Our cosmic simulation chamber (COSmIC) allows the measurement of gas phase spectra of neutral and ionized interstellar PAHs analogs by associating a molecular beam with an ionizing discharge to generate a cold plasma expansion (≈100 K) [3]. Our approach, to assign PAH as carriers of some DIBs, consists in recording the electronic spectra of the cold PAHs in the gas phase and performing a systematic search for possible correspondences with features in astronomical DIB spectra [4]. In this work, we report the UV-visible absorption spectra of neutral PAHs and PAHNs recently measured using the cavity ring down spectroscopy (CRDS) technique. We discuss the effects of the substitution of C–H bond(s) by nitrogen atom(s) in the spectral signatures of PAHs and the astrophysical implications.

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Title: IR Intensity Prediction of CO_2 Isotopologues: New Ames Line Lists vs. Existing Databases

Authors: Xinchuan Huang, David W. Schwenke, and Timothy J. Lee

Abstract:

Nowadays most high resolution IR databases used by astrophysicists are actually the collections of transitions derived from reduced/effective Hamiltonian models with parameters fitted from a limited set of measured transitions, including line positions, intensities and line shape parameters. Reliable intensity data is only available for a limited number of bands of the main isotopologues with uncertainties usually as large as 5-20%. It is far less complete for minor isotopologues due to experimental difficulties. It has been a long time pursuit to predict isotopologue IR intensities using available data of other isotopologues.

In the last decade at NASA Ames, we have adopted the "Best Theory + High-resolution Experimental Data" strategy to combine selected high resolution IR data with high quality *ab initio* electronic theory based potential energy and dipole moment surfaces to generate the best available IR line lists of CO_2 and SO_2 isotopologues, and rovibrational energy levels of $^{14}NH_3$ and $^{15}NH_3$. The focus and the biggest advantage of our strategy is wholly on **Predictions**. We are not only able to reproduce most existing measured transitions with 0.01 - 0.02 cm^{-1} line position accuracies and 2-10% intensity deviations, but also able to **make predictions with similar accuracies**! For example, the Ames CO_2 lists have reached the ~1% intensity prediction accuracy level on the 626 30013-00001 and 20013-00001 bands.

Recently, a new set of Ames-296K IR lists are computed for 13 CO_2 isotopologues. These are the most complete and reliable lists for CO_2 isotopologue related spectral analysis and simulations. The lists are compared to the CDSD-296, HITRAN, JPL databases. The comparison has confirmed that most Effective Dipole Moment (EDM) intensity models in CDSD and HITRAN do carry 5 – 20% or even larger uncertainties. More examples will show the unusually large errors or deviations in the three vibrational fundamental band intensities and the microwave band intensities of CO_2 628 and 627 isotopologues. The inter-isotopologue consistency of our Ames-296K intensity prediction should be (at least) better than 1-3% for regular bands not affected by resonances. This study further supports that theoretical IR lists can provide better alternative IR intensity data for many hard-to-determine isotopologue bands.

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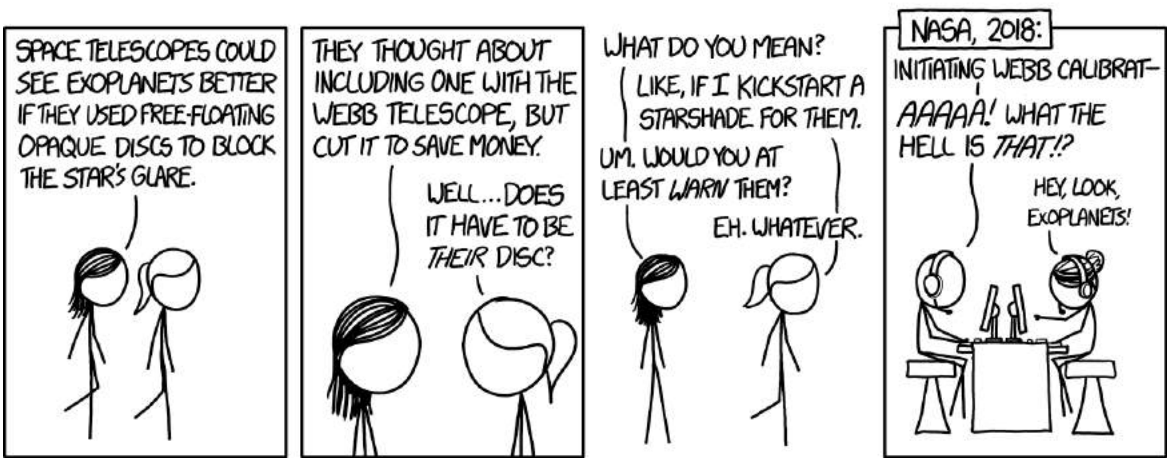

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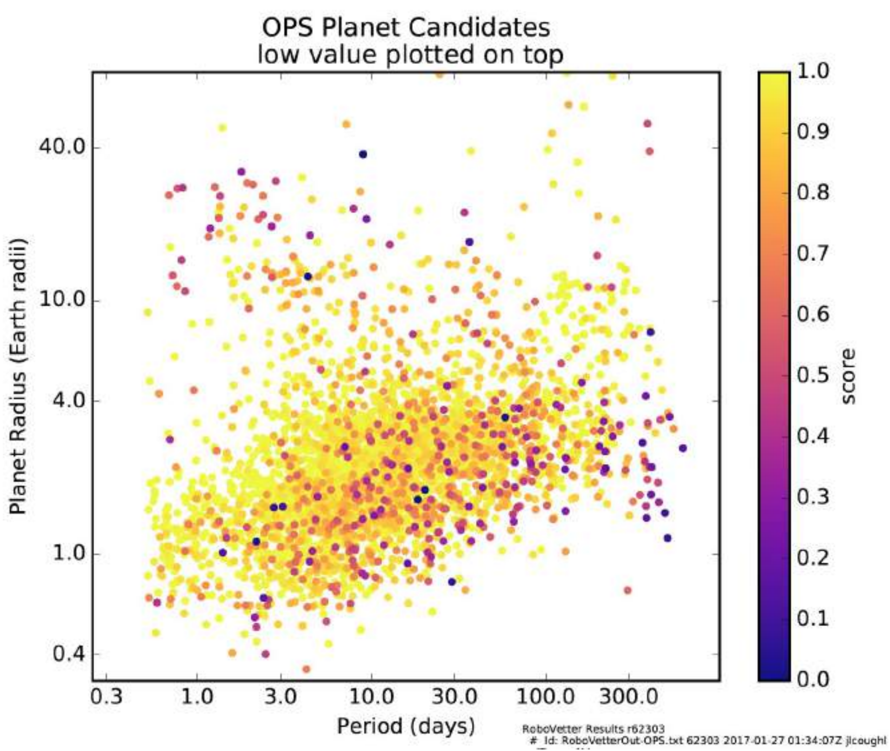
Exoplanets

Creating the Final Kepler Catalog for an Accurate Exoplanet Census

Susan E. Thompson, Jeffrey L. Coughlin, Christopher Burke, Fergal Mullally, Jessie Christiansen, Kelsey Hoffman, Michael Haas, Natalie Batalha, Jason Rowe, Steve Bryson, Joseph Catanzarite, Geert Barentsen

The Kepler Spacecraft obtained 4 years of continuous time series photometry on over 150,000 stars with the goal of detecting transits of exoplanets passing in front of their stars. Kepler is about to release its final exoplanet catalog, Data Release 25. This catalog will be the first which is capable of accurately measuring the frequency of earth analogues around sun-like stars. I will discuss the automated method we are using to create this final exoplanet catalog. Known as the robovetter, it decides whether periodic signals found in the Kepler light curves are more likely caused by transiting exoplanets or false positives. False positives include signals caused by instrumental effects, eclipsing binaries or background eclipsing binaries. To test and measure the performance of the robovetter we have created synthetic false positive populations by scrambling and inverting the data. This allows us to measure the fraction of false positives the robovetter is capable of removing and ultimately the reliability of the catalog against these types of false positives. Similarly, we have injected transit signals into the data and measured the detection efficiency of the robovetter. Measuring the catalog reliability and completeness will improve the accuracy of calculations of the occurrence rates of small exoplanets. All of the Kepler exoplanet candidates as well as the signals found from the simulated data sets will be available at the NASA Exoplanet Archive (NExScI).

The figure below plots the preliminary exoplanet candidates for the DR25 catalog as a function of period and planetary radius. The color of each point indicates the disposition score, a measure of our confidence in the disposition; a value near one is high confidence.

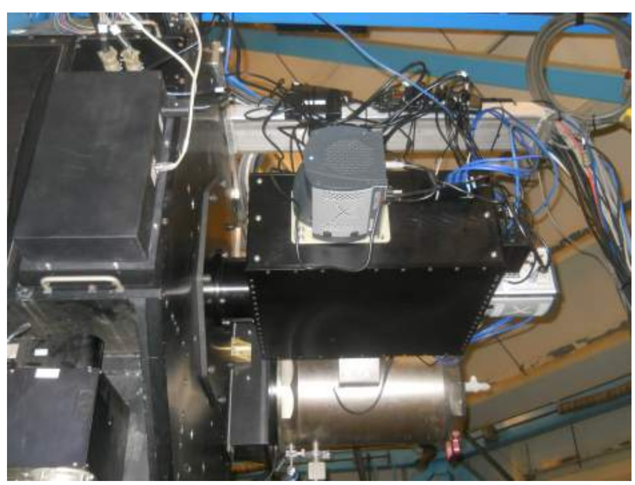


Reaching the Diffraction Limit:
High-Resolution Imaging for Exoplanet & Stellar Studies

Steve B. Howell, Nic Scott, & Elliott Horch
NASA Ames Research Center, Southern Connecticut State University

Speckle imaging allows telescopes to achieve diffraction limited imaging performance. The technique uses digital cameras capable of reading out frames at a very fast rate, effectively `freezing out' atmospheric seeing. The resulting speckles are correlated and combined in Fourier space to produce reconstructed images with resolutions at the diffraction limit of the telescope. These new instruments are based on the successful performance of the Differential Speckle Survey Instrument used for the past 8 years in support of the NASA Exoplanet missions (DSSI; Horch et al., 2009; Howell et al., 2011).

Two new instruments are being built for the Gemini-N and WIYN telescopes and will be made available to the community via the peer review proposal process in 2017. We envision their primary use to be validation and characterization of exoplanet targets from the NASA K2 and TESS missions as well as RV or other discovered exoplanets. Exoplanet host stars provide excellent follow-up candidates for both the WIYN and Gemini telescopes (e.g., Howell et al., 2016).



GLOBAL SURFACE PHOTOSYNTHETIC BIOSIGNATURES OF ANOXIC BIOSPHERES. M. N. Parenteau[1], W. B. Sparks[2], R. E. Blankenship[3], T. A. Germer[4], C. M. Telesco[5], N. Y. Kiang[6], T. Hoehler[1], E. Pallé[7], F. T. Robb[8,9], V.S. Meadows[10]; [1]Exobiology Branch, NASA Ames Research Center, Moffett Field, CA 94035 (mary.n.parenteau@nasa.gov); [2]Space Telescope Science Institute, Baltimore, MD 21218; [3]Departments of Biology and Chemistry, Washington University in St. Louis, St. Louis, MO 63130; [4]National Institute of Standards and Technology, Gaithersburg, MD 20899; [5]Univ. of Florida, Gainesville, FL 32611; [6]NASA Goddard Institute for Space Studies, New York, NY; [7]Instituto de Astrofísica de Canarias (IAC), Vía Láctea s/n 38200, La Laguna, Spain [8]Institute of Marine and Environmental Technology, Baltimore, MD 21202; [9]Univ. of Maryland School of Medicine, Baltimore, MD 21201; [10]Astronomy Department, University of Washington, Seattle, WA 98195.

Introduction: The study of potential exoplanet biosignatures -- the global impact of life on a planetary environment -- has been informed primarily by the modern Earth, with little yet explored beyond atmospheric O_2 from oxygenic photosynthesis and its accompanying planetary surface feature, the vegetation "red edge" reflectance. However, these biosignatures have only been present for less than half the Earth's history, and recent geochemical evidence suggests that atmospheric O_2 may have been at very low - likely undetectable - levels, until 0.8 Ga [1]. Given that our planet was inhabited for very long periods prior to the rise of oxygen, and that a similar period of anoxic life may occur on exoplanets, more studies are needed to characterize remotely detectable biosignatures associated with more evolutionarily ancient anoxygenic phototrophs.

Results: *Reflectance spectra*. Similar to the remotely detectable "red edge" of chlorophyll *a* – containing vegetation, we measured the reflectance spectra of pure cultures and environmental samples of purple sulfur, purple non-sulfur, heliobacteria, green sulfur, and green non-sulfur anoxygenic phototrophs. Our measurements revealed "NIR edge(s)" due to absorption of light by bacteriochlorophyll (Bchl) pigments.

We used the pure culture spectra to deconvolve complex spectra of environmental samples of microbial mats. We observed multiple NIR edges associated with multiple pigments in the mats. We initially expected only to detect the absorption of light by the pigments in the surface layer of the mat. Surprisingly, we detected cyanobacterial Chl *a* in the surface layer, as well as Bchl *c* and Bchl *a* in the anoxygenic underlayers. This suggests that it does not matter "who's on top," as we were able to observe pigments through all mat layers due to their different absorption maxima.

The presence of multiple pigments and thus multiple "NIR edges" could signify layered phototrophic communities and possibly strengthen support for the detection of a surface exoplanet biosignature. Additionally, these data characterize "ecosystem" signatures for microbial communities present in marine intertidal areas and continental lacustrine and hydrothermal settings. Future work aims to characterize anoxygenic ecosystem signatures in the open ocean (aerobic purple non-sulfur anoxygenic phototrophs).

We are also working towards understanding the "rules" that dictate the spectral features of anoxygenic phototrophs so that they can be predicted for exoplanets, and will assess their remote detectability as a function of environmental context across a range of spatial scales: (1) local field measurements of environmental samples, (2) regional on modern Earth (continents and oceans) using airborne sensors and Earth-observing satellites, and (3) planetary-scale in exoplanetary disk-averaged spectra under various atmospheres and cloud coverage levels.

Polarization spectra. The Bchls and Chls pigments are optically active molecules with several chiral centers. The phenomenon of chirality is a powerful biosignature: recent studies of universal biology describe it thus: "One of the very few universal features of biology is homochirality" [2]. Because of the optical activity of biological molecules, i.e., their influence on the polarization of light, and chirality, this biosignature can be remotely observed on planetary scales using circular polarization spectroscopy. Precision full Stokes spectropolarimetry is required. We measured the circular polarization spectra of the same samples analyzed for the reflectance work. The reflectance, transmission, and absorption spectra were obtained. We observed strong correlations between the absorption maxima of the pigments and features in the circular polarization reflectance spectra. We are currently reconciling our measurements on whole cells and complex communities with the long history of circular dichroism measurements made of isolated pigment-protein complexes in biochemical studies.

Summary: In general, this work aims to inform the search for life on exoplanets at a similar stage of evolution or biogeochemical state as the pre-oxic Earth.

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Direct imaging of circumstellar dust and debris environments with EXCEDE

Dan Sirbu[1], Ruslan Belikov[1], Eduardo Bendek[1], Glenn Schneider[2]

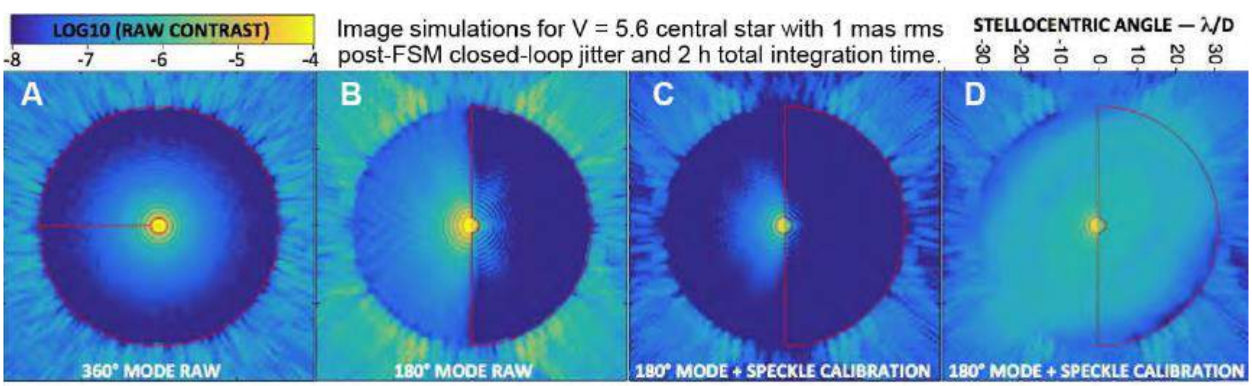
[1]NASA Ames Research Center, [2]University of Arizona

We report on the proposed starlight suppression system for the Exoplanetary Circumstellar Environments and Disk Explorer (EXCDE), a recent submission for the Midsize-Explorer (MidEX) 2016 Announcement of Opportunity. EXCEDE will survey over 200 debris disks within a sample of 350 nearby stars spanning a diverse range of stellar types and ages, probing the disk structures and their temporal variability.

EXCEDE uses a 0.7m primary enabled by nearly full-throughput of the Phase-Induced Amplitude Apodization (PIAA) coronagraph in a Lyot-style configuration. The field of view spans 2 to 30 λ/D and is enabled by the PIAA coronagraph's small inner working and with an outer working angle recovered using inverse PIAA optics.

The starlight suppression system creates creates high-contrast regions at the 10^{-7} level (with respect to the host star) in the science focal plane using a wavefront control system that consists primarily of two control loops: (a) the science camera that drives the deformable mirror (DM) to correct for mid-spatial frequency static and slowly varying aberrations, and (b) a fast wavefront control loop uses a high-frequency camera to estimate the low-order aberrations and apply settings on both the Fast Steering Mirror (FSM) and the DM to correct these low-order aberrations.

The EXCEDE instrument performance is based on experimentally validated optical models. These are based on a flight-like prototype of the proposed coronagraph instrument which has been tested in vacuum at the Lockheed Martin Advanced Technology Center meeting required performance levels.



The above figure shows the simulated starlight suppression system of a diskless star in: (A) survey mode 360-degree dark zone and showing raw contrast, (B) characterization mode 180-degree dark zone showing raw contrast, and (C) characterization mode 180-degree dark zone showing speckle post-processed contrast. An inclined 4-arcsec gapped disk with peak brightness at the $6x10^{-7}$contrast level is imaged in (D) through the same contrast field. These results assume a 3K-circular DM operating at 0.4 microns with a 10% spectral bandwidth.

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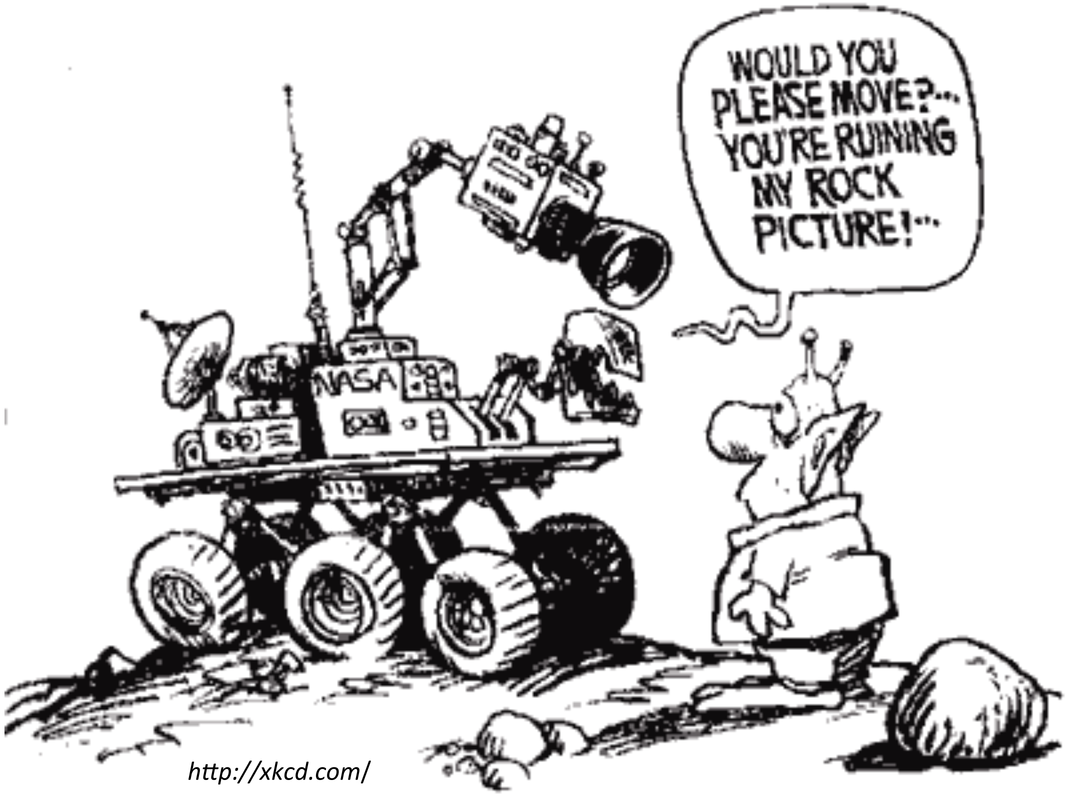

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The Impact of Planetary-Scale Waves Upon Venus' Thermal Structure In The Thermosphere Based Upon VTGCM Simulations

Amanda Brecht[1], S. W. Bougher[2], C. D. Parkinson[2], D. J. Shields[2], H. Liu[3]
[1] NASA Ames, [2] CLaSP, U. of Michigan, [3] HAO, NCAR

Abstract:
Observations of the Venusian thermal structure have been conducted by Venus Express (VEx) and its multiple instruments (i.e. SOIR, SPICAV, and VIRTIS). These VEx observations are being combined with ground based observations to create a single comprehensive database. Thus far, these observations are continuing to reveal the significant variability of Venus' upper atmosphere structure, thereby motivating an analysis of the driver(s) of this variability. A likely driver of this variability is wave deposition. Evidence of waves has been observed, but these waves have not been completely analyzed to understand how and where they are important.

The Venus Thermospheric General Circulation Model (VTGCM) will be utilized to examine the role planetary-scale waves play in driving Venus' thermosphere structure and variability (~80 – 200 km). Kelvin waves have been incorporated at the lower boundary of the VTGCM. Moreover, tests have been conducted with a self-consistent "moving" lower boundary (winds are not equal to zero and temperature is not constant). This work will demonstrate the importance of Kelvin waves with and without a "moving" lower boundary toward the global wind system variability. Specifically, the simulated thermal structure will be presented with and without Kelvin waves and the "moving" lower boundary to characterize the magnitude of change; structural change; and location of greatest impact. Since the thermal structure is strongly dependent on the global circulation, the corresponding zonal wind and O_2 IR nightglow distributions will also be presented.

Title: Effects of radiatively active clouds on wind stress dust lifting during Northern Hemisphere Summer on Mars
Authors: Vandana Jha and Melinda Kahre

The Mars atmosphere has low levels of dust during Northern Hemisphere (NH) spring and summer (the non-dusty season) and increased levels during NH autumn and winter (the dusty season). In the absence of regional or global storms, dust devils and local storms maintain a background minimum dust loading during the non-dusty season. While observational surveys and Global Climate Model (GCM) studies suggest that dust devils are likely to be major contributors to the background haze during NH spring and summer, a complete understanding of the relative contribution of dust devils and local dust storms has not yet been achieved. We present preliminary results from an investigation that focuses on the effects of radiatively active water ice clouds on dust lifting processes during these seasons. Water ice clouds are known to affect atmospheric temperatures directly by absorption and emission of thermal infrared radiation and indirectly through dynamical feedbacks. The dynamical response of the atmosphere to the presence of radiatively active clouds produces changes in the pattern and magnitude of surface wind stress and can thus directly affect the amount of dust injected into the atmosphere. Our goal is to understand how clouds affect the contribution by local (wind stress) dust storms to the background dust haze during NH spring and summer.

The primary tool for this work is the NASA Ames Mars GCM, which contains physical parameterizations for a fully interactive dust cycle (i.e., dust devil, wind stress lifting, transport and sedimentation). Two simulations that included wind stress dust lifting were executed for a period of 5 Martian years: a case that included no cloud formation, and a case that included radiatively active cloud (RAC) formation. Results show that when radiatively active clouds are included, the clouds in the aphelion cloud belt radiatively heat the atmosphere aloft in the tropics. This heating produces a stronger overturning circulation, which in turn produces an enhanced low-level flow in the Hadley cell return branch. The stronger low-level flow drives higher surface stresses and increased dust lifting in those locations. We examine how realistic these simulated results are by comparing the spatial pattern of predicted wind stress lifting with a catalog of observed local storms. Better agreement is achieved in the radiatively active cloud case. Taken together, these results suggest that wind stress lifting may contribute more to maintaining the background dust haze during NH spring and summer than what previous studies have shown.

Title: The South Residual CO_2 Cap on Mars: Investigations with a Mars Global Climate Model

Authors: Melinda A. Kahre[1], Julie Dequaire[2], Jeffery L. Hollingsworth[1], and Robert M. Haberle[1]

[1]NASA Ames Research Center
[2]Oxford University

The CO_2 cycle is one of the three controlling climate cycles on Mars. One aspect of the CO_2 cycle that is not yet fully understood is the existence of a residual CO_2 ice cap that is offset from the south pole. Previous investigations suggest that the atmosphere could control the placement of the south residual cap (e.g., Colaprete et al., 2005). These investigations show that topographically forced stationary eddies in the south during southern hemisphere winter produce colder atmospheric temperatures and increased CO_2 snowfall over the hemisphere where the residual cap resides. Since precipitated CO_2 ice produces higher surface albedos than directly deposited CO_2 ice, it is plausible that CO_2 snowfall resulting from the zonally asymmetric atmospheric circulation produces surface ice albedos high enough to maintain a residual cap only in one hemisphere. Our current work builds on these initial investigations with a version of the NASA Ames Mars Global Climate Model (GCM) that includes a sophisticated CO_2 cloud microphysical scheme. Processes of cloud nucleation, growth, sedimentation, and radiative effects are accounted for. Simulated results thus far agree well with the Colaprete et al. study—the zonally asymmetric nature of the atmospheric circulation produces enhanced snowfall over the residual cap hemisphere throughout much of the winter season. However, the predicted snowfall patterns vary significantly with season throughout the cap growth and recession phases. We will present a detailed analysis of the seasonal evolution of the predicted atmospheric circulation and snowfall patterns to more fully evaluate the hypothesis that the atmosphere controls the placement of the south residual cap.

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The Antarctic analogy for ancient lakes at Gale Crater, Mars

A.M. Kling, R.M Haberle, C.P. McKay, T.F. Bristow, F. Rivera-Hernandez

In place of the dual choice of “warm and wet” versus “cold and dry” Mars, we reconcile in this paper the notion of a cold Mars with the notion of wet Mars. Both the geological evidences at Gale's for the presence of liquid water during the Hesperian (Grotzinger et al., Science, 350 (6257), 2015) and the failure of climate models make Mars warm (Wordsworth, Review of Earth and Planetary Science, 44, 1-31, 2016) suggested that an alternative scenario could be envisioned.

The lake Untersee, Antarctica is an inspiring example of how an aqueous environment can survive for an extended period of the time in a place where the day average temperatures never reach 273K. The key process which maintains a liquid, potentially habitable, environment under the ice is the subaqueous melting of a glacial dam in contact with the lake which provides a constant latent heat flux into the lake (McKay et al, in preparation) Our calculations showed that for certain range of pressures, temperatures and ice optical properties, a large body of water at Gale's will not freeze solid even if the surface temperatures are at all times well below freezing. The rather high sublimation rates of ice at Mars', the sunlight penetrating the ice and the geothermal flux contribute to stabilize the solid/liquid interface at a certain depth. We found that for a mean annual temperature of 245K ice thicknesses range from 3-10 meters which are comparable values to the range of those for the Antarctic lakes (2-7m). Thus, the ice potentially gets thin enough to let sediments penetrate the ice (Rivera-Hernandez et al., in preparation) and geological features associated with aqueous environments may still be possible with a perennially-covered lake, on cold, but wet planet. The Antarctic lakes model is engaging as it relaxes the requirement for a long-lived active hydrological cycle involving rainfall and runoff, which no climate model has been able to produce for early Mars.

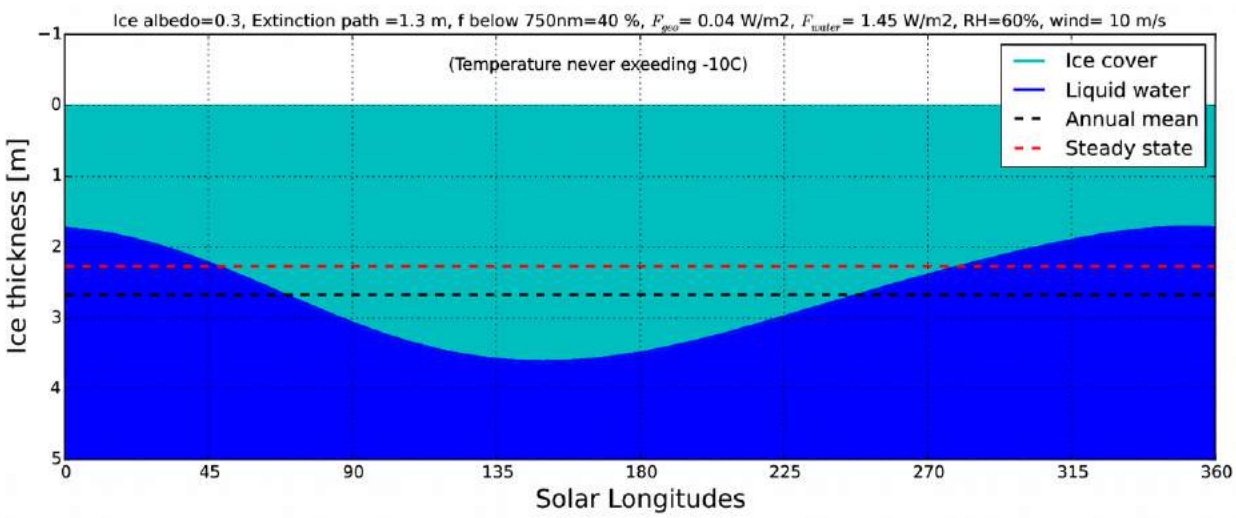

Figure1 : Ice thickness calculation for a perenially-covered lake at Gale crater as a function of the solar longitude

The Mars AutoRotating Science StationS (MARS³)

From the edge of space to the surface of the Earth: a proof of concept.

Alexandre Kling, Robert Haberle

Over the five decades of Mars' exploration history, limited meteorological data has only been available at five landing sites (Viking landers 1 and 2, Pathfinder, Phoenix, and Mars Science Laboratory) and are largely separated in both time and space. The deployment of several meteorology stations at the surface of Mars, thereby enabling simultaneous measurements at different locations, is the only way to capture the spatial variability and coupling of weather systems on Mars. The technical approach and science rational was discussed by [Haberle, et al., Planet. Space Sci. 44, 1996]

We integrated a pressure sensor, power and communication systems, and a simple atmospheric decelerator in a lightweight (few 100's g) package, able to land on its own from high altitude. A first prototype inspired of maple seed has been tested and notably uses flexible solar panels as structural elements for the wing. The advantage of the maple seed design is the low impact velocities, which eliminates the need for the bulky deceleration systems as parachutes, airbags or rockets. Drop tests from 30km altitude are in progress. Ultimately, this end-to-end technology demonstration from the edge of Space will be used as a proxy to show that the deployment of meteorology experiment at the surface of a planetary body with an atmosphere from high altitude is both feasible and affordable.

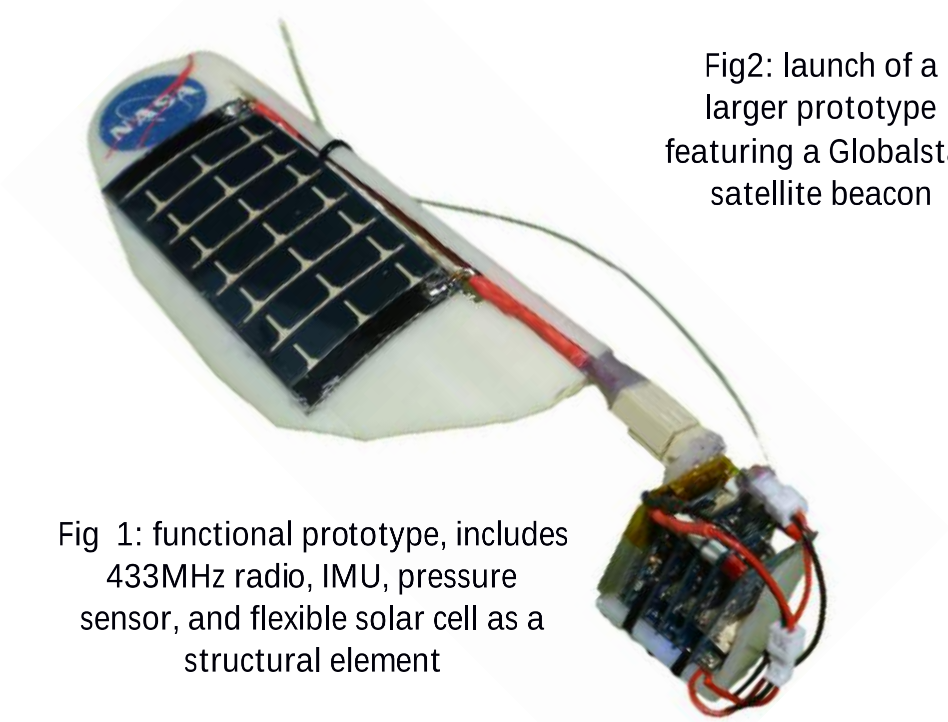

Fig 1: functional prototype, includes 433MHz radio, IMU, pressure sensor, and flexible solar cell as a structural element

1 inch

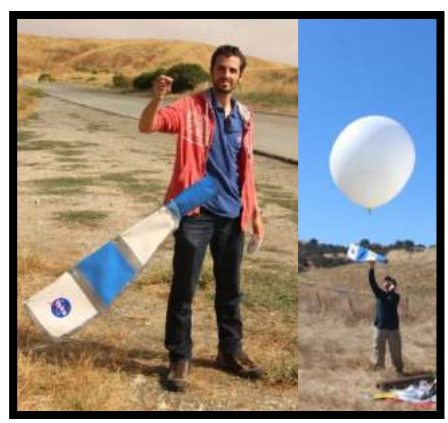

Fig2: launch of a larger prototype featuring a Globalstar satellite beacon

Fig3: testing the electronics at 30km

This work is supported by a USRA internal research grant

TEMPERATURE-DEPENDENT RADIATIVE TRANSFER MODELING OF MARTIAN WATER ICE CLOUDS

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We investigate the impacts of temperature-dependent optical parameters on the radiative effects of water ice clouds on Mars. The optical properties of water ice vary with temperature; however, past Mars climate modeling has used optical properties based on water ice refractive indices relevant to Earth's atmospheric temperatures. We use water ice refractive indices at temperatures relevant to the Martian atmosphere with Mie scattering code to provide input into the NASA Ames Mars General Circulation Model. We compare the instantaneous effects of using these optical parameters, versus values that have been traditionally used, on daytime and nighttime radiative fluxes.

This work finds that radiatively active water ice clouds may scatter more than previously thought, which could warm or cool the surface depending on the location and thickness of the cloud. We find that the use of more realistic optical parameters amplifies the cloud radiative effects over most of the planet. At the highly reflective North Polar Cap, clouds could warm the surface by backscattering energy reflected from the high albedo surface that would normally pass through the clouds and out of the planet. Equatorial clouds could lead to atmospheric warming, with increased warming at night with the more relevant optical parameters. This could result in temperature differences of several Kelvin per day, which could affect convective patterns.

Title: Significance of topography-driven vertical transport on the global water cycle on Mars

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Abstract:

We use a 3D Mars general circulation model (GCM) to show that vertical transport of water is enhanced during northern summer due to influences from topography, such as mountain waves. Additionally, an increase in the vertical transport is seen when the resolution to 2°x3°. The finer resolution improves the ability to resolve terrain-induced circulation, and boosts the vertical transport of water. The increased vertical transport places water higher in the atmosphere leading to more ice mass in the aphelion cloud belt, and greater cross-equatorial water transport via the upper branch of the Hadley cell.

Simulations of the Martian climate performed at two different resolutions (5°x6° and 2°x3°) indicate an increase in the mean vertical transport of water as resolution is increased. This has an impact on the large-scale global transport of water, as it affects the total amount of water in the upper branch of the Hadley cell. The main source of the discrepancy is the ability (or inability) to resolve large terrain features such as Olympus Mons, the other Tharsis Montes, and Elysium Mons. These mountains greatly affect the mean circulation by introducing mountain waves and transporting copious amounts of water into the upper troposphere. We conclude that the mean circulation defined by the conventional Hadley cell transport is not sufficient to model all of the vertical transport of water, and that mountain-induced waves, which only manifest as strong influences at higher resolutions, are just as important, if not more. While there was a noticeable increase in the height of the water in the transition to 2°x3°, the model results still do not match the observations. Additional testing is required to determine if the cloud placement will improve further at even higher resolutions, or if other parameterizations are necessary.

Investigating Titan's Atmospheric Chemistry with the Titan Haze Simulation Experiment

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In Titan's atmosphere, a complex organic chemistry induced by UV radiation and electron bombardment occurs between the main constituents, N_2 and CH_4, and leads to the production of larger molecules and solid aerosols. Because the reactive carbon and nitrogen species present in Titan's aerosols could meet the functionality requirements for precursors to prebiotics, the study of Titan's aerosol has become a topic of extensive research in the fields of astrobiology and astrochemistry in recent years. Since 2004, the Cassini-Huygens mission has shed light over Titan's atmospheric chemistry only to uncover a more complex system than previously suspected, in particular with the detection of benzene and toluene, known precursors of polycyclic aromatic hydrocarbons (PAHs)[1], and an unidentified spectral emission at 3.28 μm that could be explained by the presence of aromatic molecules such as PAHs[2].

Here we will present the Titan Haze Simulation (THS) experiment, which was developed at the NASA Ames COSmIC facility to investigate the formation process of large hydrocarbon aerosols, by studying the chemical pathways that link the simple precursor molecules resulting from the first steps of the N_2-CH_4 chemistry (C_2H_2, C_2H_4, HCN…) to benzene, and to polycyclic aromatic hydrocarbons (PAHs) and nitrogen containing PAHs (or PANHs) as precursors to solid aerosols. In the COSmIC/THS, the chemistry is simulated by plasma in the stream of a supersonic expansion. With this unique design, the gas is jet-cooled to Titan-like temperature (~150K) before inducing the chemistry by plasma[3], and remains at low temperature in the plasma discharge (~200K). The residence time of the gas in the pulsed plasma discharge is on the order of 3 μs, resulting in a truncated chemistry that allows us to probe the first and intermediate steps of the chemistry, and hence monitor the evolution of the chemical growth, by injecting different N_2-CH_4-based gas mixtures in the plasma, with or without the addition of heavier precursors present as trace elements on Titan (C_2H_2, C_2H_4, C_2H_6, C_6H_6…).

We will discuss the results of two complementary studies of the gas phase[4] and solid phase[5] products that have been performed in 4 different gas mixtures: N_2-CH_4, N_2-CH_4-C_2H_2, N_2-CH_4-C_6H_6 and N_2-CH_4-C_2H_2-C_6H_6 using a combination of *in situ* and *ex situ* diagnostics. The mass spectrometry analysis of the gas phase was the first to demonstrate that the THS is a unique tool to monitor the first and intermediate steps of Titan's atmospheric chemistry at Titan-like temperature, as well as investigate specific chemical pathways. In particular, the mass spectra obtained in a N_2-CH_4-C_2H_2-C_6H_6 mixture showed promising results[4] when compared to observational data from the Cassini Plasma Spectrometer – Ion Beam Spectrometer (CAPS-IBS). The solid phase is in the form of grains and aggregates that are formed in volume in the gas expansion, and can be deposited on different substrates. Differences in the morphology of these grains and aggregates, depending on the initial mixture, have been observed by scanning electron microscopy, and could be representative of potential differences in growth processes depending on the composition of the atmosphere at different altitudes on Titan. Mixtures containing acetylene (C_2H_2) appear to produce more spherical grains, and the aggregates produced in mixtures containing benzene (C_6H_6) appear to be submitted to additional growth after grain aggregation. X-ray Absorption Near Edge Structure measurements of the solid phase show the presence of nitrogen chemistry (nitrile and imine have been detected) and differences in the level of nitrogen incorporation and how it is integrated in the solid phase depending on the initial gas mixture. Mid-infrared spectroscopic analyses highlight a change in the nitrogen chemistry and an increase in aromatic abundance when benzene is present. A comparison of THS mid-IR spectra to Cassini Visible Infrared Mapping Spectrometer (VIMS) data[5] has shown that the THS aerosols produced in simpler mixtures (without benzene) i.e., samples that contain more nitrogen and incorporate this nitrogen in isocyanide-type molecules instead of nitriles, are more representative of Titan's aerosols.

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[5] Sciamma-O'Brien, E. et al., *Icarus* (under review).

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Modeling N_2/CH_4 Plasma Chemistry in the Titan Haze Simulation Experiment

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Ultraviolet radiation and electron impact drive reactions in the nitrogen-methane atmosphere of Saturn's moon Titan leading to the formation of large organics and haze [1]. The Titan Haze Simulation (THS) experiment utilizes the Ames COSmIC chamber to understand how those products form. In the THS experiment, a glow discharge plasma is triggered in supersonic flowing gas using a kilovolt-level pulse. Because of the high flow rate, the residence time in the plasma channel is short (a few μs) after which reactions are terminated by expansion to low density. The truncated reactions process enables the study of initial and intermediate steps in Titan-like chemistry.

Building on previous studies of argon plasma in the COSmIC chamber [2], [3] and nitrogen-methane plasma [4], a new computational model has been constructed to simulate the conditions of the THS experiment. There are several motivations for this model. First, the level of agreement between chemical products predicted by the model and measured in THS experiments is a way of evaluating the chemical network that has also been used to simulate Titan atmospheric chemistry. In this way, our plasma model provides a link between laboratory analog experiments and atmospheric models of Titan. Second, our plasma modeling reveals the chemical routes by which gas precursors are fragmented then grow to larger products. These routes may have implications for the predictive capability of Titan atmospheric models. Finally, our model complements time-of-flight mass spectra of positive ions recorded in the THS experiments by also tracking the neutral chemistry.

The simulation involves a one-dimensional solution of the plasma fluid equations. The electric field is calculated by Poisson's equation. The properties of the electron population are integrated in time across the one dimensional space. Electron impact and chemical kinetics for approximately 100 species are followed including about 10 excited states of nitrogen and 30 positive ions. The calculated concentrations of the ions in these species are compared with mass spectrometry measurements.

This numerical model of the THS is a detailed yet flexible platform for investigating the role of precursor composition and applied voltage. Our poster will explain the salient features and presents some typical results.

Acknowledgements: A. R. acknowledges the support of the NASA NSTRF Program.

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Title: Synoptic Traveling Weather Systems on Mars: Effects of Radiatively-Active Water Ice Clouds

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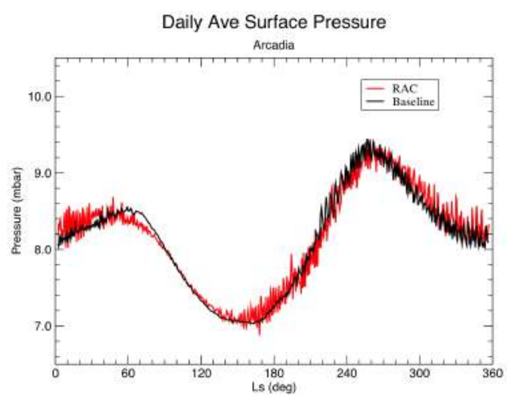
[2]Bay Area Environmental Research Institute

Atmospheric aerosols on Mars are critical in determining the nature of its thermal structure, its large-scale circulation, and hence the overall climate of the planet. We conduct multi-annual simulations with the latest version of the NASA Ames Mars global climate model (GCM), gcm2.3+, that includes a modernized radiative-transfer package and complex water-ice cloud microphysics package which permit radiative effects and interactions of suspended atmospheric aerosols (e.g., water ice clouds, water vapor, dust, and mutual interactions) to influence the net diabatic heating. Results indicate that radiatively active water ice clouds profoundly affect the seasonal and annual mean climate. The mean thermal structure and balanced circulation patterns are strongly modified near the surface and aloft. Warming of the subtropical atmosphere at altitude and cooling of the high latitude atmosphere at low levels takes place, which increases the mean pole-to-equator temperature contrast (i.e., "baroclinicity"). With radiatively active water ice clouds (RAC) compared to radiatively inert water ice clouds (nonRAC), significant changes in the intensity of the mean state and forced stationary Rossby modes occur, both of which affect the vigor and intensity of traveling, synoptic period weather systems.

Such weather systems not only act as key agents in the transport of heat and momentum beyond the extent of the Hadley circulation, but also the transport of trace species such as water vapor, water ice-clouds, dust and others.



The northern hemisphere (NH) forced Rossby waves and resultant wave train are augmented in the RAC case: the modes are more intense and the wave train is shifted equatorward. Significant changes also occur within the subtropics and tropics. The Rossby wave train sets up, combined with the traveling synoptic-period weather systems (i.e., cyclones and anticyclones), the geographic extent of storm zones (or storm tracks) within the NH. A variety of circulation features will be presented which indicate contrasts between the RAC and nonRAC cases, and which highlight key effects radiatively-active clouds have on physical and dynamical processes active in the current climate of Mars.

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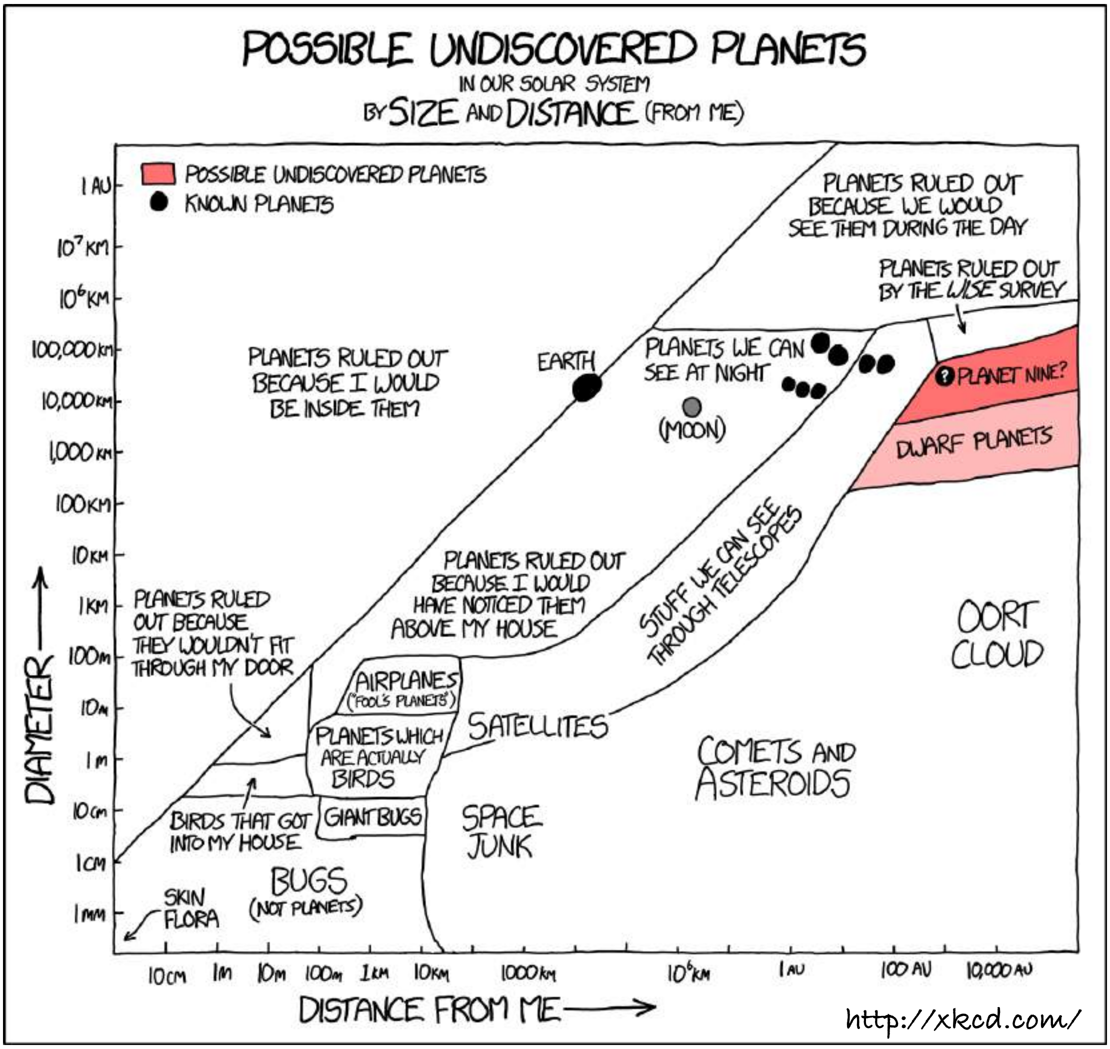
POSSIBLE UNDISCOVERED PLANETS
IN OUR SOLAR SYSTEM
BY SIZE AND DISTANCE (FROM ME)
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PLANETS RULED OUT BECAUSE WE WOULD SEE THEM DURING THE DAY
PLANETS RULED OUT BY THE WISE SURVEY
PLANETS WE CAN SEE AT NIGHT
EARTH
(MOON)
PLANET NINE?
DWARF PLANETS
PLANETS RULED OUT BECAUSE I WOULD BE INSIDE THEM
PLANETS RULED OUT BECAUSE I WOULD HAVE NOTICED THEM ABOVE MY HOUSE
STUFF WE CAN SEE THROUGH TELESCOPES
OORT CLOUD
PLANETS RULED OUT BECAUSE THEY WOULDN'T FIT THROUGH MY DOOR
AIRPLANES ("FOOL'S PLANETS")
PLANETS WHICH ARE ACTUALLY BIRDS
SATELLITES
COMETS AND ASTEROIDS
BIRDS THAT GOT INTO MY HOUSE
GIANT BUGS
SPACE JUNK
SKIN FLORA
BUGS (NOT PLANETS)
DIAMETER
1 AU
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DISTANCE FROM ME
http://xkcd.com/

Testing A Sample Delivery System for Planetary Surface Missions

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Introduction Delivery of surface samples to payload instruments can be a deceptively difficult task and if not done correctly can limit the science outcomes of the mission. The Sample Delivery System (SDS) is a versatile robotic arm end effector designed for the collection, transfer, size-sorting and delivery of Martian soil samples. The SDS is designed as a low-cost technically simple successor to the Phoenix Icy Soil Acquisition Device (ISAD). During the 2008 Phoenix mission mobilization of H2O due to solar heating and subsequent adfreezing on the device's surface impeded same sol delivery of samples for on-board analysis. Inaccuracies during sample release led to soil build-up on the lander deck and sample loss between scoop and instrument inlets (1). The CHIMRA effector on the MSL is capable of collecting and delivering measurable sorted quantities to the rover on-board instruments. We argue that the SDS can provide comparable functionality in a technically simpler package optimal for budget constrained missions.

Description The combined scoop and sorting mechanism is designed as a general purpose manipulator suitable for sample collection and size-sorting. The scoop design provides multipurpose capacity to excavate, sort and dispense sample or use for drill cuttings collection. The open funnel leads to a sorting vesicle where a rotating brush forces particles through a grill that may be mission optimized for flow rate and maximum particle size. The current test series has focused on reducing flow rate optimized for use with the Wet Chemistry Laboratory[2] onboard IceBreaker, a proposed Discovery Class mission.

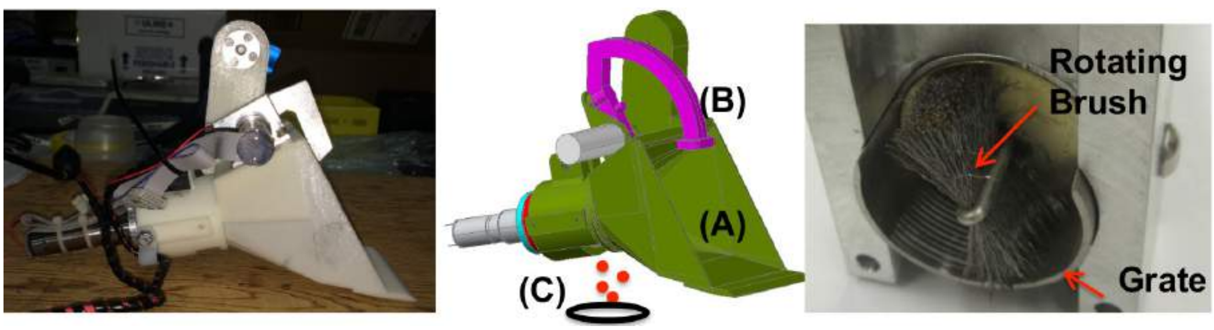

Figure 1: *SDS. a) Scoop b) Plunger*

Methods and Materials Testing conducted under Mars simulant conditions has been used to evaluate the effectiveness of the current SDS prototype. Antarctic University Valley (UV) soil was used for both the dry and saturated samples (20% water w.t). Vacuum conditions of 0.6-1 kPa and temperatures of $<-15°C$ were used for the frozen samples. Dry run sampling was consistently high yield and much greater than the targeted 1-2g delivery envelope. The saturated soil samples and pure ice samples where prepared from fresh drill cuttings using an IceBreaker drill bit and then loaded into the cooled scoop under STP conditions, then rapidly placed in a cooled vacuum chamber and pumped down to Mars pressure and allowed to cool for several hours prior to dispensing - by running the brush. The vacuum chamber was then opened and the sample dispensed collected and weighed. Dry samples were tested using similar procedures and in ambient pressure. Figure 2 shows measurements of amount dispensed.

Further Work The next tests will investigate the effect of perchlorates in saturated frozen samples and a variable brush activation. Further work needs to be conducted on the relation of initial sample density to output mass. It is essential to know if any sample sublimation can lead to clogging within the system and a performance degradation. Testing of earlier prototypes highlighted the concepts ability to effectively sort out or reduce larger particles.[3]

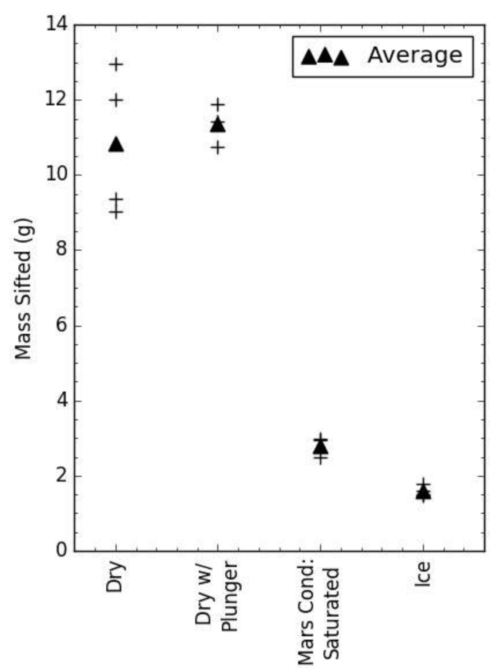

Figure 2: *Test yields for thirty seconds of operation. Only the first 'Dry' sample run did not have the plunger activated*

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Adhesion, and Adfreezing of Sticky Mars Dirt to Various Scoop Materials

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Introduction: The 2008 Phoenix mission planned to dig into icy soils and deliver them to instruments for analysis using it's robot arm scoop (Icy Sample acquisition device (ISAD)) (Fig 1) (Chu P et al 2008). Sample transfer was unexpectedly difficult as samples were sticky adhering to metal surfaces and cohesive soils bridging over instrument inlets. By end of mission dirt covered the deck, filters on instrument inlets were clogged, and dirt stuck to the scoop even when it was tipped upside down (Arvidson et al 2000). An explanation is high concentrations of Perchlorate salts in the soil lowered the water freezing temperature allowing liquid water to be present in the cold conditions enabling soils to be more cohesive.

Fig 1: Mars Phoenix mission ISAD Scoop

Objective: In 2016 we investigated Adhesion and Adfreezing properties of simulated icy salt rich Mars soils with various metals and plastics that might be used as scoop liners.

Methods & Materials: A rotating shear box apparatus was made (Fig 1), consisting of a circular plate loaded with a weight bearing down onto Mars simulant soil. The plate and soil were at -20°C. A torque was applied to the circular plate until it rotated. The torque is a measure of Shear stress between the plate and soil and the bearing weight a measure of Normal Stress on the soil and plate. Shear stresses for a range of bearing weights were measured for different circular plate materials: Silcone, Teflon, Acetal, Nylon, ceramics, UHMW PE, anodized Aluminium and Aluminium. Mars simulant salty soil was used consisting of by weight of 87.5% MMS, 10% water, and 2.5% NaCL.
The shear and normal stresses were plotted (Fig 2). Adhesion is the intercept and slope determined the Friction Coefficient. Adhesion & Coefficient of Friction values for various materials were plotted (Fig 3). Adfreezing loads were measured on soil resting on the plate at room temperature then frozen to -20°C.

Conclusion: 1) The Adhesive strength to plastics and ceramics was less than metals. 2) PTFT and Ceramics had the lowest Friction Coeff. 3) All Friction Coefficients were higher than expected. 4)..Adfreezing strengths were ~1000x Adhesion strength

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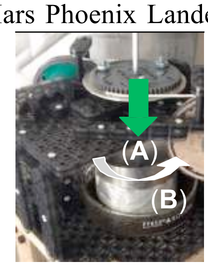

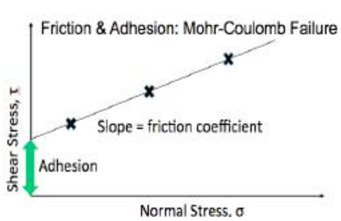

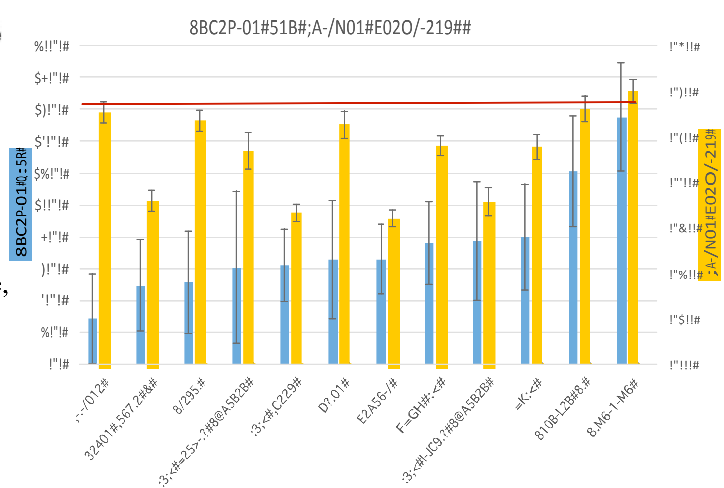

Left Fig 2: Rotating Shear box. (A) Circular plate, bearing and torque loads applied. (B) Mars soil.
Middle Fig 3: Shear Stress Vs Normal Stress: Adhesion & Friction Coeff
Right Fig 4: Table of Adhesion & Friction Coefficients for various materials

A FRAMEWORK FOR INFERRING TAXONOMIC CLASS OF ASTEROIDS

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Introduction: Taxonomic classification of asteroids based on their visible / near-ir spectra or multi band photometry has proven to be a useful tool to infer other properties about asteroids. Meteorite analogs have been identified for several taxonomic classes, permitting detailed inference about asteroid composition [1], [2]. Trends have been identified between taxonomy and measured asteroid density [3]. Thanks to NEOWise and Spitzer, approximately twice as many asteroids have measured albedos than the number with taxonomic classifications. (If one only considers spectroscopically determined classifications, the ratio is > 40.) We present a bayesian framework that provides probabilistic estimates of the taxonomic class of an asteroid based on its albedo. Although probabilistic estimates of taxonomic classes are not a replacement for spectroscopic or photometric determinations, they can be a useful tool for identifying objects for further study or for asteroid threat assessment models [4].

Inputs & Framework:
The framework relies upon two inputs: the expected fraction of each taxonomic class in the population and the albedo distribution of each class. Luckily, numerous authors have addressed both of these questions. For example, the taxonomic distribution by number, surface area and mass of the main belt has been estimated by [5] and a diameter limited estimate of fractional abundances of the near earth asteroid population was made by [6]. Similarly, the albedo distributions for taxonomic classes have been estimated by [7] and [8] for the combined main belt and NEA populations in different taxonomic systems and by [6] and [9] for the NEA population specifically.
The framework utilizes a Bayesian inference appropriate for categorical data. The population fractions provide the prior while the albedo distributions allow calculation of the likelihood an albedo measurement is consistent with a given taxonomic class. These inputs allows calculation of the probability an asteroid with a specified albedo belongs to any given taxonomic class.

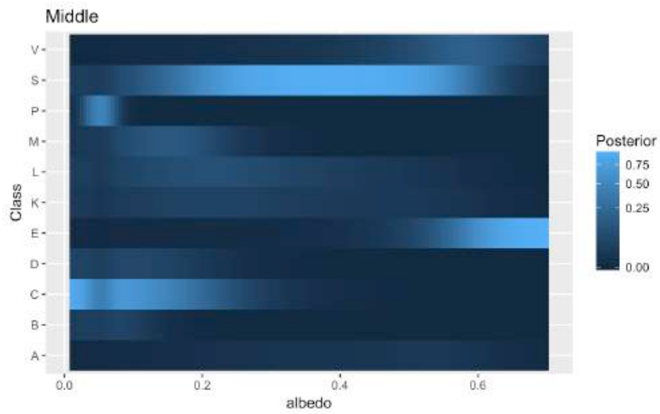

Figure 1. The likelihood a Middle Main Belt Asteroid of a given albedo belongs to the specified taxonomic class based on priors derived from [5].

Acknowledgments: This work was funded by NASA's Planetary Defense Coordination Office (PDCO).

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THE AMES VERTICAL GUN RANGE. J. S. Karcz[1] (john.s.karcz@nasa.gov), D. Bowling[2] , C. Cornelison[1] , A. Parrish[2] , A. Perez[3] , G. Raiche[1] , and J.-P. Wiens[3] , [1]National Aeronautics and Space Administration (NASA) Ames Research Center, Moffett Field, CA 94035, [2]Jacobs Technology Inc., 600 William Northern Boulevard., P.O. Box 884, Tullahoma, TN 37388, [3]Qualis Corporation, 689 Discovery Drive, Suite 400, Huntsville, AL 35806

Introduction: The Ames Vertical Gun Range (AVGR) is a national facility for conducting laboratory-scale investigations of high-speed impact processes. It provides a set of light-gas, powder, and compressed-gas guns capable of accelerating projectiles to speeds up to 7 km s^{-1}. The AVGR has a unique capability to vary the angle between the projectile launch vector and the gravity vector between 0 and 90°. The target resides in a large chamber (diameter ~ 2.5 m) that can be held at vacuum or filled with an experiment-specific atmosphere. The chamber provides a number of viewing ports and feed-throughs for data, power, and fluids. Impacts are observed via high-speed digital cameras along with investigation-specific instrumentation, such as spectrometers. Use of the range may be included in grant proposals through any Planetary Science Research Program element of the NASA Research Opportunities in Space and Earth Sciences (ROSES) calls. Exploratory experiments (one to two days) are additionally possible in order to develop a new proposal.

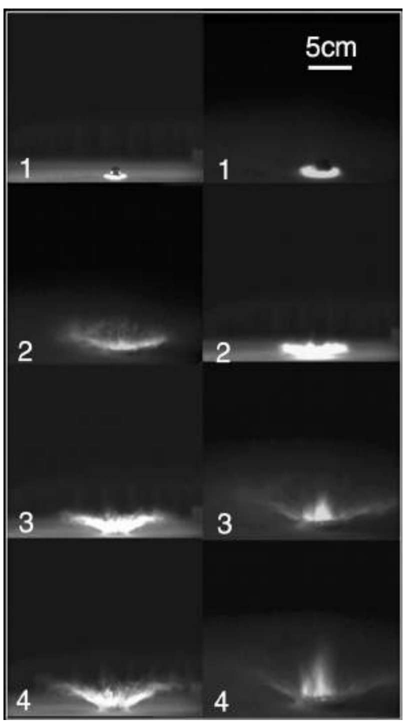

Figure 1: Comparison of the plume produced by solid (left) and hollow (right) projectiles. The hollow-projectile plume has a central, narrow-angle component. This experiment was conducted as part of a series that examined the behavior of ejecta during the LCROSS lunar impact. The LCROSS impactor, a Centaur upper stage, was a hollow structure. Modified from [5].

Purpose: Since the Apollo program, the AVGR has enabled investigations into fundamental impact processes and supported numerous NASA science missions. It was created in 1966 to assess the nature of the lunar regolith and to determine crater-scaling relations that could be used to constrain the age of the lunar surface. After closure in 1977, it was reopened in 1979 as a national facility in response to user interest. Investigations conducted using the AVGR have contributed to understanding of impact physics and the geological processes responsible for features observed throughout the Solar System. They have stimulated the development of new computational approaches and served as benchmarks for computational models. AVGR experiments have contributed input for missions including Deep Impact, LCROSS (Figure 1), Stardust, the Mars Exploration Rovers, and Cassini. In addition, experiments have contributed to the analysis of mission results from Surveyor to Dawn. Examples of recent investigations include examination of the effects of early-stage coupling between the projectile and the target on main-stage crater development [1]; assessment of cratering, disruption, and momentum transfer due to impacts into porous asteroids [2]; high-speed spectroscopic examination of the temporal and spatial evolution of impact-generated vapor [3]; and determination of the temperatures reached during aerogel capture of hypervelocity particles, as employed by the Stardust sample-return mission [4].

Further information: A complete description of the facility is available in the NASA Ames Thermophysics Facilities Test Planning Guide, which is available at the Thermophysics Branch website (http://www.nasa.gov/centers/ames/thermophysics-facilities/). Instructions for investigators interested in incorporating AVGR experiments into their proposals are included in the Planetary Science Research Program section of the ROSES call. Potential users are invited to contact the authors.

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Fluid Flow and Tholin Transport on Pluto, an Analysis of *New Horizons* Data

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with contributions from the *New Horizons* Composition and Geology-Geophysics teams

1. NASA Ames, 2. SETI Institute, 3. SWRI Boulder, 4. Univ. Virginia, 5. Lowell Observatory, 6. Goddard Space Flight Center, 7. Applied Physics Lab.

The material that colors most of the surface of Pluto and the north polar region of Charon is almost certainly organic complexes (tholins) produced in Pluto's atmosphere and in the surface ices by energetic processing of gas or ice composed of N_2, CH_4, and CO. Charon's colored polar region may represent processed CH_4 that condensed in that coldest region of the satellite's surface by from the outflow of CH_4 gas escaping from Pluto's atmosphere, currently at the rate of 5 E25 molecules/s (Grundy et al. 2016). The production of the organic tholin, which we have simulated in the laboratory (Materese et al., 2014, 2015), has not been uniform over Pluto's history. Layering in the surface structures (crater and valley walls, tilted ice blocks) reveals episodes of the formation of the tholin, which appears dark in tone and usually red-brown in color sandwiched in the geologic column of mostly ice (primarily N_2 and CH_4). Mechanisms for voluminous and episodic production of tholins from processing of the atmosphere and surface include activity from the early young Sun and the episodic migration of the heliosheath into the planetary region by the influence of external pressure from nonuniformities in the local interstellar medium as the Sun moves through the Galaxy. Lower production rates occur from more continuous irradiation of Pluto in its normal position deep within the heliosphere. Furthermore, the tholins show a distribution on Pluto that indicates transport and local accumulations, which from a geomorphological point of view suggests both fluid- and wind-borne movement. Regions of Pluto's surface from which tholins have been removed show exposed H_2O ice, which is regarded as bedrock underlying the surface layers of much more volatile ices of N_2, CH_4, and CO in various combinations.

In this analysis, topographic gradients measured for several channels (fossae) from the *New Horizons* digital elevation map (DEM), together with regional exposures of H_2O bedrock and accumulations of colored tholin are presented as geomorphological evidence for fluid flow on Pluto. Similarly, other regions of heavy accumulations of tholin that appear to be consistent with wind deposition are shown. Both the transporting fluid and the thicker and more dynamic atmosphere needed to pickup and carry tholins are thought to be nitrogen, which can liquefy and evaporate under conditions expected to occur many times as a result of Pluto's extreme climatic variations induced by long-term (3 My) Milankovich-type cycles (Stern et al. 2017, Binzel et al. 2017).

Binzel, R. P. et al. 2017 Icarus in press; Grundy, W. et al. 2016 Nature 539, 65.; Materese, C. K. et al. 2014 Ap.J.788:111.; Materese, C. K. et al. 2015 Ap.J. 812: 150.; Stern, S. A. et al. 2017 Icarus in press.

RESOURCE PROSPECTOR LANDING SITE AND TRAVERSE PLAN DEVELOPMENT. R. C. Elphic[1], A. Colaprete[1], M. Shirley[1], A. McGovern[2], R. Beyer[3], [1]NASA Ames Research Center, Moffett Field, CA 94035 USA; [2]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723 USA; [3]SETI/NASA Ames Research Center, Moffett Field, CA 94035 USA.

Introduction: Resource Prospector (RP) will be the first lunar surface robotic expedition to explore the character and feasibility of in situ resource utilization at the lunar poles. It is aimed at determining where, and how much, hydrogen-bearing and other volatiles are sequestered in polar cold traps. To meet its goals, the mission should land where the likelihood of finding polar volatiles is high [1,2,3]. The operational environment is challenging: very low sun elevations, long shadows cast by even moderate relief, cryogenic subsurface temperatures, unknown regolith properties, and very dynamic sun and Earth communications geometries force a unique approach to landing, traverse design and mission operations.

Landing Site Identification: In addition to a high potential of volatile sequestration, a landing site candidate must meet engineering and mission operations requirements: sufficient solar access to power the rover over mission lifetime, sufficient visibility to ground stations for real time communications, manageable hazards such as slopes and block abundance, etc. A landing site must have acceptable slopes within the 3-sigma landing ellipse (200-m diameter); it should also have at least 48 hours of sun and DTE communications access to accommodate checkout, rover egress, and initial operations, with margin.

At this time, four landing sites are being used to study mission design and feasibility, two in the north and two in the south. These are shown in Table 1.

Table 1. Design Reference Mission Landing Sites

Pole	Site Name	Lat.	Lon.
SP	N. Nobile	85.194S	35.436E
SP	N. Shoemaker	87.185S	59.921E
NP	Erlanger	87.19N	29.119E
NP	Hermite-A	87.436N	-49.039E

Maps Needed for Study: Layers in a landing site and traverse planning tool must include the following: *time-varying* sun and comm access; slopes (digital terrain models); water ice stability depth models; hydrogen concentration maps; permanently shadowed regions; LROC NAC photomosaics; LRO Diviner blockiness or rock abundance measure.

Traverse Design Tool: To incorporate the static and time-varying constraints on mission design, a traverse design tool has been developed that combines the functionality of a geographic information system with mission activity planning. The RP tool relies on the ability to use the time-varying parameters of sun and comm access together with static constraints (slope limits, block hazards, etc) to determine a viable and safe traverse corridor through space and time (Fig. 1). By performing a Boolean "and" operation between relevant layers, through time, it is possible to forward-flood the landing site area to establish such corridors. A key capability in this development is "reachability analysis": determining what areas can be attained (with margin) in a given period of time assuming selectable and realistic rover mobility capabilities and science activity durations. Rover performance and real-time decision-making on the ground will vary with the types of terrain, the level of hazard, and limits on situational awareness; these are incorporated into the tool as adjustable parameters based on testing and simulation.

The RP traverse design tool is currently being used to gauge the impact of various rover design attributes on achieving mission success at the four representative landing sites. Details will be provided.

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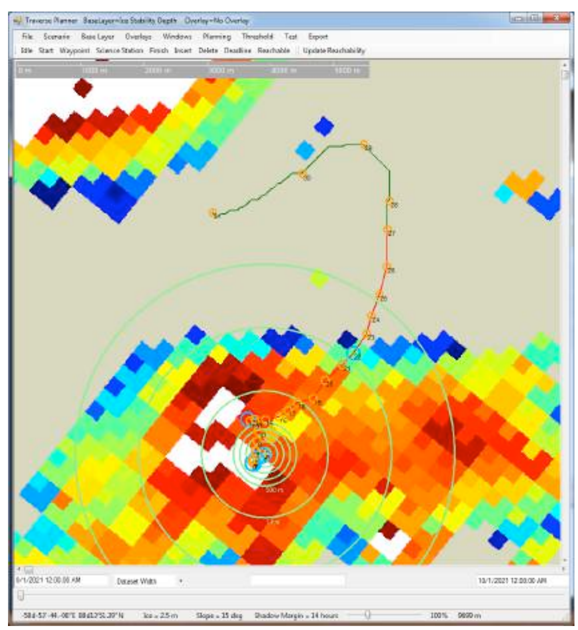

Fig. 1. Example of a traverse design for Hermite-A. The base layer is model depth to stable ice.

Advanced optical characterization of simulated complex organic matter for solar system objects and beyond.

Hiroshi Imanaka, Hiroharu Yui, Dale P. Cruikshank, Christopher P. McKay
(NASA Ames)

Understanding of organic chemical processes among the extraterrestrial environments is crucial to elucidate the possibility of habitable environments. For instance, the recent observations by the New Horizon Mission have revealed the complex coloration of Pluto's surface along the geological units. Complex organic materials generated on icy surface and in the atmosphere may be the origins of such colorations, which probably reflect the long-term history of surface-atmosphere interactions on Pluto. Laboratory measurements of optical constants for possible complex organic materials are the necessary step for putting constraints on their composition and physico-chemical processes. However, laboratory simulated organic matters often result in non-uniform films or irregular particulates with sub-micrometer to millimeter sizes. Thus, it has been quite difficult for long time to obtain reliable optical constants of such materials. We have been developing a suite of novel microscopic techniques to determine optical constants of such non-uniform organic materials. The new microscopic spectrometer allows us to measure the transmittance and reflectance simultaneously at the same measurement spot size (~100 μm). This broadband microscopic transmittance and reflectance spectrometer (μTR) helps us to determine optical constants of non-uniform film samples, where optical absorption is sufficiently large. Microscopic photothermal deflection spectrometer (μPDS) enables us to measure the optical absorption of the irregular particles with sensitivity $10^{3\text{-}4}$ times better than the conventional transmittance spectrometers. Combinations of these microscopic techniques would allow us to determine the optical constants of a wide variety of complex organic materials useful for interpreting remote sensing observations now and in near future.

Science Return of a hydrophone on-board an Ocean World lander.
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Introduction:
For this presentation we describe the science return, design and cost of a microphone on-board a Europa lander mission. In addition to the E/PO benefit of a hydrophone to listen to the Europa Ocean, a microphone also provides scientific data on the properties of the subsurface ocean.

A hydrophone is a small lightwieght instrument to that could be used to achieve two of the three Europa Lander mission anticipated science goals of: 1) Asses the habitability (particularly through quantitative compositional measurements of Europa via in situ techniques uniquely available to a landed mission. And 2) Characterize surface properties at the scale of the lander to support future exploration,including the local geologic context. [1].
Acoustic properties of the ocean would lead to a better understanding of the water density, currents , seafloor topography and other physical properties of the ocean as well as lead to an understanding of the salinity of the ocean.
The engineering design of the hydrophone instrument will be designed to fit within a portion of the resource allocation of the current best estimates of the Europa lander payload (26.6 Kg, 24,900 cm^3, 2,500 W-hrs and 2700 Mbits). The hydrophone package will be designed to ensure planetary protection is maintained and will function under the current Europa lander mission operations scenario of a two-year cruise phase, and 30-day surface operational phase on Europa.

The hydrophone is designed to be lowered into the subsurface ocean, the hydrophone is at a TRL six with the prototype demonstrated in a relevant (cold, salty, and high radiation) environment.

Reference: Pappalardo, R. T., et al. "Science potential from a Europa lander." *Astrobiology* 13.8 (2013): 740-773.

Low Velocity Impacts on Phobos.

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Introduction: We present evidence for low velocity impacts on Phobos resulting from material transfer from Deimos to Phobos and/ or recaputure of Phobos ejecta.

Mars's inner moon, Phobos, is located deep in the planet's gravity well and orbits far below the planet's synchronous orbit. Images of the surface of Phobos, in particular from Viking Orbiters, MGS, MRO, and MEX, reveal a spectral heteogenity, rich collisional history, including fresh-looking impact craters and subdued older structures, very large impact structures (compared to the size of Phobos), such as Stickney, and much smaller ones [1, 2, 3, 4].

Sources of impactors colliding with Phobos include *a priori:* A) Impactors from outside the martian system (asteroids, comets, and fragments thereof); B) Impactors from Mars itself (ejecta from large impacts on Mars); and C) Impactors from Mars orbit, including impact ejecta launched from Deimos and ejecta launched from, and reintercepted by, Phobos. In addition to individual craters on Phobos, the networks of grooves on this moon have also been attributed in part or in whole to impactors from some of these sources[5,6 7} as shown in Figure 1.

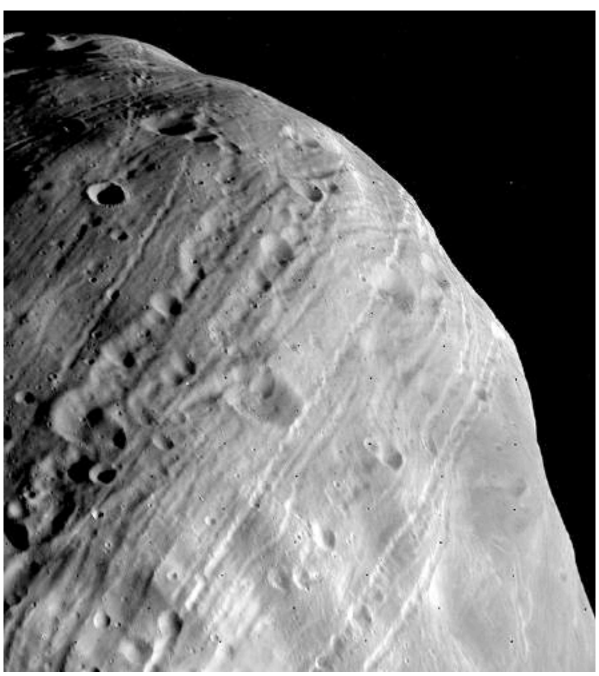

Figure 1. Grooves and crater chains on Phobos. Image taken by the Viking 1 Orbiter

Method: We report the preliminary results of a systematic survey of the distribution, morphology, albedo, and color characteristics of fresh impact craters and associated ejecta deposits on Phobos. Considering that the different potential impactor sources listed above are expected to display distinct dominant compositions and different characteristic impact velocity regimes, we identify specific craters on Phobos that are more likely the result of *low velocity impacts by impactors derived from Mars orbit* than from any alternative sources. Our finding supports the hypothesis that the spectrally "Redder Unit" on Phobos may be a superficial veneer of accreted ejecta from Deimos, and that Phobos's bulk might be distinct in composition from Deimos[8,9].

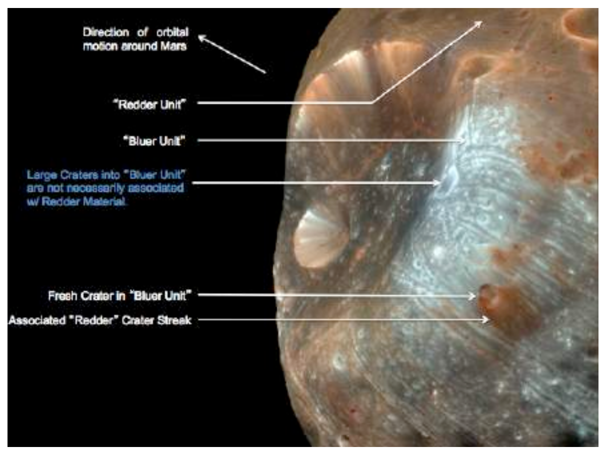

Figure 2. MRO image of Phobos showing the spectral units, orbital direction, and surface features supporting the transfer of material from Deimos to Phobos.

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Urban Biomining: Biological Extraction of Metals and Materials from Electronics Waste Using a Synthetic Biology Approach

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Abstract:

Integrated circuits (IC chips) are critical to modern technology and while relatively inexpensive on the Earth, a supply in space must be regenerated, repurposed or repaired *in situ*. If an IC chip is damaged or outdated, the processes for extracting and recycling the materials require high heat and chemical treatments; thus, repair or replacement of IC chips is not a feasible task in space or extraterrestrial environments where small size and low mass are required. We propose using a biological approach to depolymerize the silicate matrix of metals- and glass-containing electronic components to release the metals contained within. After enzymatic depolymerization of the silica, there is the additional challenge of separating the individual elemental components. We address this issue by using rationally-designed peptides that bind specific metals for the separation of metals from a solution at ambient temperature and under non-toxic conditions.

Using synthetic biology tools, we have developed a recycling method for e-waste. Our innovation is to use a recombinant version of a naturally-occurring silica-degrading enzyme to depolymerize silica, and subsequently, to use engineered bacterial surfaces to bind and separate metals from a solution. The bacteria with bound metals can then be used as "bio-ink" to print new circuits using a novel plasma jet electronics printing technology. Here, we present the results from our initial studies that focus on the specificity of metal-binding motifs for a cognate metal. The candidate motifs that show high affinity and specificity will be engineered into bacterial surfaces for downstream applications in biologically-mediated metal recycling.

Since the chemistry and role of Cu in metalloproteins is relatively well-characterized, we are using Cu as a proxy to elucidate metal and biological ligand interactions with various metals in e-waste. We assess the binding parameters of 3 representative classes of Cu-binding motifs using isothermal titration calorimetry; 1) natural motifs found in metalloproteins, 2) consensus motifs, and 3) rationally designed peptides that are predicted, *in silico*, to bind Cu. Our results indicate that naturally-occurring motifs have relative high affinity and specificity for Cu (association constant for Cu $K_a \sim 10^4\ M^{-1}$, Zn $K_a \sim 10^3\ M^{-1}$) when competing ions are present in the aqueous milieu. However, motifs developed through rational design by applying quantum mechanical methods that take into account complexation energies of the elemental binding partners and molecular geometry of the cognate metal, not only show high affinity for the cognate metal (Cu $K_a \sim 10^6\ M^{-1}$), but they show specificity and discrimination against other metal ions that would-be competitors for the same binding sites. This is an initial proof-of-concept study that focuses on Cu-binding; however, the overall objective of this research is to have peptides that selectively bind many metals from e-waste and this would allow for the separation of the metals from a solution, at ambient temperatures and under non-toxic conditions.

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