DEEP SPACE GATEWAY CONCEPT SCIENCE WORKSHOP

February 27-March 1, 2018
DENVER, COLORADO

Program

LPI

USRA

Lunar and Planetary Institute   3600 Bay Area Boulevard   Houston TX 77058-1113

Deep Space Gateway Concept Science Workshop

February 27–March 1, 2018 • Denver, Colorado

Institutional Support

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Abstracts for this workshop are available via the workshop website at

https://www.hou.usra.edu/meetings/deepspace2018/

Abstracts can be cited as

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Guide to Sessions

Tuesday Morning, February 27, 7:00 a.m.

Grand Foyer	Registration

Tuesday Morning, February 27, 8:30 a.m.

Alder Ballroom	Opening Plenary

Tuesday Afternoon, February 27, 1:00 p.m.

Aspen Meeting Room	Astrophysics: Fundamental Physics
followed at 3:15 p.m. by	
	Astrophysics: Astrophysics
Birch Meeting Room	SLPSRA: Discussing and Defining Deep Space Gateway Radiation Environment
followed at 2:25 p.m. by	
	SLPSRA: Discussing the Genetic Impact of Radiation at the Deep Space Gateway
followed at 3:15 p.m. by	
	SLPSRA: Discussing the Effects of Deep Space Gateway Radiation on Humans, Cells, and Drugs
followed at 4:35 p.m. by	
	SLPSRA: Aligning the Deep Space Gateway Science Investigations with the Decadal Survey and the Space Biology Science Plan
Boxelder Meeting Room	Lunar and Planetary: External Instruments
followed at 3:10 p.m. by	
	Lunar and Planetary: CubeSats
followed at 3:45 p.m. by	
	Lunar and Planetary: Near-Earth Objects Science
followed at 4:35 p.m. by	
	Lunar and Planetary: Telerobotics

Tuesday Afternoon, February 27, 1:00 p.m.

Cherry Meeting Room	Earth Observations: External Instruments I
Douglas Fir Meeting Room	Heliophysics: External Payloads
followed at 3:50 p.m. by	
	Heliophysics: Dusty Plasmas — Small Particles

Wednesday Morning, February 28, 8:30 a.m.

Aspen Meeting Room	Astrophysics: Telescope Assembly and Servicing
followed at 10:00 a.m. by	
	Astrophysics: Low Frequency Telescope and Surface Telerobotics
Birch Meeting Room	SLPSRA: Discussing Astronaut Impacts of Living at the Deep Space Gateway
followed at 9:55 a.m. by	
	SLPSRA: Requirements for Investigations at Deep Space Gateway
followed at 11:25 a.m. by	
	SLPSRA: Moving Forward with Expanded Deep Space Gateway Science Concepts
Boxelder Meeting Room	Lunar and Planetary: Samples
followed at 11:00 a.m. by	
	Lunar and Planetary: Surface Instrument Delivery
Cherry Meeting Room	Earth Observations: External Instruments II
Douglas Fir Meeting Room	Heliophysics: Space Weather
followed at 11:30 a.m. by	
	Heliophysics: CubeSats and SmallSats

Wednesday Afternoon, February 28, 1:00 p.m.

Alder Ballroom	Orbit Discussion
Boxelder Meeting Room	Potential Future Capabilities

Wednesday Afternoon, February 28, 1:40 p.m.

Alder Ballroom	Supporting Human Exploration Science

Wednesday Afternoon, February 28, 2:40 p.m.

Alder Ballroom	Crosscutting: External Instruments
followed at 4:40 p.m. by	
	Crosscutting: Sample Collection and Handling at Deep Space Gateway

Thursday Morning, March 1, 8:30 a.m.

Alder Ballroom	Crosscutting: Telerobotics and Leveraging the Deep Space Gateway for Untethered Science Operations
followed at 10:45 a.m. by	
	Crosscutting: Internal Payloads

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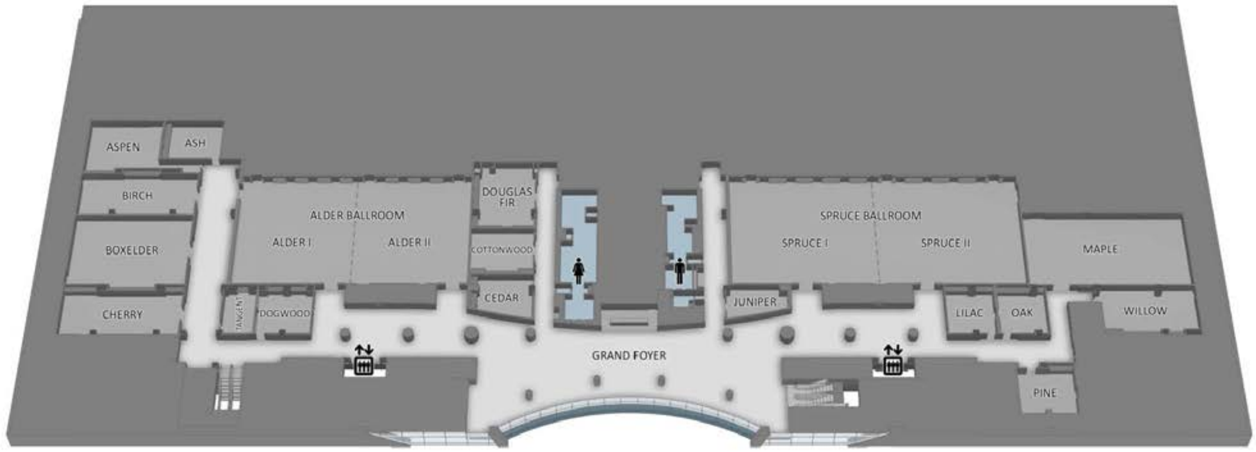

Program

Tuesday, February 27, 2018
OPENING PLENARY
8:30 a.m.   Alder Ballroom

Chair: **Ben Bussey**
Michael New

8:30 a.m.	Bussey B. * *Welcome and Goals of the Workshop*
8:45 a.m.	Zurbuchen T. * *SMD Overview*
9:00 a.m.	Crusan J. * *Human Exploration and Operations Mission Directorate Overview*
9:15 a.m.	Craig D. * *Deep Space Gateway Overview*
9:45 a.m.	Whitley R. * *Deep Space Gateway Orbits*
10:15 a.m.	BREAK
10:30 a.m.	Robinson J. * *International Space Station Utilization*
11:00 a.m.	Carpenter J. * *Review of European Space Agency Deep Space Gateway Science Workshop*
11:15 a.m.	Hipkin V. * *Review of Canadian Space Agency Deep Space Gateway Science Study*
11:30 a.m.	DISCUSSION

Tuesday, February 27, 2018
ASTROPHYSICS: FUNDAMENTAL PHYSICS
1:00 p.m. Aspen Meeting Room

Chair: **Jack Burns**

1:00 p.m. Gozutok A. A. * Gozutok M. I.
Compact Experimental High Energy Telescope on Deep Space Gateway **[#3003]**
Compact sized high energy telescope is an advantageous project which would be conducted on Deep Space Gateway. The project includes the exploration of higher energetic universe with wider spectrum reach in order to use lunar orbits efficiently.

1:15 p.m. Turyshev S. G. * Shao M. Hahn I.
Testing Fundamental Gravity with Interplanetary Laser Ranging **[#3013]**
Very accurate range measurements with the Interplanetary Laser Ranging Terminal (ILRT) will push high-precision tests of astrophysics/gravitation into a new regime. It could be used for navigation and investigations in planetary/lunar science.

1:30 p.m. Mohageg M. * Strekalov D. Dolinar S. Shaw M. Yu N.
Deep Space Quantum Link **[#3039]**
The Deep Space Quantum Link will test the effects of gravity on quantum systems, test the non-locality of quantum states at deep space distances, and perform long distance quantum teleportation to an Earth-based receiver.

1:45 p.m. Williams J. R. Yu N. *
Clock Comparison and Distribution Beacon at Cislunar Orbits **[#3088]**
We propose an advanced optical clock system for Deep Space Gateway as a high-precision time beacon, seeking direct detection of dark matter fields; tests of gravity-induced frequency shifts for fundamental physics; and precision one-way spacecraft tracking/ranging.

2:00 p.m. Eubanks T. M. * Matsakis D. Rodal J. J. A. Fearn H. Radley C. F.
Time, Metrology, and Fundamental Physics with the Deep Space Gateway **[#3172]**
We describe how the Deep Space Gateway, equipped with optical atomic clocks, can be used to both test fundamental physics and develop chronometric spacecraft navigation techniques.

2:15 p.m. Chiow S. -w. * Yu N.
Dark Energy and Gravity Experiment Explorer and Pathfinder **[#3040]**
We propose to utilize the unique gravity and vacuum environment in the orbits of the Deep Space Gateway for direct detections of dark energy using atom interferometers, and for pathfinder experiments for future gravitational wave and dark matter detections.

2:30 p.m. Losekamm M. J. * Berger T.
Low-Energy Cosmic Rays: Radiation Environment Studies and Astrophysics on the Deep Space Gateway **[#3108]**
The Deep Space Gateway will be ideally located to investigate the cosmic radiation that astronauts are subjected to in deep space and to help shed light on one of the most intriguing astrophysical mysteries of today: What is the universe made of?

2:45 p.m. DISCUSSION

3:05 p.m. BREAK

Tuesday, February 27, 2018
ASTROPHYSICS: ASTROPHYSICS
3:15 p.m.   Aspen Meeting Room

Chair: **Harley Thronson**

3:15 p.m. Hahn I. *   Shao M.   Turyshev S. G.
Microarcsecond Astrometry Telescope on the DSG **[#3015]**
Microarcsecond Astrometry Telescope is a small size telescope which extends accuracy beyond the current space telescopes to a microarcsecond level, by measuring systematic errors in the telescope optics and the focal plane using a laser metrology.

3:30 p.m. Miller R. S. *   Ajello M.   Beacom J. F.   Bloser P. F.   Burrows A.   Errando M.   Goldsten J. O.   Hartmann D.   Hoeflich P.   Hungerford A.   Lawrence D. J.   Leary J. C.   Leising M. D.   Milne P.   Peplowski P. N.   The L. -S.
The Lunar Occultation Explorer (LOX): Establishing the Moon as a Platform for Next-Generation Nuclear Astrophysics Investigations **[#3094]**
The Lunar Occultation Explorer (LOX) is a paradigm shift that will leverage the power of a new observational paradigm to transform our understanding of the nuclear cosmos (0.1–10 MeV) and establish the Moon as a platform for astrophysics.

3:45 p.m. Hui C. M. *   Briggs M. S.   Goldstein A.   Jenke P.   Kocevski D.   Wilson-Hodge C. A.
MoonBEAM: A Beyond-LEO Gamma-Ray Burst Detector for Gravitational-Wave Astronomy **[#3060]**
MoonBEAM, together with an Earth-orbit instrument, would probe the extreme processes in cosmic collision of compact objects and facilitate multi-messenger time-domain astronomy to explore the end of stellar life cycles and black hole formations.

4:00 p.m. Tauscher K. *   Burns J. O.   Monsalve R.   Rapetti D.
The Gateway to Cosmic Dawn: A Low Frequency Radio Telescope for the Deep Space Gateway **[#3096]**
We suggest that, with a suitable antenna and receiver, the Deep Space Gateway can be used to measure the highly redshifted, global 21-cm signal from neutral hydrogen, a spectral imprint of the history of the universe onto cosmic background radiation.

4:15 p.m. Caldwell D. A. *   Marchis F.   Batalha N. M.   Cabrol N. A.   Smith J. C.
Earth as an Exoplanet: Spectral Monitoring of an Inhabited Planet **[#3180]**
We propose a spectrometer for the Deep Space Gateway to monitor Earth as an exoplanet. We will measure the variability with illumination phase, rotation, clouds, and season. Results will inform future searches for biomarkers on distant exoplanets.

4:30 p.m. DISCUSSION

Tuesday, February 27, 2018
SLPSRA: DISCUSSING AND DEFINING DEEP SPACE GATEWAY RADIATION ENVIRONMENT
1:00 p.m. Birch Meeting Room

Chair: Jim Mantovani

1:00 p.m. Minow J. I. * Neergaard Parker L.
Space Radiation and Plasma Science Enabled by the Deep Space Gateway **[#3182]**
Deep Space Gateway (DSG) opportunities for investigating space radiation and plasma environments are discussed, including options that can be done at the DSG vehicle in lunar orbit, from DSG logistics vehicles, and subsatellites supported by DSG.

1:05 p.m. Spence H. E. * Jordan A. P. Joyce C. Rahmanifard F. Schwadron N. A. Smith S. S. Wilson J. K. Winslow R. Blake J. B. Mazur J. E. Townsend L. deWet W. Kasper J. C. Case A. W. Zeitlin C. J.
From Tempe to Denver: Realizing the Wargo Axiom with the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) **[#3150]**
We present a retrospective of LRO from the perspective of space radiation. We review synergies between exploration enabling science and science enabling exploration. We describe how CRaTER's flight spare contributes both to the Deep Space Gateway.

1:10 p.m. Hassler D. M. * Ehresmann B.
Next Generation Fast Neutron Detector for Space Exploration (Mini-FND) **[#3175]**
SwRI has developed a miniature Fast Neutron Detector (mini-FND), for use in the Deep Space Gateway, to characterize the neutron albedo radiation. Mini-FND will provide coverage of the biologically relevant neutrons at energies of 500 keV and greater.

1:15 p.m. Kennedy S. O. Jr. * Dunn A. Lecomte J. Buchheim K. Johansson E. Berger T.
Alamos: An International Collaboration to Provide a Space Based Environmental Monitoring Solution for the Deep Space Network **[#3069]**
This abstract proposes the advantages of an externally mounted instrument in support of the human physiology, space biology, and human health and performance key science area. Alamos provides Space-Based Environmental Monitoring capabilities.

1:20 p.m. Narici L. * Baiocco G. Berrilli F. Giraudo M. Ottolenghi A. Rizzo A. Salina G. **CANCELED**
Autonomous Monitoring of Radiation Environment and Personal Systems for Crew Enhanced SPE Protection (AMORE and PSYCHE) **[#3065]**
Understand the relationship between SPE precursors, the related SPE radiation inside the Deep Space Gateway, and the associated risk levels, validating existing models, proposing countermeasures actions via a real time, autonomous intelligent system.

1:25 p.m. Leitgab M. Semones E. * Mcleod C.
High Fidelity Measurement of Deep Space Gateway Intra-Vehicular Neutron Environment **[#3144]**
This neutron experiment will be designed to measure and characterize, at various locations inside the Deep Space Gateway, the neutron fields, and indirectly, the human impact of the shielding distribution of the vehicle and its payloads.

1:30 p.m. Rahmanifard F. * Schwadron N. A. Wilson J. Jordan A. Joyce C. J. Spence H. E. Blake J. B. Case A. W. Farrell W. M. Kasper J. C. Looper M. D. Lugaz N. Mays L. Mazur J. E. Petro N. Smith C. W. Townsend L. W. de Wet W. C. Winslow R. Zeitlin C.
The Worsening Space Environment: Increased Galactic Cosmic Radiation from Historically Weak Solar Magnetic Fields But with a Sun Still Spawning Historically Intense Solar Particle Events **[#3143]**
We report on observations from CRaTER on LRO and predict the dose rates of galactic cosmic rays throughout the next solar cycle. We use these results to predict the most conservative allowable mission durations.

1:35 p.m. Mantovani J. G. *
Deep Space Gateway as a Testbed to Study Effects of Regolith-Derived Radiation Shielding on Plant Growth During Long-Duration Exposure to Space Radiation **[#3148]**
Study of hydrogen-rich regolith as a radiation shield for plant growth during long-duration exposure to high energy space radiation. Comparable long-duration testing on Earth under similar radiation and vacuum conditions is not feasible due to costs.

1:40 p.m. DISCUSSION

2:10 p.m. BREAK

Tuesday, February 27, 2018
SLPSRA: DISCUSSING THE GENETIC IMPACT OF RADIATION AT THE DEEP SPACE GATEWAY
2:25 p.m. Birch Meeting Room

Chair: **David Smith**

2:25 p.m. Zea L. * Niederwieser T. Anthony J. Stodieck L.
Utilizing the Deep Space Gateway to Characterize DNA Damage Due to Space Radiation and Repair Mechanisms **[#3100]**
The radiation environment experienced in the Deep Space Gateway enables the interrogation of DNA damage and repair mechanisms, which may serve to determine the likelihood and consequence of the high radiation risk to prolonged human presence beyond LEO.

2:30 p.m. Venkateswaran K. * Wang C. Smith D. Mason C. Landry K. Rettberg P.
Characterization of Outer Space Radiation Induced Changes in Extremophiles Utilizing Deep Space Gateway Opportunities **[#3007]**
Extremophilic microbial survival, adaptation, biological functions, and molecular mechanisms associated with outer space radiation can be tested by exposing them onto Deep Space Gateway hardware (inside/outside) using microbiology and molecular biology techniques.

2:35 p.m. Griko Y. V. * Smith D. J.
Testing Survivability of Life Forms in Open Space Beyond LEO **[#3036]**
The Deep Space Gateway survivability experiments of microorganisms in open space beyond LEO are proposed in order to establish how deep space conditions are uniquely influential.

2:40 p.m. DISCUSSION

3:00 p.m. BREAK

Tuesday, February 27, 2018
SLPSRA: DISCUSSING THE EFFECTS OF DEEP SPACE GATEWAY RADIATION ON HUMANS, CELLS, AND DRUGS
3:15 p.m. Birch Meeting Room

Chair: **Marianne Sowa**

3:15 p.m. Hussey S. Blue R. S. Daniels V. Bayuse T. Zoldak J. Antonsen E. Lehnhardt K. *
Deep Space Radiation Effects on Pharmaceuticals **[#3149]**
This proposal seeks to identify detrimental effects on pharmaceutical stability imposed by the deep space radiation environment over time.

3:20 p.m. Almeida E. A. C. *
Deep Space Gateway as a Platform to Study Synergistic Radiation and Microgravity-Induced Tissue Degeneration Using the Bioculture System Single Cassette Hardware Design **[#3011]**
A major unknown for human exploration of deep space is the question of how the degenerative effects of microgravity unloading of cells and tissues may synergize with radiation. Here we describe cell culture hardware to study those combined effects.

3:25 p.m. Sowa M. B. * Lusby T. C. Straume T.
Considerations for the Study of Biological Effects in the Deep Space Environment **[#3121]**
Accurate prediction of the fundamental biological responses induced by radiation and microgravity exposures in deep space will benefit from inclusion of high-throughput data collection, computational approaches, and integrated radiation dosimetry.

3:30 p.m. Anthony J. H. * Niederwieser T. Zea L. Stodieck L.
Key Challenges for Life Science Payloads on the Deep Space Gateway **[#3107]**
Compared to ISS, Deep Space Gateway life science payloads will be challenged by deep space radiation and non-continuous habitation. The impacts of these two differences on payload requirements, design, and operations are discussed.

3:35 p.m. Jejelowo O. A. * Tariq M. A.
Exploring the Role of Piwi/piRNA Pathway in Epigenetic Dysregulation in Low Dose Radiation Induced Cardiovascular Disease **[#3178]**
We will utilize multi-omics to identify robust biomarkers and to understand radiation effects and develop countermeasures. Information obtained will enhance development of capabilities to monitor health in real time and for mitigation of risks.

3:40 p.m. Norsk P. * Simonsen L. C. Alwood J.
Synergistic and Additive Effects of Deep-Space Radiation and Weightlessness on Cell and Organ Function **[#3051]**
Investigations of mammalian cell cultures as well as organs-on-chips will be done from the Deep Space Gateway by telemetry. Cells will be monitored regularly for metabolic activity, growth, and viability, and results compared to ground control data.

3:45 p.m. Gaza R. * Hussein H. Murrow D. Hopkins J. Waterman G. Milstein O. Berger T. Przybyla B. Aeckerlein J. Marsalek K. Matthiae D. Rutczynska A.
Matroshka AstroRad Radiation Experiment (MARE) on the Deep Space Gateway **[#3042]**
The Matroshka AstroRad Radiation Experiment is a science payload on Orion EM-1 flight. A research platform derived from MARE is proposed for the Deep Space Gateway. Feedback is invited on desired Deep Space Gateway design features to maximize its science potential.

3:50 p.m. DISCUSSION

4:20 p.m. BREAK

Tuesday, February 27, 2018
SLPSRA: ALIGNING THE DEEP SPACE GATEWAY SCIENCE INVESTIGATIONS WITH THE DECADAL SURVEY AND THE SPACE BIOLOGY SCIENCE PLAN
4:35 p.m. Birch Meeting Room

Chair: **Kevin Sato**

4:35 p.m. Ferl R. J. *
Space Life and Physical Sciences in Deep Space: Perspective from an Observer of the Current Decadal **[#3064]**
Perspectives from the current Decadal Study on Space Life and Physical Sciences.

4:40 p.m. Quincy C. D. * Charles J. B. Hamill D. L. Sun S. C.
Deep Space Gateway Science Opportunities **[#3052]**
Life sciences see the Deep Space Gateway as an opportunity to investigate biological organisms in a unique environment that cannot be replicated in Earth-based labs or on LEO platforms. The needed capabilities must be built into the Gateway facility.

4:45 p.m. Bhattacharya S. *
The Importance of Conducting Life Sciences Experiments on the Deep Space Gateway Platform **[#3023]**
Life science research on the Deep Space Gateway platform is an important precursor for long term human exploration of deep space. Ideas for utilizing flight hardware and well characterized model organisms will be discussed.

4:50 p.m. Paul A-L. * Ferl R. J.
Plants as Part of the Deep Space Exploration Schema **[#3059]**
Modern molecular data evaluating the physiological impact of the deep space environment on terrestrial biology are non-existent. The cis-lunar habitat of Gateway can provide a research platform to fill this gap in knowledge crucial to exploration.

4:55 p.m. Sato K. Y. * Tomko D. L. Levine H. G. Quincy C. D. Rayl N. A. Sowa M. B. Taylor E. M. Sun S. C. Kundrot C. E.
Space Biology Model Organism Research on the Deep Space Gateway to Pioneer Discovery and Advance Human Space Exploration **[#3081]**
Model organisms are foundational for conducting physiological and systems biology research to define how life responds to the deep space environment. The organisms, areas of research, and Deep Space Gateway capabilities needed will be presented.

5:00 p.m. DISCUSSION

Tuesday, February 27, 2018
LUNAR AND PLANETARY: EXTERNAL INSTRUMENTS
1:00 p.m. Boxelder Meeting Room

Chairs: **Rick Elphic**
Dana Hurley

1:00 p.m. Stickle A. M. * Cahill J. T. S. Greenhagen B. T. Ernst C. M.
Moon Watch: Continuous Monitoring of the Lunar Surface to Constrain Impact Flux **[#3128]**
Current impact flux / Watch light curves and images / To find where and when.

1:05 p.m. Klene S. A. * Gural P. S.
Enhanced Benefits of Lunar Orbit Video Astrophotography **[#3160]**
Video astrophotography is capable of detecting transient events, which could be meteoroid impact flashes on the Moon, light curves from approaching near-Earth asteroids, and various forms of stellar occultations.

1:10 p.m. Needham D. H. * Moser D. E. Suggs R. M. Cooke W. J. Kring D. A. Neal C. R. Fassett C. I.
Impact Flash Monitoring Facility on the Deep Space Gateway **[#3031]**
Cameras mounted to the Deep Space Gateway exterior will detect flashes caused by impacts on the lunar surface. Observed flashes will help constrain the current lunar impact flux and assess hazards faced by crews living and working in cislunar space.

1:15 p.m. Keszthelyi L. * Gaddis L. Archinal B. Kirk R. Stone T. Portree D.
Using the Deep Space Gateway to Map Resources and Defend Earth **[#3116]**
The Deep Space Gateway would be a valuable platform for assessing lunar and asteroid resources for in situ utilization and for characterizing potentially hazardous near-Earth objects.

1:20 p.m. Englert C. R. * Nicholas A. C. Janches D. Pokorny P.
Lightsheet Meteoroid Detector **[#3070]**
Detecting meteoroids close to the Moon presents unique science opportunities. A novel instrument concept that uses a lightsheet to create a “virtual witness plate” allows large sensitive areas without requiring a physical structure to support it.

1:25 p.m. DISCUSSION

1:45 p.m. Honniball C. I. * Lucey P. G. Petro N. Hurley D. Farrell W.
Lunar Volatile System Dynamics: Observations Enabled by the Deep Space Gateway **[#3101]**
A UV spectrometer-imager and IR spectrometer are proposed to solve questions regarding the lunar volatile system. The instrument takes advantage of highly elliptical orbits and the thermal management system of the Deep Space Gateway.

1:50 p.m. Livengood T. A. * Anderson C. M. Chin G. Cohen B. Feaga L. Hewagama T. Protopapa S. Racette P.
SOLVENT – Simultaneous Observations of the Lunar Volatile EnvironmeNT **[#3125]**
SOLVENT will make Simultaneous Observations of the Lunar Volatile EnviornmeNT in complementary wavelength regimes, to measure the abundance of water and hydroxyl in the illuminated lunar surface and in the free space above it.

1:55 p.m. Hayne P. O. * Greenhagen B. T. Paige D. A. Cohen B. A.
Detection and Mapping of Lunar Ice with Active Illumination from the Deep Space Gateway **[#3141]**
We propose to illuminate the Moon’s permanently shadowed regions using a high-power light source from the Gateway, to search for water and other volatiles.

2:00 p.m. Siegler M. * Ruf C. Putzig N. Morgan G. Hayne P. Paige D. Nagihara S. Weber R.
Lunar Heat Flux Measurements Enabled by a Microwave Radiometer Aboard the Deep Space Gateway **[#3123]**
We would like to present a concept to use the Deep Space Gateway as a platform for constraining the geothermal heat production, surface, and near-surface rocks, and dielectric properties of the Moon from orbit with passive microwave radiometery.

2:05 p.m. Archinal B. Gaddis L. Kirk R. Edmundson K. Stone T. Portree D. Keszthelyi L. *
Global Lunar Topography from the Deep Space Gateway for Science and Exploration **[#3174]**
The Deep Space Gateway, in low lunar orbit, could be used to achieve a long standing goal of lunar science, collecting stereo images in two months to make a complete, uniform, high resolution, known accuracy, global topographic model of the Moon.

2:10 p.m. Nuth J. A. III * Jenniskens P. M.
Gateway Studies of Dust Impacts at the Earth and Moon **[#3159]**
Analysis of ultraviolet meteor spectra impacting Earth would provide unbiased data for meteors and meteor streams traceable to their sources to provide chemical data for large samples of small bodies and better models of particle flux in cislunar space.

2:15 p.m. DISCUSSION

2:35 p.m. BREAK

Tuesday, February 27, 2018
LUNAR AND PLANETARY: CUBESATS
3:10 p.m. Boxelder Meeting Room

Chair: **Shankar Bhattarai**

3:10 p.m. Cadavid S. C. *
Mission Design and Selection of Nanosatellite Subsystems for Exploration of Lunar Water Deposits **[#3047]**
This project presents an initiative for the development of a lunar exploration mission, looking to cover the first steps of mission design and the specifications of the mission subsystems; the Cubesat 6U configuration is taken as the low cost platform.

3:15 p.m. Fisher K. R. *
Utilizing the Deep Space Gateway as a Platform for Deploying CubeSats into Lunar Orbit **[#3138]**
The Deep Space Gateway could serve as a platform to deploy CubeSats into lunar orbit by utilizing technology already developed for this purpose on the International Space Station.

3:20 p.m. Batchelor D. A. *
Occultation and Triangulation Camera (OcTriCam) Cubesat **[#3071]**
A camera at Sun-Earth L2 would provide a 240,000 km triangulation baseline to augment near-Earth object observations with Earth-based telescopes such as Pan-STARRS, and planetary occultation research to refine ephemerides and probe ring systems.

3:25 p.m. Dunham D. W. * Stakkestad K. Vedder P. McAdams J. Horsewood J. Genova A. L.
Exploration of Near-Earth Objects from the Deep Space Gateway **[#3140]**
The paper will show how clever use of orbital dynamics can lower delta-V costs to enable scientifically interesting missions. The high-energy Deep Space Gateway orbits can be used to reach NEOs, a trans node for crews, or to deploy small sats. Examples are given.

3:30 p.m. DISCUSSION

Tuesday, February 27, 2018
LUNAR AND PLANETARY: NEAR-EARTH OBJECTS SCIENCE
3:45 p.m. Boxelder Meeting Room

Chair: **Angela Stickle**

3:45 p.m. Asphaug E. * Thangavelautham J. Schwartz S.
Low-Gravity Centrifuge Facilities for Asteroid Lander and Material Processing and Manufacturing **[#3179]**
We are developing space centrifuge research facilities for attaining low-gravity to micro-gravity geological environmental conditions representative of the environment on the surfaces of asteroids and comets.

3:50 p.m. Graham L. * Fries M. Hamilton J. Landis R. John K. O'Hara W.
Deep Space Gateway "Recycler" Mission **[#3122]**
Use of the Deep Space Gateway provides a hub for a reusable planetary sample return vehicle for missions to gather star dust as well as samples from various parts of the solar system including main belt asteroids, near-Earth asteroids, and Mars moon.

3:55 p.m. Landis R. R. * Graham L. D.
Poor Man's Asteroid Sample Return Missions **[#3152]**
A cislunar platform at a Near-Rectilinear [Halo] Orbit in the vicinity of the Moon could provide an opportunity for a small NEA sample return mission at relatively low cost. There are a couple potential small (~1m) object target dynamical groups.

4:00 p.m. Shao M. * Turyshev S. Zhai C. Trahan R. Saini N.
Search for Near-Earth Objects from the Deep Space Gateway **[#3020]**
Synthetic tracking is a technique that can significantly increase sensitivity to detecting moving objects. A 30cm telescope on the Deep Space Gateway would significantly increase our discovery rate of small NEOs and of interstellar asteroids by ~30X.

4:05 p.m. DISCUSSION

4:20 p.m. BREAK

Tuesday, February 27, 2018
LUNAR AND PLANETARY: TELEROBOTICS
4:35 p.m. Boxelder Meeting Room

Chair: **David Kring**

4:35 p.m. Head J. W. * Pieters C. M. Scott D. R.
Deep Space Gateway Facilitates Exploration of Planetary Crusts: A Human/Robotic Exploration Design Reference Campaign to the Lunar Orientale Basin **[#3157]**
We outline an Orientale Basin Human/Robotic Architecture that can be facilitated by a Deep Space Gateway International Science Operations Center (DSG-ISOC) (like McMurdo/Antarctica) to address fundamental scientific problems about the Moon and Mars.

4:45 p.m. Lester D. F. *
Exploration Telepresence for Science, and Options at the Deep Space Gateway **[#3045]**
This paper reviews science opportunities for exploration telepresence, which is using low-latency telerobotics to perform high quality research from a safe and convenient site. This pertains to doing lunar surface science from the Deep Space Gateway.

4:55 p.m. Mellinkoff B. J. * Spydell M. M. Burns J. O.
Operational Constraints of Low-Latency Telerobotics from the Deep Space Gateway Due to Limited Bandwidth **[#3089]**
The operational constraints of low-latency telerobotics must be investigated to prepare for science missions enabled by telerobotics from the Deep Space Gateway. We conducted low-latency telerobotic experiments to identify constraints due to reduced bandwidth.

5:05 p.m. Walker M. E. * Burns J. O. Szafir D. J.
VR Simulation Testbed: Improving Surface Telerobotics for the Deep Space Gateway **[#3095]**
Design of a virtual reality simulation testbed for prototyping surface telerobotics. The goal is to create a framework with robust physics and kinematics to allow simulated teleoperation and supervised control of lunar rovers and rapid UI prototyping.

5:15 p.m. Da-Poian V. D.P. * Koryanov V.V. K. **CANCELED**
CRAFT: Collaborative Rover and Astronauts Future Technology **[#3030]**
Our project is focusing on the relationship between astronauts and rovers to best work together during surface explorations. Robots will help and assist astronauts, and will also work autonomously. Our project is to develop this type of rover.

5:25 p.m. DISCUSSION

Tuesday, February 27, 2018
EARTH OBSERVATIONS: EXTERNAL INSTRUMENTS I
1:00 p.m. Cherry Meeting Room

Chair: **Michael Ramsey**

1:00 p.m. Krotkov N. * Bhartia P. K. Torres O. Li C. Sander S. Realmuto V. Carn S. Herman J.
Volcanic Cloud and Aerosol Monitor (VOLCAM) for Deep Space Gateway **[#3076]**
We propose complementary ultraviolet (UV) and thermal Infrared (TIR) filter cameras for a dual-purpose whole Earth imaging with complementary natural hazards applications and Earth system science goals.

1:20 p.m. Marchenko S. V. *
Monitoring the Earth's Radiation Budget **[#3027]**
The proposal describes a suite of broad-band radiometers aimed at precise (~0.1%) long-term monitoring of the Earth's radiative budget.

1:40 p.m. Marshak A. * Herman J.
Deep Space Earth Observations from DSCOVR **[#3005]**
The Deep Space Climate Observatory (DSCOVR) at Sun-Earth L1 orbit observes the full sunlit disk of Earth. There are two Earth science instruments on board DSCOVR — EPIC and NISTAR. We discuss if EPIC and NISAR-like instruments can be used in Deep Space Gateway.

2:00 p.m. Swartz W. H. * Lorentz S. R. Erlandson R. E. Cahalan R. F. Huang P. M. **CANCELED**
Measuring Earth's Radiation Budget from the Vicinity of the Moon **[#3105]**
We propose to measure Earth's radiation budget (integrated total and solar-reflected shortwave) using broadband radiometers and other technology demonstrated in space. The instrument is compact, autonomous, and has modest resource requirements.

2:20 p.m. BREAK

2:40 p.m. Butler J. J. * Thome K. J.
Radiometric Calibration of Earth Science Imagers Using HyCalCam on the Deep Space Gateway Platform **[#3053]**
HyCalCam, an SI-traceable imaging spectrometer on the Deep Space Gateway, acquires images of the Moon and Earth to characterize the lunar surface and terrestrial scenes for use as absolute calibration targets for on-orbit LEO and GEO sensors.

2:55 p.m. Hu Y. * Marshak A. Omar A. Lin B. Baize R.
A Concept for Differential Absorption Lidar and Radar Remote Sensing of the Earth's Atmosphere and Ocean from NRHO Orbit **[#3130]**
We propose a concept that will put microwave and laser transmitters on the Deep Space Gateway platform for measurements of the Earth's atmosphere and ocean. Receivers will be placed on the ground, buoys, Argo floats, and cube satellites.

3:25 p.m. Huemmrich K. F. * Campbell P. E. Middleton E. M.
Deep Space Gateway Ecosystem Observatory **[#3153]**
Advance global understanding of seasonal change and diurnal variability of terrestrial ecosystem function, photosynthesis, and stress responses using spectral reflectance, thermal, and fluorescence signals.

3:45 p.m. Knyazikhin Y. * Park T. Hu B.
Earth Observation and Science: Monitoring Vegetation Dynamics from Deep Space Gateway **[#3181]**
Retrieving diurnal courses of sunlit (SLAI) and shaded (ShLAI) leaf area indices, fraction of photosynthetically active radiation (PAR) absorbed by vegetation (FPAR), and Normalized Difference Vegetation Index (NDVI) from Deep Space Gateway data.

4:05 p.m. Davis A. B. * Marshak A.
Complex Cloud and Radiative Processes Unfolding at the Earth's Terminator: A Unique Perspective from the Proposed Deep Space Gateway **[#3187]**
The Deep Space Gateway offers a unique vantage for Earth observation using reflected sunlight: day/night or night/day terminators slowly marching across the disc. It's an opportunity to improve our understanding of clouds at that key moment in their daily cycle.

4:25 p.m. DISCUSSION

Tuesday, February 27, 2018
HELIOPHYSICS: EXTERNAL PAYLOADS
1:00 p.m.   Douglas Fir Meeting Room

Chairs: **Edward DeLuca**
Sabrina Savage

1:00 p.m. Savage S. * DeLuca E. Cheimets P. Golub L. Kobayashi K. McKenzie D. Rachmeler L. Winebarger A.
CisLunar Interchangeable Observatory for Heliophysics (CLIOH): A Deep Space Gateway Solar Viewing Platform for Technology Development and Research Payloads **[#3061]**
The Deep Space Gateway offers an unparalleled opportunity to test and operate solar instrumentation in a radiation hard environment, which can be achieved via an external pointing platform designed to accommodate multiple interchangeable payloads.

1:15 p.m. Cooper J. F. * Habbal S. R. Stubbs T. J. Glenar D. A.
Lunar Solar Origins Explorer (LunaSOX) for the Deep Space Gateway **[#3038]**
A solar telescope on Deep Space Gateway in lunar orbit could provide unprecedented brightness and spatial resolution for measurements of complex structures and small-scale features in the inner solar corona by using the lunar limb for occultation.

1:25 p.m. Newmark J. S. * Davila J. M.
Solar Coronagraphs from the DSG **[#3079]**
A solar coronagraph mounted on the Deep Space Gateway will enable unprecedented observations of the low solar corona; in particular provide key observational constraints on the initiation of Coronal Mass Ejections (CMEs).

1:35 p.m. Dennis B. R. Christe S. D. Shih A. Y. Holman G. D. Emslie A. G. Caspi A. *
Solar X-Ray and Gamma-Ray Imaging Spectroscopy **[#3186]**
X-ray and gamma-ray Sun observations from a lunar-based observatory would provide unique information on solar atmosphere thermal and nonthermal processes. EUV and energetic neutral atom imaging spectroscopy would augment the scientific value.

1:45 p.m. Provornikova E. P. * Izmodenov V. V. Laming J. M. Strachan L. Wood B. E. Katushkina O. A. Ko Y.-K. Tun Beltran S. Chakrabarti S.
Diagnostics of the Solar Wind and Global Heliosphere with Lyman-α Emission Measurements **[#3154]**
We propose to develop an instrument measuring full sky intensity maps and spectra of interplanetary Lyman-α emission to reveal the global solar wind variability and the nature of the heliosphere and the local interstellar medium.

1:55 p.m. Kontar E. P. * Emslie A. G.
Radio Imaging Spectroscopy of Physical Processes in the Inner Heliosphere **[#3185]**
Radio observations below ~100 MHz made using an array of small radio antennae on the lunar surface can provide unique insight into non-thermal processes in the corona and heliosphere. Such an array fits within reasonable weight, power, telemetry, and cost constraints.

2:05 p.m. DISCUSSION

2:15 p.m. BREAK

2:25 p.m. Paxton L. J. *
Imaging Geospace from Cis-Lunar Orbit **[#3098]**
I will discuss far ultraviolet remote sensing of the geospace environment from a platform in near-Earth space — in particular one in a cis-lunar orbit. I will discuss simple instrument designs that could be used to provide a low-cost solution.

2:40 p.m. Chua D. H.   Socker D. G.   Englert C. R.   Carter M. T.   Plunkett S. P. *
Korendyke C. M.   Meier R. R.
Global Magnetospheric Imaging from the Deep Space Gateway in Lunar Orbit **[#3161]**
We propose to use the Deep Space Gateway as an observing platform for a magnetospheric imager that will capture the first direct global images of the interface between the incident solar wind and the Earth's magnetosphere.

2:50 p.m. Waldrop L. *   Immel T.   Clarke J.   Fillingim M.   Rider K.   Qin J.
Bhattacharyya D.   Doe R.
Geocoronal Imaging from the Deep Space Gateway **[#3134]**
UV imaging of geocoronal emission at high spatial and temporal resolution from deep space would provide crucial new constraints on global exospheric structure and dynamics, significantly advancing models of space weather and atmospheric escape.

3:00 p.m. Sibeck D. G. *   Collier M. R.   Porter F. S.
Observing the Magnetosphere in Soft X-Rays: The Lunar X-Ray Observatory (LXO) **[#3019]**
Wide field-of-view soft X-ray imagers in lunar orbit or on the lunar surface can be used to address many heliophysics objectives, including the nature of the solar wind magnetosphere-interaction, the lunar exosphere, and the helium focusing cone.

3:10 p.m. Halekas J. S. *   Poppe A. R.
Monitoring the Outflow of Matter from the Earth and the Moon from the Deep Space Gateway **[#3106]**
The Deep Space Gateway provides an ideal vantage point from which to monitor the outflow of matter from the Earth and the Moon.

3:20 p.m. DISCUSSION

3:40 p.m. BREAK

Tuesday, February 27, 2018
HELIOPHYSICS: DUSTY PLASMAS — SMALL PARTICLES
3:50 p.m. Douglas Fir Meeting Room

Chair: **Mihaly Horanyi**

3:50 p.m. Malaspina D. M. * Horanyi M. Sternovsky Z.
Revolutionizing Our Understanding of Heliospheric Dust Dynamics from the Deep Space Gateway **[#3010]**
The Deep Space Gateway provides an opportunity for novel measurements of heliospheric nanometer dust grains, quantifying their interaction with the solar wind and leading to new advances in both dust physics and dust impact predictive capability.

4:00 p.m. Horanyi M. * Kempf S. Malaspina D. Poppe A. Srama R. Sternovsky Z. Szalay J.
Dust Measurements Onboard the Deep Space Gateway **[#3169]**
A dust instrument onboard the Deep Space Gateway will revolutionize our understanding of the dust environment at 1 AU, help our understanding of the evolution of the solar system, and improve dust hazard models for the safety of crewed and robotic missions.

4:10 p.m. Farrell W. M. * Orlando T. M. Dyar M. D. Hurley D. M. Hibbitts C. A. Jones B. M. McLain J. L.
Long Duration Exposure Platform (LDEP) **[#3132]**
We describe a facility to analyze material samples exposed externally to the harsh space plasma and meteoroid environment. We especially focus on examining any hydroxylation occurring within the top layers of the plasma-activated samples.

4:20 p.m. Wiens R. C. * Burnett D. S. Jurewicz A. Rieck K. Reisenfeld D. Kasper J. Clark B.
Solar Wind Sample Collection at the Deep Space Gateway **[#3151]**
A simple, long-term collection of solar wind at the Deep Space Gateway would provide new, higher-fluence samples to address a number of science objectives relating to solar abundances, solar physics, and heliophysics.

4:30 p.m. BREAK

4:40 p.m. Fries M. * Fisher K.
Direct Characterization of Comets and Asteroids via Cosmic Dust Analysis from the Deep Space Gateway **[#3120]**
The Deep Space Gateway can allow direct analysis of dust from over a dozen comets, using an instrument similar to the successful Cassini Dust Analyzer (CDA). Long-term measurements are preferred. Compositions of over a dozen asteroids and comets can be obtained.

4:50 p.m. Westphal A. J. * Butterworth A. L. Jilly-Rehak C. E. Gainsforth Z. Messenger S. R. Ogliore R. Stroud R. M.
DISC: Deep-Space Interstellar Dust Collector **[#3037]**
Deep Space Gateway presents an unprecedented opportunity to carry out an interstellar dust sample return mission with a collecting power sufficient to collect and return hundreds of tiny interstellar rocks to terrestrial laboratories.

5:00 p.m. Hu Z. W. *
What Could Be Learned from Phase Contrast X-Ray Nanotomography Analysis of Cosmic Dust Potentially Collected in Deep Space? **[#3099]**
Collecting cosmic dust in deep space would provide unbiased samples of primitive solar system materials for study. Nanotomography analysis of the most primitive dust particles would reveal direct new information on formation of our solar system.

5:10 p.m. DISCUSSION

Wednesday, February 28, 2018
ASTROPHYSICS: TELESCOPE ASSEMBLY AND SERVICING
8:30 a.m.   Aspen Meeting Room

Chair: **Slava Turyshev**

8:30 a.m. Siegler N. * Mukherjee R. Greenhouse M. A. Grunsfeld J. M. MacEwen H. A. Peterson B. M. Pollidan R. S. Thronson H. A.
In-Space Assembly of Large Telescopes for Exoplanet Imaging and Characterization **[#3146]**
We will present a few different concepts in which the Deep Space Gateway can be used to robotically assemble large space telescopes and interferometers.

8:45 a.m. Peterson B. M. * Feinberg L. D. Greenhouse M. A. Grunsfeld J. M. Polidan R. S. Siegler N. Thronson H. A.
Servicing Large Space Telescopes with the Deep Space Gateway **[#3024]**
Future large space telescopes will require servicing to operate over lifetimes long enough to realize their full value and justify their expense. We discuss scenarios that will make servicing telescopes at Sun-Earth L2 possible.

9:00 a.m. Apai D. * Milster T. D. Arenberg J. Kim D. Liang R. Bixel A. Fellows C. Grunsfeld J.
Nautilus Deep Space Observatory: A Giant Segmented Space Telescope Array for a Galactic Biosignature Survey **[#3127]**
The preliminary design for a very large array of light-weight telescopes that will provide a light-collecting area equivalent to a 50m telescope, enabling an atmospheric biosignature survey in 1,000 earth-like transiting planets.

9:15 a.m. Grunsfeld J. M. * Siegler N. Mukherjee R.
Starshade Assembly Enabled by the Deep Space Gateway Architecture **[#3136]**
A starshade is a large external coronagraph which will allow the direct imaging and analysis of planets around nearby stars. We present how the Deep Space Gateway would enable the robotic/astronaut construction of a starshade.

9:30 a.m. DISCUSSION

9:50 a.m. BREAK

Wednesday, February 28, 2018
ASTROPHYSICS:
LOW FREQUENCY TELESCOPE AND SURFACE TELEROBOTICS
10:00 a.m. Aspen Meeting Room

Chair: **Jennifer Heldmann**

10:00 a.m. Burns J. O. * Fong T. Kring D. A. Hopkins J. B.
Space Science and Exploration on the Lunar Farside Facilitated by Surface Telerobotics from the Deep Space Gateway **[#3004]**
We discuss how surface telerobotics from the Deep Space Gateway can be used to collect geological samples from the Moon's far-side and deploy a low frequency radio telescope to study the unexplored Cosmic Dawn epoch of the early universe.

10:15 a.m. MacDowall R. J. * Farrell W. M. Burns J. O.
Importance of a Low Radio Frequency Interference Environment for the DSG **[#3165]**
The Deep Space Gateway (DSG) can serve radio astronomy in a variety of ways. Thus, it is important that DSG electronics, transmitters, and the instruments located on the DSG avoid contaminating the radio-quiet environment of the lunar far-side.

10:30 a.m. Monsalve R. A. * Burns J. O. Tauscher K. Rapetti D.
Telerobotic Deployment and Operation of a Lunar Farside Low Radio Frequency Cosmology Telescope from the Deep Space Gateway **[#3109]**
The Deep Space Gateway represents a unique opportunity to enable cosmological observations of the redshifted 21-cm line from the Lunar Farside, which emitted hydrogen gas during the formation of the first galaxies in the universe.

10:45 a.m. Rapetti D. * Tauscher K. Burns J. O. Switzer E. Mirocha J. Furlanetto S. Monsalve R.
Hydrogen Cosmology from the Deep Space Gateway: Data Analysis Pipeline for Low-Frequency Radio Telescopes **[#3087]**
The Deep Space Gateway will provide a unique opportunity for low-frequency radio telescopes shielded by the Moon to study the unexplored Cosmic Dawn, which our novel pipeline is able to constrain by extracting the spectrum of a neutral hydrogen line.

11:00 a.m. Bowman J. D. * Hallinan G. W. MacDowall R. J. Burns J. O.
Lunar Farside Radio Array Pathfinder Enabled by the Deep Space Gateway **[#3129]**
Two pressing questions in astrophysics and heliophysics can be addressed by a radio array on the lunar farside enabled by the Deep Space Gateway: 1) what is the habitability of exoplanets? and 2) how are energetic particles accelerated in solar bursts?

11:15 a.m. DISCUSSION

Wednesday, February 28, 2018
SLPSRA: DISCUSSING ASTRONAUT IMPACTS OF LIVING AT THE DEEP SPACE GATEWAY
8:30 a.m. Birch Meeting Room

Chair: **Jennifer Fogarty**

8:30 a.m. Shelhamer M. * Mindock J. A.
Tools for Systematic Identification of Cross-Disciplinary Research Relevant to Exploration Missions **[#3034]**
A Contributing Factor Map and text analytics on articles and reports can identify connections between major factors contributing to health and performance on Deep Space Gateway missions. Connections suggest experiment complements to maximize use of these flights.

8:35 a.m. Crucian B. * Zwart S. Smith S. M. Simonsen L. C. Williams T. Antonsen E.
Deep Space Environmental Effects on Immune, Oxidative Stress and Damage, and Health and Behavioral Biomarkers in Humans **[#3054]**
Biomarkers will be assessed in biological samples (saliva, blood, urine, feces) collected from crewmembers and returned to Earth at various intervals, mirroring (where feasible) collection timepoints used on the International Space Station (ISS).

8:40 a.m. Douglas G. L. * Barr Y. R.
Long-Term Stability of Spaceflight Food for Multi-Year Exploration Missions **[#3049]**
Stability of macro- and micro-nutrients and undesirable changes to texture and taste will be evaluated in food samples returned from the Deep Space Gateway after 1, 3, and 5 years of storage in the deep space radiation environment.

8:45 a.m. Thaxton S. S. Williams T. J. * Norsk P. Zwart S. Crucian B. Antonsen E. L.
Deep Space Spaceflight: The Challenge of Crew Performance in Autonomous Operations **[#3168]**
Distance from Earth and limited communications in future missions will increase the demands for crew autonomy and dependence on automation, and Deep Space Gateway presents an opportunity to study the impacts of these increased demands on human performance.

8:50 a.m. Williams T. J. * Norsk P. Zwart S. Crucian B. Simonsen L. C. Antonsen E.
Deep Space Spaceflight Hazards Effects on Cognition, Behavioral Health, and Behavioral Biomarkers in Humans **[#3167]**
Deep Space Gateway missions provide testing grounds to identify the risk of both behavioral performance and cognitive perturbations caused by stressors of spaceflight such as radiation, fluid shifts, sleep deprivation, chronic stress, and others.

8:55 a.m. Wotring V. E. * Strangman G. E. Donoviel D.
TRI-Worthy Projects for the Deep Space Gateway **[#3158]**
Preparations for exploration will require exposure to the actual deep space environment. The new TRI for Space Health proposes innovative projects using real space radiation to make medically-relevant measurements affecting human physiology.

9:00 a.m. Lagarde T. L. *
Habitability Study for Optimal Human Behavior **[#3113]**
The habitable volume per crew on the Deep Space Gateway will be smaller than on the ISS, going from 60 cubic meters to 20. This new confined space requires new accommodations and new techniques. This study will explore those techniques and the decisions required.

9:05 a.m. Stenger M. B. * Laurie S. S. Macias B. R. Barr Y. R.
Retinal Evaluation Using Optical Coherence Tomography (OCT) During Deep Space Gateway Missions **[#3063]**
Optical Coherence Tomography (OCT) imaging will be conducted before, during, and after Deep Space Gateway missions to evaluate changes in the retina and, in particular, the optic nerve head and surrounding structures. Additional parameters will be collected before and after flight.

9:10 a.m. DISCUSSION

9:40 a.m. BREAK

Wednesday, February 28, 2018
SLPSRA: REQUIREMENTS FOR INVESTIGATIONS AT DEEP SPACE GATEWAY
9:55 a.m. Birch Meeting Room

Chair: **Charles Quincy**

9:55 a.m. Lewis R. * Wright M.
Packing a Punch: Enabling Cutting Edge Science and Research on the Deep Space Gateway — Despite Constraints **[#3183]**
Techniques, systems, and processes employed to enable, enhance, produce, and deliver significant, breakthrough science and research results under mass-volume-energy constraints, as with the Deep Space Gateway, are discussed.

10:00 a.m. Santa Maria S. R. * Liddell L. C. Tieze S. M. Ricco A. J. Hanel R. Bhattacharya S.
Using Autonomous Bio Nanosatellites for Deep Space Exploration **[#3022]**
NASA's BioSentinel mission will conduct the first study of biological response to deep-space radiation in 45 years. It is an automated nanosatellite that will measure the DNA damage response to ambient space radiation in a model biological organism.

10:05 a.m. Anikushina V. * Taratukhin V. Stutterheim C. v. Gushin V.
Innovative Method in Improving Communication Issues by Applying Interdisciplinary Approach. Psycholinguistic Perspective to Mitigate Communication Troubles During Cislunar Travel. **[#3102]**
A new psycholinguistic view on the crew communication, combined with biochemical and psychological data, contributes to noninvasive methods for stress appraisal and proposes alternative approaches to improve in-group communication and cohesion.

10:10 a.m. Niederwieser T. * Zea L. Anthony J. Stodieck L.
Basic and Applied Algal Life Support System Research on Board the Deep Space Gateway **[#3104]**
We study the effect of long-term preservation methods on DNA damage of algal cultures for BLSS applications. In a secondary step, the Deep Space Gateway serves as a technology demonstration platform for algal photobioreactors in intermittently occupied habitats.

10:15 a.m. Smith D. J. * Parra M. Lane M. Almeida E. A. Space Biosciences Research Branch
Gateway BioBox: A Compact, Multi-Purpose Biological Hardware Suite for In Situ Experiments and Analyses in Deep Space **[#3041]**
A compilation of NASA's smallest biological hardware systems (plus 1-g gravity controls and ancillary sensors) that will allow for a wide range of specimen cultivation and analysis, from molecular measurements to broader cell and tissue assays.

10:20 a.m. Alwood J. S. * Shirazi-Fard Y. Pletcher D. Globus R. K.
Semi-Autonomous Rodent Habitat for Deep Space Exploration **[#3115]**
More autonomous rodent research systems will facilitate longer duration experiments to be conducted farther from Earth.

10:25 a.m. Fritsche R. F. * Romeyn M. W. Massa G.
The Gateway Garden — A Prototype Food Production Facility for Deep Space Exploration **[#3026]**
CIS-lunar space provides a unique opportunity to perform deep space microgravity crop science research while also addressing and advancing food production technologies that will be deployed on the Deep Space Transport.

10:30 a.m. Morrow R. C. * Wetzel J. P. Richter R. C.
Hybrid Life Support System Technology Demonstrations **[#3126]**
Demonstration of plant-based hybrid life support technologies in deep space will validate the function of these technologies for long duration missions, such as Mars transit, while providing dietary variety to improve habitability.

10:35 a.m. Brassard D. Clime L. Daoud J. Geissler M. Malic L. Charlebois D. Buckley N. Veres T. *
Microfluidic-Based Platform for Universal Sample Preparation and Biological Assays Automation for Life-Sciences Research and Remote Medical Applications **[#3190]**
An innovative centrifugal microfluidic universal platform for remote bio-analytical assays automation required in life-sciences research and medical applications, including purification and analysis from body fluids of cellular and circulating markers.

10:40 a.m. DISCUSSION

11:10 a.m. BREAK

Wednesday, February 28, 2018
SLPSRA: MOVING FORWARD WITH EXPANDED DEEP SPACE GATEWAY SCIENCE CONCEPTS
11:25 a.m. Birch Meeting Room

Chair: **Doris Hamill**

11:25 a.m. Menezes A. A. *
Realizing a Self-Reproducing Space Factory with Engineered and Programmed Biology **[#3145]**
We propose testing a data-driven, technologically-backed space biomanufacturing platform at the Deep Space Gateway that realizes a highly-valued concept, a self-reproducing space factory.

11:30 a.m. Meier A. J. * Hintze P. E.
Closing the Loop on Space Waste **[#3086]**
A heat transfer study of mission mixed waste streams in a reactor hot zone, along with solid, tar, and water recovery. This research enables reliability and benefit on waste conversion systems to manage our environmental impact, on- and off-Earth.

11:35 a.m. Wallace S. * Graham L.
Partial Gravity Biological Tether Experiment on the Deep Space Gateway **[#3184]**
A tether-based partial gravity bacterial biological experiment represents a viable biological experiment to investigate the fundamental internal cellular processes between altered levels of gravity and cellular adaption.

11:40 a.m. Raychev R. * Griko Y. V.
Technology Assessment for External Implementation of Artificial Gravity Utilizing the Deep Space Gateway Platform **[#3083]**
Scenario drafting for early technology assessment of the external space centrifuge with little mass and variable radius of rotation is proposed to counteract micro gravity-associated physiological alterations in all physiological systems.

11:45 a.m. Seyedmadani K. * Gruber J. A. Clark T. K.
The Linear Sled "Hybrid" Approach for Artificial Gravity as a Countermeasure for Crewed Deep Space Gateway Missions **[#3082]**
Our proposed linear sled-hybrid artificial gravity subsystem is a potential comprehensive approach to physiological deconditioning due to microgravity for the crew during long-duration and Deep Space Gateway missions.

11:50 a.m. Hamill D. L. *
Biological Observatory at the Deep Space Gateway **[#3033]**
The Deep Space Gateway offers invaluable opportunities for important life sciences research. But the research needs vastly outstrip the Deep Space Gateway's capacity to support them. A biological observatory would enhance its ability to support life sciences.

11:55 a.m. DISCUSSION

Wednesday, February 28, 2018
LUNAR AND PLANETARY: SAMPLES
8:30 a.m. Boxelder Meeting Room

Chair: **Cindy Evans**

8:30 a.m. Bakambu J. N. Shaw A. * Fulford P. Osinski G. Bourassa M. Rehmatullah F. Zanetti M. Rembala R.
Lunar Science Enabled by the Deep Space Gateway and PHASR Rover **[#3103]**
The Deep Space Gateway will be a tremendous boon to lunar surface science. It will enable the PHASR Rover, a concept for a Canadian rover system, with international contributions and the goal of sample acquisition and lunar surface science.

8:35 a.m. Bourassa M. * Osinski G. R. Cross M. Hill P. King D. Morse Z. Pilles E. Tolometti G. Tornabene L. L. Zanetti M.
Science Goals and Objectives for Canadian Robotic Exploration of the Moon Enabled by the Deep Space Gateway **[#3135]**
Canadian contributions to the science goals and objectives of a lunar precursor rover for HERACLES, an international mission concept, are discussed. Enabled by the Deep Space Gateway, this rover is a technical demonstrator for robotic sample return.

8:40 a.m. Kring D. A. *
Accessing the Lunar Farside and Facilitating Human-Assisted Sample Return with the Deep Space Gateway **[#3043]**
The Deep Space Gateway provides a platform for crew to tele-operate a sample-collecting rover and also provides a communication relay to farside surface sites.

8:45 a.m. Downes H. * Crawford I. A. Alexander L.
Lunar Sample Return Missions Using a Tele-Robotic Lander **[#3025]**
Deep Space Gateway would allow tele-robotic landers and rovers to access regions of the Moon which have not been previously sampled. Scientific questions, e.g., the nature and duration of volcanic activity and the composition of the mantle/lower crust, could be addressed.

8:50 a.m. Lupisella M. * Bleacher J. Lewis R. Dworkin J. Wright M. Burton A. Rubins K. Wallace S. Stahl S. John K. Archer D. Niles P. Regberg A. Smith D. Race M. Chiu C. Russell J. Rampe E. Bywaters K.
Low-Latency Telerobotic Sample Return and Biomolecular Sequencing for Deep Space Gateway **[#3032]**
Low-latency telerobotics, crew-assisted sample return, and biomolecular sequencing can be used to acquire and analyze lunar farside and/or Apollo landing site samples. Sequencing can also be used to monitor and study Deep Space Gateway environment and crew health.

8:55 a.m. Berinstain A. * Richards R. D.
Low-Cost Planetary Missions Enabled by the Deep Space Gateway **[#3092]**
The authors will present options for discussion among participants of how low-cost lunar and planetary missions using the Moon Express family of spacecraft can be enabled by the presence of the Deep Space Gateway.

9:00 a.m. Cichan T. * Hopkins J. B. Bierhaus B. Murrow D. W.
Communications Relay and Human-Assisted Sample Return from the Deep Space Gateway **[#3084]**
The Deep Space Gateway can enable or enhance exploration of the lunar surface through two capabilities: 1. communications relay, opening up access to the lunar farside, and 2. sample return, enhancing the ability to return large sample masses.

9:05 a.m. DISCUSSION

9:25 a.m. Regberg A. B. * Fries M. D. Harrington A. D. Mitchell J. L. Snead C. McCubbin F. M.
The Deep Space Gateway as a Testbed for Advanced Curation Concepts **[#3112]**
Samples need a home / For preliminary science / Cold and sterile.

9:30 a.m. DiGregorio B. E. *
The Moon: A 100% Isolation Barrier for Earth During Exobiological Examination of Solar System Sample Return Missions **[#3077]**
The only 100% guarantee of protecting our planet’s biosphere from a back contamination event is to use the Moon as a sample return examination facility to qualify samples for eventual return to Earth.

9:35 a.m. Spry J. A. Siegel B. Race M. Rummel J. D. * Pugel D. E. Groen F. J. Kminek G. Conley C. A. Carosso N. J.
Advances in Planetary Protection at the Deep Space Gateway **[#3111]**
Planetary protection knowledge gaps that can be addressed by science performed at the Deep Space Gateway in the areas of human health and performance, space biology, and planetary sciences that enable future exploration in deep space, at Mars, and other targets.

9:40 a.m. DISCUSSION

9:55 a.m. BREAK

10:10 a.m. Cohen B. A. * Eigenbrode J. A. Young K. E. Bleacher J. E. Trainer M. E.
Enabling Global Lunar Sample Return and Life-Detection Studies Using a Deep-Space Gateway **[#3012]**
The Deep Space Gateway could uniquely enable a lunar robotic sampling campaign that would provide incredible science return as well as feed forward to Mars and Europa by testing instrument sterility and ability to distinguish biogenic signals.

10:15 a.m. Calaway M. J. * Evans C. A. Garrison D. H. Bell M. S.
An Integrated Science Glovebox for the Gateway Habitat **[#3058]**
A Deep Space Gateway astromaterials glovebox facility would enable science to return to Earth collected astromaterials from the Moon and ultimately Mars. Next generation habitats will benefit from on-board glovebox capability.

10:20 a.m. Evans M. E. * Needham D. H. Fisher K. R. Lawrence S. J. Niles P. B. Harmeyer S. G. Nguyen H. T. Othon W. L.
Developing Science Procedures for Deep Space Gateway Habitat Mockup Ground Testing **[#3078]**
Science procedures for telerobotics, observations, and lunar sample return packaging have been developed and tested to evaluate NextStep contractor habitation mockups. Test results from these procedures aid requirements development for the Deep Space Gateway.

10:25 a.m. Gernhardt M. L. * Bekdash O. S. Trevino R. C.
Utilizing the Habitable Airlock Transfer Port as a Modular, Low Volume Science Airlock **[#3085]**
The Habitable Airlock, one of several Deep Space Gateway options for providing airlock capabilities, provides the capability of integrating a low volume science airlock for bringing in samples, ORUs, and other hardware into and out of the vehicle.

10:30 a.m. Bleacher J. E. * Gendreau K. Arzoumanian Z. Young K. E. McAdam A.
Using Instruments as Applied Science, Multipurpose Tools During Human Exploration: An XRD/XRF Demonstration Strategy for the Deep Space Gateway **[#3137]**
Science instruments to be used during human exploration should be designed to serve as multipurpose tools that are of use throughout a mission. Here we discuss a multipurpose tool approach to using contact XRD/XRF onboard the Deep Space Gateway.

10:35 a.m. Sibille L. * Mantovani J. G. Townsend I. I. Mueller R. P.
Multifunctional Interface Facility for Receiving and Processing Planetary Surface Materials for Science Investigation and Resource Evaluation at the Deep Space Gateway **[#3142]**
The concepts describe hardware and instrumentation for the study of planetary surface materials at the Deep Space Gateway as a progressive evolution of capabilities for eliminating the need for special handling and Planetary Protection (PP) protocols inside the habitats.

10:40 a.m. DISCUSSION

Wednesday, February 28, 2018
LUNAR AND PLANETARY: SURFACE INSTRUMENT DELIVERY
11:00 a.m. Boxelder Meeting Room

Chair: **Greg Chavers**

11:00 a.m. Nagihara S. * Zacny K. Chu P. Kiefer W. S.
Lunar Global Heat Flow Mapping with a Reusable Lander Deployed from the Deep Space Gateway Spacecraft **[#3009]**
We propose to equip the Deep Space Gateway spacecraft with a reusable lander that can shuttle to and from the lunar surface, and use it for collecting heat flow measurements globally on the lunar surface.

11:05 a.m. Huang S. *
Deep Space Gateway as a Deployment Staging Platform and Communication Hub of Lunar Heat Flow Experiment **[#3072]**
The idea is to use Deep Space Gateway as a staging platform for the deployment of lunar heat flow experiment, and consequentially as a communication hub of the installed heat flow experiment. The concept was derived from the canceled Lunar-A mission.

11:10 a.m. Weber R. C. * Neal C. R. Kedar S. Panning M. Schmerr N. C. Siegler M. Banerdt W. B.
Lunar Seismology Enabled by a Deep Space Gateway **[#3091]**
The lunar community recognizes geophysics as a high-priority science objective for future lunar landed missions. We outline several concepts for lunar seismology as enabled by the Deep Space Gateway.

11:15 a.m. Wang X. * Sternovsky Z. Horanyi M.
In-Situ Measurements of Electrostatic Dust Transport on the Lunar Surface **[#3066]**
A design of the Cubesat Electrostatic Dust Analyzer (CEDA) is described to verify and characterize the electrostatic dust transport process on the lunar surface and to estimate its effect on the surface evolution.

11:20 a.m. Chi P. J. * Russell C. T. Strangeway R. J. Farrell W. M. Garrick-Bethell I. Taylor P.
Science Investigations Enabled by Magnetic Field Measurements on the Lunar Surface **[#3173]**
We present examples of the geophysical and heliophysics investigations that can be performed with magnetic field measurements on the lunar surface enabled by the support/servicing of lunar landers from the Deep Space Gateway.

11:25 a.m. Chavers D. G. * Whitley R. J. Percy T. K. Needham D. H. Polsgrove T. T.
Enhancing Return from Lunar Surface Missions via the Deep Space Gateway **[#3193]**
The Deep Space Gateway (DSG) will facilitate access to and communication with lunar surface assets. With a science airlock, docking port, and refueling capability in an accessible orbit, the DSG will enable high priority science across the lunar surface.

11:30 a.m. DISCUSSION

Wednesday, February 28, 2018
EARTH OBSERVATIONS: EXTERNAL INSTRUMENTS II
8:30 a.m.   Cherry Meeting Room

Chair: **Alexander Marshak**

8:30 a.m. Jiang J. H. *   Natraj V.   Herman J.   Zhai C.   Su H.   Yung Y.
A Lunar Orbiter for Earth and Exoplanet Studies **[#3191]**
A study to explore the science and technology of building an Earth observatory in Moon's orbit to provide a stable, serviceable, long-term, global, continuous full spectral view of the Earth from the UV to IR.

8:50 a.m. Varnai T. *   Marshak A.
Specular Reflection of Sunlight from Earth **[#3171]**
The Deep Space Gateway vantage point offers advantages in observing specular reflection from water surfaces or ice crystals in clouds. Such data can give information on clouds and atmospheric aerosols, and help test algorithms of future exoplanet characterization.

9:10 a.m. Wu D. L. *
Earth's Microwave Pulses from a Lunar Orbit **[#3008]**
Terrestrial microwave emissions contain rich information on its climate as well as man-made changes. The envisioned instrument is a single-beam spectro-radiometer from a lunar orbit measuring Earth full-disk emissions at 1-2000 GHz.

9:30 a.m. Gorkavyi N. *   DeLand M.
Earth-from-Luna Limb Imager (ELLI) for Deep Space Gateway **[#3155]**
The new type of limb imager with a high-frequency imaging proposed for Deep Space Gateway. Each day this CubeSat' scale imager will generate the global 3D model of the aerosol component of the Earth's atmosphere and Polar Mesospheric Clouds.

9:50 a.m. BREAK

10:05 a.m. Ramsey M. S. *   Christensen P. R.
Thermal Infrared Earth Imaging from the DSG **[#3164]**
Thermal infrared (TIR) image-based and spectral-based data from the Deep Space Gateway would allow for the detection of thermally-elevated features and detailed compositional analysis of atmospheric and surface processes on the Earth.

10:35 a.m. Ackleson S. G.   Bowles J. H. *   Mouroulis P.   Philpot W. D.
EARTHS (Earth Albedo Radiometer for Temporal Hemispheric Sensing) **[#3133]**
We propose a concept for measuring the hemispherical Earth albedo in high temporal and spectral resolution using a hyperspectral imaging sensor deployed on a lunar satellite, such as the proposed NASA Deep Space Gateway.

10:55 a.m. Lang T. J. *   Blakeslee R. J.   Cecil D. J.   Christian H. J.   Gatlin P. N.   Goodman S. J.   Koshak W. J.   Petersen W. A.   Quick M.   Schultz C. J.   Tatum P. F.
The Deep Space Gateway Lightning Mapper (DLM) — Monitoring Global Change and Thunderstorm Processes through Observations of Earth's High-Latitude Lightning from Cis-Lunar Orbit **[#3017]**
We propose the Deep Space Gateway Lightning Mapper (DLM) instrument. The primary goal of the DLM is to optically monitor Earth's high-latitude (50° and poleward) total lightning not observed by current and planned spaceborne lightning mappers.

11:15 a.m. Majid W. A. *   **CANCELED**
Global Multi-Wavelength Observation of Terrestrial Gamma-Ray Flashes **[#3119]**
Global multi-wavelength observation of terrestrial gamma-ray flashes using platforms on-board the Deep Space Gateway.

11:35 p.m. Luvall J. C. * Tkaczyk T S. Alexander D. Pawlowsk M. E. Dwight J. G. Howell B. Tatum P. F.
Tunable Light-Guide Image Processing Snapshot Hyperspectral Spectrometer (TuLIPSS) for Earth and Moon Observations **[#3139]**
A tunable light-guide hyperspectral image processing snapshot spectrometer (TuLIPSS) for Earth science research and observation is being developed through a NASA instrument incubator project with Rice University and Marshall Space Flight Center.

11:55 a.m. DISCUSSION

Wednesday, February 28, 2018
HELIOPHYSICS: SPACE WEATHER
8:30 a.m. Douglas Fir Meeting Room

Chair: **Yaireska Collado-Vega**

8:30 a.m. Berger T. E. * Baker D. N. Woods T. N.
Space Weather Research and Operational Observing from a Cis-Lunar Deep Space Gateway **[#3147]**
We review the status of observational architectures for space weather research and operational forecasting and suggest ways in which the Deep Space Gateway may act as an ideal supplement to current and future space weather observing platforms.

8:40 a.m. Barjatya A. *
Spacecraft Charging and Space Environment Monitoring System Using Distributed Langmuir Probes Around the Deep Space Gateway **[#3162]**
The use of a a Langmuir probe suite of instruments distributed around the Deep Space Gateway/habitat to monitor spacecraft charging as well as space environment in the spacecraft vicinity.

8:50 a.m. DeForest C. E. * Laurent G.
Instruments for Deep Space Weather Prediction and Science **[#3176]**
We discuss remote space weather monitoring system concepts that could mount on the Deep Space Gateway and provide predictive capability for space weather events including SEP events and CME crossings, and advance heliophysics of the solar wind.

9:00 a.m. DeLuca E. E. * Golub L. Korreck K. Savage S. McKenzie D. D. Rachmeler L. Winebarger A. Martens P.
Using DSG to Build the Capability of Space Weather Forecasting in Deep Space **[#3050]**
The prospect of astronaut missions to deep space and off the Sun-Earth line raises new challenges for space weather awareness and forecasting. We need to identify the requirements and pathways that will allow us to protect human life and equipment.

9:10 a.m. St Cyr O. C. Davila J. M. Newmark J. *
Space Weather Diamond: A 10x Improvement in Real-Time Forecasting **[#3057]**
Space Weather Diamond is based on a constellation of four platforms that are phased into eccentric heliocentric orbits but, from the perspective of a fixed Sun-Earth line, the spacecraft appear to orbit Earth.

9:20 a.m. Parker L. Minow J. Pulkkinen A. * Fry D. Semones E. Allen J. St Cyr C. Mertens C. Jun I. Onsager T. Hock R.
Evaluating Space Weather Architecture Options to Support Human Deep Space Exploration of the Moon and Mars **[#3170]**
NASA's Engineering and Space Center (NESC) is conducting an independent technical assessment of space environment monitoring and forecasting architecture options to support human and robotic deep space exploration.

9:30 a.m. Collado-Vega Y. M. * Kuznetsova M. Mays L. Pulkkinen A. Zheng Y. Muglach K. Thompson B. Chulaki A. Taktakishvili A. CCMC Team
Space Weather Research and Forecasting Capabilities at the Community Coordinated Modeling Center (CCMC) **[#3090]**
The Community Coordinated Modeling Center (CCMC) supports and enables the research and development of the latest and future space weather models and facilitates the deployment of the latest advances in research of space weather operations.

9:40 a.m. DISCUSSION

9:50 a.m. BREAK

10:00 a.m. Spence H. E. * Jordan A. P. Joyce C. Rahmanifard F. Schwadron N. A. Smith S. S. Wilson J. K. Winslow R. Blake J. B. Mazur J. E. Townsend L. deWet W. Kasper J. C. Case A. W. Zeitlin C. J.
From Tempe to Denver: Realizing the Wargo Axiom with the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) **[#3150]**
We present a retrospective of LRO from the perspective of space radiation. We review synergies between exploration enabling science and science enabling exploration. We describe how CRaTER's flight spare contributes both to the Deep Space Gateway.

10:10 a.m. Wu X. * Ambrosi G. Bertucci B.
Real-Time Penetrating Particle Analyzer (PAN) **[#3029]**
The PAN can measure penetrating particles with great precision to study energetic particles, solar activities, and the origin and propagation of cosmic rays. The real-time monitoring of penetrating particles is crucial for deep space human travel.

10:20 a.m. Schwadron N. A. * Bloser P. Jordan A. Legere J. Mazur J. Rahmanifard F. Ryan J. Spence H. E. Wilson J. Zeitlin C.
Dose Spectra from Energetic Particles and Neutrons (DoSEN) **[#3097]**
DoSEN is an early-stage space technology project that offers advantages for active measurement of the complete spectrum of radiation. DoSEN combines two advanced radiation detection concepts with fundamental advantages over traditional dosimetry.

10:30 a.m. Leitgab M. *
High Fidelity Measurement of Free Space Solar Particle Event and Galactic Cosmic Ray Environments at Intermediate Energies **[#3117]**
A charged particle measurement experiment mounted externally to the Deep Space Gateway is proposed, contributing to improving astronaut radiation exposure management during Solar Particle Events and Extra Vehicular Activities.

10:40 a.m. Martens P. C. *
Forecasting Space Weather Hazards for Astronauts in Deep Space **[#3188]**
Deep Space Gateway provides a unique platform to develop, calibrate, and test a space weather forecasting system for interplanetary travel in a real life setting. We will discuss requirements and design of such a system.

10:50 a.m. Rahmanifard F. * Schwadron N. A. Wilson J. Jordan A. Joyce C. J. Spence H. E. Blake J. B. Case A. W. Farrell W. M. Kasper J. C. Looper M. D. Lugaz N. Mays L. Mazur J. E. Petro N. Smith C. W. Townsend L. W. de Wet W. C. Winslow R. Zeitlin C.
The Worsening Space Environment: Increased Galactic Cosmic Radiation from Historically Weak Solar Magnetic Fields But with a Sun Still Spawning Historically Intense Solar Particle Events **[#3143]**
We report on observations from CRaTER on LRO and predict the dose rates of galactic cosmic rays throughout the next solar cycle. We use these results to predict the most conservative allowable mission durations.

11:00 a.m. Hassler D. M. * Ehresmann B.
Next Generation Fast Neutron Detector for Space Exploration (Mini-FND) **[#3175]**
SwRI has developed a miniature Fast Neutron Detector (mini-FND), for use in the Deep Space Gateway, to characterize the neutron albedo radiation. Mini-FND will provide coverage of the biologically relevant neutrons at energies of 500 keV and greater.

11:10 a.m. Solomey N. * Barghouty N. Christl M. Johnson L. Meyer H.
Deep-Space Test of a Neutrino Detector **[#3002]**
Changes in solar neutrino flux make it advantageous to take a detector into space since it changes as the inverse square of the distance from the Sun. A space-craft with a neutrino detector in solar orbit would perform science study opportunities.

11:20 a.m. DISCUSSION

Wednesday, February 28, 2018
HELIOPHYSICS: CUBESATS AND SMALLSATS
11:30 a.m. Douglas Fir Meeting Room

Chairs: **Justin Kasper**
Pamela Clark

11:30 a.m. Kasper J. C. *
Heliophysics Radio Observations Enabled by the Deep Space Gateway **[#3163]**
This presentation reviews the scientific potential of low frequency radio imaging from space, the SunRISE radio interferometer, and the scientific value of larger future arrays in deep space and how they would benefit from the Deep Space Gateway.

11:40 a.m. Vourlidas A. * Ho G. C. Cohen I. J. Korendyke C. M. Tun-Beltran S. Plunkett S. P. Newmark J. St Cyr O. C. Hoeksema T.
Using the Deep Space Gateway to Build the Next Generation Heliophysics Research Grid **[#3055]**
The Heliophysics Research Grid (HRG) consists of in situ and imaging sensors, distributed in key locations in the heliosphere for research and to support space exploration needs. The Deep Space Gateway enables the HRG as a storage and staging hub for HRG launches.

11:50 a.m. Ho G. C. * Vourlidas A. Westlake J. H. Cohen I. J.
The Deep Space Gateway Opportunity for Next Generation Space Weather Measurements **[#3046]**
The near-Earth vicinity of the Deep Space Gateway could represent the first step in formulation of a new space weather system, potentially providing a broad range of infrastructure to enable a paradigm-shifting approach to how measurements are made.

12:00 p.m. Sibeck D. G. * Batchelor D. A.
Investigation of the Magnetic Fieldsand Energetic Particles in Earth's Magnetotail **[#3124]**
An opportunity to deploy a spacecraft from the Earth-Sun L2 libration point would enable important scientific research to be performed in a region of Earth's magnetic environment that deserves much further study, the region known as the magnetotail.

12:10 p.m. Clark P. E. * Collier M. R. Farrell W. M.
In-Situ Environmental Monitoring and Science Investigations Enabled by the Deep Space Gateway **[#3035]**
A distributed network of instrument packages in an ARTEMIS-like orbit will serve as the much-needed basis for on-going monitoring of cislunar environmental dynamics, critical for a successful human presence on the Moon.

12:20 p.m. DISCUSSION

Wednesday, February 28, 2018
ORBIT DISCUSSION
1:00 p.m. Alder Ballroom

Chair: **Ryan Whitley**

1:00 p.m. Ryan Whitley *
Deep Space Gateway Orbit Review

1:15 p.m. Gorjian V. *
Breakthrough Science Enabled by Regular Access to Orbits Beyond Earth **[#3118]**
Regular launches to the Deep Space Gateway (DSG) will enable smallsats to access orbits not currently easily available to low cost missions. These orbits will allow great new science, especially when using the DSG as an optical hub for downlink.

1:20 p.m. Genova A. L. * Dunham D. W. Hardgrove C.
Supporting a Deep Space Gateway with Free-Return Earth-Moon Periodic Orbits **[#3131]**
Earth-Moon periodic orbits travel between the Earth and Moon via free-return circumlunar segments and can host a station that can provide architecture support to other nodes near the Moon and Mars while enabling science return from cislunar space.

1:25 p.m. DISCUSSION

Wednesday, February 28, 2018
POTENTIAL FUTURE CAPABILITIES
1:00 p.m. Boxelder Meeting Room

Chair: **Steve Mackwell**

1:00 p.m. Othon W.L. *
Evaluating Deep Space Gateway Habitats for Science via Ground Test

1:05 p.m. Smitherman D. V. * Needham D. H. Lewis R.
Research Possibilities Beyond Deep Space Gateway **[#3048]**
This abstract explores the possibilities for a large research facilities module attached to the Deep Space Gateway, using the same large module design and basic layout planned for the Deep Space Transport.

1:10 p.m. Wald S. I. * Cummins C. K. Manber J.
Ixion: A Wet-Lab Habitat Platform for Leo and the Deep Space Gateway **[#3192]**
Cislunar and LEO habitats derived from launch vehicle upper stages are technically feasible and continues development toward flight. Present station specifications, configurations, and concepts for scientific, exploration, and commercial utilization.

1:15 p.m. Humphries P. * Barez F. Gowda A.
Manned Mission Space Exploration Utilizing a Flexible Universal Module **[#3068]**
The proposed ASMS, Inc. “Flexible Universal Module” is in support of NASA’s Deep Space Gateway project. The Flexible Universal Module provides a possible habitation or manufacturing environment in support of Manned Mission for Space Exploration.

1:20 p.m. Barnes P. K. Haddock A. T. * Cruzen C. A.
Autonomous Science Operations Technologies for Deep Space Gateway **[#3073]**
Autonomous Science Operations Technologies for Deep Space Gateway (DSG) is an overview of how the DSG would benefit from autonomous systems utilizing proven technologies performing telemetry monitoring and science operations.

1:25 p.m. Haddock A. T. Olden G. W. * Barnes P. K.
“Smart” Vehicle Management System: A Necessity for Future Endeavors **[#3074]**
The “Smart” Vehicle Management System (VMS) will give an overview of how a robust VMS would enable experiments to be conducted on the spacecraft in both manned and unmanned states, increasing the scientific benefits.

1:30 p.m. Foster B. D. Matthews B. *
Laser-Assisted Wire Additive Manufacturing System for the Deep Space Gateway **[#3166]**
Investigation on the Deep Space Gateway will involve experiments/operations inside pressurized modules. Support for those experiments may necessitate a means to fabricate and repair required articles. This capability can be provided through an additive manufacturing (AM) system.

1:35 p.m. Galluzzi M. C. *
Remote In-Space Manufacturing Applied with the Science of Interplanetary Supply Chain Modeling for Deep Space Gateway Application **[#3075]**
Three goals can be achieved by 2030: 1. NASA will have the capability for remote on-demand 3d printing of critical hardware using regolith material as feedstock, 2. Logistics footprint reduced by 35%, 3. Deep Space Gateway will become 75% self-sustaining.

1:40 p.m. Koryanov V. V. K. Da-Poian V. D.P. *
INFLATE: INFlate Landing Apparatus Technology **[#3028]**
Our project, named INFLATE (INFlatable Landing Apparatus Technology), aims at reducing space landing risks and constraints and so optimizing space missions (reducing cost, mass, and risk and in the same time improving performance).

1:45 p.m. Cohen M. M. * Bianco S. Avery T.
Antaeus II: Planetary Quarantine Facility at the Deep Space Gateway **[#3189]**
This abstract describes how the Deep Space Gateway would afford the ideal space-time coordinates for the Mars returned sample science receiving lab.

1:50 p.m. DISCUSSION

2:10 p.m. BREAK

Wednesday, February 28, 2018
SUPPORTING HUMAN EXPLORATION SCIENCE
1:40 p.m. Alder Ballroom

Chair: **Alex MacDonald**

1:40 p.m. Kring D. A. *
Deep Space Gateway Support of Lunar Surface Ops and Tele-Operational Transfer of Surface Assets to the Next Landing Site **[#3044]**
The Deep Space Gateway can support astronauts on the lunar surface, providing them a departure and returning rendezvous point, a communication relay from the lunar farside to Earth, and a transfer point to Orion for return to Earth.

1:50 p.m. Corrigan A. M. * Kitmanyen V. A. Prakash A.
Development of a Lunar Surface Architecture Using the Deep Space Gateway **[#3114]**
Prior to sending crews to Mars, the ability to perform activities intended for martian missions must first be thoroughly tested and successfully demonstrated in a similar environment. This paper outlines a lunar surface architecture to meet this goal.

2:00 p.m. Cassady R. J. * Carberry C. Cichan T.
The Deep Space Gateway: The Next Stepping Stone to Mars **[#3110]**
Human missions to Mars will benefit from precursor missions such as the Deep Space Gateway (DSG) that achieve important science and human health and safety milestones. The DSG can perform lunar science and prepare for future Mars mission science.

2:10 p.m. DISCUSSION

2:25 p.m. BREAK

Wednesday, February 28, 2018
CROSSCUTTING: EXTERNAL INSTRUMENTS
2:40 p.m. Alder Ballroom

This session is a review of the resources required to support externally mounted instruments.

2:40 p.m. Rosenqvist J. F. * Bhardwaj A. Nazarious M. I. Martín-Torres J. Zorzano Mier M. -P. Fernandez-Remolar D. Ramirez-Luque J. Soria-Salinas A. Vakkada A. Mathanlal T. Konatham S.
Platform for Conducting Experiments to Study the Long-Term Exposure Effects of Spacecraft Coating, Materials, and Components in a Deep-Space Environment **[#3067]**
The Central Exposure Platform is designed to hold any type of experiment for testing in a deep-space environment, such as coatings, materials, and technological components. It is designed to optimize the limited useable exterior area on the Deep Space Gateway.

2:45 p.m. Engelhardt J. P.* Heath K.
External Long-Duration Materials Instrument Research Observatory **[#3080]**
The External Long-duration Materials and Instrument Research Observatory (ELMIRO) is a commercial facility that will allow for continuous and repeatable external testing on the Deep Space Gateway of materials, electronics/instruments for future deep space spacecraft.

2:50 p.m. *Earth Science Review*

3:05 p.m. *Heliophysics Review*

3:20 p.m. Astrophysics Review

3:35 p.m. *Lunar and Planetary Review*

3:50 p.m. *SLPSRA Review*

4:05 p.m. DISCUSSION

4:25 p.m. BREAK

Wednesday, February 28, 2018
CROSSCUTTING: SAMPLE COLLECTION AND HANDLING AT DEEP SPACE GATEWAY
4:40 p.m. Alder Ballroom

This session will recap the sample-related presentations from the Heliophysics, Lunar, and SLPSRA themes to discuss both unique and common elements of collecting, receiving at Deep Space Gateway, handling, potential analysis, and return of physical samples.

4:40 p.m. *SLPSRA Review*

4:50 p.m. *Lunar and Planetary Review*

5:10 p.m. *Heliophysics Review*

5:20 p.m. DISCUSSION

Thursday, March 1, 2018
CROSSCUTTING: TELEROBOTICS AND LEVERAGING THE DEEP SPACE GATEWAY FOR UNTETHERED SCIENCE OPERATIONS
8:30 a.m. Alder Ballroom

In this session, we will discuss how the Deep Space Gateway can be used to leverage untethered science operations, including telescope servicing, CubeSat deployment, lunar lander deployment, telerobotics for orbital and surface operations, and communication between orbiting and surface assets.

The session will begin with summaries of infrastructure needs identified by each relevant science session, delivered by a representative from each science session. Then we will have topical presentations from each of five capabilities the Deep Space Gateway should have to support the science objectives identified in the science sessions, including:

- *In-orbit telescope servicing*
- *CubeSat deployment*
- *Lunar lander deployment*
- *Telerobotics for orbital and surface operations*
- *Communication relay for orbiting and surface assets*

These presentations will be followed by general discussion of presented topics.

8:30 a.m. *Lunar and Planetary Review*

8:35 a.m. *Astrophysics Review*

8:40 a.m. *Heliophysics Review*

8:45 a.m. *SLPSRA Review*

8:50 a.m. *In-Orbit Telescope Servicing*

8:55 a.m. Shaw A.* Rembala R. Fulford P.
Advantages of Science Cubesat and Microsat Deployment Using DSG Deep Space Exploration Robotics **[#3056]**
Important scientific missions can be accomplished with cubesats/microsats. These missions would benefit from advantages offered by having an independent cubesat/microsat deployment capability as part of Deep Space Gateway’s Deep Space Exploration Robotics system.

9:00 a.m. Wald S.
CubeSat Deployment

9:05 a.m. Gonthier Y.
Capabilities for a Deep Space Gateway Robotic Arm: A Potential Canadian Contribution to the Global Exploration Roadmap (GER)

9:10 a.m. DISCUSSION

9:40 a.m. Percy T.
Lunar Lander Deployment

9:45 a.m. Fong T.
Telerobotics of Orbiting and Surface Assets

9:50 a.m. Robinson B. S. * Shih T. Khatri F. I. King T. Seas A.
High-Rate Laser Communications for Human Exploration and Science **[#3014]**
Laser communication links has been successfully demonstrated on recent near-Earth and lunar missions. We present a status of this development work and its relevance to a future Deep Space Gateway supporting human exploration and science activities.

9:55 a.m. *Communication Relay for Orbiting and Surface Assets*

10:00 a.m. DISCUSSION

10:30 a.m. BREAK

Thursday, March 1, 2018
CROSSCUTTING: INTERNAL PAYLOADS
10:45 a.m. Alder Ballroom

In this session, we will begin with presentations on characterization of the deep space environment and potential impacts and effects on the Deep Space Gateway assets and payloads, and current thoughts regarding design criteria and internal configuration and development of the vehicle for research utilization. We will discuss internal infrastructure needs identified during each relevant science session, and conclude with an overall summary of needed capabilities and actions for further study. Topics will include:

- *Internal payload overview*
- *Deep space environment characterization and impact*
- *Vehicle design and interfaces — research facilities, utilities, resources, arrangement*
- *Payload interface design and operations*

Chairs: **Ruthan Lewis**
Rod Jones

10:45 a.m. Lewis R.
Internal Payload Overview

11:00 a.m. Pellish J.
Space Environment

11:15 a.m. Jones R.
Internal Vehicle Design Criteria

11:30 a.m. DISCUSSION

CONTENTS

EARTHS: (Earth Albedo Radiometer for Temporal Hemispheric Sensing). S.G. Ackleson[1], J. H. Bowles[1], P. Mouroulis[2], and W. D. Philpot[3], [1]U.S. Naval Research Laboratory, Washington, DC, steve.ackleson@nrl.navy.mil, [2]Jet Propulsion Laboratory, Pasadena, CA, pantazis.mouroulis@jpl.nasa.gov, and [3]Cornell University, Ithaca, NY; philpot@cornell.edu.

Abstract: The planetary albedo of the Earth is key to understanding the global radiation budget and, measured spectrally, can reveal useful information pertaining to the chemical composition of the atmosphere and the state of oceanic and terrestrial ecosystems. With appropriate temporal and spectral coverage, observations of planetary albedo will enhance our knowledge of changes in global climate, impacts of episodic events such as volcanic eruptions, variability in the planetary biosphere, and potentially yield proxies for life that can be applied to astrobiological exploration. Currently, the primary methods of measuring the planetary albedo are directly with satellite-based, Earth-viewing sensors and indirectly with ground-based measurements of Earthshine reflected from the moon. Satellite-based methods are data and computation intensive and are currently limited in spectral coverage. Earthshine methods can yield measurements in high spectral resolution, but are limited in temporal and spatial coverage.

We propose a concept for measuring the hemispherical Earth albedo in high temporal and spectral resolution using a hyperspectral imaging sensor, Earth Albedo Radiometer for Temporal Hemispheric Sensing (EARTHS), deployed on a lunar satellite, such as the proposed NASA Deep Space Gateway (DSG). By imaging the Earth disc at low to moderate spatial resolution multiple times per Earth day and across a range of lunar phase, EARTHS will generate a detailed time series of Earth albedo that will reveal hemispherical variability across a broad range in time (daily, seasonal, annual, decadal) and illumination/viewing geometry.

An example hyperspectral data set of the Earth was collected from lunar orbit in 2009 using the JPL M3 (Moon Mineralogy Mapper) sensor (Fig. 1). The data were parsed into a variety of Earth features, e.g., clouds, vegetation, water, and land, revealing subtle differences between each. We believe that a suitably configured sensor yielding time series of feature-specific spectra would not only be valuable to the climate modeling community, but would also yield new insights regarding the temporal variability in the albedo of an Earth-like planet that could be applied to astrobiological problems.

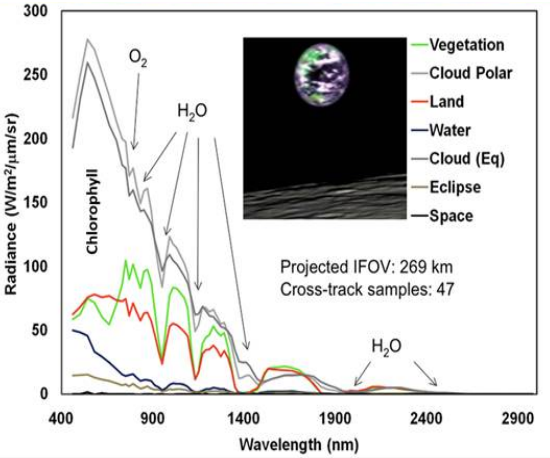

Fig. 1. M3 measurements of the spectral reflectance of the Earth's disc collected in 2009 from a lunar orbit.

Ideally, the sensor would be mounted externally, operate autonomously, and utilize the power and communications capabilities of the DSG.

A pointing mechanism would be developed to maintain a constant pointing vector centered on the Earth. Calibration procedures, such as deep space and solar viewing, would be incorporated in order to maintain a high degree of sensor calibration. Imaging spectrometer designs are advancing rapidly in terms of power and weight and the expected viewing geometry will permit time lapse sensing, resulting in high signal relative to sensor noise. In order to accommodate potential limitations in data volume, preference may be given to spectral coverage at the expense of spatial resolution. At a minimum, the visible and near-IR portions of the spectrum, e.g., 400 nm - 1000 nm would be represented with a spectral resolution of < 5 nm. However, since some planets reported so far that have been found to be cooler than the Earth with more radiation in the infrared, it would also be useful to capture imagery within selected SWIR bands, perhaps up through 2500 nm.

Deep Space Gateway as a Platform to Study Synergistic Radiation and Microgravity-Induced Tissue Degeneration Using the Bioculture System Single Cassette Hardware Design.

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Abstract: One of the major space biosciences unknowns for human exploration outside of LEO is the question of how the degenerative effects of microgravity unloading of cells and tissues might be magnified under deep space radiation conditions in cislunar space and on solar system voyages to Mars and beyond(Blaber, Sato, and Almeida 2014). Although our group and others have already studied some of these interactions in microgravity(Blaber et al. 2013; Blaber et al. 2014; Blaber et al. 2015) and ground models such as rodent hindlimb unloading and charged particle radiation from accelerated protons and iron at Brookhaven NASA Space Radiation Laboratory, these earth-based models of microgravity and space radiation have serious limitations and only offer a glimpse of the real interactions of the two major biological spaceflight factors (radiation and microgravity) outside of LEO. Specifically, the complexity of space radiation particle composition, energies, and dose rates is virtually impossible to simulate on earth, making our conclusions at best uncertain. Likewise, hindlimb unloading and other models only mimics limited aspects of real microgravity exposure, and effects on indicators such as gene expression in bone in these models vary significantly from real microgravity. Prior to long-term human exploration voyages in the solar system we must understand how real microgravity and real space radiation might interact, and to what extent they can synergize to promote irreversible human tissue degeneration. In microgravity during spaceflight in LEO, under low space radiation exposure conditions, our research team already identified the activation of cell cycle arrest mechanisms via p21/CDKN1, leading to bone degenerative effects on the bone formation osteoprogenitor differentiation pathway. In addition to being microgravity-induced in mouse bone tissue, p21/CDKN1a is also a canonic radiation-response gene, temporarily arresting the cell cycle to allow for DNA repair following radiation exposure. Because of these dual p21 roles (in radiation and microgravity response), we have hypothesized that microgravity and space radiation may potently synergize to arrest fundamental tissue regenerative processes in deep space outside of LEO. The affected biological systems may include the regeneration by adult stem cells of bone and muscle, blood and immune system regeneration from marrow, intestinal lining regeneration from crypts, skin regeneration, neural stem cell differentiation and migration to establish new memories and learning, etc. The Deep Space Gateway is an ideal experimental platform for testing the extent and mechanisms of real microgravity and deep space radiation effects on cells and tissues, and to obtain key information needed for enabling safe human exploration of space outside of LEO. Specifically, we propose to leverage our existing LEO p21/CDKN1a science briefly described above and the newly developed cell and tissue culture Bioculture System hardware for ISS, now being validated on SPX-13, to achieve these goals(Blaber, Sato, and Almeida 2014). The proposed new hardware development for the Deep Space Gateway utilizes the existing NASA Bioculture System cassette and flowpath design, and downscales the 10-cassette ISS express rack locker full system, to a streamlined 1-cassette system with less than one quarter of the mass and volume of the current hardware. A single cassette will be used to culture multiple non-

proliferating human heart beating tissue organoids as currently being validated on SPX-13 for one month or longer. Additional technical capabilities will be added to the cassette including remote monitoring of heart tissue electrical activity and live video microscopic imaging of beating heart tissue that can provide science outputs without sample return. Cells can also be remotely fixed and cold stored in the Bioculture System cassette for on orbit analysuis using the ISS WetLab-2 we recently deployed on ISS(Parra et al. 2017) or for later retrieval or returned to earth alive. The advantage of basing the new hardware for the Deep Space Gateway on a modular component of novel ISS hardware just coming online, is the fact that the extremely complex development process including for gas exchange and cell/tissue biocompatibility and fluidics has already been resolved, and the fact that the existing cassette module will be used in a much smaller but essentially functionally similar to existing enclosure, allowing us to develop more rapidly, with less expense, and to focus more on the science and less on new hardware development complexities. In addition, the current validation experiment of the Bioculture System on SPX-13, with human cardiomyocytes, will offer valuable baseline information about the responses of these human heart tissue organoids to microgravity in LEO, without elevated space radiation, setting the stage and providing background science data to compare results to microgravity exposure in cislunar space, this time with elevated space radiation levels. Overall this science and hardware concept proposal for exploration biological research in cislunar space using the Deep Space Gateway combines a key exploration biological science unknown, based on strong hypothesis driven science, with a feasible hardware development plan, greatly enhancing its chances for successful completion

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SEMI-AUTONOMOUS RODENT HABITAT FOR DEEP SPACE EXPLORATION.

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NASA has flown animals to space as part of trailblazing missions and to understand the biological responses to spaceflight. Mice travelled in the Lunar Module with the Apollo 17 astronauts and now mice are frequent research subjects in LEO on the ISS. The ISS rodent missions have focused on unravelling biological mechanisms, better understanding risks to astronaut health, and testing candidate countermeasures. A critical barrier for longer-duration animal missions is the need for humans-in-the-loop to perform animal husbandry and perform routine tasks during a mission. Using autonomous or telerobotic systems to alleviate some of these tasks would enable longer-duration missions to be performed at the Deep Space Gateway.

Rodent missions performed using the Gateway as a platform could address a number of critical risks identified by the Human Research Program (HRP), as well as Space Biology Program questions identified by NRC Decadal Survey on Biological and Physical Sciences in Space, (2011). HRP risk areas of potentially greatest relevance that the Gateway rodent missions can address include those related to visual impairment (VIIP) and radiation risks to central nervous system, cardiovascular disease, as well as countermeasure testing. Space Biology focus areas addressed by the Gateway rodent missions include mechanisms and combinatorial effects of microgravity and radiation.

The objectives of the work proposed here are to 1) develop capability for semi-autonomous rodent research in cis-lunar orbit, 2) conduct key experiments for testing countermeasures against low gravity and space radiation. The hardware and operations system developed will enable experiments at least one month in duration, which potentially could be extended to one year in duration. To gain novel insights into the health risks to crew of deep space travel (i.e., exposure to space radiation), results obtained from Gateway flight rodents can be compared to ground control groups and separate groups of mice exposed to simulated Galactic Cosmic Radiation (at the NASA Space Radiation Lab). Results can then be compared to identical experiments conducted on the ISS. Together results from Gateway, ground-based, and ISS rodent experiments will provide novel insight into the effects of space radiaiton.

Health checks and telemetry measurements will be collected throughout the mission. Rodents are either euthanized on-board and samples stored until opportunity for return to Earth, or animals are returned live to Earth on return vehicle for later analysis. Samples collected on orbit can be further processed on the Gateway using WetLab-style instruments for molecular biology.

Areas ripe for autonomous, telerobotic, or telemetric monitoring and operations include: monitoring animal health, food delivery, and sample processing. We propose a system be developed to achieve these tasks.

In conclusion, more autonomous rodent research systems will facilitate longer duration experiments to be conducted farther from Earth. The capacity for animal experimentation for biological research, in particular, to determine the effects of space radiation exposure at the Deep Space Gateway, has the potential to complement and enable human exploration of space.

Required Resources: (1 EXPRESS Rack Locker; a second unit could be added to improve sample size.)

- Max. # of mice: ~20 mice (1 locker).
- Mass ~ 60 lbs / 23 kg (with locker)
- Power ~ 75 W
- Volume ~ 8 in. x 19 in. x 21 in.
  (20 cm x 49 cm x 54 cm)
- Temperature Control: 21-30 °C
- CO_2 control: 0.2 in Hg / 5.32 mm Hg (0.7% at 1atm) or lower.
- Oxygen: average 19.5 - 21% (assuming ambient pressure 760 Torr). Oxygen must be greater than 16%.
- Humidity: 30-70%
- Videocamera and Telemetry capacity: TBD
- Other resource needs:
    - Hardware designed to minimize excess noise and vibration and to provide life support conditions equivalent to those provided for astronauts (oxygen, low CO_2).
    - Air flow requirement.
    - Radiation dosimetry.
    - Auxiliary Wetlab-like sample processing capability.

INNOVATIVE METHOD IN IMPROVING COMMUNICATION ISSUES BY APPLYING INTERDISCIPLINARY APPROACH. PSYCHOLINGUISTIC PERSPECTIVE TO MITIGATE COMMUNICATION TROUBLES DURING CISLUNAR TRAVEL.

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Introduction: Communication during long-term space flights is a crucuial factor for mission success, both regarding the in-group, onboard, communication and communication between the crew and the MCC. The present study aims to explain verbal communication evolvement of crew members of both genders whilst a long-lasting isolation as a simulation of a flight situation. In repsect to that, the data from such scientific disciplines like linguistics, psycholinguisitcs, psychology, and biochemistry will be described toghether to prove/ discredit the hypothesis outlined here below. This interdisciplinary approach is an innovative method of noninvasive practice in the field of communication research.

However, there have been a number of studies dedicated to verbal beaviour of people in dangerous and confined environments, i.e. cockpit communication [1] analysed psycholinguistically in line with the research of the Russian Academy of Sciences Institute for Biomedical Problems (IMBP) on communication patterns with focus on discourse and semantic analysis of isolated crews for space missions [2]. Additionally, the problem of effectiveness of team communication is being thoroughly investigated by the d.school at Stanford University in collaboration with SAP and Hasso-Plattner-Institute [3], [4]. Nevertheless, the verbal behavior of people under stress has not been investigated from the biological perspective so far. Therefore, the present research builds a bridge between the existing research foundings and proposes a biological, cognitive explanation of communication phenomena.

The psycholinguistic view on the issue of communication under stress is, though, an extremely developing approach in various sciences, i.e. computer science. Accordingly, there is a publication on the application of psycholinguistics for improvement and enrichment of AI capacity [5] which was presented on an annual international conference on Biologically Inspired Cognitive Architectures (BICA 2017).

Hypothesis information: In accordance with the coping theory [6] and the previous experiments, e.g [7], [8], [9], there are various human types to deal with a stress situation, differing, firstly, with respect to their physical reaction (i.e. ACTH hormones level [10] etc.) and, secondly, considering their values, consequently, phycological apprehension of stress in life in general (primarily conducted by the Institute for Biomedical Problems (Moscow), i.e. [2]).

Study interest: The interest of the present study is based on the linguistic behavior of the female and masculine subjects with diverse cultural background in a small group (6 to 9 persons), who show different psychological constellation patterns, while being exposed to relative equal stress of a long-term isolation. The isolation of 4-month in an on Earth chamber (Moscow, IMBP) is a simulation of a long-term space flight, i.e. to the Moon and Mars, of an international crew.

Hypothesis: Since there are empirically proved diverse psychological coping strategies to stress conditions, we aim to examine the cognitive-psychological outcomes over the cognitive-linguistic ones.

According to some studies, humans are highly dependent on their emotional state [11] and personal traits when communicating verbally; especially speaking in a foreign language due to additional cognitive load. Therefore, it is expected that in line with the psychological coping of stress, the linguistic performance could also be grouped regarding different psycholinguistic personal traits. Hence we anticipate a correlation of the psychological and linguistic coping strategies. This assumption underlies a shared cognitive basis of both mental activities.

Considering the linguistic behavior in a frame of the current study we divide it into formal and functional, where the formal ones are “linguistic pure” (i.e. grammar, speech speed, word choice etc.) and the functional ones reveal psycholinguistic ones (i.e. information sharing, initiation etc. [1]).

Relevance: Estimated linguistic coping strategies will enrich noninvasive methods for emotional state appraisal of crew members imposed on every possible kind of stressors during a space flight, especially a long-term one and which consists of multinational crew members. Further the study results will contribute to harmonization of in-group communication dynamics and increase group communication efficiency through a deeper understanding of a nature of human verbal behavior in extreme and confinied environments.

Experiment frame: As background information for the psycholinguistic experiment will serve the following personal data of each crew member: educational level and obtained profession, experience in space missions, knowledge of further (foreign) languages, if applicable – linguistic eloquence, and intercultural experience.

Data prior to the experiment. Psychological tests on predominant personal values, frustration, and stress coping strategies will be a baseline prior to the isolation experiment. In case a lingua franca is a foreign language for one of the crew member, the level of his/her fluency in the respected language must be measured. Additionally, the level of stress hormones, like cortisol, testosterone and alpha-amylase, pulse, and respiratory rate in a stress-free environment must build a biochemical baseline of each crew member for further analyses of physiological stress state ("individual coping portrait").

4-month isolation. During the 4-month isolation, conducted in Moscow at IMBP and which serves as an analog of a space flight, communication patterns of crew members will be analyzed by observing their in-group discussions and mutual problem solving. Their linguistic performance will be analyzed in percentual manner regarding the physical stress response indicated by respiratory rate, stress hormones in salvia etc. By the percentual character of the linguistic performance we understand quantity of formal or functional deviants by each crew member under stress condition of different extent.

Expectations: The isolation period will be roughly divided into 4 phases according to the previous psychological studies on the behavior of people in confined environments [2] and which we expect to have an impact on the verbal performance in the subjects. Therefore, firstly, we anticipate a change in in-group communication dynamics and transformation of individual verbal performance due to the temporal evolvement of isolation stress – in-group linguistic adaptation. Secondly, linguistic adaptation characteristics, formal and functional, should depend on the individual psychological constellation and stress level – individual linguistic adaptation.

Conclusion and future work: Thus, we aim to describe and classify linguistic adaptation patterns during different stages/levels of stress. This will contribute to noninvasive methods for emotional stress appraisal and enable to propose alternative approaches to improve in-group communication and overall sociometrical indexes. The latter will lead to an increase in creativity performance because of greater group cohesion.

Establishing psycholinguistic patterns of the reaction on stress depending on the biological and psychological individual variables, we will also enhance the exisiting methods of education, particullary those of austraunauts and cosmonauts. Moreover the outcomes of the study should be applicable to other situational communication contexts.

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KEY CHALLENGES FOR LIFE SCIENCE PAYLOADS ON THE DEEP SPACE GATEWAY.

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Radiation Challenges: The Deep Space Gateway (DSG) offers life scientists the opportunity to explore new scientific variables of interest not previously accessible on LEO platforms such as the Space Shuttle and ISS. These new variables include deep space radiation, potential access to planetary surface samples, and superior microgravity conditions compared to continuously occupied habitats. Arguably the most intriguing among these variables is deep space radiation which poses a threat to both human health and spacecraft electronics [1].

Compared to the ISS which is protected by the Van Allen Belts, the internal radiation dose rate within the DSG could be roughly 4.2 times as large based on data collected by the MSL spacecraft which recorded a Mars transit dose rate of 1.84 ± 0.33 mSv/day [2]. This assumes relatively minimal shielding on the DSG that is comparable in efficacy to what the MSL RAD instrument featured. It is important to note that this difference not only reflects overall magnitude but also differences in radiation composition such as particle species and energy distributions. Although radiation exposure facilities are available on Earth, they cannot precisely replicate the composition of deep space radiation [3].

Access to higher space radiation dose rates may offer significant scientific value. For example, higher dose rates outside the DSG during solar quiescence might be more representative of dose rates within the DSG during active solar periods. Since solar weather is unpredictable, it cannot be assured that a given experiment will experience desired solar weather conditions. In general, larger dose rates can improve the effect size of experiments thereby expediting the discovery and characterization of radiobiology effects. A key tradeoff however is that both the DSG crew and onboard electronics would benefit from radiation shielding and lower dose rates.

Within the pressurized and somewhat shielded modules of the ISS, the typical approach for payload radiation tolerance is to largely ignore it. NASA currently provides no official requirements to ISS internal payload developers to utilize radiation hardened components or design payload systems with sufficient redundancy to continue operating without issue through single event upsets. For ISS, this is indeed a rational and cost-effective approach given the high added cost of radiation-tolerance engineering and the low frequency and consequence of radiation-related payload failures. Further, this approach has enabled the design of payloads incorporating low-cost COTS components designed originally for terrestrial usage. For DSG, it is important to reassess this approach based on the final radiation exposures expected within the pressurized habitat to ensure that the implicit assumptions that it is dependent upon remain valid. These are, namely, low frequency and low consequence of radiation-related payload failure.

Compared to the ISS, the DSG will feature a lower launch rate (1 or 2 per year) and reduced volume available for science hardware. In that sense, DSG experiments can be considered “higher-stakes” than ISS experiments due to fewer overall flight opportunities.

Accordingly, for new hardware and ISS-repurposed hardware, it would perhaps be prudent to provide some basic requirements or guidelines to payload developers to improve radiation tolerance without adding significant cost. For example, incorporating software watchdogs, using radiation-tolerant (but not hardened) components, and designing failure tolerance into systems.

That said, it is crucial not to apply radiation requirements that are too stringent and result in ballooning system cost, complexity, and volume. Unchecked payload requirement creep will decrease the quantity of science that DSG can feasibly process. A 90% experiment success rate with 10 experiments is preferable to a 100% experiment success rate with only 5 experiments.

Additionally, care should be taken that experimental designs take into account the internal DSG radiation exposure and any additional shielding provided by the payload hardware itself. This will ensure ahead-of-time that experiments can feasibly observe their targeted effects in a statistically significant manner.

If necessary, a pressurized volume with less shielding should be considered to provide pressurized experiments access to higher dose rates than achievable within DSG itself. To simplify individual experiment design, this could be accomplished as an external facility-class payload consisting mainly of a simple pressure vessel containing multiple internal pressurized payloads along with appropriate thermal, power, and data accommodations. The individual payloads could be periodically swapped out via an airlock as DSG crews come and go.

Autonomy Challenges: A unique operational aspect of the DSG compared to ISS is that it will only be intermittently occupied with current NASA plans indicating annual stays of 42 days in duration [4]. As previously discussed with radiation, longer experiments with a larger total dose can provide superior data with a larger effect size than shorter experiments. Additionally, when uncrewed, experiments will be subject to fewer microgravity disturbances [5]. As such, it would be valuable to perform experiments while the DSG is uncrewed.

On ISS, crew activities are an integral component of experiment design. For instance, a typical ISS life science payload may feature the crew setting up the experiment, performing periodic media exchanges and data collection, and then terminating the experiment and preparing it for transport back to Earth for further analysis. Crewmembers are also counted on to perform corrective actions as necessary to keep experiments running smoothly. For uncrewed DSG, crewmembers will only be able to set up and tear down experiments and will be unavailable to perform experiment maintenance, data collection, and corrective actions for the bulk of the experiment duration.

This operational shift will place increased emphasis on payload autonomy. Accordingly, payloads operating while DSG is uncrewed will need to be capable of executing experiments without crew assistance and with a reasonably high degree of certainty that they will successfully return quality science.

To this end, there are several ways that the DSG can support uncrewed experiments to make this task easier. For example, DSG could provide generalized internal robotics support similar to Robonaut or Dextre. Alternatively, common analysis payloads such as spectrometers or DNA sequencers could be strategically positioned near experiment hardware with standardized sample-transfer interfaces so that data can be collected continuously during uncrewed operations. Finally, utilization of ISS flight-heritage hardware with demonstrated reliability and autonomous operation can be used for experiment control. Utilization of flight-heritage hardware where possible will also reduce cost and enable greater funding for experiments and truly new hardware capabilities and avoid the committal of funds to the reengineering of capabilities that already exist.

As an example of ISS flight-heritage hardware that could be suitable for DSG usage, BioServe has developed the Space Automated Bioproduct Lab (SABL), a smart incubator capable of controlling temperature and carbon dioxide concentration while providing experiments with standardized interfaces for power, experiment control, and data collection [6]. SABL incorporates several key software and hardware features that enable it to rapidly and autonomously recover from single event upsets and other hardware failures without impacting experiment success. This behavior has been verified several times on-orbit and BioServe does not currently anticipate any significant issues operating SABL on DSG.

In parallel to hardware reliability, long-term untended biological specimen maintenance will also present a major challenge. For cell-culture experiments, sterility will have to be carefully controlled to combat contamination. For small animal experiments where some level of contamination is virtually guaranteed by microbiota, appropriate measures must be taken to prevent growth. With higher-order animals such as rodents that carry with them regulations for their care and use, uncrewed experiment design will be rather complicated and perhaps require automated euthanasia systems that can terminate the experiment in the event of unacceptable conditions or communications failure. These complications may well render such experiments unfeasible to perform on DSG while uncrewed.

Conclusion: Several key challenges facing life science payloads operating on the DSG have been identified as related to deep space radiation and payload autonomy during uncrewed operations. These challenges are not insurmountable but should be considered during DSG's scope definition and design so as to not preclude valuable science from being performed. Ultimately, principal investigators and payload developers must overcome or work around these challenges when designing experiment hardware to ensure successful science return.

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Nautilus Deep Space Observatory: A Giant Segmented Space Telescope Array for a Galactic Biosignature Survey.

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Introduction: With over 4,000 exoplanets known – many of which may be similar to Earth – the systematic characterization of exo-earths and the search for atmospheric biosignatures is emerging as one of the highest-level science goals of modern astrophysics. With no prior knowledge on the probability of the emergence of life on other planets, the characterization of a very large number of potential earth-analogs is desirable to ensure statistically meaningful results.

As our baseline goal we identify an atmospheric compositional study of 1,000 earth-sized habitable zone planets. This survey will target a large enough sample to allow statistically significant conclusions on biosignatures occurrence rates, exo-earth diversity, climate stability, and atmospheric loss mechanisms.

Our survey requires a very large aperture space telescope.

The Deep Space Gateway, and specifically the infrastructure for the Gateway, offers a unique opportunity to (partially) fabricate and assemble a very large (50 m diameter equivalent) segmented space telescope that will be capable of carrying out the ambitious atmospheric biosignatures survey outlined above. Such a segmented giant space telescope will also transform observational astrophysics.

Key Science Requirement for Transmission Spectroscopic Biosignature Survey: We aim to determine the occurrence rate of life in the galaxy by measuring the atmospheric abundances of H_2O, O_2, O_3, and CO_2 in the atmospheres of 1,000 transiting habitable zone earth-like exoplanets around broadly sun-like stars. Studying a large number (~1,000) transiting earth-like planets will require observing relatively distant stars (G and K-type stars up to 200 pc, considering the number densities of G and K-type stars and geometric probabilities of habitable zone planet transits). The spectral feature depths for key absorbers in Earth twins are about 1 ppm ([1], Fig. 1). A confident ($>10\ \sigma$) detection of H_2O, O_2, and O_3 for a target 200 pc away will require a telescope with a collective area equivalent to that of a 50m telescope (assuming overall throughput of 0.25). This is 200 times greater area than that of the largest mirror flown in space.

Current telescope architectures cannot be scaled up so dramatically. Therefore, our science goal requires a revolutionary new telescope technology and design.

Baseline Telescope Design: We envision a giant segmented space telescope with the following design (see also Figure 1):

1) A segmented telescope with a combined light-collecting area equivalent to a that of a 50m diameter telescope.
2) Hexagonal segments with individual segment diameters between 1.5m to 3m. Each segment group (7 hexagons) phased coherently, but light from the segment groups combined incoherently (i.e., digitally co-added).
3) The segment groups are located in a large, lightweight hexagonal honeycomb-like grid system, providing individual two-axis pointing and tracking capability for each unit. The entire telescope will not need to coherently combine light, i.e., it will not provide diffraction-limited performance for its entire 50m diameter.
4) A modular design allows sub-units (segment groups) to be used as individual telescopes or to be used in a coordinated array mode (common target). The modular design will also enable step-wise construction of the telescope and operations with the partial telescope aperture.
5) We envision very lightweight and thin optical elements, preferably fabricated in space. The in-space fabrication reduces the structural strength that would be required if the optical elements would be fabricated on Earth.

Operations: The Nautilus Deep Space Observatory (NDSO) will operate in two modes:

1) Transit Search Mode: The unit telescopes will monitor sun-like stars independently of each other, and through their parallel operation carry out the most sensitive and most comprehensive exoplanet search yet.

2) Follow-up Transit Spectroscopy Mode: During known transit events all unit telescopes will obtain the transmission spectrum of the same planet; the signal will be combined non-coherently (by digitally coadding), enabling the confident detection (>10 sigma) of major atmospheric absorbers (O_2, O_3, H_2O) in Earth twins up to 200 pc distance (scaled from [1]).

Assembly at or near the Deep Space Gateway: NDSO is a modular system assembled from identical telescope cells, which itself are constructed from a very small set of unique components. Only two different types of telescope segments are required: on-axis and off-axis segments.

The modular design and identical elements provide greatly reduced fabrication costs. The honeycomb structure provides an excellent structural strength / mass ratio. The support structure of the NDSO telescope array could be launched as a folded structure as a compact payload, which would be deployed by the DSG crew in orbit. The individual segment groups would be inserted and connected to the honeycomb support structure. As the units primarily function as independent telescopes, no precise alignment is necessary between the segment groups.

Reflective or Diffractive-Transmissive Optics: With an overall design similar to the James Webb Space Telescope the Nautilus Deep Space Observatory will provide a viable framework for reflective segmented telescopes. However, our team is also working on developing the capability to design and injection mold large-scale on- and off-axis transmissive-diffractive (multi-order) optical elements [e.g., 2,3,4]. Large-scale transmissive-diffractive optical elements have been explored in the LLNL and DARPA-funded Eyeglass [5] and MOIRE projects [6] aimed at constructing 25 meter diameter earth-observing space telescopes.

Our team has designed, fabricated, and replicated (via injection molding) two generations of small-scale multi-order diffractive engineered material lenses (MOD-EML). As part of our technology maturation process we are currently carrying out on-sky and laboratory tests with a MOD-EML-equipped astronomical telescope. Equipping NDSO with lightweight MOD-EMLs instead of mirrors would provide a significant reduction in launch weight.

In-orbit Fabrication: If the molding of large MOD-EMLs can be successfully demonstrated, the extension of this process may also provide a natural opportunity for the Nautilus Deep Space Observatory and the Deep Space Gateway. By launching the two *molds* (one on-axis and one off-axis segment) and unmolded glass, the injection molding process could conceivably be carried out in orbit. This step would allow for even lighter optical elements, as the elements would not need to survive the launch stresses.

Scientific Impact: The NDSO array will provide a light-gathering capability that exceeds current state-of-the-art (Hubble Space Telescope, 2.4m mirror diameter) by about 400 times. The NDSO system will be capable of carrying out the first large-scale assessment of atmospheric biosignatures in the galaxy, leading to profound breakthroughs in science. Furthermore, the powerful light-gathering capability combined with the flexibility to observe the same target with all unit telescopes or to survey large fields simultaneously will transform multiple modern observational astrophysics, cosmology, and planetary science.

Estimated Requirements: NDSO is a preliminary concept that builds on a similarly ambitious space mission concept (Nautilus Array) under development by our team. Here we provide preliminary, baseline estimates for the fundamental requirements and will provide more comprehensive assessment at the workshop.

Mass: Approx. 500-700 kg per unit. A 40 unit telescope array would be between 20,000 to 28,000 kg.

Power: None. Power will be supplied from NDSO's own solar panels.

Cost: We do not yet have a reliable cost estimate. Nevertheless, assuming the first unit cost to be between \$0.5B and \$0.7B and an exponential cost scaling law with a coefficient between 0.4 and 0.7, the 40 unit array cost would be between \$2.5B and \$9B.

Volume: No volume within DSG.

Amount of Crew Interaction: The NDSO deployment and installation would require crew interactions (multiple EVAs). Once deployed, the NDSO will require additional crew interactions only during expansion and servicing.

Desired Orbit: An orbit similar or identical to DSG is desired; our desired orbit is Near Rectilinear (NRO).

Nautilus website: http://nautilus-array.space/

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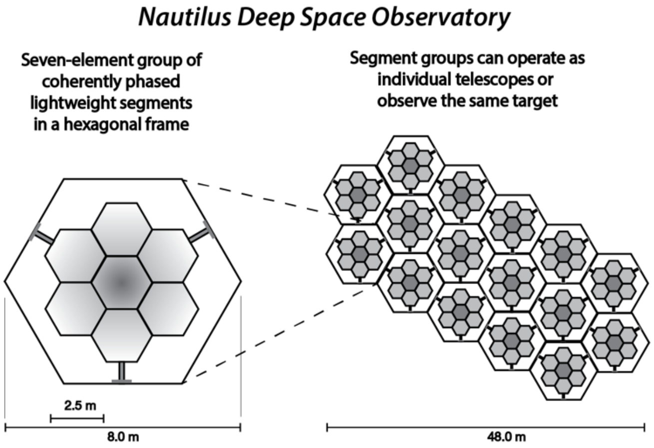

Figure 1 The Nautilus Deep Space Observatory comprises of an array of individual, segmented telescopes. The entire array is build using only two distinct type of optical elements: on-axis and off-axis hexagons. The modular construction that minimizes unique elements allows for low construction and assembly costs, flexible operations, and increased serviceability.

GLOBAL LUNAR TOPOGRAPHY FROM THE DEEP SPACE GATEWAY FOR SCIENCE AND EXPLORATION.

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Introduction: *When we decided to add the scientific instrument module bay to Apollo missions 15 through 17, photography from orbit was high on our list of scientific objectives. The Apollo metric camera system was flown to acquire photographic data with high accuracy to aid the effort of Moon mapping, both for operational reasons and for future study and research.* - Rocco A. Petrone, Apollo Program Director [1].

We propose that the Deep Space Gateway (DSG) carry a new instrument that will finally realize the goal of Petrone and other NASA planners – and indeed many other investigators and space agencies – to generate a uniform high resolution global topographic model of the Moon. The Apollo Metric and Panoramic cameras in the end acquired sufficient data for such coverage over about 20-25% of the Moon, although only recently have the topographic products from those data begun to be completed (e.g. [2]). However, even with many new spectacular lunar datasets, it is still not possible to generate such a model over most of the lunar surface.

Such an instrument on the DSG could collect global stereo imaging from low lunar orbit for the generation of a global uniform high resolution (5 m/pixel imaging, 15 m post-spacing) lunar topographic model. Such a model would fulfill long stated science and exploration needs. Primarily, it would address a critical need to orthorectify all imaging datasets to a level of high resolution. It would fulfill science needs to properly process color, multi-, and hyper-spectral data [3], for the best possible understanding of lunar surface composition and processes, facilitating global geologic mapping and other lunar surface structural and composition investigations. It would also support landing site selection and surface operations of any science and exploration missions to any illuminated area of the Moon. It would further allow for the identification of and location of lunar surface changes from crater formation, landslides, and boulder movement.

Past high-resolution lunar topographic datasets: The availability of global topographic information at landing site scales has always been considered critical. As noted, this was a primary goal of the latter Apollo missions, where coverage was achieved for 20-25% of the Moon. In this zone, the Metric camera provided ~7 m ground sample distance (GSD) photographs which have been digitized [http://apollo.sese.asu.edu/] and recently processed into ~40 m GSD topographic and mosaic information (e.g. [4]). Similar work to process the Panoramic camera data, with ~1-3 m GSD stereo coverage, is now underway for Apollo 15 data at USGS [2]. However, the later data are from panoramic cameras, and as such have some jitter-like distortions similar to those of line scanner cameras. The JAXA Kaguya mission also considered collection of such data a priority, with its TC line scanner cameras obtaining global 10 m stereo imaging [http://www.kaguya.jaxa.jp/en/equipment/tc_e.htm]. The TC data provide the best near global stereo and therefore topographic coverage, and provides post spacing of ~25-30 m, but are still not geodetically controlled and only approximately registered to the LOLA topography and reference frame [5]. The ISRO Chandrayaan-1 mission TMC [https://tinyurl.com/TMC-ISRO] operated in a similar mode using 5 m GSD line scanner cameras, and provide coverage over some tens of percent of the Moon. It is not clear how much of those data have been controlled or processed into topographic models. The LOLA topographic model provides global topographic data over the entire lunar surface, including shadowed areas, and does so in a global reference frame that is probably accurate to the 15-25 m level. The LOLA gridded topography model is derived from along track sampling of ~10-12 m, but in low to mid latitudes the spacing between tracks can still be several hundred meters. The alignment of the LOLA track data has been improved via cross over solutions and registration of new data onto existing data [6]; however, few meter elevation discrepancies often persist between adjacent tracks, making the topographic models problematic (e.g. for orthoprojection of high resolution images, for slope determination, and illumination reconstruction) at high resolution in the cross track direction. The LROC Narrow Angle Camera (NAC, part of the LRO Camera (LROC) instrument) has been used to obtain repeat stereo coverage and for construction of many topographic DTMs at high resolution, with GSD of ~50-200 cm, and post spacing of 1.5-6 m [7]. However, such coverage only exists for a few percent of the Moon, and even with many more years of LRO operation will probably only approach several percent of the Moon. Some of the images and therefore resulting topographic models are also affected by jitter.

Operations: The proposed instrument would use fore and aft pointing *framing cameras*, with a GSD from a nominal 50 km orbit of 5 m, thus providing topographic post spacing of 2.5-3 times that (12.5-15 m), and expected vertical precision of 1.4 m which would provide global characterization of illuminated terrain at landing site and surface operations scales. Each of the two identical cameras would consist of 4Kx4K CCD imaging sensors (using either an active shutter or frame transfer shuttering) and a ~20 cm telescope. Such an image scale could be used to support the location of crater and boulder hazards at that (5 m) scale and where needed, allow reconstruction of topography via photoclinometry (e.g. [8]) at the same scale. This concept follows from historic aerial cameras, a previous proposal for such a lunar camera [9], the successful DLR HRSC camera currently operating at Mars [https://tinyurl.com/HRSC-DLR], and the lunar TC and TMC cameras.

In a significant change from the previously flown cameras, we argue that framing cameras should be used, rather than line scanner cameras to largely eliminate effects of spacecraft jitter. Jitter, of unknown but possibly large amplitude, seems likely on the DSG, due to the movement of gyros, the large solar electric propulsion solar panels, antennas, hydrazine thrusters, other instruments, and of astronauts when occupied. Eliminating image distortion due to jitter is extremely important for terrain relative navigation systems that use image correlation matching. This is currently a critical issue for Mars landing site mapping for Mars 2020, since high resolution image coverage there is from line scanner cameras (HiRISE and CTX) [Yang Chen and Richard Otero, personal comm]. Staring at a given location to achieve higher SNR in low light (e.g. polar) conditions will also be possible.

Complete stereo mapping of the Moon can be accomplished in two months, so the time required for the DSG to be in low lunar orbit would not be extensive. Extending the observation time or making a return visit might be desirable to fill in gaps, obtain coverage of polar or other areas under better lighting conditions, or obtain higher resolution data from a lower orbit. It is assumed that the two cameras would be rigidly fixed at a 40° stereo angle, but that the entire instrument would be place on a scan platform, with or without other instruments, to avoid reorienting the entire Gateway to point the camera. Camera pointing would nominally be toward the nadir, but off-nadir pointing would be necessary to fill in areas missed for operational reasons, and for off-nadir target of opportunity images.

The overall instrument could be repaired or upgraded in the future when human visits occur. Filters could be changed or inserted to obtain global stereo imaging in color. Astronauts could also operate the cameras to image targets of opportunity or areas on the surface (e.g. at the lunar poles, once per orbit) where robotic or human operations are taking place.

Processing of the stereo images into topographic models could be accomplished for the global dataset using established techniques and software, such as the Ames Stereo Pipeline [10], the stereo matching method used to create a Mercury global topographic model, using USGS ISIS3 software [11], and techniques available since the first (low resolution) global lunar topographic model from Clementine stereo data [12].

Other options: The expected GSD and topographic model resolution could be improved by scaling up to a larger instrument (telescope), but with a consequent increase in observing time and data volume. An additional higher resolution nadir pointing camera could also be used to do high-resolution mapping in selected locations, e.g. completing or extending the same type of work that the LROC cameras are currently doing. Some overlap in operations with LRO would be expected. It would also be useful to have a single or multi-beam lidar instrument (similar to LOLA) in operation to better connect the stereo images to the LOLA (and/or new lidar instrument) reference frame.

Rigorous combined photogrammetric solutions could also be used to process all available data simultaneously to improve the global lunar reference frame down to the resolution of the highest resolution global dataset. The resulting global topographic model would be comparable if not better in resolution and positional accuracy than those for the entire Earth.

Benefits: After over 40 years of planning and incomplete attempts, such an instrument would finally make available a global topographic model that would serve as the basis or the foundational topographic product [13] of all lunar orbital and surface observations, for any and all scientific and exploration purposes. Such a model would serve literally as the basis for such purposes for decades, and would likely only need to be updated due to surface changes from impacts and robotic and human operations on the Moon. And not incidentally, the goal of many lunar missions, dating back to the end of the Apollo missions, would finally be achieved.

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LOW-GRAVITY CENTRIFUGE FACILITIES FOR ASTEROID LANDER AND MATERIAL PROCESSING AND MANUFACTURING.

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Introduction: The Deep Space Gateway has the potential to open new avenues for human exploration towards the Moon, asteroids and Mars. In the next 35 years, we aspire to be on our way to sending human and robotic explorers to perform orbital, surface and subsurface exploration. These explorers will pave the way towards cataloging the diverse surface environments, physical processes and structures of the planets and small bodies answering fundamental questions about the origins of the solar system, conditions to sustain life and prospects for resource utilization and off-world human settlement. Achieving this major exploration milestone remains technologically daunting and therefore we consider the DSG as an ideal proving ground for the requisite technologies. Conditions on some of these planets and small bodies are not well understood.

Challenges: One of the major challenges in recreating or even understanding these off-world conditions is the low surface gravity. We lack fundamental knowledge of surface material properties, especially the dangers that may prematurely end a mission. Our lack of understanding poses a major risk due to inherent uncertainties in the design and development of robotic and human vehicles to explore the far reaches of the solar-system. This leads to significant cost increases, schedule delays and lack of technical or political confidence in these missions. This is a major concern for small-body exploration, where the low gravity makes surface landing and mobility extremely challenging, as evidenced by JAXA's first Hayabusa mission and ESA's Philae lander aboard Rosetta [1–2].

Physical processes in these alien environments may be simulated using ever-realistic computer models, but these models are dependent on our current domain knowledge. Ultimately, these computer simulations, as well as analytical scaling relations (e.g., [3]), need to be validated against the real thing. The logistics and resources required to reach these far corners of the solar system make the process of simulation validation and trial-and-error learning a very slow and cumbersome process as a mission, from concept to launch, may take 5–10 years or longer.

On-Orbit Centrifuge Laboratory: Our work has identified the use of on-orbit centrifuge science laboratories (**Fig. 1**) as a key enabler towards low-cost, fast-track understanding and simulation of off-world environments for the dual purpose of planetary science and exploration engineering. We have developed AOSAT I (Asteroid Origins Satellite I) [4–7], a 3U CubeSat (**Fig. 2**) that is intended as a low-cost proof-of-concept on-orbit demonstrator to show the feasibility of a centrifuge science laboratory for planetary science and to simulate asteroid surface conditions. The concept of an on-orbit centrifuge is not new [8–10]. Our work identifies new use for these as laboratories and proving grounds to simulate off-world environments. We envision follow-on missions that include enlarged centrifuges with much larger internal volume to test instruments and major parts of a spacecraft under alien surface conditions.

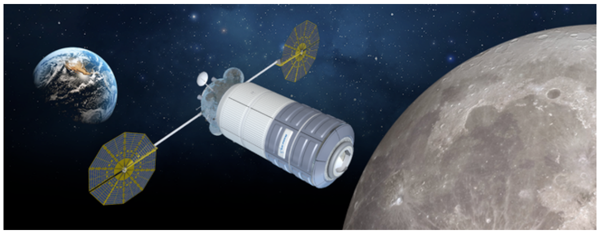

Fig. 1. An on-orbit centrifuge based on existing Space Station service vehicles (shown: Orbital ATK Cygnus) can be used as a laboratory and proving ground to simulate the range in gravitational conditions that exist on asteroids, comets and small moons. Planetary science instruments, scaled or full size spacecraft, and even astronauts can be trained or tested in these laboratories ahead of deep space missions.

Persistent Link to Off-World Environments: Using such laboratories it is possible to simulate alien environments (different gravity, atmospheric pressure, electrical conditions and so on) and test hypotheses for unknown or poorly understood planetary surface processes; this, in turn, may be used to validate computer models in order to develop advanced simulation proxies for science, exploration, mining, habitation, and hazardous asteroid deflection. By recreating alien surface environments we can test and validate robotic landing technology and human adaptation to these environments, and broaden our understanding and prove the feasibility of risky off-world surface exploration techniques before going to these locations [6].

These laboratories can be enlarged and transformed into miniature proving grounds for testing and demonstration of entire spacecraft and landing systems. They may be used to train and condition astronauts for efficient mobility and to perform both basic and complex tasks in the low-gravity environments of Moon and

Mars to sustain long-life expeditions. This may include evaluating self-sustaining farms and an artificial ecosystem to sustain the health and the well-being of human explorers. As a specific example, directly determining the effect of Martian gravity on plant-life will be critical in long term exploration and settlement of Mars and can be done in LEO (see **Fig. 3**).

Further, these facilities will require significantly less resources and budget to maintain, operating in LEO, compared to the voyages to deep space, and will hence serve an important tactical goal of preparing and maintainning readiness, even when missions are delayed or individual programs cancelled. Imagine being able to recreate Mars or lunar surface conditions to sand grain detail without having to go there. Imagine recreating a patch of the Moon and having astronauts train and adapt to lunar conditions from the end of the Apollo mission in 1972 till now. The technologies we propose facilitates our abilitiy to effectively accumulate and maintain knowledge to explore the diverse environments in our solar system.

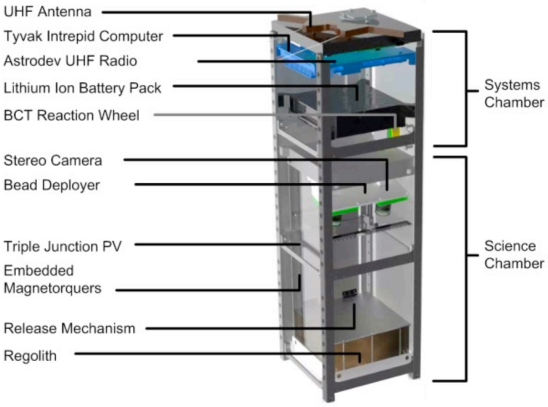

Fig. 2. Asteroid Origins Satellite 1 is proof-of-concept CubeSat demonstrator to be launched in the 2018-2019 timeframe. The mission will demonstrate an on-orbit centrifuge laboratory to simulate asteroid gravity conditions

By letting us have persistent access to simulated versions of these off-world environments, these laboratories will allow us to forecast and avoid surprises in-situ, and to increase confidence and support for such ambitious exploration endeavours. We also believe these facilities will be critical for resource prospecting and mining as they can be used to rapidly perform trial-and-error experiments, followed by refinement of the technology towards efficient surveying, extraction and processing of resources in-situ both for fuel, parts repair and settlement/infrastructure construction.

Conclusions: Centrifuge science laboratories, from CubeSat and larger scales, can be used to recreate the low-gravity off-world conditions of the Moon, Mars, asteroids and other small bodies in the solar system. The laboratories can provide a persistent link to better understand and perform hypothesis-testing of planetary surface processes. The power of hypothesis-testing of planetary science processes, being able to fully recreate them in controlled laboratory conditions in low-Earth orbit, and to prove or disprove hypotheses directly, will have major consequences for the field. Detailed numerical simulation environments can be developed and validated for end-to-end process testing. Furthermore, this technology can be applied to de-risk next generation spacecraft technology especially for landing, surface mobility and even for subsurface exploration with increased confidence and long term planning.

Estimated Resources:

- Mass: 1000 kg
- Power: 120 W
- Cost: $100 M
- Volume: 2 m^3
- Crew interaction: limited
- Preferred orbit: L2 (or any)
- Temperature control: -50 to +80°C

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Lunar Science Enabled by the Deep Space Gateway and PHASR Rover.

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Introduction: The Deep Space Gateway (DSG) will be a tremendous boon to lunar surface science. It will allow unprecedented access to the lunar surface which will provide invaluable support for acquiring samples of the Moon and for surface science rovers and landers.

A Rover for Lunar Science: The Precursor to Human and Scientific Rover (PHASR) is a concept for a Canadian rover system with international contributions and the goal of sample acquisition and lunar surface science. The PHASR Rover is part of the larger HERACLES concept which includes a Lunar Ascent Element (LAE) as well as a future crewed rover.

Bringing pieces of the Moon to Earth: The best way to find out what the Moon is made of is to bring pieces of it back to Earth. This will allow lunar samples to be analyzed by scientists at laboratories across the world and by scientists who are not yet born. By supporting the acquisition and transport of lunar samples to Earth, the Deep Space Gateway will allow these samples to be analyzed by future instruments that are currently just ideas brewing in the minds of scientists and engineers. The Apollo samples are an incredible legacy of lunar exploration and they continue to be analyzed to this day.

An important region of the Moon from which we do not have any samples is a large basin on its far side [1]. This basin was formed billions of years ago when a large object hit the Moon creating the largest crater in the solar system. The area is now known as the South Pole-Aitken (SPA) Basin. The impact event that formed it excavated material from deep inside the Moon. So this location on lunar surface is the best location for finding material that originated from the lunar interior. Because of its high scientific value, the SPA Basin is one of the potential sampling sites currently under discussion.

The PHASR rover would acquire a lunar sample early on in its mission and bring it to the Lunar Ascent Element (LAE). The LAE will carry the sample to the Gateway, and the DSXR (Deep Space Exploration Robotics) robotic arm will accept the LAE, assist it in docking with the Gateway, and then retrieve the sample canister.

Lunar Surface Science: Compared to the rest of the solar system, the Moon is practically in our back yard. This means that it shares history with our home planet. It “grew up” in the same environment. And it holds a much more well-preserved record of the history of its formation and growth than the Earth does. This means that the Moon can tell us about our own planet’s history. For this reason, as well as others, understanding the Moon is an incredibly important scientific goal.

The lunar far side and the poles have not been explored on site. There are no surface-based measurements from these regions. The Deep Space Gateway could help change that.

To help scientists understand the Moon better, the Deep Space Gateway can provide support to PHASR’s full mission which includes a surface science traverse after the initial sample collection has been accomplished.

Deep Space Gateway Resources:

One of the major obstacles facing the lunar science community currently is the lack of communications infrastructure at the Moon. The Deep Space Gateway could remove this obstacle to furthering lunar science.

The PHASR rover would require Deep Space Gateway support for communications and teleoperation as well as for sample return. Parts of this discussion are already underway between the HERACLES team and the Deep Space Gateway team. The specific requirements will depend on the outcomes of future work on both HERACLES (Phase 0) and Deep Space Gateway.

Current Status: The Canadian Space Agency **(**CSA) has awarded industry and academic contracts to develop the PHASR concept. MDA is currently working on a concept for the rover, including mobility system. This work involves refining mission requirements and options as well as developing a preliminary business case for use by the CSA in future planning phases. The University of Western Ontario is currently working on a Science Maturation Study to advance the PHASR science investigation to Science Readiness Level 4, including developing science scenarios, refining science requirements and providing payload recommendations as well as outlining potential preparatory activities in the form of a potential analog deployment.

Conclusion: Deep Space Gateway will be enabling for important science goals that help us understand the Moon and what the Moon can tell us about the history of planet Earth. This is accomplished by providing communications, teleoperation and sample return support for the PHASR Rover and HERACLES mission.

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The LSM (Lunar Surface Mobility) contracts were awarded by the Canadian Space Agency to study potential Canadian mobility contributions to the human exploration of the Moon and Mars, including a precursor rover (PHASR) for the HERACLES lunar demonstration mission concept and a preliminary science scenario.

The HERACLES mission concept, enabled by the Deep Space Gateway, is being jointly studied by ESA, CSA and JAXA and includes the objective of demonstrating technologies in preparation for the human exploration of the Moon and Mars, while robotically returning lunar samples to the Earth and performing in-situ investigations on the surface.

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SPACECRAFT CHARGING AND SPACE ENVIRONMENT MONITORING SYSTEM USING DISTRIBUTED LANGMUIR PROBES AROUOND THE DEEP SPACE GATEWAY.

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Abstract: One of the critical elements of any space habitat, in low earth orbit or deep space, is a monitoring system for spacecraft floating potential as well as space environment in the vicinity of the spacecraft. Spacecraft floating potential (i.e. spacecraft charging) is critical on manned missions that involve extra-vehicular activity for astronaut safety. Floating Potential Measurement Unit (FPMU) aboard the International Space Station is a suite of Langmuir probe instruments that not only monitors the varying levels of spacecraft charging as the ISS enters and exits eclipse [1], but it is also an important long term tool to measure environmental parameters such as plasma density and temperature (see figure below)

Any deep space habitat needs to have a spacecraft potential measurement tool akin to FPMU on the ISS. A Langmuir probe type instrument installed on the deep space habitat would not only perform 'space science' by continuously measuring plasma density and temperature around the Moon as it orbits Earth, but also 'spacecraft science' by monitoring spacecraft charging as the habitat enters and exits the eclipse behind the moon. A critical understanding of varying floating potential of manned spacecrafts is necessary as future deep space manned missions leave the relatively safe confines of Earth's plasmasphere and magnetosphere. Additionally, unlike FPMU which is located at a single location on ISS, this tool should likely have 3 - 4 copies installed around the spacecraft to study wake effects and differential charging. In tenuous plasmas, such as what one may encounter in deep space missions, density in the wake might likely exceed densities in the ram direction [2, and references therein]. Langmuir probes have been miniaturized to fly aboard satellites as small as CubeSats [3]. Thus, operating 3-4 of these low power devices (less than 1 W each) distributed around the deep space habitat is a low cost way to monitor one of the vital parameters of spacecraft health: spacecraft charging. And plasma parameters (density and temperature) as observed by such a suite of instruments on the deep space habitat will be an important measurement of the cislunar environment, which is pertinent to heliophysics.

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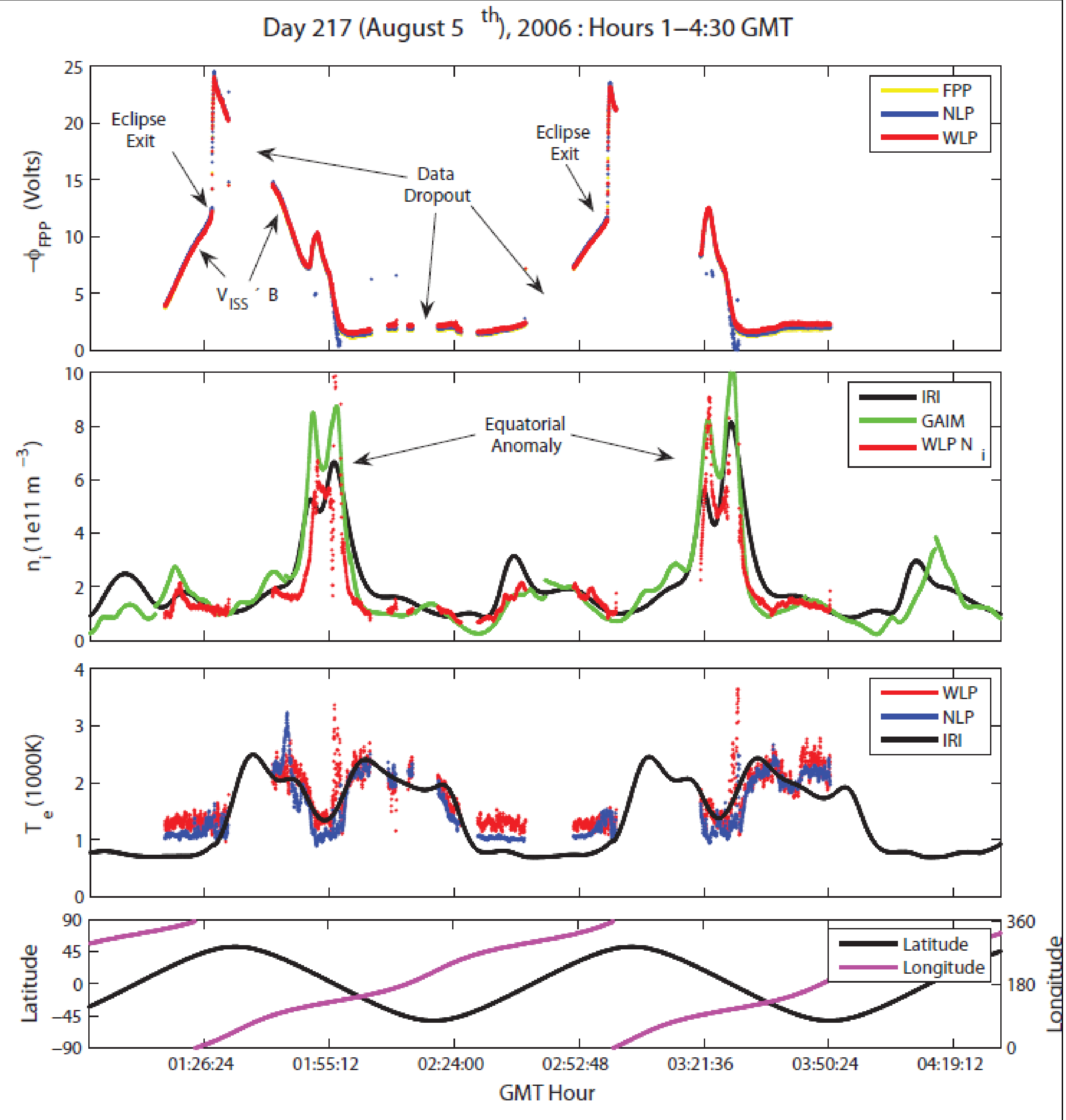

Fig. A two orbit dataset showing the floating potential of the International Space Station as observed by the FPMU suite of instruments: Wide Langmuir Probe (WLP), Narrow Langmuir Probe (NLP), and the Floating Potential Probe (FPP). The plasma density and temperature as observed by the WLP and compared with IRI and assimilative model such as GAIM is shown in rows 2 and 3. The last row shows the latitude and longitude of the orbital location. As can be clearly seen, the ISS floating potential changes by an order of magnitude, all while the ISS is inside the relatively safe confines of the Earth's plasmasphere. [from Barjatya et al 2009]

Autonomous Science Operations Technologies for Deep Space Gateway

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Introduction: Beginning in 1999, software engineers at the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center in Huntsville Alabama, working in collaboration with the Charles Stark Draper Laboratory, began developing autonomous blocks of software, called Timeliner Bundles, in new and innovative ways to reduce ground controller workload, add reliability, and to a certain extent, put a virtual-controller onboard the target spacecraft (the International Space Station). From those humble beginnings to the present, engineers, scientists, and flight controllers have developed an autonomous and continuously executing system onboard called Higher Active Logic (HAL). HAL incorporates the Timeliner Language constructs and is integrated in such a way so as to mimic human decision processes in order to minimize flight controller interaction in routine tasks, while at the same time incorporating a conservative and safe approach to autonomous operations on a manned spacecraft [1].

Traveling to and from cislunar space (lunar orbit) will take longer and will probably occur less frequently than trips to the ISS. And given the Deep Space Gateway's (DSG) comparatively smaller size, these stints would be shorter in length than those aboard the ISS. This will greatly reduce the amount of available crew time to perform science operations. Since the DSG would be initially placed in a near-rectilinear halo orbit (NRHO) around the Moon, it is likely to have longer periods of Loss Of Signal (LOS) data outage than the ISS, implying earthbound scientists will have no insight into their experiment's state during this time period. Given these limitations, DSG science platforms could benefit from the capability of autonomous systems utilizing proven technologies, such as Timeliner, for assistance performing telemetry monitoring and science operations.

Language Constructs That Model Human Decisions: Timeliner provides higher level programming constructs that model many human decisions that are made day to day. It is worth noting that Timeliner is the only flight proven human rated scripting language. These constructs relate directly to the decision processes made by ground flight controllers each day concerning such things as traffic control, manufacturing processes, and any other work environments that are procedural [2]. These constructs provide an easier coding paradigm that allows non-computer programmers the ability to follow and understand the execution as it takes place. The English language type constructs allow the actual compiler listings to be used for following the execution of autonomous operations. Ground flight controllers can also scan the compiler listings to predict autonomous operations behavior prior to events taking place. As long as both Timeliner and the monitoring system are active, there will be constant communication with the science instrument or experiment being monitored. This communication path is confined to the vehicle and is not reliant on any ground flight controller decision(s) or any ground originated commanding. In stark contrast, earth bound scientist are dependent upon satellite communication and ground equipment to receive telemetry and issue commands. Timeliner is a proven technology that has demonstrated operational usefulness on the ISS [2]. Timeliner scripts that operate on the ISS make science and payload operations safer, easier and much more reliable. At this time, it is envisioned the DSG will employ a similar type tier structured computer architecture as the ISS.

Higher Active Logic: The concept for HAL was driven by constraints of bundle management, processor utilization limits, and of course, crew and system safety. Thus, the system became "event driven." The architecture of the ISS command and control system is based on locations of devices or Remote Terminals (RTs). Each RT location has a Remote Power Controller (RPC) that determines if the unit is powered. Allowing a master Timeliner bundle (HAL_MAIN) to monitor the status of these RPCs (powered or unpowered), has been a very reliable and safe method to manage which specific payload bundle should be active. Conversely if the RPC is "closed" or powered, the bundle is installed. With this control mechanism in place, autonomous monitoring or commanding is only possible when a RT, or payload, is powered. As mentioned, within the HAL structure are bundles and within those bundles are individually executable sequences. HAL has been employed extensively by ISS flight controllers in the form of non-autonomous ISS sequences that are started and stopped by ground flight controllers based on operational dependence. In this situation HAL will load the bundles into memory when a facility is powered or a payload is sending health and status data, however, sequences will remain dormant until a ground flight controller commands sequence execution. This initial work has been expanded upon to include more complete automation of predefined activities.

Autonomous Payload Monitoring: The HAL system aids in automatically configuring the ISS Payload Multiplexor, DeMuliplexor (PL MDM). As part of the PL MDM initialization process, the HAL_MAIN bundle is installed. Once this action has taken place, the HAL system continuously monitors power and status data from all facility RT(s) and some subordinate payloads. HAL_MAIN will be loaded into memory by the PL MDM anytime a PL MDM is initialized or transitioned. There are several fully autonomous and continuously running sequences within the HAL system [3]. One example, the ISS MAMS DOWNLINK bundle, supports a payload called the Microgravity Acceleration Measurement System (MAMS). This experiment is a sensitive set of accelerometers deployed in different ISS modules. MAMs has the requirement to downlink its memory buffer to the ground every 24 hours. Initially, this was a scheduled set of commands sent by a ground flight controller. The developers at MSFC realized this was a perfect application for Timeliner. The MAMS bundle monitors for a specific GMT time and at this time it will check to verify a good communication path is present between the payload and flight hardware. Once this verification is complete the sequence will downlink the MAMS buffer twice and then reset it until the next downlink. However, if throughput is not available, it will loop every 5 minutes and check until the status is good or the sequence is stopped by ground commanding. After the MAMS buffer has been successfully downlinked to the ground, the sequence will monitor for the specified GMT time and repeat the check/downlink process until it is stopped by ground commanding.

Autonomous Facility Class Payload Rack Activation/Deactivation Functionality: There are currently 2 Autonomous Mission Operations (AMO) science rack bundles that are not currently part of the HAL system compliment. These bundles are manually loaded by flight ground controllers to the PL MDM memory, as needed to fulfill the proof of concept activities. These two bundles consist of core command and rack command capabilities. Together they ensure the ISS science rack is activated and configured properly. Each sequence in the bundles model conventional ground control procedures, to mimic the human decision processes of flight controllers, in order to perform the rack activation [4]. When activated by ground flight controllers, more than 60 commands can be sent to properly activate and configure each ISS science rack. The activation of these racks is one of the most complex activities performed by ISS payload flight controllers, and the AMO experiment has demonstrated that through the use of Timeliner it can be completed with a simple push of the button by any crew member when needed [4]. This effort if incorporated into future science equipment and/or payloads will greatly reduce the dependency on ground based commands and the availability of both ground flight controllers and extended periods of communication between the ground and flight hardware in proposed environments such as the DSG and beyond.

Conclusion: The HAL system has proven over the last decade to be a very reliable system to monitor and control the execution and use of Timeliner bundles and their sequences on the ISS for science operations. The experience gained on ISS can be easily leveraged for future automation to make DSG science operations less reliant on manual procedures and ground flight controllers. Knowledge based intelligent systems will be mandatory for missions with long communication delays in order to operate and control complex onboard systems. Now that the Timeliner and HAL autonomous systems have been well proven onboard a crewed spacecraft such as the ISS with commanding to tier 2 and tier 3 MDM's and RT's, the natural progression would be to increase all levels of automated intelligence and to eventually design and implement a fully automated real-time monitoring, commanding, planning and re-planning system. If the DSG is designed with consideration of the operational automated system design, more can be accomplished with less crew safely and efficiently.

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Occultation and Triangulation Camera (OcTriCam) Cubesat

Deep Space Gateway Science Mission Abstract

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Category: Planetary Science

An opportunity to deploy a spacecraft from the proposed Deep Space Gateway at the Earth-Moon L2 libration point (EML2) would enable important scientific research to be performed to identify solar system objects and precisely measure their orbits with unprecedented accuracy and with unprecedented speed. For example, near-Earth asteroids now can be identified and have their orbits measured with Earth-based telescopes such as the Pan-STARRS survey telescope in Hawai'i and the Hubble Space Telescope (HST), typically by making a sequence of observations on successive nights. By comparison, a camera at Earth-Moon L2, working with a camera on a ground-based telescope or HST, would provide a baseline of order 240,000 km. By comparing two images of the same target obtained from both ends of this baseline, triangulation would enable distances of planetary objects to be measured without the delay of successive nights, and in many cases simultaneously.

Employing binocular viewing with a camera at EML2 and an Earth-based telescope or HST, the process of finding near-Earth asteroids would be accelerated dramatically. The motions of more distant solar system objects could also be measured with greater rapidity. Occultations (eclipses of one planetary body by another or eclipses of astronomical objects by planetary bodies) are used to refine the ephemerides of planets and other solar system objects. They are also used to probe the ring systems of distant planets like Uranus and Neptune. Observations of occultations with HST, Earth-based telescopes and a camera at EML2 would obtain results much faster, using multiple simultaneous observations. (Of course many complementary observations can be performed that are not exactly simultaneous. The point is that triangulation can be obtained without delay times to wait for target motion that are now necessary.)

As mentioned in the report on the Astronomy Decadal Survey, *New Worlds, New Horizons: A Midterm Report* (National Academy Press, DOI: 10.17226/23560, p. 34), the Pan-STARRS survey telescope is operated by NASA primarily as a near-Earth object detector. The proposed spacecraft at EML2 would provide triangulation data that could be combined with Pan-STARRS observations to dramatically improve the rate of target identification and ranging – a significant capability cited in the Decadal Survey Report. Location of near-Earth objects is, of course, an important strategic element in the planetary protection responsibility of NASA.

This mission can be performed with a small spacecraft such as a cubesat, with low-thrust propulsion such as solar electric ion drive. No requirement of astronaut intervention would be necessary post-deployment.

Reference

Solar System's First Interstellar Visitor Dazzles Scientists:

https://www.nasa.gov/feature/solar-system-s-first-interstellar-visitor-dazzles-scientists

Space Weather Research and Operational Observing from a cis-Lunar Deep Space Gateway T. E. Berger[1] , D. N. Baker[2], and T. N. Woods[2] [1]University of Colorado at Boulder, Space Weather Technology, Research, and Education Center (LASP SPSC W201C, Boulder, CO, 80309, thomas.berger@colorado.edu), [2]University of Colorado at Boulder Laboratory for Atmospheric and Space Physics.

Introduction: We review the current and optimal observing architectures for space weather forecasting and discuss possible uses of a cis-Lunar "Deep Space Gateway" (DSG) platform in contributing to space weather operational and research observations. The 2007 NASA report "Heliophysics Science and the Moon: potential solar and space physics science for Lunar exploration" was written prior to the advent of many of the modern developments in space weather forecasting. In particular, Theme 2 on space weather focuses mainly on the role that energetic particle detectors in lunar orbit or on the surface of the Moon can play in characterizing or "now-casting" space weather radiation events, e.g. Solar Energetic Particle (SEP) events associated with solar magnetic eruptions. However, since the 2007 report several space weather models have been transitioned to operations for the purpose of forecasting solar wind and Coronal Mass Ejection (CME) events at Earth and other solar system bodies, geomagnetic storms caused by magnetospheric reaction to solar wind and CME impacts, and ionospheric and upper atmospheric response to these geomagnetic storms including physics-based estimates of thermospheric drag increases due to space weather events.

The DSG platform offers novel observational inputs that could both increase model forecast accuracy and act as validating observations to increase model fidelity and accuracy. In addition to radiation and plasma detectors to characterize the near-Moon environment, the DSG could in principle carry solar imaging telescopes to augment Earth-based observations or observations from off-Sun-Earth line locations such as the L4 and L5 Lagrangian points. Depending on orbit selection or companion platforms ("sub-satellites") that use DSG as a communications link, continual full-Sun imaging (optical, EUV, and coronagraph) and irradiance observations could be enabled with no interference from Earth eclipses or atmospheric absorption (as on the ISS) while retaining the advantage of instrument access by DSG astronauts for repair or upgrades, as demonstrated by the Skylab mission.

The additional advantage of providing particle and magnetic field measurements both in and outside of the magnetosphere as the Moon orbits the Earth would enable supplemental vantage-point observations during large space weather impacts to the magnetosphere. The DSG can be viewed as an ideal platform for space weather operational and research observations that will uniquely supplement current and future proposed space weather observing platforms.

LOW-COST LUNAR AND PLANETARY MISSIONS ENABLED BY THE DEEP SPACE GATEWAY CONCEPT.

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Introduction: The Deep Space Gateway concept will offer opportunities for Science and Exploration that will generate breakthrough science, continue to expand humanity's presence in space, and provide opportunities for commercial enterprise in space.

Moon Express' vision is to open the lunar frontier with turn-key payload, data and services for missions to the Moon for a wide range of customers globally, including governments, NGO's, commercial enterprises, universities, and consumers.

Like the Earth, the Moon has been enriched with vast resources through billions of years of bombardment by asteroids and comets. Unlike the Earth, these resources are largely on or near the lunar surface, and therefore relatively accessible. Moon Express is blazing a trail to the Moon to seek and harvest these resources to support a new space renaissance, where economic trade between countries will eventually become trade between worlds. All Moon Express expeditions will prospect for materials on the Moon as candidates for economic development and in-situ resource utilization.

One of the greatest practical space discoveries of our generation is the presence of vast quantities of water on the Moon. Water not only supports life but its constituents, hydrogen and oxygen, are energetic and clean rocket fuel. The discovery of water on the Moon is a game changer, not just for the economic viability of lunar resources, but for the economics of humans reaching Mars and other deep space destinations. Water is the oil of the solar system, and the Moon can become a gas station in the sky to fuel human space exploration, development and settlement of the solar system. Moon Express will begin prospecting for water resources on the Moon with its very first expedition.

The MX family of spacecraft: Moon Express has developed a family of flexible, scalable robotic explorers that can reach the Moon and other solar system destinations from Earth orbit. The MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science or commercial expeditions to distant worlds.

The MX robotic explorer spacecraft are optimized for launch on existing and emergent rocket systems:

MX-1: A single stage spacecraft capable of delivering up to 30kg to the lunar surface.

MX-2: A dual-stage spacecraft that doubles the capability of the MX-1 and can reach the moons of Mars.

MX-5: A cis-lunar workhorse spacecraft that can deliver up to 150kg to lunar orbit or 50kg to the surface.

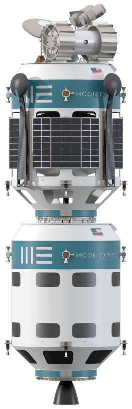
MX-9: A lunar prospector/harvester that can deliver up to 500kg to the lunar surface, including an embedded MX-1R spacecraft that can launch from the lunar surface and return lunar samples to Earth.

The MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science expeditions to distant worlds.

Designed for Scout Class exploration capabilities starting from low Earth orbit, MX-1 delivers flexibility and performance to revolutionize access to the Moon and cis-lunar space.

MX-1 Spacecraft

Dual stage flexibility drives more payload to the lunar surface or extends the reach to deep space. Compatible with existing and emergent launch vehicles, the MX-2 delivers Scout Class possibilities for exploration and commerce at low cost.



MX-2 Spacecraft

Designed as a workhorse that can deliver 150kg to low lunar orbit from low Earth orbit, with a range of configurations to support lunar landing and cis-lunar operations, the MX-5 can also be outfitted with MX-1 or MX-2 staged systems that can bring the entire solar system within reach. Available in orbiter, lander, deep space probe and sample return configurations.

MX-5 Spacecraft

Designed for Frontier Class exploration capabilities, MX-9 will support robust lunar sample return operations. Like it's MX-5 little brother, the MX-9 can also be outfitted with MX-1 or MX-2 staged systems that can deliver over 10kms ΔV and extend its reach to span the solar system, and beyond.

MX-9 Spacecraft

Currently-Planned Lunar Missions: Our first expedition will utilize our MX-1E robotic explorer to deliver a diverse manifest of scientific and commercial payloads to the lunar surface. Our customers for this mission include the International Lunar Observatory Association, the University of Maryland, The National Laboratories of Frascati, Celestis and Google.

Following our initial "Lunar Scout" expedition next year, we will offer payload accommodations on future voyages, planned at the rate of one per year. But we can also scale up and increase the frequency of our lunar flights to meet market demand and opportunity.

Our second expedition in 2019, "Lunar Outpost", will enable the first commercial presence and exploration of the lunar South Pole. It may in fact be the first-ever soft-landing at a lunar pole. The primary goals of this mission are to set up the first lunar research outpost at a "peak of eternal light", prospect for water and useful minerals, and accommodate a variety of research instruments for our expedition partners.

Our third expedition, "Harvest Moon", will take place by 2020 and includes the first commercial sample return, beginning our business phase of lunar resource prospecting and harvesting. The samples brought back will be the only privately obtained lunar materials on Earth, and will be used to benefit science as well as commercial purposes.

The opportunity that Deep Space Gateway represents: Although the current architectures for Moon Express missions involve going from Low Earth Orbit directly to Lunar orbit, then Lunar surface, or to other destinations in the solar system, integrating the MX family spacecraft into an architecture that involves the Deep Space Gateway presents new and exciting opportunities for science and for cis-lunar operations in general.

Mission concepts that assume that the DSG is available as a hub of operations in Lunar orbit can enable much larger landed masses on the lunar surface and/or continuous shuttle service for assets on the surface or for returned samples to DSG.

The Deep Space Gateway can also be a starting point for repeat robotic science and exploration missions to Mars or its moons, or to other solar system destinations. One could imagine scenarios in which refuelling of MX spacecraft could occur at DSG.

The long-term vision of using the Deep Space Gateway as a staging and fueling location can be facilitated by using the MX spacecraft family.

Moon Express has been able to collapse the cost of Lunar missions, and the incorporation of DSG into mission scenarios enable even lower mission costs with a workhorse for small payloads to and from the surface of the Moon, and from the Deep Space Gateway itself.

The Importance of Conducting Life Sciences Experiments on the Deep Space Gateway Platform.

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Introduction: Over the last several decades important information has been gathered by conducting life science experiments on the Space Shuttle and on the International Space Station. It is now time to leverage that scientific knowledge, as well as aspects of the hardware that have been developed to support the biological model systems, to NASA's next frontier – the Deep Space Gateway.

In order to facilitate long duration deep space exploration for humans, it is critical for NASA to understand the effects of long duration, low dose, deep space radiation on biological systems. While carefully controlled ground experiments on Earth-based radiation facilities have provided valuable preliminary information, we still have a significant knowledge gap on the biological responses of organisms to chronic low doses of the highly ionizing particles encountered beyond low Earth orbit. Furthermore, the combined effects of altered gravity and radiation have the potential to cause greater biological changes than either of these parameters alone. Therefore a thorough investigation of the biological effects of a cis-lunar environment will facilitate long term human exploration of deep space.

Approach: Several pieces of hardware that have been validated in low Earth orbit can be utilized for Deep Space Gateway experiments using relevant genetic model organisms. Some of the critical needs for life sciences experiments include an internal centrifuge in order to differentiate the effects of radiation and other spaceflight factors from that of microgravity. Similarly the availability of life support systems within the Deep Space Gateway will allow environmental conditions to be maintained in habitats for supporting life sciences samples. In some cases, unpowered/ambient habitats could be utilized to maintain multigenerational populations of small model organisms, with sample return or sample fixation to facilitate post-flight analyses. In the case of powered habitats, automated features such as videography/imaging, food-changeout etc. will allow for more complex experiments to be handled with little or no crew intervention. Currently available hardware options can be utilized to further science goals and enable the efficient ulilization of the Deep Space Gateway platform. Such hardware options and potential scientific benefits will be discussed.

Resource needs: The resource requirements will depend on the hardware used. For example with some of the powered and automated hardware options that have an internal centrifuge, the specifications could include a volume ranging between $0.004m^3$ and $0.01m^3$, with peak power usage between 0.03kw and 0.37kw and lower during nominal use, temperature range accommodation of 14^0 – 40^0C. On the other hand, unpowered ambient payloads could occupy a volume of $0.004m^3$ and require no power and return biological samples for processing on the ground post-flight.

Relevance to NASA: Both the National Academy of Science's Decadal Survey as well as the Space Biology Science plan describe the need for biological studies at the molecular, genomic, genetic, physiological and behavioral levels. The areas of study that are of importance to NASA include immunology, neurobiology, oxidative stress, cardiovascular, radiation biology, microbiology, plant biology, structural biology etc. All of these focus areas can be studied on the Deep Space Gateway using well characterized genetic model organisms and leveraging many of the tools that have been developed previously.

USING INSTRUMENTS AS APPLIED SCIENCE, MULTIPURPOSE TOOLS DURING HUMAN EXPLORATION: AN XRD/XRF DEMONSTRATION STRATEGY FOR THE DEEP SPACE GATEWAY.

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Introduction: The Deep Space Gateway (DSG) could serve as a platform from which surface science is enabled on the Moon and Mars either directly by humans or via telepresence. From a scientific perspective, providing as much data as possible about the geologic context of a sample, from the outcrop scale to the local and regional scale of the surrounding terrain, is absolutely crucial in exploring an area. A well trained geologist inherently conducts such analyses in real time, factoring this information into sample selection and traverse execution. However, miniaturization of instrument components over the last several decades has enabled smaller and quicker portable versions of traditional laboratory instruments to be developed and tested during field science operations.

Portable instruments can provide humans with enhanced awareness of surface units [1], whether the instrument is in the hand of a human or mounted on a teleoperated rover. Such approaches enable basic science research and could also be applied to laboratory settings inside of a DSG [2]. However, instruments intended for basic scientific research can also be designed to have applied science value throughout a human mission such that they are useful beyond science research activities. Here we present a model for instrument development as a multipurpose tool for use during human exploration. The DSG offers a laboratory for testing not only the basic research capablities of an instrument in a realistic environment but also its utility as a tool for providing data of value to the safety and success of the mission as a whole.

Instrument Development: Portable, contact X-ray fluorescence (XRF) is a technique used to assess sample chemical composition. Although typically applied to industrial and archealogical applications, contact XRF has recently been a focus of geologic field activities [3]. Contact X-ray diffraction (XRD) is an area of technology development that requires no sample preparation (e.g., crushing and sieving). We have built a brass-board contact XRD/XRF device, CMIST (Chromatic Mineral Identification and Surface Texture), that provides chemical and unique crystalline “texture” analyses for unprepared samples, revealing surface crystal phases, morphologies, and orientations, including unambiguous identification of volatiles such as water ice.

The apparatus consists of two key components: a collimated broad-spectrum X-ray source and a low noise, photon-counting X-ray CCD. The CCD detects individual X-ray photons, reporting their (x,y) positions as well as their energies (and thus wavelengths) with ~2% resolution. When X-rays strike the sample, some are diffracted in accordance with Bragg’s law. Other X-rays are stopped by atoms in the sample, which then emit characteristic lines with known energies through fluorescence. The CMIST CCD captures diffracted and fluoresced X-rays, generating an “event list” of all individually detected photons. The measured photon properties are then transformed so that diffraction and fluorescence signatures are largely distinct: for each event, a unique *d*-spacing value is derived given the photon energy and its position (and thus 2θ) using Bragg’s law. X-ray intensity images over energy and *d* describe elemental composition (XRF) and mineral identification (XRD).

Our goal is to develop a tool that quickly differentiates relevant minerals to inform planetary sample collection during surface traverses, at reduced cost (in analysis time, volume, and power) and risk (through elimination of sample preparation steps) compared to existing systems. Depending on the sample’s crystalline structure, a CMIST measurement can be obtained in < 10 minutes, often within several tens of seconds. CMIST will consist of a low power (< 5 W), low mass (< 5 kg), compact (large coffee-cup size) XRD/XRF spectrometer and optical imager for measuring element abundances, distinguishing mineral phases including ices, and determining the unaltered sizes and orientations of crystals over a few-mm^2, with no sample preparation. The lack of moving parts and sample preparation requirements, coupled with the instrument’s small size, make this an ideal tool for use during future human exploration missions.

Application: The application of CMIST to silicate sample analysis has been described [4]. We briefly discuss here the unique other uses of

CMIST as well as the requirements for system integration as a multipurpose tool.

Science: The CAPTEM-LEAG report on lunar sample acquisition and curation identifies low mass, low power, and rapid measurement (minutes) as crucial enabling capabilities for future sample return missions [5,6]. CMIST is designed to quickly inform sample selection during real-time field operations. Because CMIST requires no sample preparation, unbound and frozen volatiles are readily detected. This unique capability of contact XRD enables analysis of native ices and other planetary materials that would be modified during sample collection and preparation, determinations of brine chemistries, and assessment of the environmental impact that human presence may have at an outpost or landing site.

Curation: If samples are to be collected and returned to Earth for analysis, CMIST can provide a baseline geochemical, mineralogical, and volatile measurement for comparison with subsequent laboratory analyses. This would enable an assessment of possible phase changes upon exposure of samples to a habitat or terrestrial environment. One manner in which CMIST could be used throughout a DSG mission is to routinely evaluate stored samples without removing them from their storage container. Sample storage interfaces can be designed to enable measurements to be made at regular intervals during transit from the exploration target to Earth, thereby tracking the effects of any contamination of the sample.

Safety & Health: We envision additional capabilities related to health and safety of crew and hardware during lengthy missions in deep space. Long-term exposure (e.g., through breathing) to dust and other contaminants poses potential health hazards for astronauts. CMIST enables in-situ analysis of air filters to assess the chemistry, mineralogy, and structure of particulates that are cleaned from a habitat's atmosphere; regular measurements would provide insights into the nature and concentrations of airborne contaminants, as well as any changes with time. Components integral to CMIST also easily adapt to medical use: extremely low-dose CT (computed tomography) imaging enables crew health monitoring or urgent-care diagnostic capability.

CMIST is also suited to evaluating the effects of exposure to the environment—irradiation or accumulated deposition of contaminants—on internal or external surfaces critical to scientific capabilities or crew health; e.g., leak localization through surface deposition mapping is possible. XRF is used in aircraft Non-Destructive Testing (NDT). NDT approaches could be used on DSG to evaluate welding quality or to assess material fatigue associated with space weather.

DSG Test Plan: The DSG, as envisioned, involves reusable hardware in the form of a human-rated transit vehicle and could potentially include transfer vehicles to move science experiments to other locations (astrophysics observatories or lunar landing/return vehicles). Humans could potentially stay on the DSG for increasing periods of time throughout its development and utilization as a gateway to exploration of the Solar System. Beyond its primary application as a real-time sample triage instrument, CMIST can serve as an in situ mission assurance tool, providing assessments of environments and equipment vital for crew health and mission success.

Taking advantage of CMIST's potential applications as a multipurpose tool requires advance thought on system integration. Filtration systems can be designed to enable CMIST to analyze filters, potentially integrating for 1-2 days in order to map particulates accurately, as demonstrated in preliminary analyses of airborne filters. Similarly, sample curation hardware can be designed to enable NDT approaches to be applied by instruments such as CMIST. A common design effort for CMIST and a medical CT imager will enable mass-efficient implementation of both.

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Science Goals and Objectives for Canadian Robotic Exploration of the Moon Enabled by the Deep Space Gateway.

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Introduction: The Moon is the focus of renewed interest by the world's space agencies, and there are major fundamental science drivers for lunar surface robotic and human missions. Returning to the surface of the Moon is critical as exploration and return of lunar samples are vital to answering outstanding lunar science and terrestrial planet questions and addressing the formation of our solar system and early evolution of the Earth-Moon system. The proximity of the Moon makes robotics and in-situ human exploration of the surface of the Moon a high priority topic in the context of exploration beyond low Earth orbit. A key driver of lunar surface exploration is to have human presence in the cis-Lunar space on the Deep Space Gateway (DSG).

Mission Concept: Human Enabled Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES) is an international mission concept to prepare for human exploration of the Moon [1]. An early component of HERACLES involves landing a rover on the lunar surface as part of a demonstrator/precursor mission. This Precursor to Human and Scientific Rover (PHASR) mission is a technical demonstrator and focuses on robotic lunar sample return to Earth using the DSG architecture. As a demonstration of the Canadian commitment to joining the international community's exploration of the lunar surface, we are conducting a science maturation study for PHASR based on the HERACLES and DSG architecture. The goal of PHASR is to land on the lunar far side (tentatively Schrödinger Basin) and cache samples over a 70-day period. The samples would then be transferred to the ascent module which would rendezvous with the DSG and return to Earth. The rover would continue with follow-up science there-after. The purpose of the SMS contract is to mature the preliminary science requirements of PHASR by developing the science investigation, creating a science plan for Canadian scientific contributions to the PHASR mission, and preparing an analogue science mission scenario. The preliminary science goals for PHASR have been divided into four broad categories with each goal consisting of multiple specific objectives to describe the mission investigation. The goals are: lunar chronology, impact cratering, volcanics, and preparing for human return to the Moon.

Lunar Chronology: Presently, the absolute ages of lunar rocks are constrained based on studies of Apollo and Luna samples and lunar meteorites. To constrain the early bombardment history of the solar system, characterize the lunar crust, and constrain the thermal evolution of the Moon, returning lunar sample to the Earth is essential. This goal can be achieved by completing the following objectives:

- Acquire chemical data and return samples of:
    - Clast-poor impact melt rock produced by the Schrödinger impact event for isotopic analysis in order to determine the age of the Schrödinger Basin, better approximate the end of the Late Heavy Bombardment period in the early solar system.
    - Ejected impact melt rock from SPA Basin for isotopic analysis in order to determine a date of the oldest lunar impact structure and its implications for the Late Heavy Bombardment. A sample from the SPA basin also provides the opportunity to examine the lower-crust, or even upper-mantle, compositions of the Moon and the timing of mantle processes.
    - Peak ring material (anorthosite, norite, troctolite) to characterize the lunar crust, date the formation of the target material, and better understand peak-ring basin formation.
    - Exotic material from secondary craters for age dating to help constrain the ages of large impacts (e.g., from SPA and Orientale basins, Antoniadi Crater) in order to improve the accuracy of age dating via crater counts.

Impact Cratering: A fundamental geological process on all planetary bodies, impact cratering is the most important process on the Moon, affecting its surface, crust, and possibly even the mantle [2]. Acquiring samples and in-situ measurements from Schrödinger Basin impactites would provide insight into peak ring basin formation, impact melting, and short metamorphic processes, as well as help to understand the provenance of uplifted and excavated lunar crustal materials. The specific objectives of this science goal for PHASR are to:

- Acquire chemical/mineralogical data and return samples of:
    - Impact material (i.e., impactites) along a multi-km traverse within Schrödinger Basin in order to sample a wide range of crater-forming events and to investigate the extent of lateral mixing within the lunar regolith.
    - Peak ring material from Schrödinger Basin in order to understand peak-ring formation and determine the depth of origin material that is uplifted and exposed with the peak-ring.

  - Impact-melt material exposed by selected craters along a multi-kilometer traverse to assess composition of the melt and to seek out evidence of sheet melt differentiation.
- Investigate shock effects in lunar materials (i.e., plagioclase, pyroxene) and determine the shock level of rocks and minerals through Schrödinger Basin.
- Characterize the geology of secondary craters.

Volcanics: Volcanism is one of the most important geologic processes on the Moon [3]. To better understand of the overall history of lunar volcanism and its relation to the thermal and compositional evolution of the Moon, PHASR will acquire samples and in-situ measurements of mare and pyroclastic volcanic deposits from Schrödinger Basin. To address the goal of studying lunar volcanism via the PHASR mission, the following objectives were defined:

- Acquire chemical/mineralogical data and return samples of:
  - Mare deposits to determine their composition, mantle source depths, the age of some of the potentially oldest mare samples.
  - Pyroclastic deposits to provide information on the depth of the magma ocean and the character of the lunar mantle, as well as the nature of the mare basalt source regions on the lunar far side.
  - Volcanic material along a multi-km traverse within Schrödinger Basin.

Prepare for Human return to the Moon: In addition to the fundamental science being addressed, PHASR, is a precursor for human activity on lunar surface. As such, PHASR will also analyze the topographic, radiation, and temperature environments within Schrödinger Basin. This will involve completing the following objectives:

- Measure the radiation environment to prepare for the return of humans to the lunar surface.
- Measure the surface temperature variations across several day/night transitions.
- Create detailed outcrop-scale geologic and terrain maps in preparation for human return to Schrödinger Basin and future navigation and landing logistics.

Current Status: At the time of this workshop, the SMS will be at its mid-term point. The science goals and objectives have been defined, as well as the list of science payloads to be used on the PHASR rover. The science investigation which includes detailing a traverse plan within Schrödinger Basin and to create a traceability matrix for the payloads will have been completed. A draft of the analogue mission science scenario document will also be complete.

Deep Space Gateway Requirements: To enable the PHASR mission as part of HERACLES, the DSG architecture would require a system in place to robotically capture the ascent vehicle after take-off from the lunar surface and a mechanism to transfer the sample container from the ascent vehicle to the DSG. Constant communications with PHASR is also paramount to the success of the mission and to maximize the ability to operate the rover over the 70-day primary mission phase. As such, utilizing the communication system of the DSG to permit an Earth-based ground control team to communicate with PHASR would be required. This communication setup could be made possible if the DSG were to be placed in a halo orbit around lunar L2 to allow for constant line-of-sight with the lunar far side and the Earth. The aforementioned traverse plan could also utilize real-time driving opportunities for the rover supported by astronauts on the DSG wherever possible. This would be made possible by a small mission control system setup within the DSG.

Conclusion: The results of this study will help ensure that Canada is poised to be a major contributor to the international effort to explore the lunar surface. The DSG can play a major role in that exploration effort. In addition to the science opportunities possible on-board the habitat, its close proximity and communications access to the far side of the Moon is an instrumental part of HERACLES architecture which would facilitate a lunar rover mission to collect and return samples from Schrödinger Basin.

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LUNAR FARSIDE RADIO ARRAY PATHFINDER ENABLED BY THE DEEP SPACE GATEWAY.

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Introduction: Two of the most pressing questions in astrophysics and heliophysics can be addressed by a radio array operating below 20 MHz on the lunar farside: 1) what is the habitability of exoplanets? and 2) how are energetic particles accelerated in solar bursts? The Deep Space Gateway (DSG) will enable such an array.

Science: The impact of stellar magnetic activity on planetary atmospheres, and the importance of planetary magnetic fields in negating such activity, may define exoplanet habitability. Kepler has shown that most M dwarf stars harbor terrestrial-scale planets, with approximately 2.5 planets of 1-4 Earth radii per star [1] [2]. However, many M dwarfs are known to be magnetically active, flaring frequently and with much higher energy than produced in solar flares [3] (see Figure 1). Studies of possible flares and coronal mass ejection (CME) events on planets orbiting such stars suggest that these events severely impact the ability of such planets to retain their atmospheres [4] [5]. However, no CME on a star other than the Sun has ever been detected. Similarly, direct detection of planetary magnetic fields has yet to be achieved and remains the most crucial ingredient in assessing planetary habitability in the context of stellar activity.

Both stellar CMEs and planetary magnetic fields can be probed via extremely bright radio emission at low radio frequencies. As an analogous example, the Sun produces intensely bright radio bursts (Type II bursts) typically at frequencies below 100 MHz and associated with fast CMEs. These bursts are attributed to plasma radiation, an intensely bright coherent emission process whereby accelerated electrons cause radiation at the electron plasma frequency. Thus, the characteristic drift in frequency often observed in the dynamic spectrum of a burst reflects the large-scale transport of a body of plasma through density gradients in the solar corona and/or interplanetary medium.

Solar bursts and space weather activity in our own Earth-Sun system are known to have important consequences for human activities on Earth and for spacecraft. Imaging of Type II and Type III solar radio bursts from our Sun would determine where and how the radiating particles are accelerated. Thus, a lunar radio observatory would also complement the upcoming NASA Parker Solar Probe and the ESA Solar Orbiter missions to the inner heliosphere, as it would image emission from electrons and shocks as they pass by and are measured directly by the spacecraft.

Figure 1. Artist's illustration of space weather in an extrasolar system. Understanding both stellar flares and planetary magnetic fields is key to determining exoplanet habitability. A lunar farside radio array enabled by the Deep Space Gateway will provide the first detailed characterization of large radio bursts from stellar flares in our two nearest-neighbor systems, Alpha and Proxima Centauri, thereby providing crucial insights into stellar magnetic fields and space weather beyond the local Solar System.

Pathfinder: The Earth's ionosphere absorbs astronomical radio emission below ~200 MHz and blocks it completely below ~30 MHz, necessitating a space-based array for solar and extrasolar burst monitoring and exoplanet habitability studies. A radio array in lunar orbit or on the lunar suface would avoid the the limitations imposed by Earth ionosphere. Locating the radio observatory on the lunar surface compared to orbit has a number of advantages, including fixed locations for the antennas that require no propulsion to maintain, simpler operations, and no terrestrial interference (on the lunar farside). The Moon's farside is uniquely shielded from human-generated radio interference.

The two nearest star systems beyond our Solar System are ideal targets for pathfinder stellar burst monitoring for exoplanet habitability studies. Alpha Centauri is a binary star system, containin G and K spectral type stars similar to our Sun, whereas Proxima Centauri is an M dwarf star with known exoplanets, including the Earth-sized Proxima b planet that has radius 1.27 Earth radii and mass 1.1 Earth masses. Both Alpha and Proxima Cetauri are about 1.3 pc from Earth.

The collecting area requirement for the pathfinder array is set by the sensitivity needed to detect the expected extrasolar bursts, which should be ~1 Jy below 20 MHz for the brightest flares from Alpha and Proxima Centauri. Sensitivity sufficient to detect these large flares could be accomplished with ~100 low-gain antennas tuned to 1-20 MHz. Solar bursts from our Sun are even brighter and will be easily detected by such an array.

The angular resolution requirement for the array is modest. Alpha and Proxima Centauri are separated by ~2° on the sky and the need is only to resolve from which star a burst originates. Similarly, candidate regions for particle acceleration by solar CMEs may be separated by many solar radii, hence high angular resolution is not required for solar burst imaging. Resolving potential sites of particle acceleration, e.g., the shock front or the flanks of a CME, also requires ~2°. Hence the array would need a radius of approximately 1 km to achieve the needed angular resolution to both image solar bursts and discern stellar bursts from our two nearest neighbors.

The pathfinder array will generate a raw data rate of 4 GB/s that must be collected at a single location for digital signal processing to form the interferometric products needed for imaging and burst detection. Digital signal processing is estimated to require between 10 and 100 W, which will be refined through further study. The DSG will provide key infrastructure as a communications hub and relay to collect and process raw and/or reduced data from the array. It could also provide a consistent power source for the processing unit if it is installed on the DSG or by beaming power to the array on the farside surface. Thus, the DSG can alleviate the challenge of powering and heating critical components of the array during the (two-week) lunar night.

Operational scenarios for the array consist of data acquisition during the lunar day, with daily data downlinks to coordinate with other space weather assets, and either hibernation or continued operation during the lunar night. A fully-functional pathfinder radio observatory could be based on the design for the Radio Observatory on the Lunar Surface for Solar studies [6]. Our team is presently undertaking a detailed trade study to identify optimized designs for a pathfinder array.

Summary of impact: An operational pathfinder radio array on the lunar farside utilizing the DSG as a communications hub, possibly combined with telerobotic array infrastructure deployments controlled from the DSG, would provide immediate scientific benefit on the high-priority science of exoplanet habitability and solar shock acceleration and enable crucial experience and investigation of the environmental and technical challenges of deploying and operating a large-area scientific station on the Moon.

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Microfluidic-Based Platform for Universal Sample Preparation and Biological Assays Automation for Life-Sciences Research and Remote Medical Applications

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Background: The capacity to separate and analyse critical cellular and sub-cellular targets from complex matrices such as bodily fluids is required for emerging precision medicine approaches. Such approaches are important not only for remote crew medical care, but also for research on long term effects of space travel on living systems. Access to relevant bio-molecular information represents today a critical capacity gap, particularly for long term and deep-space missions, as it would provide the possibility to develop and implement adequate countermeasures aimed at protecting astronauts against detrimental effects of space flights.

Fueled by their diagnostics importance, chip-based methods for isolation and on-site analysis of blood components, such as plasma, red blood cells, white blood cells, extracellular vesicles (EV, e.g., exosomes, microvesicles), proteins, and circulating nucleic acids (cfDNA, miRNA) are developing rapidly. Examples include the need for monitoring the expression level for a number of soluble proteins currently used in clinical diagnostics such as the immune system panels (IL2, IL4, IL5, IL6 and IFNγ). This is particularly relevant for remote applications, as it enables quantitative evaluation of the effect of exposure to radiation, stress or low gravity on human body. Today, these analyses are almost exclusively performed on Earth using samples collected and stored on the International Space Station. In practice, this mode of operation is costly and incompatible with timely assessment, since biological samples collected from astronauts must be preserved (often over extended periods of time) and returned to Earth before they are transferred to a dedicated laboratory for investigation. These challenges are compounded by the need to process diverse samples (whole blood, saliva, urine, cell cultures, water and food) across a large set of volumes (from µl to few ml). *The rapid, on-site, automated preparation from body fluids and molecular analysis of circulation biomarkers that have scientific and clinical value is critically important for timely decision making process and has not been addressed so far. This is particularly important for remote applications including space research and medical support for long term missions.*

Methods: Microfluidics and lab-on-chip (LOC) technologies have been developed over the last decade driven by the need for automation of complex analytical procedures in many clinical, industrial or research applications. LOC technologies can simplify human manipulations, reduce associated risks of contamination, decrease assay times, improve analytical throughput, and decrease reagent consumption. They also enable minimally trained personnel to perform analytical procedures outside laboratory settings. Several approaches for the manipulation of liquids have been developed including external pressure mediated pumping, electrowetting, centrifugal and capillary forces. Centrifugal microfluidic technologies stand out as a promising platform for sample preparation and integration of sample-to-answer assays able to handle samples ranging from 1 µl to few ml with almost no dead volume. For space applications, this type of microfluidic platform is particularly appealing as the presence of a strong on-chip centrifugal acceleration, not only offers unique sample preparation capabilities (sedimentation of debris, density fractionation, etc.), but also makes the entire microfluidic process independent of normal gravity.

We have developed a novel centrifugal microfluidic actuation method called "*Power-Blade*" (*Veres et. al., WO2015132743 A1, PCT/IB2015/05159*), combining regulated pressure control in a centrifugal microfluidic platform as a mean to facilitate integration of complex assays in centrifugal microfluidic and improve reliability of fluidic manipulations. In this method (*Fig. 1(a)*), a programmable air pump and multiple miniature electromechanical valves are placed on a rotating stage and connected to microfluidic devices. The valves, pump and other active elements can be computer-controlled in real time while the platform is rotating at high speed to trigger fluidic displacements inside the microfluidic devices. Centrifugal fluidic actuation becomes independent of liquid-solid contact angles, the nature of the samples, and the chip fabrication materials, making this method very suitable for the manipulation of complex samples in space applications.

Results: The Power-Blade platform's exceptional capabilities to automate complex biological samples preparation and integrate biomolecular assays has been demonstrated in a number of diverse applications. These applications include extraction of genomic DNA from cell culture lysates (*L. Clime et al., Lab Chip. 2015, 15, p.2400*) and rapid (1h) sample-to-answer VTEC *E. coli* bacteria detection and sub-typing with a very simple 5×10 cm cartridge fabricated in low-cost thermoplastic (*Fig.1 (c)*). More recently, we have demonstrated automated extraction and purification of multiple target proteins and total genomic DNA from large volumes of whole blood. *Figure 2(b)* demonstrates that high efficiencies for protein extraction from blood samples can be achieved across the entire physiological range of interest. Three target protein biomarkers, TNF-α, PTH and ALP, that encompass the whole physiological concentration range of interest for proteins biomarkers were tested (TNF-α, low 0.3 to 1.3 pg/mL; PTH, average 10 to 70 pg/mL; ALP, high 10 to 70 ng/mL). *Figure 3(c)* shows a summary of the extraction efficiency obtained for an average of 3 runs performed on each of 5 different blood donors (n=3 per donor). The results confirm that we can achieve very high extraction efficiencies (~80% on average) with relatively low variance. The average extraction efficiency obtained for the manual assays is significantly lower (~45%) and exhibits much higher test-to-test variation. We have also demonstrated (*D. Brassard et al. AACC 2017 July 30th, San Diego)* automated workflow taking less than 1h for total nucleic acids extraction from large samples whole blood using P-Blade operated microfluidic cartridges. As shown in *Figure 3(b, c)*, the microfluidic protocol outperforms the most widely used commercially available NA extraction kits by providing significantly higher extraction yields and high eluted sample purity. The NA extraction yield, A260/280 and A260/230 ratios are also shown.

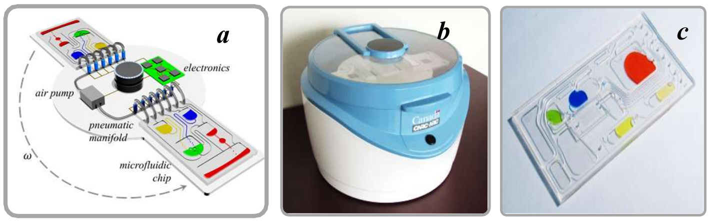

Figure 1: *a) Schematic representation of the "Power Blade" centrifugal microfluidics principles; b) Laboratory version of the "Power Blade" hardware having PCR cycling built-in capability (tested in parabolic flights conditions); and c) Power-Blade operated polymer microfluidic device (5x10 cm) performing bacterial lysis, on-chip DNA amplification implementing a molecular assay for VTEC E.Coli molecular sub-typing.*

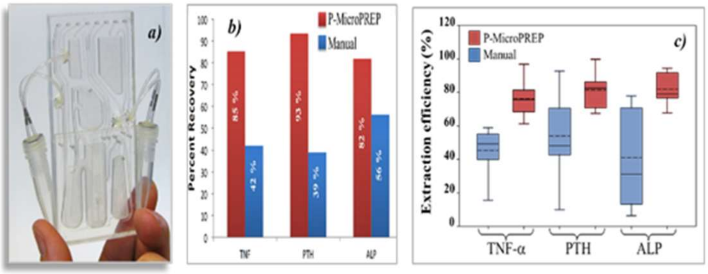

Figure 2: *a) 5x10 cm three layers thermoplastic polymer device operated on the power-Blade used for automated (45 min) extraction of multiple proteins from 1 ml whole blood; b) Comparison of protein extraction efficiency for a test performed with the automated microfluidic cartridge (P-MicroPREP) and test performed manually; and c) Boxplot showing a summary of the protein extraction efficiency measured for all experiments performed with a manual procedure and with the automated microfluidic cartridge.*

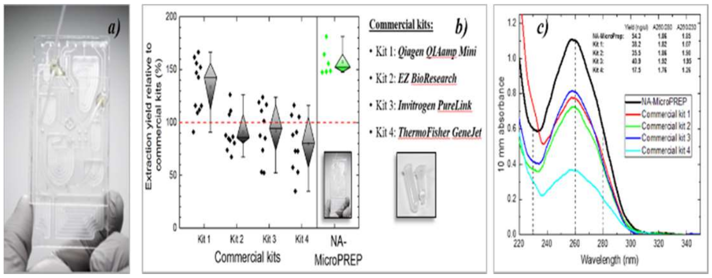

Figure 3: *a) Image of the 5x10 cm device performing automated and rapid (60 min) total nucleic extraction (NA) from 1 ml whole blood; b) Measured total DNA extraction yield from whole blood samples for multiple experiments performed on four commercial nucleic acids extraction kits and the performances of the microfluidic extraction on the same samples; and c) Spectra showing the absorbance of eluted NA solution from whole blood using the microfluidic cartridges and various NA exaction commercial kits.*

Conclusion: We have demonstrated the Power-Blade's capacity to perform automated and complex biological samples processing. This system is an unprecedented solution for a portable, easily-reconfigured diagnostics platform capable of handling diverse biological and environmental samples. Different microfluidic cartridges, operated by the same hardware, provide different assays *ranging from isolation and purification of cellular, extracellular and circulating markers (proteins, cfDNA, miRNA) to sample-to answer analyses*.

The development of a generalizable platform for biological sample preparation and assay automation, such as the Power Blade, is a critical step toward autonomous analyses and opens new possibilities for support of post-ISS human exploration missions.

SPACE SCIENCE AND EXPLORATION ON THE LUNAR FARSIDE FACILITATED BY SURFACE TELEROBOTICS FROM THE DEEP SPACE GATEWAY.

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Introduction: During the early phases of development of cis-lunar infrastructure, there is an exciting opportunity to begin a new era of space science and exploration on the lunar farside facilitated by telepresence from NASA's planned Deep Space Gateway (DSG) [1]. Surface telerobotics (i.e., astronauts in orbit remotely operating planetary rovers or other robots on the lunar surface) can be used to collect geological samples from the Moon's farside and to deploy a low frequency radio telescope to study the unexplored Cosmic Dawn epoch of the early Universe. During the time when the DSG is not occupied by astronauts, it can serve as a telecommunications relay to operators on Earth. This is a necessary and enabling capability for affordable missions to the lunar farside.

Surface Telerobotics Simulations: Our laboratory experiments with surface telerobotics are beginning to provide requirements on bandwidth, video frame rates, and latency for effective scientific exploration on the lunar surface [2]. In addition, we previously conducted a series of NASA-funded tests involving astronauts aboard the International Space Station (Figure 1) that demonstrated the viability of surface telerobotics using a high-fidelity operational environment [3]. The ISS served as a proxy for Orion/DSG. NASA's K10 planetary rover was operated by ISS astronauts over a simulated lunar terrain at the NASA Ames Research Center to deploy an engineering prototype of a radio telescope array. More recently, ESA conducted a similar experiment to operate a ground-based rover from the ISS.


Figure 1. Surface telerobotics testing aboard the International Space Station during three crew sessions. *Top:* NASA astronaut Chris Cassidy surveys the NASA Ames "roverscape" site; *Middle:* ESA astronaut Luca Parmitano uses the K10 rover to deploy three "arms" of a simulated radio telescope array; *Bottom:* NASA astronaut Karen Nyberg remotely operates K10 to document the deployed radio telescope array.

Planetary Science and Cosmology on the Lunar Farside: Cutting edge science (e.g., National Academy Decadal Surveys) can be conducted from the lunar farside using surface telerobotics as a precursor to a human return to the Moon [4].

A teleoperated lunar rover remotely operated by astronauts in the DSG could be used to collect and return rock samples from the Moon's South Pole Aitken (SPA) Basin, as recommended by the NRC Planetary Sciences Decadal Survey [5] and the NRC-2007 report [6]. The highest priority science is to test the lunar cataclysm hypothesis which posits that the Moon and Earth were exposed to heavy bombardment via solar system debris ~4 billion years ago. The Schrodinger impact basin within the SPA basin may be ideal to investigate this science goal, and most other science goals of [6], including age-dating the SPA basin, with short-duration [7] and long-duration [8] missions.

This lunar rover could also be used to deploy a low frequency radio telescope array to observe the redshifted 21-cm power spectrum originating from structure within the intergalactic medium surrounding the first stars and galaxies [4]. The array would operate at frequencies from 20-80 MHz (corresponding to redshifts of 70-17). At frequencies down to 20 MHz, the lunar farside is the best location in the inner solar system to perform these observations because it is free of human-generated radio frequency interference and distortions from the Earth's ionosphere [9]. The hyperfine line of neutral hydrogen probes the gas surrounding the first stars and galaxies, allowing us to infer their properties (e.g., ignition times, masses, stellar populations) for the first time [10]. Such an array, labeled the Cosmic Dawn Mapper in the NASA Astrophysics Roadmap [11], allows us to investigate the nature and evolution of the first structures in the Universe in a way not possible with any other planned ground or space mission. One approach to deploy such a low frequency array is to unroll a polyimide substrate, with electrically-conducting antennas embedded. An artist's impression of this rover-based deployment is shown in Fig. 2.

Requirements for Surface Telerobotics from the Deep Space Gateway: For science and exploration missions using telerobotics, the preferred location of the DSG would be a compact halo orbit about the Earth-Moon L2 Lagrange Point, which sits ~65,000 km above the lunar farside. This would provide uninterrupted line of sight to most of the farside [12]. If an orbit providing continuous telecom is not selected, an orbit that allows uninterrupted communications for one lunar daylight period (~12-14 Earth days) or an orbit that minimizes the duration of loss of contact would be best; such a location for the DSG might be within a Near-Rectilinear Polar Halo Orbit [13].

In general, the DSG can provide a valuable communciations relay between Earth and landed assets on the lunar farside. In Table 1, we present estimates of requirements for data communication equipment.

Table 1. Communication Equipment Requirements

Requirement	Value
Mass	30-100 kg
Volume	2-6 m^3 external
Power	75-150 W
Temperature	Some heat rejection depending upon power level
DSG location	External, lunar-pointing to accuracy of ~1°
Operational Frequency	S, X, K, or Ka band subject to ITU allocation
Data Rate Relayed to Earth	• 64 kbps for a stationary lander • 1 Mbps for a rover with realtime operations • 16 Mbps for data generated by a radio astronomy array

Feed-forward to Mars: Such surface telerobotics support "off-board" autonomy and also prepare for human Mars missions. Cis-lunar experiments will train astronaut crews to virtually explore the surface of Mars from orbit using robots as avatars. Such teleoperation could enable multiple rovers to be used for exploring tens to hundreds of kilometers of Mars' terrain - even before the first humans set foot on the surface.

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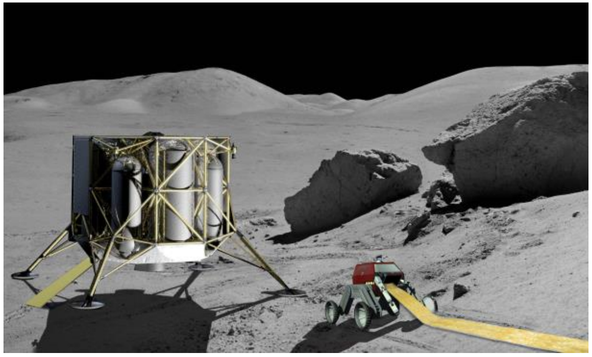

Figure 2. Surface teleoperation of a rover from the Deep Space Gateway is a key technology for astronaut-assisted deployment of a lunar farside polyimide antenna and the collection of geological samples. Image is courtesy of R. MacDowell and NASA GSFC.

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Radiometric calibration of earth science imagers using HyCalCam on the Deep Space Gateway platform.

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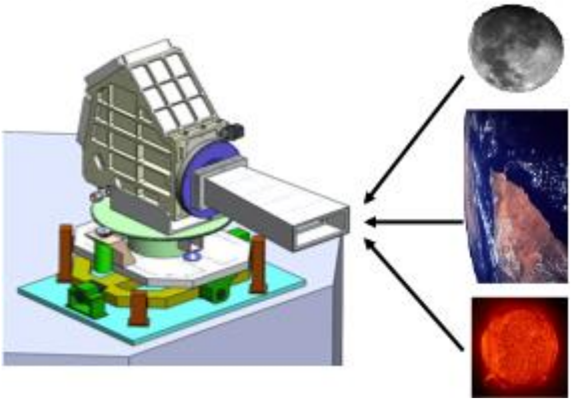
Introduction: The need to improve the accuracy of data obtained from Earth observing satellite instruments has been internationally recognized and extensively documented [1-5] with on-orbit sensor intercalibration identified as a key component. The importance of on-orbit instrument intercalibration in quantifying the relative biases between satellite instrument measurements and in bridging potential data gaps in measurement records is reinforced by the large number of existing intercalibration techniques [6]. Still, the major limitation of satellite sensor intercalibration is the lack of a high accuracy, on-orbit reference standard instrument with calibration traceable to the International System of Units (SI). Advances in the metrology of satellite instrument calibration, such as the National Institute of Science and Technology's (NIST) facility for Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) [7, 8], and in on-orbit instrument calibration techniques using the Moon and well-characterized Earth surface sites can now be used in tandem to realize order of magnitude levels of improvement in satellite instrument intercalibration.

The HyCalCam instrument on the Deep Space Gateway platform in a cis-lunar orbit meets the requirements for an SI-traceable, high accuracy, reference standard for satellite instrument calibration. HyCalCam is an imaging spectrometer that combines views of the moon and earth to characterize the lunar surface and various terrestrial scenes for use as absolute calibration sources for LEO and GEO sensors. Measurements are referenced to solar views to place the data on an absolute, SI-traceable scale. Cost estimates based upon current instrument builds of a similar nature are <$60M for the sensor and gimbal interface that allows pointing of earth sites and solar views. Crew interaction would be needed for set up only and such efforts would be of similar nature as the CLARREO Pathfinder mission that is planned for the International Space Station.

Deployment and operation of the HyCalCam instrument on the Deep Space Gateway provides a large number of important benefits to Earth remote sensing. HyCalCam provides a factor of 4 to 10 improvement in current on-orbit radiance measurements of Earth targets such as pseudo-invariant calibration sites, sites used in Simultaneous Nadir Overpass (SNO) studies, vicarious ground and airborne campaign sites, and uniform natural atmospheric targets such as Deep Convective Clouds (DCCs). Lunar radiance measurements of the Moon by HyCalCam over a period of at least 3 years to ensure sufficient sampling of the Moon across phase and libration establishes the Moon as a on-orbit absolute radiometric standard or common "solar diffuser" for both LEO and GEO instruments capable of viewing the Moon. Absolute, SI-traceable lunar radiances and irradiances from HyCalCam could be used to bridge potential gaps in the acquisition of data used in Earth observation records. Since the Moon visible to on-orbit satellite instruments exactly repeats over a period of 18 years, satellite instruments which have acquired lunar images in the past could be retroactively calibrated using the lower uncertainty, absolutely calibrated lunar radiances and irradiances derived from HyCalCam.

Sensor design: The sensor design of HyCalCam is based on an Offner imaging spectrometer similar to that of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Reflected Solar Instrument design to provide rigorous SI traceable observations The instrument is designed to retrieve an at-sensor reflectance over the spectral range from 320 to 2300 nm with a 500-m GIFOV and a 100-km swath width. Modifications to the design would be needed to allow similar spatial resolutions from Deep Space Gateway orbits. Reflectance is obtained from the ratio of measurements of radiance while viewing the earth's surface to measurements of irradiance while viewing the sun.

The instrument approach is an Offner imaging spectrometer operating as a pushbroom scanner relying on heritage hardware to reduce sensor complexity. The sensor would rely on a MgCdTe focal plane to provide spectral coverage for the 320 to 2300 nm.. spectral range. An all-aluminum design limits the impacts of thermal effects on the sensor behavior. A final optical design would depend on the final orbit selected for the package.



Operations: The overall mass of the spectrometer sensor is 20 kg with an overall sensor mass including pointing gimbal and electronics of 70 kg based on similar past sensors and a recent balloon-borne sensor. Estimated volume for the sensor package is 50 cm x 20 cm x 30 cm. The senosr would require 100 W average power and 120 W peak power with a data volume of 70 Gb/day. The detector package requires a cryoradiator view to <180 K source (deep space ideal) and the sensor design makes use of an all-aluminum structure to minimize impacts from temperature changes.

The use of the sun as the calibration reference means that clear views of the solar disk are needed to allow conversion of the earth and lunar views to reflectance. A gimbal mount was designed to allow operation of the CLARREO RS to view solar disk, lunar surface, and earth surface. Solar disk views are required on a bi-weekly basis. The choice of orbit is ideally one which would allow a near-full disk view of the lunar surface with regular views of the earth's surface between 45 degrees north and south.

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MISSION DESIGN AND SELECTION OF NANOSATELLITE SUBSYSTEMS FOR EXPLORATION OF LUNAR WATER DEPOSITS.

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Introduction: The space exploration is an activity that promote the development of new technologies and scientific knowledge, through new low cost platforms the access to space environment can be achieved more effectively, having the technological capabilities of making space missions allow to boost the creation of new strategies of space exploration, the moon properties and its distance from earth make it the ideal site to develop tests for future planetary exploration missions.

This project present an initiative for the development of a lunar exploration mission, looking to cover the first steps of mission design and the specifications of the mission subsystems, the Cubesat 6U configuration is taken as the low cost platform, from this configuration different off the shelf subsystems will be describe, the SMAD methodology is used for the mission design, this mission will be proposed for the Deep Space Gateway.

For the advance in the space exploration it is necessary to increase the capacity of manned missions, for this purpose the moon will serve as a testing site for which the resources available in it must be very clearly detailed; In recent years it has been confirmed that the moon has frozen water deposits, this resource is essential to achieve the extension of lunar missions, therefore the approach of a low-cost mission with the capabilities of carrying out a lunar mapping to define the Position and characteristics of lunar deposits is one of the main goals for the near future of space exploration, right now NASA is carrying out one initiative of this kind (Fig 1).

Fig 1. NASA Lunar IceCube concept

The space exploration is an economic and research area that has had an exponential growth in recent years, along with the growth also come the problems, one of these is the manned exploration of the solar system, taking this into account it is necessary to have a special testing area and for this one of the most viable options is the moons because of its distance, space environment and resources. Once established the lunar test missions it is necessary to exploit its resources and one of the most important is water, which allows the possibility of being used for plant irrigation, for research or for breathing systems.

Proposal main goal: Evaluate a mission design, to select the subsystems of a 6U configuration nanosatellite, applicable to a project to explore water deposits on the moon

The project also aim to Identify from bibliographic analysis in databases, the type of Earth-moon orbit transfer that will be used for the mission; Design from known locations of lunar water deposits, a low lunar orbit; Analyze and determine which "off-the-shelf" subsystems are the most suitable for the proposed Nano-satellite configuration; Propose a design for the spatial distribution of the subsystems chosen for the nanosatellite; Calculate the power requirements, uplink and downlink of the communication system, for the handling and data transfer in the moon-earth distance.

Subsystems: For the selection of subsystems the following subsystems were identified as the main elements of study:

Attitude Control, To change the satellite to the required orientation, external control systems such as Ion thruster or magnetic torquers can be used, but also use of internal control systems such as reaction wheels.

Power, Photovoltaic solar cells to convert solar energy into electric energy.

Thermal control, To make a design that meets the temperature requirements of the components, the heat parameters of the sun, the earth and the electrical and electronic components have to be taken into account

Communication, the functions of this subsystem should include: tracking of the carrier, reception and detection of commands, modulation and transmission of telemetry, receiving and processing oscillatory signals and self-operation.

Payload, The payload requirements are the most important to be defined according to the characteristics of the Deep Space Gateway capabilities. [1]

The project will be structured to cover the Lunar and Planetary sciences Science area and the Use of the gateway as a communication hub for CubeSat's and for science enabled by support/servicing of lunar landers and/or independent satellites topics

There is a methodology called SMAD (Space Mission Analysis & Design), this is addressed in different ways by multiple authors, for this specific case a SMAD methodology of ten steps is defined to be used in the subsystems selection process. [2]

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AN INTEGRATED SCIENCE GLOVEBOX FOR THE GATEWAY HABITAT.

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Introduction: Next generation habitats for deep space exploration of cislunar space, the Moon, and ultimately Mars will benefit from on-board glovebox capability. Such a glovebox facility will maintain sample integrity for a variety of scientific endeavors whether for life science, materials science, or astromaterials. Glovebox lessons learned from decades of astromaterials curation, ISS on-board sample handling, and robust analog missions provide key design and operational factors for inclusion in on-going habitat development.

On Earth, NASA's astromaterial collections are stored in controlled environments – high purity positive pressure nitrogen atmosphere. Most sample handling and characterization of astromaterials are conducted in gloveboxes to prevent cross-contamination and preserve the scientific integrity of each sample. There are a variety of human spaceflight operational scenarios where such a glovebox facility could be used on a planetary surface, and on the Moon. However, a sample handling glovebox facility in cislunar orbit could also be used in a variety of ways to aid in receipt and preparation for transfer of samples collected from the lunar surface or other destinations. A Deep Space Gateway astromaterials glovebox facility could serve as a staging and storage area for later return to Earth of collected extraterrestrial materials.

From 2009-13, NASA Advanced Curation scientists built and integrated a high-fidelity analog sample handling glovebox called GeoLab inside NASA's Habitat Demonstration Unit (HDU) that deployed during Desert Research and Technology Studies (Desert RATS) expeditions in Flagstaff (2010 and 2011) and in Houston (2012) [fig. 1, 2][1-9]. We describe our earlier GeoLab concepts and discuss applicability of the hardware, various instruments, and operational concepts. The lessons learned from the GeoLab tests can be built upon to design the next generation of gloveboxes for human surface exploration as well as a cislunar orbit Deep Space Gateway astromaterials glovebox facility.

GeoLab Glovebox Integrated into HDU: GeoLab was NASA's first generation geoscience laboratory designed for a pressurized habitat to support human space exploration. GeoLab's goal was to foster the development of critical operational concepts and technologies for sample handling, preliminary examination, curation and prioritization of extraterrestrial samples for future sample return missions. GeoLab tested progressively more complex operations to determine the utility of such a facility inside a future planetary surface habitat, called the HDU-Pressurized Excursion Module Lunar surface configuration (2010), as well as the HDU-Deep Space Habitat configuration (2011 and 2012). Over the three years of field operations, GeoLab analog activities evaluated sample handling environments (field and lab), new technologies for sampling tools and analytical instruments, and a variety of operational concepts involving both robotic and human sample handling procedures.

Fig. 1: GeoLab Glovebox integrated into the HDU during Desert RATS analog operations in 2010, 2011, and 2012.

Fig. 2: GeoLab Glovebox integrated into the HDU: Pressurized Excursion Module for Lunar surface operations (left); HDU: Deep Space Habitat for cislunar operations (right).

The GeoLab glovebox design supported evolving sample handling tests and configurations including:

- *Clean environment*: constructed with materials that have low off-gassing and particle shedding.
- *Sample preservation*: built to support positive pressure, enriched nitrogen atmosphere.
- *Direct Sample transfer*: three antechambers, or mini-airlocks, to the outside for sample transfers.
- *Analytical Instrument Ports*: configurable for instrument exchange within the habitat.
- *Rapid-Transfer Port*: transfer of samples and tools.
- *Environmental Monitoring*: Pressure, oxygen, temperature, and humidity/moisture sensors.

GeoLab also tested the following instruments for preliminary characterization and examination:

- *X-ray fluorescence analyzer* for geochemical analyses of Mg to U.
- *Multispectral microscopic imaging* for mineral identification.
- *Robotic Arm* for sample manipulation [fig. 3].
- *Stereomicroscope* for detailed characterization.
- *Digital balance* for mass measurements.
- *Video surveillance cameras* provided imagery of glovebox sample handling and astronaut activities; including a camera installed outside of the habitat for sample airlock activities.
- *Two HP Touchsmart computers* ran software to monitor the glovebox environment and provide interfaces for controlling cameras and analytical instruments.
- *Voice recognition* custom software for hands free control of GeoLab instrumentation and robotic arm.
- *RFID* for sample tracking and database management.

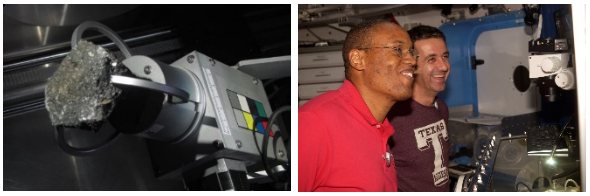

Fig. 3: GeoLab Glovebox Robotic Arm (left); Astronaut Alvin Drew and crew member (right) during Deep Space Habit GeoLab Ops.

After three years, GeoLab participated in 19 days of simulated mission testing in full analog settings, and monitored operations with 18 different test subjects. GeoLab also conducted stand-alone tests with nearly 20 other operators. GeoLab primary results reported [1, 3]:

1) The GeoLab design supports autonomous crew operations of the basic glovebox functions.
2) Good sample imagery is key for preliminary characterization.
3) Robotic assists for sample handling are critical in microgravity.
4) A combination of imaging tools and robotic tools provides significant flexibility for designing facilities and operations related to sample characterization and sample handling.
5) Preliminary sample characterization data leads to smart decisions during mission operations.

Flown Space-based Gloveboxes: Two notable rigid gloveboxes have flown in space that supported NASA human spaceflight missions: the Glovebox (GBX) and Microgravity Science Glovebox (MSG) [fig. 4]. In 1992, STS-50 flew the USML-1 Glovebox (GBX). This glovebox was a multi-user facility technology demonstration that supported 16 experiments in fluid dynamics, combustion sciences, and crystal growth. The GBX was again flown on USML-2 STS-73 in 1995. The GBX compact design not only allowed this glovebox to be adapted to the Space Shuttle's Spacelab module and the middeck area, but was also tested on the Priorda module of the Russian Space Station Mir.

After GBX, the MSG was developed by ESA/NASA for the International Space Station (ISS) Columbus laboratory module and flew to space in 2002. The MSG is a sealed glovebox enclosure for experiments conducted in microgravity. The MSG supports experiments in biotechnology, combustion science, fluid physics, fundamental physics, and materials science. The MSG is designed to provide any experiment with power, data acquisition, computer communications, vacuum, nitrogen, and specialized tools. In many cases, the design mimics working laboratory conditions on the ground.

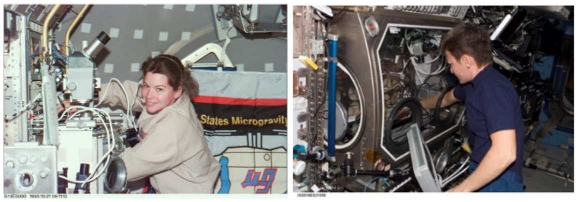

Fig. 4: Astronaut Catherine G. Coleman (left) working in the glovebox science module aboard the Space Shuttle Columbia in Earth-orbit during STS-73 (Oct. 23, 1995; NASA Photo: STS073-E-5000). Astronaut Peggy A. Whitson (right), Expedition 16 commander, uses the MSG in the Destiny laboratory onboard the International Space Station. (Jan. 5, 2008; NASA Photo: ISS016-E-021059)

Future Glovebox in Cis-Lunar Space: The GBX, MSG, and GeoLab provide a solid foundation and critical lessons learned for designing the next generation of gloveboxes for use in space. Before humans explore the Moon, Mars or elsewhere, scientists will define new protocols for the handling and return of unique extraterrestrial samples. NASA will implement innovative curation techniques aimed at preserving the pristine nature of the samples for study by earth-based scientists. A cislunar orbit Deep Space Gateway astromaterials glovebox facility could support a critical staging and storage area for later return to Earth of collected extraterrestrial materials.

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Earth as an Exoplanet: Spectral Monitoring of an Inhabited Planet.

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Introduction: In the past two decades, the study of exoplanets has grown from a niche science to being a major part of the goals of NASA's future flagship missions. Led by ground- and space-based projects, we now know that planets are common in our galaxy as are planets the size of Earth in the habitable zone around their star [1, 2]. Scientists have detected atmospheres around some of these exoplanets and through spectroscopy, are working to identify the constituents of these atmospheres [3, 4]. One of the key goals of future missions, including JWST, WFIRST, and LUVOIR is to detect and characterize the atmospheres of terrestrial size habitable zone planets. The ultimate purpose of these studies is to detect indications of life, or "biomarkers" in these atmospheres.

In order to understand and interpret the data that will come from these measurements, we have to have detailed models that allow for the retrieval of atmospheric constituents and properties from the spectra [5, 6]. Since there is only one known inhabited planet (Earth), these models rely on Earth observations as a ground-truth. While there are detailed high-spatial resolution data of the Earth from weather and climate-monitoring satellites, there are limited observations of the spectrum of the Earth seen as an exoplanet. To date these observations have been done using Earth-shine on the Moon [7], or during lunar eclipse [8]. More recent work has relied on serendipitous measurements that collected spectra of the whole-Earth from the EPOXI [9] and LCROSS [10] satellites. While these observations have provided valueable ground-truth spectra for models, they cover only a limited time and set of conditions and do not span the full range of variability of the Earth's atmosphere.

We propose a spectrometer for the Deep Space Gateway to monitor Earth as an exoplanet. We will take whole-Earth spectra measure the variability with illumination phase, rotation (land vs ocean), cloud cover, and season. Results will inform instrumentation, models, and analyses for future NASA missions to search for biomarkers on distant exoplanets.

The mission concept is to mount a small satellite at the Deep Space Gateway with one or more spectrometers viewing the whole Earth disk several times per day over 1 or more years. The instruments would include visible, near-infrared (NIR), and mid-infrared (MIR) spectrometers. The spectrometers will be based on small instruments developed for flight missions such as LCROSS [11], or under development for Earth observing missions [12]. Spatially resolved spectra are not needed, or even really desired, so the optical requirements are minimal. Based on these designs, the instrument to have a mass of ~30 kg and power requirements of a few 10's of watts. Detailed instrument requirements based on the science goals are under development.

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The Deep Space Gateway: The Next Stepping Stone to Mars

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Abstract: Human missions to Mars will benefit from precursor missions that achieve important science and human health and safety milestones. A human habitation and operations system in the vicinity of the Moon has for many years been assessed as the necessary “transition facility” between the capabilities being developed on ISS in LEO and the mission that will carry humans to Mars. The current incarnation of such a system in cis-lunar space is the Deep Space Gateway (DSG), which should be outfitted to enable science at its operations site and, critically, prepare for scientific operations at Mars, the ultimate goal for human exploration.

Capable missions that use new telerobotic capabilities for increasingly autonomous investigation with large and complex instrument suites, have more substantial landed and sample acquisition mass, and demonstrate relevant entry techniques could be important risk mitigation and improve the combined life cycle costs when the science and human missions are considered together. The Deep Space Gateway can enable these technologies, reduce cost and risk to Mars science missions, and eventually human missions to Mars. Autonomously mapping water or other mineral resources on the lunar surface, processing data locally using high performance spaceflight computing capabilities, and returning results to Earth could be demonstrated and improved at the DSG before being used at Mars. Telerobotic mobility technologies and relevant power systems could enable more capable surface investigation platforms. The DSG architecture enables lunar science to be conducted with robotic sample return using an aggregation point much like the Mars architecture, making crew operations and collaboration between crewmembers and scientists on Earth relevant to Mars missions. These Mars missions would be more likely to be conducted concurrently with a lunar science campaign, or shortly thereafter, when components for the mobility, power, and launch platforms are the same.

If, in addition to robots, astronauts are on the lunar surface, demonstration of different protocols for robot-astronaut cooperation can be explored in depth, which will be critical for scientific exploration of Mars. Specifically, processes for identification of attractive lunar samples via different roles for humans and robots will be important preparation for Mars exploration. One of the benefits of using the DSG is the ability of the crew to manage the inspection and quarantine of the samples, confirming that the sample cache is contained and not damaged. The DSG’s logistics trail (i.e.,Orion) will allow very large samples to be returned to Earth.

The DSG provides an important capability for both lunar and Mars mission science and allows for a broad range of potential missions to benefit. At the same time it is a platform for preparing humans to venture deeper into space. Crews can use this platform to prepare for critical science that will be performed on the way to Mars and on the return. This further links the science and exploration endeavors in a way which benefits both and provides for exciting near-term discoveries.

Enhancing Return from Lunar Surface Missions via the Deep Space Gateway.

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Science Objective: NASA has recently been directed to "return humans to the surface of the Moon for long-term exploration and utilization" (National Space Policy, December, 2017). Access to and exploration of the lunar surface through both robotic and crewed missions are required to address the seven highest priority objectives identified for lunar science [1]. These high priority science objectives require either the deployment of long-lived surface instrumentation, or the collection of samples returned to Earth from many locations on the lunar surface (e.g., [2], also see results from the Lunar Science for Landed Missions Workshop, 01/2018).

Although missions to the lunar surface from Earth may be most efficient without a stop at the Deep Space Gateway (DSG), the DSG can substantially enhance the return from both robotic and crewed round-trip lunar surface missions.

Robotic Surface Missions: Current landers under development through the Lunar Catalyst program and other commercial endeavors are designed for direct access to the lunar surface from Earth, conducting one-off missions of complexity that evolves with time. With the DSG in place, these landers could evolve further, developing into reusable platforms that deliver permanent surface instruments distributed across the Moon and return surface samples to the DSG from multiple locations.

In particular, robotic missions such as the Lunar Geophysical Network [3] that require deployment of multiple permanent surface instruments require a method to robotically transport and release landers at set intervals. Although LGN does not require DSG for deployment, DSG could greatly reduce cost and risk to LGN mission success by employing a single lander that is reused to deploy multiple suites of long-lived instrument suites on the lunar surface. The lander could be refueled and re-outfitted with new instrument suites delivered by Logistics Modules to the DSG prior to each deployment.

Additionally, the DSG facilitates sample return by reducing complexity requirements of sample return vehicles, which would otherwise need to include heat shields (etc.) for Earth reentry. Crew will transfer samples from a lunar return vehicle to a vehicle already designed for Earth reentry (e.g., Orion or international/industry-provided crew capsule) through human-assisted sample return procedures. Furthermore, the DSG could facilitate return of cryogenic samples via Orion or international/industry-provided return capsules by providing access to cold storage facilities onboard. Such facilities would enable investigations that would promote the development of *in situ* resource utilization procedures as well as human research in deep space.

Crewed Surface Missions: The DSG also benefits crewed surface missions through providing a communications relay for farside and south polar operations and by providing a safe haven for surface crews in the event of a surface mission anomaly.

DSG Requirements: Lander and ascent vehicles are separate architectures that are beyond the scope of this paper. However, these elements directly affect design requirements of the DSG. To facilitate deployment and return of lander and ascent vehicles, the DSG must have 1) a science airlock (e.g., ~0.2–0.5 m diameter) for a sample canister, 2) a docking port for a crew return vehicle, and 3) a way to refuel vehicles to enable reusability.

The science airlock would benefit from having a robotic arm that can be manipulated from inside the DSG or from Mission Control to transfer a sample canister from the return vehicle to the DSG interior. This science airlock could be co-located with the crew airlock to reduce risk. Crew must stow returned samples inside the DSG because Orion does not have external capacity dedicated for stowage.

The docking port is required to grant crew access to the DSG from the lunar ascent vehicle. Ideally, this port would be independent of the Orion docking port to allow both vehicles to be present simultaneously. This would serve as safety redundancy for crew, providing two vehicles in case the DSG and one vehicle are both compromised.

A refueling capability would greatly improve the ability to reuse the surface transport assets. This would facilitate robotic sample return missions to multiple locations without the need for replacing assets, improving the return-on-investment from not only the lander and ascent vehicles, but also on surface assets such as rovers that could be operated tele-robotically from crew on the DSG.

Orbit Requirements: One significant impact on lunar surface access is the DSG orbit (Table 1).

DSG location affects both the ΔV required to deliver payload from the DSG to the lunar surface as well as the time required to complete the landing (Table 2). Minimizing ΔV requirements for surface access is desired for both crewed and robotic missions in order to minimize propellant mass required for descent as well as to maximize the mass allowance for delivery to and, critically for sample return, return from the lunar surface. For crewed surface missions, time of descent (transfer time) is a concern for crew safety – shorter descent durations are preferred. For robotic surface missions, transfer time is a concern if instruments require activation prior to descent; otherwise, descent time is less of a concern. If the transfer time is permitted to increase, the ΔV from NRHO, EM L_2 and DRO could be reduced by ~100 m/s each way.

The current reference orbit for DSG is the Earth-Moon L_2 Near-Rectilinear Halo Orbit (NRHO) as it appears to best balance competing constraints and requirements. The NRHO meets Orion's performance and thermal requirements and trades well for habitat design, especially in the areas of orbit maintenance, thermal design, lunar polar surface access, accessibility to smaller launch vehicles and south pole/far side communication coverage [4]. For science, the NRHO offers >60% communication coverage at ~20°N up to 86% communication coverage at the lunar south pole; coverage is <10% north of ~30°N on the farside and north of ~10°S on the nearside (Figure 1). (If a North family NRHO was selected, relative coverages would be swapped between poles.) Additionally, the NRHO can facilitate near-global access to the lunar surface with 0.5-day transfers from the DSG, though ΔV costs increase near the equatorial regions (Table 2).

Table 1: Orbit Characteristics

Orbit	Period	Amplitude Range (km)	Earth-Moon Orientation
LLO	2 hrs	100	Any inclination
NRHO	7 days	2,000x75,000	~Polar
EM-L_2	14 days	60,000	Varies
DRO	14 days	70,000	Equatorial

From [4]. LLO – Low Lunar Orbit; NRHO – Near Rectilinear Halo Orbit; EM-L_2 – Earth Moon Lagrangian Point 2; DRO – Distant Retrograde Orbit.

Table 2: One-Way Surface Costs from Various Orbits

Orbit	ΔV (m/s)	ΔT
LLO (0° plane change)	2000	<1 hr
LLO (30° plane change)	2846	<1 hr
NRHO (Polar site)	2730	0.5 days
NRHO (Equatorial site)	2898	0.5 days
EM-L_2 (Polar site)	2800	3 days
EM-L_2 (Equatorial site)	2750	3 days
DRO (Polar site)	2830	4 days

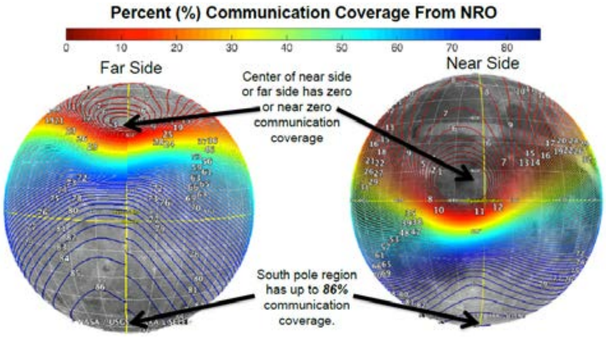

Figure 1: Communication coverage from NRHO, from [4].

Table 3: Total Costs from Earth Back to Earth

Vehicle	Phase	LLO	NRHO
Launch Vehicle Costs	LEO to TLI	3.2 km/s	3.2 km/s
	Subtotal LV	**3.2 km/s**	**3.2 km/s**
Crew Vehicle Costs	TLI to Lunar Orbit	0.9 km/s	0.45 km/s
	Lunar Orbit to EI	0.9 km/s	0.45 km/s
	Subtotal Crew	**1.8 km/s**	**0.9 km/s**
Robotic Vehicle Costs	BLT to Orbit	0.63 km/s	0.01 km/s
	Orbit to Surface	2.0 km/s	2.75 km/s
	Surface to Orbit	2.0 km/s	2.75 km/s
	Subtotal Robotic	**4.63 km/s**	**5.51 km/s**
	Total	**9.63 km/s**	**9.61 km/s**

Notes: LEO – Low Earth Orbit; TLI – Trans Lunar Injection; EI – Earth Interface; BLT – Ballistic Lunar Transfer (slow transfer to Moon)

It is important to note that the NRHO is on an efficient path from Earth to the lunar surface, and a choice between NRHO and LLO does not change the total cost when all spacecraft are considered together. The orbit determines how cost is divided between each spacecraft (Table 3). If the DSG is in an NRHO, more ΔV must be done by the lander, and if the DSG could get to LLO (which is not accessible by Orion) more ΔV must be done by the DSG and crew vehicle, requiring an additional propulsion element (Table 3).

In summary, the DSG will facilitate access to and communication with the lunar surface, which will be a boon for science ops in cislunar space.

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SCIENCE INVESTIGATIONS ENABLED BY MAGNETIC FIELD MEASUREMENTS ON THE LUNAR SURFACE.

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Introduction: Observations by the Lunar Surface Magnetometers (LSM) of the Apollo Lunar Surface Experiments Package (ALSEP) in the 1960s and 1970s established the basic understanding of the magnetic field variations on the lunar surface. The variations in the magnetic field include the fluctuations in the ambient plasma, the magnetic induction of the eddy electric currents in the lunar interior, the crustal magnetic field and its interaction with the solar wind, and possibly the ion cyclotron waves due to the pickup ions escaping from the lunar exosphere. Surface measurements of the lunar magnetic field can provide useful information not only about the Moon but also the space environment surrounding it.

The Apollo LSM measurements were obtained at locations that were not ideal for addressing many outstanding science questions identified after the Apollo era, but no surface magnetometer has been set up since the last Apollo LSM ended in 1975. The Lunar Geophysical Network mission concept reviewed by the latest planetary decadal survey [1] has identified four science objectives for which surface magnetic field measurements can play a major or supporting role. These science objectives are (a) to determine the nature and the origin of the lunar crustal magnetic field, (b) to determine the internal structure of the Moon, (c) to determine the distribution and origin of lunar seismic activity, and (d) to determine the bulk composition of the Moon. NASA's Deep Space Gateway concept, including the support/servicing of lunar landers, can enable new surface magnetic field measurements to meet these science objectives.

This paper presents a few examples of the geophysical and heliophysics investigations that can be made with magnetic field measurements on the lunar surface. The consideration includes scenarios where concurrent spacecraft magnetic field measurements near the Moon supported by the Deep Space Gateway or other programs are also available. The paper concludes by discussing the deployment methods of lunar surface magnetometers and the needed resources from the Deep Space Gateway or other programs.

Examples of Science Investigations:

Lunar interior. The magnetic field measurements by the Apollo LSM and Explorer 35 in the lunar orbit motivated a series of magnetic sounding studies of the lunar interior to constrain core size, mantle free-iron and alumina abundance, and interior temperature and thermal evolution. (see a review by [2]). The transfer-function method used in these studies compares the wave spectrum measured on the surface with that measured in the lunar orbit. The advantage of this method is that the frequency-dependent transfer function can be used for immediate interpretation of the internal electrical conductivity as a function of depth.

Unresolved scientific questions on this topic include: (a) What is the electrical conductivity structure of the outermost 500 km of the moon and its lateral variations? This zone is important as it contains a possible transition from upper-mantle melt residuum to the pristine lower mantle, as well as differences in crustal composition and lithospheric thickness and heat flow associated with the primary geological provinces of the moon. (b) What it is the deep structure of the moon and its heterogeneity? A tighter average mantle conductivity profile will better constrain temperature and composition. Lateral variations in internal temperature could be evidence of mantle convection. Very long-period measurements could distinguish a molten silicate from an iron core. [3]

The transfer-function method requires simultaneous magnetic field measurements by one spacecraft monitoring the external condition near the Moon and one or more surface magnetometers. The surface magnetometers are best placed at locations with minimal crustal magnetic field, and the locations can be on either the nearside or the farside. Because the driving signals are the magnetic fluctuations in the solar wind or the magnetosheath, farside locations can accrue relevant measurements faster.

Lunar Magnetic Anomalies and Lunar Swirls. Portions of the lunar crust are highly magnetized, which, when considered together with sample paleointensities, indicates the existence of an early high-field epoch. Other strong magnetic anomalies are correlated with basin ejecta materials and with lunar swirls of high-albedo markings.

The origin of lunar swirls is still a mystery. All lunar swirls are co-located with lunar magnetic anomalies, but the reverse does not hold true. At present, the proposed formation hypotheses can be summarized in three categories: (a) the solar wind standoff mechanism, (2) micro-meteoroid and comet impacts, and (c) magnetic and electrostatic sorting of high-albedo dust.

The surface investigation of lunar swirls is perhaps best made by a rover that conducts a magnetic survey and sample analysis. Swirls can also be surveyed by low-altitude satellites [4], and surface magnetometers at fixed locations can support satellite observations by identifying the temporal features in the magnetic field. An interesting observation target of is the much-studied Reiner Gamma magnetic anomaly on the nearside. The two swirls on the farside that lie directly opposite to Mare Imbrium and Mare Orientale are also of high interest because of their possible connection to impacts.

Ion Cyclotron Waves at the Moon. The restored Apollo LSM data have shown clear narrowband ion cyclotron waves when the Moon is situated in the terrestrial magnetotail ([5] and Figure 1). Two mechanisms have been proposed to explain the excitation of these waves: the first mechanism involves the absorption of ions at the lunar surface and the resulting temperature anisotropy, and the second mechanism is the excitation of ion cyclotron waves by the pickup ions from the lunar exosphere.

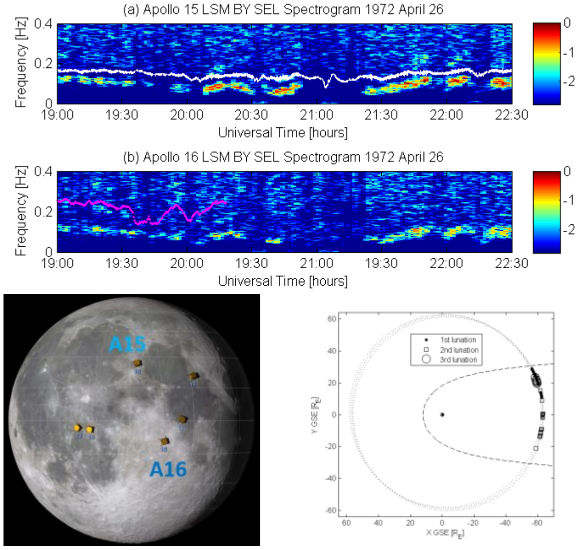

Figure 1. *Upper*: (a) A series of narrowband ion cyclotron waves with frequencies ~0.1 Hz observed by the Apollo 15 LSM. The white trace indicates the local proton gyrofrequency at the Apollo 15 site. (b) Similar waves simultaneously observed by the Apollo 16 LSM. The magenta trace shows the proton gyrofrequency inferred from the magnetic field measured by the Apollo 16 sub-satellite orbiting the Moon (but with 24-sec time resolution that is too low to measure cyclotron waves associated with light ions). Lower Left: The locations of Apollo 15 and 16 ALSEP sites. *Lower Right*: The locations of narrowband ion cyclotron waves observed by the Apollo 15 LSM over three lunations in 1972. The plot is centered at the Earth.

Because pickup ions are the end loss process for all surface volatiles, understanding the role of pickup ions in exciting ion cyclotron waves can help determine whether these waves provide hints to the source and distribution of the associated lunar volatiles. A recent study based on Kaguya and Geotail observations of the narrowband waves in the magnetotail, however, suggests that these waves are observed much less often in orbit [6]. It is unclear whether the spacecraft altitude or motion affects the detection of these waves, or if the wave source is on the nearside closer to the ALSEP sites.

The ultimate answers to these outstanding questions require joint space-based and surface-based observations with sufficient time resolution. It is best to measure not only the magnetic field but also the velocity distribution of ions to provide the critical information for determining the responsible mechanisms for wave excitation.

Deployment of Lunar Surface Magnetometers: Magnetometers can be deployed on the lunar surface easily by astronauts, who can identify the location suitable for installation near the lander, carry and install the magnetometer to the desired location, and align the magnetic sensors with the chosen coordinates. The technology available today also allows robotic deployment. In both scenarios, the major deployment requirement is that the sensor should be placed at a location with minimal magnetic interference from the lander/rover or other instruments.

Resources Needed from the Deep Space Gateway: A modern surface magnetometer can be made compact and low-power. The weight of sensors and electronics in each magnetometer system is approximately ~2 kg. The power consumption without heating is approximately ~3 W or less. The volume of the magnetometer system is likely to be dominated by the support structure and the cable to be determined by the lander/rover design.

If the surface instrument is to be deployed by an astronaut, the installation and alignment can be completed within an hour. A robotic installation without the help by astronauts can also be designed.

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DARK ENERGY AND GRAVITY EXPERIMENT EXPLORER AND PATHFINDER.

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Introduction: Dark energy and gravity experiment explorer and pathfinder (DEEP) will utilize the unique gravity and vacuum environment in the proposed orbits of the Deep Space Gateway (DSG) for direct detection of dark energy scalar fields using atom interferometers. DEEP will also perform technology pathfinder experiments for future gravitational wave and dark matter detections with long-baseline atomic sensor network in deep space.

Objectives: Quantum atomic sensors based on atom interferometry use atoms as test masses and exploit the wave property of atoms for interferometric weak force measurements with high precision and accuracy [1]. By shining laser pulses on laser-cooled atoms in ultra-high vacuum, the matter wave of each atom is split-redirected-combined to interfere with itself in an atom interferometer (AI), analogous to electromagnetic waves of photons in a laser interferometer. Due to the quantum nature of the atom-light interactions, AIs are inherently stable, governed by fundamental physics constants and the frequency of the interrogating laser. AI sensors promise great potentials for astrophysics and fundamental physics measurements in direct dark energy detection [2], dark matter detection [3], and gravitational wave detection [4]. DEEP is an AI instrument designed to achieve the following scientific objectives.

Direct Dark Energy Detection. Dark energy composes of nearly 80% of the Universe, and is responsible for its accelerated expansion [2]. One possible explanation for dark energy is that it is a scalar field in nature. Its interaction with normal matter is assumed to have the gravitational strength on cosmological scales, but must be highly suppressed in the Solar System to be consistent with current gravity measurements and observations. The suppression is referred as “screen mechanism”: dark energy is screened by dense matter in the scalar field theory framework. Promising theories of dark energy include the chameleon scalar field, the symmetron scalar field, and the Vainshtein scalar field. Point-like particles such as atoms do not subject to the screening mechanism in the chameleon and the symmetron theories, and thus are orders of magnitude more sensitive to dark energy than bulk test masses. Laboratory experiments using AI for detecting extra forces originated from dark energy have placed strong constraints in the parameter space of dark energy theories [5]. DEEP, a dedicate AI apparatus under microgravity, will allow prolonged interrogation times in a compact setup, leading to a sensitivity that will completely rule out the chameleon dark energy while significantly constraining others [6].

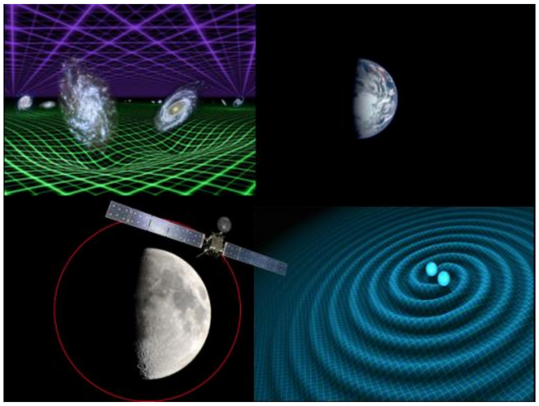

Figure 1. DEEP for direct dark energy detection and for gravitational wave detection.

Technology Pathfinder for dark matter and gravitational wave detections. Gravitational waves induce relative accelerations between distant locations via space-time perturbations. Precise tracking of two distant inertial points is the key for GWD. In the proposed schemes of using AI for GWD, atoms serve as ideal inertial references and the link laser noise is common mode between remote AIs. AI GWD provide strain sensitivity in frequency bands complementary to LISA and LIGO [7]. Likewise, in the frame work of the B-L model on ultra-light particle of dark matter, the particle field introduces extra composition-dependent acceleration of atomic test masses. A network of atomic sensors can detect dark matter waves, clumps, and stochastic backgrounds. For the atomic sensors to achieve the needed precision, atomic test masses need avoid of spacecraft self-gravity disturbances, and require atomic wavepacket separations of more than 100 m. These can only be practically achieved with atomic test masses outside the spacecraft. The high vacuum space environment of DSG orbits offers this possibility. DEEP will demonstrate such an “open-space” AI measurement technique. With the success of this capability demonstration, combined with long laser baseline links, such an AI network would provide a relative motion sensitivity better than $10^{-20}/\sqrt{\text{Hz}}$ below 1 Hz for future GW and dark matter field detection experiments in space.

DSG Justifications: For AIs with prolonged interrogation times $T > 1$ s, control of gravity gradients and platform rotation becomes critical. As shown in Ref. [8] for a scenario onboard the ISS in LEO, the

Earth's gravity gradient (~ 2500 nm/s^2 /m) would smear out the AI contrast, and additional techniques would be required to recover the contrast. Similarly, a 1000:1 rotation compensation for ISS's 91-min orbital period would be barely sufficient for the proposed experiment. The gravity gradients in all of the DSG candidate orbits, except the Low Lunar Orbit (LLO), would be lower than 3 nm/s^2 /m most of the time, which is ideal for all conceived experiments. Long orbital periods will also significantly reduce the technical challenge of platform rotation compensation.

The ultra-high vacuum that a long T AI requires is 10^{-10} Torr or better, so that atoms have negligible chance of colliding with residual gas molecules within T. The vacuum environment in the DSG orbits is expected to be $< 10^{-11}$ Torr, which will support the open-space AI experiment concepts.

Instrument Concept: DEEP will consist of an ultracold atom source and a laser-optics system for manipulation and detection of atoms for AI measurements. JPL has extensive experience on cold atom generation in space, namely the Cold Atom Laboratory (CAL) to launch to ISS in 2018 [9], and long history of AI development and demonstration. In DEEP a cloud of 10^8 atoms of pK temperature will be prepared within few seconds, serving as the source for following AI operations. For the *Direct Dark Energy Detection*, dual AI of $T \sim 10$ s will be performed simultaneously through a specifically designed local mass distribution. The instrument and the AI can be inside the DSG spacecraft or outside. Differential measurements between the AIs will cancel most of common-mode systematics and reveal fifth forces from the existence of the dark energy scalar field. For open-space AI experiments, DEEP will need to have access to the external space and an external retroreflector at the end of a long boom structure. The cloud of atoms will first be transported to the exterior using laser beams. The laser pulses for AI will then shine on the atoms from the instrument few meters away from the spacecraft. After the AI sequence, the atoms are transported back inside the apparatus for detection,

The size, weight, and power of DEEP is estimated to be 1 m^3, < 500 kg, and 500 W, based on comparison to JPL's development effort on CAL and engineering studies of other similar missions [8].

Orbit Preference: DEEP will operate the best with low gravity gradients, long orbital periods, and direct line of sight to Earth for GWD pathfinder. Thus, the order of preference among five proposed orbit types are Distant Retrograde Orbit, Earth-Moon L2 Halo, Near-Rectilinear Halo Orbit, Elliptical Lunar Orbit, and lastly LLO.

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Global Magnetospheric Imaging from the Deep Space Gateway in Lunar Orbit. D. H. Chua[1], D. G. Socker[1], C. R. Englert[1], M. T. Carter[1], S. P. Plunkett[1], C. M. Korendyke[1], and R. R. Meier[2], [1]Naval Research Laboratory, Space Science Division, 4555 Overlook Ave SW, Code 7686, Washington DC, 20375, damien.chua@nrl.navy.mil, [2]George Mason University.

The Deep Space Gateway (DSG) in lunar orbit provides an ideal vantage point from which critical remote sensing observations of the Earth's magnetosphere may be made. We propose to use the DSG as an observing platform for a magnetospheric imager that will capture the first direct global images of the interface between the incident solar wind and the Earth's magnetosphere, and the response of the coupled magnetosphere-plasmasphere-ionosphere system to all incident solar plasmas. Our magnetospheric imager concept is described by [1], who demonstrated that the optical detection of the faint magnetosphere surrounding the bright Earth is feasible using the same techniques as those used to image the faint solar corona and solar wind. This method measures the brightness of light in the visible portion of the spectrum that is Thomson-scattered by electrons in the solar wind and magnetospheric plasmas. The Thomson scattering brightness is proportional to the line of sight column electron density.

The highly variable, out-flowing solar wind drives the extent, shape, and state of the Earth's magnetosphere. The variability in the magnetosphere propagates inward toward Earth where space weather effects are a growing concern for navigation and communication technologies that are increasingly reliant on systems operating in space. Observations of the solar wind-magnetosphere interface are mostly in situ measurements of particles and fields from satellites whose orbits cross the magnetopause and magnetospheric bow shock. These measurements are crucial for understanding the microphysics of the plasma processes that occur at these boundary regions. However, the characteristics and behavior of the plasma at the solar wind-magnetosphere interface is poorly described observationally at large scales. For example, the extent to which wave structures associated with plasma instabilities (e.g. Kelvin-Helmholtz) exist along the magnetopause has not been established outside of global-scale simulations of the magnetosphere. These phenomena are thought to be significant mechanisms for transporting mass and energy from the solar wind into the magnetosphere.

The large-scale context afforded by globally imaging the magnetosphere promises major advances in both our fundamental understanding of solar wind-magnetosphere coupling and our ability to forecast the state of the geospace environment in response to solar wind driving. Global magnetospheric imaging would enable seamless tracking of solar wind disturbances from the heliosphere to the Earth's magnetosphere. [2] demonstrated how a co-rotating interaction region (CIR) could be tracked from the Sun to the Earth by STEREO SECCHI images and how its impact could be assessed simultaneously across geospace using simulated white-light Thomson scattering images of the magnetosphere. Such images would reveal how electrons in the magnetosphere and plasmasphere are redistributed in response to solar wind forcing, particularly when CMEs and CIRs interact with geospace. Global images of the magnetosphere would also be useful for proving global boundary conditions to ionospheric specification models.

Our global magnetospheric imager on DSG would be implemented as an externally mounted instrument suite that would not require any crew interaction under normal operation. The instrument suite would consist of an Earth-centered geocoronagraph (analogous to a solar coronagraph) with an external occulter of radius 1.2 – 1.5 Earth radii (RE) and a magnetospheric imager (analogous to a heliospheric imager such as HI1 or HI2 on STEREO SECCHI, SoloHI, and WISPR). The instrument suite would require 28V DC bus power from the DSG. We estimate a total average operational power draw of 24-30 W for both instruments. The geocoronagraph mass is estimated to be about 10 kg with a physical size within a 150 cm (L) 🎞 20 cm (D) cylindrical envelope. The magnetospheric imager mass is estimated to be about 15 kg with a physical size within a 50 cm (L) 🎞 30 cm (W) 🎞 40 cm (H) envelope. These size, weight, and power estimates are based on previous design specifications for heritage instrumentation that we have developed including the coronagraphs on SOHO LASCO and STEREO, the Compact Coronagraph (CCOR), SoloHI, and WISPR.

We assume the DSG platform would be in lunar orbit at a geocentric distance of approximately 60 RE. From this orbit, a geocoronagraph with an Earth-centered field of view of 25🎹would observe out to 26 RE. This is sufficient to observe the entire cross section of the dayside magnetosphere, including the bow shock and magnetopause, the polar cusps, and a significant portion of the tail lobes. The magnetospheric imager would have an overlapping field of view approximately

30🎹wide that could be pointed upstream of the magnetosphere to image solar wind structures approaching the magnetosphere or downstream of Earth to observe the dynamics of the magnetotail plasma sheet**.**

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COMMUNICATIONS RELAY AND HUMAN-ASSISTED SAMPLE RETURN FROM THE DEEP SPACE GATEWAY.

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Introduction: The Deep Space Gateway can enable or enhance exploration of the lunar surface through two capabilities: communications relay opening up access to the lunar farside, and sample return enhancing the ability to return large sample masses.

Lunar Communications Relay: The lunar farside is of great scientific interest for planetary science and astrophysics, but no spacecraft has ever landed there because no communications relay infrastructure exists to support missions there. Many lunar polar landing sites also have challenging geometry for direct communications with Earth. The Deep Space Gateway can enable otherwise infeasible robotic science missions to these lunar surface destinations by providing a communications relay to the surface. We envision adding a 2 to 3 m diameter S or Ka-band high-gain antenna on the DSG pointed at the Moon. Data would be transmitted to scientists and engineers on Earth via the DSG's planned Earth-pointing high gain antenna and/or a optical communication terminal. Optical communication enables a significant increase to downlink bandwidth capability compared to traditional radio frequency communication. For example, NASA's Lunar Laser Communication Demonstration demonstrated a record-breaking Moon to Earth downlink rate of 622 Mbps.

Data rate demands for the communications relay system may vary widely. A stationary lander may only need <100 kbps for imagery and data return. A rover may require on the order of 1 Mbps or more depending on video frame rate and image quality. The highest data rate requirement may be set by a radio astronomy interferometer array. The lunar farside has long been recognized as a unique astronomical platform for conducting radio astronomy at frequencies below 10-30 MHz [1]. With the Gateway in orbit over the lunar farside, low frequency receivers can be placed on the lunar surface for continuous radio measurements. Burns et al. have developed a novel concept for telerobotically deploying such an antenna array on the lunar farside [2] and estimate that the interferometer will generate data at 16 Mbps continuously (depending on the number of elements of the array).

Human-Assisted Sample Return: The Moon is key to understanding the early history of the inner Solar System, since the first few billion years of the geological record have been nearly erased on the terrestrial planets. The South Pole-Aitken (SPA) Basin, on the lunar farside, is the oldest impact basin on the Moon and potentially the largest in the inner Solar System. SPA sample return has been identified as a priority in the past two planetary science decadal surveys by the National Research Council and the Lunar Exploration Analysis Group [3]. Returning samples of polar volatile deposits has also been identified as a priority.

Lunar sample return missions which return a few kg of samples can be readily implemented as stand alone missions, returning their samples directly to Earth. This class of mission fits on existing launch vehicles and can use heritage Earth entry systems [4]. However, if the goal is to return a much larger sample mass (perhaps >20 kg), such a mission can benefit from using the Deep Space Gateway as a return transportation node. The lunar ascent vehicle would deliver the sample container to the DSG where it can be retrieved by the Gateway using the robotic arm and airlock elements. Astronauts would transfer the samples to Orion for return to Earth. This saves the mass of carrying a sample return capsule down to the lunar surface and back up to space. Apollo opted for Lunar Orbit Rendezvous for the same reason. By using Orion as the Earth return vehicle, a large quantity of samples can be returned to Earth on a flight-proven system without developing a new robotic re-entry vehicle with a large capacity. This capability would be most useful for lunar polar volatile samples because of the ability of Orion to maintain environmental conditions. Using a non-standard mission kit, Orion can carry a freezer similar to the ISS GLACIER freezer to return frozen samples to Earth in a pristine condition to be analyzed by scientists.

During the sample collection phase of a return mission, trained astronaut-geologists in the Gateway could teleoperate rovers in near real-time operating conditions to focus their expertise on identifying the best samples possible. In doing so, more samples could be collected in a shorter period of time such as to fit within a single lunar day. Human assisted sample return using orbital teleoperations and Orion return would also be a demonstration of future Mars exploration capabilities, such as described in Lockheed Martin's Mars Base Camp concepts [5].

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In-Situ Environmental Monitoring and Science Investigations Enabled by the Deep Space Gateway.

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Overview: Within a decade, NASA intends that the Deep Space Gateway would provide routine low-cost opportunities to deliver state-of-the-art instrument packages to locations that previously had very limited access. The Gateway's placement in a family of long-term lissajous lunar orbits, similar to those utilized by the ARTEMIS mission, would facilitate SmallSat access to similar orbits or Lagrange point halo orbits, enabling, for the first time, a network providing a true hazard monitoring capability for the space environment around the Moon and Earth.

Benefits: A distributed network of instrument packages in an ARTEMIS-like orbit would serve as the much-needed basis for on-going monitoring of cislunar environmental dynamics, critical for a successful human presence on the moon. A spatially and temporally distributed network would assure frequent crossings of the Earth's magnetosheath, bow shock, plasma sheet and tail lobes enabling full characterization of the moon’s varying plasma environment. Proximity to the moon’s terminator, wake, and poles would reveal how the moon responds to the measured input, closing the loop by providing the necessary data to predict and respond to environmental hazards.

Strategic Knowledge Gaps (SKGs): Such investigations support human health and safety in space and respond to NASA Human Exploration Strategic Knowledge Gaps II (Understand the lunar environment and its effects on human life) and III (Understand how to work and live on the lunar surface). These networks could form the basis for an early warning system for potentially dangerous conditions, such as those resulting from solar mass ejections, as well as provide a thorough knowledge of the lunar plasma environment at all times, lunar “situational awareness.” Deployment to halo orbits of Earth-Moon Lagrange points also might be possible, where visual and infrared imagers would detect potentially dangerous incoming asteroids.

Instrument Complement: Instruments of particular interest for cislunar environment monitoring would take advantage of more compact, advanced versions of instruments like those flown on the ground-breaking ARTEMIS mission, including fluxgate and VHS magnetometers, search coils (radio wave), electric field probes, and particle analyzers covering a broad range of energies and species from thermal through galactic cosmic ray. In addition, the network would work in conjunction with current ground- and space-based assets that already alert us to potentially dangerous conditions in the near-Earth environment.

Requirements: In this concept, each 6 to 12U deployable cubesat-scale package would consist of two to three of the instruments described above and have a mass of <25 kg. Each package would carry its own deployable power generation and storage system, and require deployment via a standard deployer (analogous to cubesat deployment on ISS) by the crew. A minimum of four packages would be deployed. The goal would be periodic communication with the Earth via the DSN but, depending on package orbits, frequency of close proximity to the Gateway, and the Gateway's communication system (UHF and X-band preferred), communication via the Gateway might be advantageous.

ENABLING GLOBAL LUNAR SAMPLE RETURN AND LIFE-DETECTION STUDIES USING A DEEP-SPACE GATEWAY.

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Introduction: Sample studies underpin the foundation of our knowledge of the origin and evolution of the Moon and other planets [1]. The Moon is the best understood extra-terrestrial object because of the samples returned by the Apollo program. Samples provide a unique perspective based on the high spatial resolution and high analytical precision capabilities of terrestrial laboratories. Even relatively small samples record planetary- and solar system-scale processes. Combined with orbital and ground-based measurements, samples provide ground truth and enable interpretation within a planetary context.

Samples also help prepare for human lunar return and in situ resource utilization for commercial exploitation. Samples help validate orbital observations in unvisited terrains, enabling prospecting for similarly-sited deposits, as well as providing detailed evaluation of the composition (and contamination) of potential resources, e.g., Ti in pyroclastic deposits and lunar polar volatiles.

There are many more sites representing the Moon's rich geologic diversity than we have visited. Sites that would benefit from sample return include (but are certainly not limited to) impact-melt flows in lunar basins such as the South Pole-Aitken Basin, Nectaris and Crisium, key benchmark craters such as Copernicus, young volcanic materials with a range of compositions, felsic extrusive provenances, resource-bearing deposits, and places where orbital remote sensing has identified lithologies that are not present in the current sample collection [2-4].

Lunar Sample Return: The Deep-Space Gateway (DSG) could uniquely enable a lunar robotic sampling campaign that would provide incredible science return for a drastically reduced cost, compared with traditional approaches of single-launch robotic sample return to earth. In this scenario, the DSG would be the base of a cycler system for lunar landers, each of which would be refueled at the DSG and redeployed to different landing sites. Such an approach could be coupled with commercial interest in lunar cargo services and international interest in robotic lunar missions to further leverage a cycler concept.

Returning samples to the DSG as a stepping stone for returning samples to Earth would allow for sample high-grading as well as, in a multiple lander scenario, allow for designing future traverses. Complementary DSG analysis also allows more sample weight, which translates to more and larger samples that can be studied in context and by consortium. Risk and cost of sample return (SR) missions are perceived as having a higher risk and cost than other planetary exploration missions.

Not having to launch separate lunar surface missions, but rather using a reusable lander refitted with descent and ascent solid rocket motors at the DSG, would uniquely enable samples from multiple locations to be returned. This would represent an incredible bounty of lunar science at a drastically reduced cost, pushing the "science per dollar" through the roof.

A campaign of multiple landers could also update and test technologies at system and subsystem levels – for example, new algorithms for precision landing and hazard avoidance, and different modes and controls for coring and sample manipulation. International cooperation on SR missions could be enabled by specific reusable hardware contributions, or by revising the science team for each mission based on science and technology interests across international programs.

Onboard sample processing: Returning samples to the DSG also opens up the possibility of human-tended onboard sample processing. The main value of sample return lies in the ability of terrestrial laboratories to collaborate using sophisticated analysis techniques enabling high spatial resolution and high analytical precision. Despite advances in in situ instrumentation, it is unlikely that onboard examination will be sufficient to answer the questions motivating scientific sample return. However, there is an important role for onboard processing, which is using lunar samples as an *in situ* life-detection blank.

Life detection techniques are being developed for in situ analyses of extant and extinct lifeforms at destinations like Mars, Europa, and Enceladus. However, two fundamental issue with these techniques are how to sufficiently decontaminate instruments (removal of biomolecules and other interferences) as to maintain science integrity, and how to disentangle abiotic organic signals from biotic ones. Analytical approaches to life detection involve molecular detection, often at trace levels. Thus, removal of biological materials and other organic molecules from devices used for sampling and analysis is essential for ascertaining meaningful results.

The Moon is known to be lifeless, but its regolith has a non-trivial organic component contributed over aeons by comets and asteroids. These samples could be analyzed by instruments in a BioLab/GeoLab-like configuration [5] that has been sterilized using best practices and segregated from the crew cabin or otherwise attached to the external surface of the DSG. If a sample return capsule is configured with dual chambers, astronauts aboard the DSG would be able to ingest and manipulate a subsplit of samples without opening the main lunar sample container. BioLab/GeoLab instruments would include those for the detection of biotic and abiotic molecular signatures (e.g. chromatography combined with mass spectrometry or capillary electrophoresis, tests for polyelectrolytes and related biopolymers), contextual measurement devices (e.g. spectral mapping, x-ray diffraction, gas analysis instruments), and instruments for investigating morphological features or activities (various forms of microscopy from fluorescence to scanning electron).

Such activities would buy down significant risk in future life-detection activities by demonstrating required blank levels, testing sterilization techniques, and developing confidence in the community in how to robustly interpret life-detection results.

In a mission architecture with multiple landers that will potentially include teleoperating robotic assets on the surface, having a GeoLab capable of providing a quick look at the chemistry and mineralogy of samples prior to SR to Earth would provide the robotic operators (whether they be Earth or DSG-based) with more information about how to plan and execute traverses as well as how to select landing sites. Though the most valuable scientific work will occur in laboratories on Earth, this near in situ processing gives the distinct advantage of providing the crew and supporting science teams with a higher resolution look at the samples without undergoing the risk of returning samples all the way to the Earth's surface.

Conclusions: Sample analysis is an extremely critical step in the process of unraveling the history and evolution of our nearest neighbor. Though DSG-based analyses will never replace the need for more thorough laboratory work, these analyses do have the ability to maximize the science return of a sustained human presence in lunar orbit. Including sample analysis capabilities on the DSG could provide scientists with an efficient and valuable way to interrogate samples prior to return to Earth, while preserving and even enhancing the ability of scientists in Earth-based laboratories to access and analyze the most valuable sampling targets.

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ANTAEUS II: PLANETARY QUARANTINE FACILITY AT THE DEEP SPACE GATEWAY.

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Introduction: In 1981 NASA published The Antaeus Report: Orbiting Quarantine Facility (NASA SP-454). This study proposed to create an Earth orbital space station to quarantining any material returned from Mars:

> ". . .To detect the presence of biologically active agents—either life forms or uncontrolled (replicating) toxins—in the sample and to assess their potential impact on terrestrial systems. Only when the sample could be certified safe or controllable would it be transmitted to laboratories on Earth for physical analysis."[1]

The authors named the mission after Antaeus, a "half-giant" whom Hercules fought as his 11th Labor. The only way Hercules could defeat Antaeus was by lifting him off the Earth, from which he received his power. The analogy they authors applied was that if they could keep Mars samples away from contact with the surface of the Earth, they could control any dangerous microbes, and if necessary, kill them. Figure 1 shows the concept for the Antaeus orbital quarantine space station.

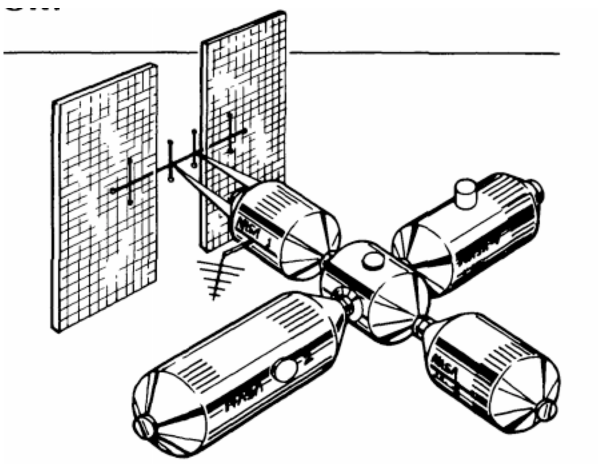

Figure 1. Design Concept for the Antaeus Orbiting Quarantine Facility, (NASA SP–454, 1981).

Adaptation of Bioisolation Technology for Mars Returned Sample Handling (MRSH): During the Mars exploration fanfare of the late 1990s, NASA funded a series of contractor studies to examine the design, mission, and operational problems of collecting samples from Mars and returning them to the Earth without creating or allowing any biological hazards from "back contamination." Much of this discussion assumed the use of Bioisolation technologies at the highest BioSafety Levels (BSLs) as defined and certified by the National Institutes of Health and the Centers for Disease Control. The CDC publishes standards for BSL–1 through BSL–4, the latter being most restrictive set of precautions against the inadvertent release of a pathogen into the environment or allow outside contamination of samples.

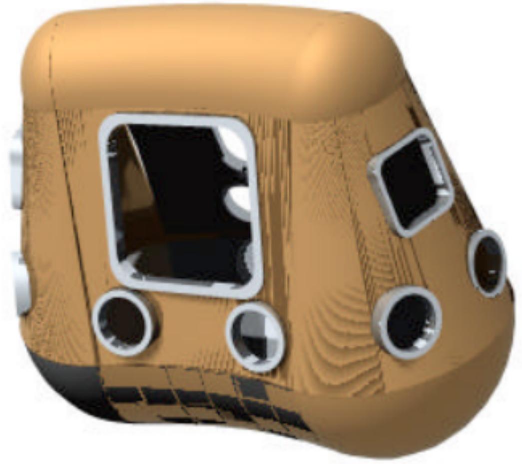

Figure 2. Ergonomically designed, vacuum jacketed "BSL–5" ΔP "glovebox" that mounts mechanical manipulators at the glove ports. [3]

Some study authors began thinking about creating a *BSL–4+ or BSL–5* measure of protection, although these ideas never made their way back into the CDC system of BSLs. The essence of BSL–5 would be to wrap the sample handling "glove-boxes" with a vacuum jacket that would be continuously evacuated through an autoclave, as shown in Figure 2. That way, if any organism should escape the sample handling enclosure, it would suffer immediate incineration.

Another leading challenge was how to actually handle and manipulate the Mars samples. The astrobiologists in the NASA Ames Center for Mars Exploration (CMEX), distrusted robotic manipulators, and as one said, he wanted to "hold the sample in his own hand." Since bare hands and rubber gloves were emphatically ruled out, the design team proposed to adapt mechanical manipulators from the AX-5 Space Suit Advanced Development Project. Figure 3 shows the Jameson Prehensor as an example of such a manipulator that affords force feedback to the operator, while maintaining a proven pressure seal around the manipulator rods.

Where on Earth? Initially, during the this activity at CMEX, the emphasis on Mars sample handling was for astronauts to do it in a Mars surface science laboratory, based on NASA's 1997 *Mars Design Reference*

Mission 1.0. [5]. Following this period of study and speculation that accompanied the "Follow the Water" philosophy, NASA began looking more seriously at returning Mars samples to Earth under highly controlled and guarded conditions.

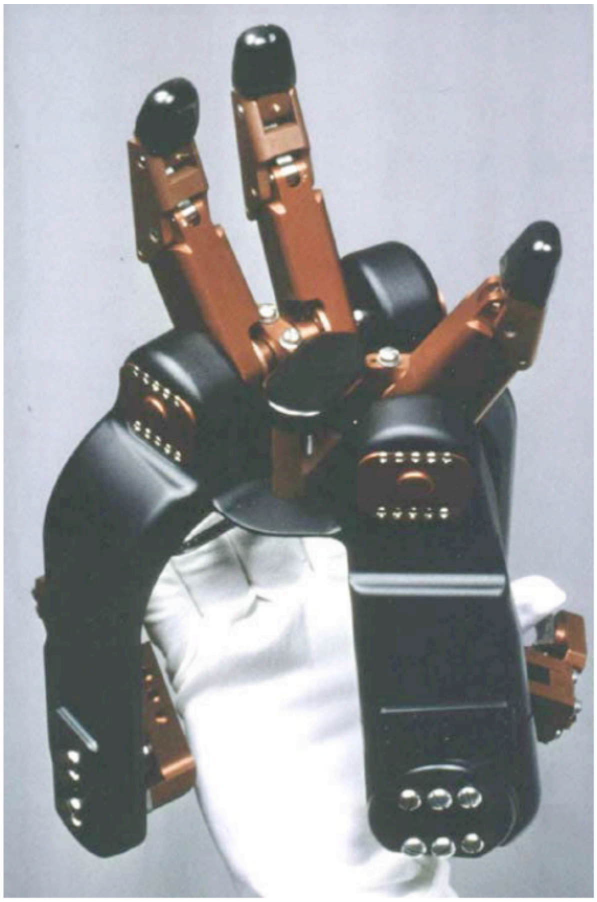

Figure 3. The Jameson Stanford/Ames Direct Linkage Prehensor, show out of its pressure shell.

One of the key realizations to emerge was that the Bioisolation technology and operations might not be the most challenging part of the Mars Sample Return mission. Instead, the most challenging aspect might be "writing the environmental impact statement to locate a MRSH laboratory on Earth."

One participant's not entirely sardonic solution was to return Mars samples to an orbital storage module, until such time as it was possible to complete construction of the BSL–5 Mars sample receiving and handling facility. Estimates for the completion of the Earth-based facility ranged up to three times as long as the entire Mars sample return mission itself, from project start to sample return to an orbiting "short stop."

These studies extended into the early 2000s, and applied both system engineering and urban and regional planning methods to identify the appropriate landing site on Earth and where to transport the samples from there to a permanent curatorial facility. [6,7]. However, the lead author came to the then unpublishable conclusion that the original Antaeus Mission was the best idea and most correct from a system analysis perspective. It would be far more efficient, economical, and safe to process and analyze Mars returned samples in a space-based laboratory.

The Deep Space Gateway would afford the ideal space-time coordinates for the Mars returned sample science receiving lab. It provides the essential Bioisolation from Earth to prevent back contamination. Surgical and industrial robots are now sufficiently advanced to provide all the capabilities a scientist could need to manipulate, slice, dice, and assay a Mars sample. The two-second time latency to Earth from the distant retrograde orbit of the Deep Space Gateway might be slightly annoying, but far less of an obstacle than sending commands to the Mars surface with up to 40 minutes latency. Finally, it would be feasible for astrobiologist scientist-astronauts to work directly on Mars samples at the Deep Space Gateway, in concert with remote "telecommuting" researchers.

The baseline requirements for the Planetary Sample Receiving Laboratory at the Deep Space Gateway include a dedicated module equipped with BSL-4 grade containment systems and telerobotics. A dedicated sample airlock to pass returned samples directly into the PSRL, without need to pass other through pressurized portions of the DSG station, would greatly simplify control of potential back-contamination. The PSRL would attach to the DSG station via a dedicated airlock, with decontamination capability, including showers and evacuation to vacuum. The operational design for the PSRL mission would concentrate on teleoperated or autonomous operation of the analytical capabilities, while being crew tended in terms of sample selection, loading, unloading, and packaging for return of sterile samples to Earth.

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SPACE WEATHER RESEARCH AND FORECASTING CAPABILITIES AT THE COMMUNITY COORDINATED MODELING CENTER (CCMC).

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Abstract The mission for the Community Coordinated Modeling Center (CCMC) is to support and enable the research and development of the latest and future space weather models and facilitate deployment of latest advances in research in space weather operations. The CCMC is hosting an expanding collection of space weather models and disseminating simulation results of historic and on-going events through custom web-based systems. The CCMC is also evaluating models and tools for performance, robustness and value to end users of space weather information for potential transition to operational organizations. Since 2010 the CCMC have established a very diverse group of scientists from different space science fields working every day to provide space weather forecasting and anomaly analysis services in support of NASA's space weather needs. As a part of its mission the CCMC is prototyping space weather models, new forecasting techniques and procedures, builds test beds for future missions planning (including missions to Mars and Deep Space), and also provides space weather training and hands-on educational opportunities. Over the years the CCMC established great partnerships with NASA's robotic mission specialists, the Space Radiation Analysis Group from Johnson Space Center, and other groups at NASA in need of custom space weather information. This presentation will describe the forecasting concepts of operations, notification processes, anomaly analysis, our partnerships and the tools used. The tools include systems that are completely open and available to the public's use like the Integrated Space Weather Analysis (iSWA) tool and the Database of Notifications, Knowledge and Information (DONKI). We will also discuss the education and training activities like the Space Weather Research, Education and Development Initiative (REDI) Bootcamp that we have every year during the summer.

LUNAR SOLAR ORIGINS EXPLORER (LUNASOX) FOR THE DEEP SPACE GATEWAY.

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Introduction: We propose the Lunar Solar Origins Explorer (LunaSOX) as a remote sensing suite of telescopes for exploring physics of the solar corona onboard Deep Space Gateway (DSG). Our goal is to capitalize on the unique observing conditions offered by total solar eclipses to achieve breakthroughs in the exploration of the corona and the source regions of the solar wind through imaging in coronal emission lines with rich diagnostic capabilities, over a distance range covering the first few solar radii, starting from the surface. Onboard DSG in lunar orbit, with periodic solar eclipses at cadences of hours to days depending on the orbit, our proposed imaging solar coronagraph would observe the solar corona to low solar altitudes with solar disk occultation by the lunar limb. Here we describe only the visible wavelength coronagraph, but other telescopes could be added as part of LunaSOX for limb-occulted observations of the solar corona, the geocorona, and lunar gas & dust at other wavelengths.

The highest spatial resolution images of the solar corona are achieved at present only by ground-based coronal observations during total solar eclipses (Figure 1). Emission from coronal forbidden lines in the visible to near-infrared range 400 – 1000 nm traces density and temperature of coronal plasma through excitation of heavy ions. Although dominated by Fe, spectral lines also include the weaker yet resolved Ni, Ar, and S line. Ratios of lines from ions with low (Fe, Ni) to high (Ar, S) first ionization potential at similar plasma temperatures, respectively, trace the evolution of abundances from closed to open magnetic field lines. The spatial evolution of coronal electron temperatures can be determined from ratios of Fe X (Fe^{+9}) – Fe XIV (Fe^{+13}) line emission. Altitude evolution of Fe charge states and corresponding electron temperature can be tracked across coronal structures and out into solar wind acceleration along open field lines. Since collisional excitation falls off rapidly with coronal density, whereas detectable radiative excitation continues into the outer corona beyond three solar radii, observations can track transition to collisionless plasma where charge states and temperature become “frozen-in” and correlated to solar wind ion charge state measurements near Earth. Such observations are fundamental for determining the location of the transition from closed to open field lines, essential for understanding coronal heating and solar wind ion acceleration.

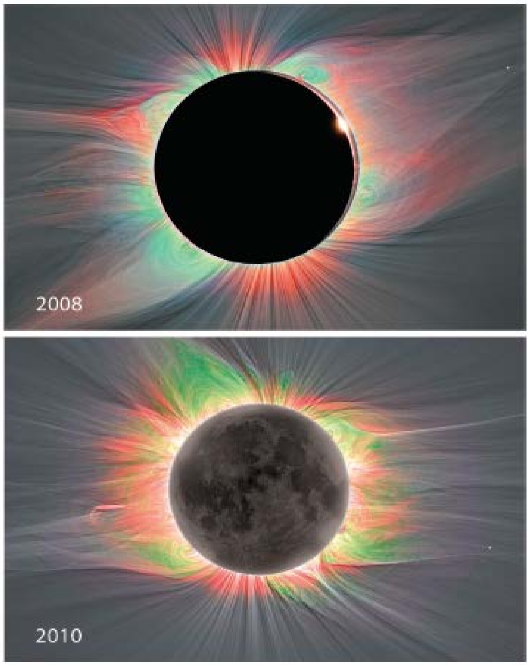

Figure 1. Coronal white-light and multi-wavelength (color) electron temperature distributions from ground-based solar eclipse observations in Fe XI (red) and Fe XIV (green) in 2008 and 2010 [1]. DSG images would be at higher brightness sensitivity and resolution.

In addition to these diagnostics, eclipse observations have also led to the discovery of the dynamic evolution of plasma instabilities, ranging from vortex rings, twisted helices, expanding loops, faint nested loops, turbulence structures, and plumes, all occurring in the immediate neighborhood of prominences [2], which are invariably surrounded by the hottest coronal material. Forming in the stronger magnetic field near the Sun, the features are likely to expand in the weakening magnetic field with the solar wind to become larger density structures observed at 1 AU [3]. Textural inhomogeneity of solar wind structures [4] is likely born in these small-scale nonuniformities. Tracking outward evolution in size, density, speed, and temperature of these features, otherwise invisible to currently operating space coronographs, could inform space weather forecast models for the geospace environment.

There is currently no operational capability for multi-wavelength imaging of coronal structures spanning several solar radii starting from the solar surface. The still operational LASCO C2 and C3 coronagraphs use external occulters, with a maximum white-light sensitivity only beyond 2 and 3 R_S respectively, have no multi-wavelength imaging capability. The same applies to the Sun Earth Connection Coronal and Heliospheric Investigations (SECCHI) on the twin Solar Terrestrial Relations Observatory (Stereo) A and B spacecraft, and SECCHI.

Two international missions, currently slated for operation around 2020, could significantly advance the state of the art for multi-wavelength imaging of the inner solar corona. The dual PROBA-3 satellites of the European Space Agency will operate in 2021 – 2022 with two narrow-band filters for He and Fe emission lines, and a resolution of 5.6 arcsec. They would fly in formation with one satellite carrying the ASPIICS coronagraph [7] and the other acting as an external occulter for coronal observations at 1.08 – 3 R_S. The 100-meter spacecraft separation would minimize vignetting effects that normally degrade sensitivity and spatial resolution. India will launch the 5-year mission Aditya satellite to L1 in 2020 – 2021. It will include coronal measurements at 1.05 – 3 R_S with the Visible Emission Line Coronagraph (VELC) and an internal occulter to minimize vignetting. It will have one spectral channel for white-light imaging at 1.25 arcsec and three for narrow-band imaging.

From the United States, however, there are no plans to develop and launch comparable coronagraphs. Current NASA heliophysics decadal survey priorities and funding are focused on the Parker Solar Probe (PSP) whose Wide-field Imager (WISPR) will image the inner white-light corona only beyond 2.3 R_S at perihelion [8]. Other coronagraphs capable of inner corona imaging may conceivably be developed for small satellites that could launch in the PSP epoch or thereafter. But current developmental focus at NASA and NOAA seems to be on compact coronagraphs of lower spatial resolution for space weather applications.

LunaSOX High-Resolution Inner Coronagraph: To fill a critical gap in the exploration of the physics of the inner corona, we propose a high-resolution coronagraph, using the Moon as an occulter. It would take advantage of the unique vantage point from a lunar orbit on DSG and return spectroscopic images at daily to hourly cadence comparable to those of Figure 1. We propose a 200-mm optical telescope, with a ~ 1 arcsec resolution for white light imaging and ~ 4 arcsec for coronal emission lines, using a rotating wheel of narrow-band filters. This would allow detection of small-scale density structures down to ~ 1.1 R_S and tracking of coronal density, temperature, and compositional evolution with increasing altitude into the solar wind acceleration region at 2 – 6 R_S. All of this would be done at a daily to hourly cadence, depending on the DSG orbit, far surpassing that provided by ground-based solar eclipse observations.

For equatorial or polar orbits the consecutive lunar limb crossings, as viewed from DSG, would allow viewing of the east-west or north-south hemispheres of the solar corona with complete images for each pair of limb crossings in circular to elliptical orbits. A low altitude orbit would provide full images every two hours, while an elliptical orbit 1x10 R_M would do so every 24 hours. Higher perilunes would generally give slower cadences. Viewing times of the occulted corona at 3 R_S [1] would vary accordingly from 20 seconds per limb crossing in the low-altitude orbit to twenty minutes in the 1x10 R_M elliptical case.

Observations at lowest solar altitude would need to contend with Bailey's Beads arising from solar disc light scattering through the irregular topography ±8 km of the lunar limb and seen by ground observers just prior to and after totality. However, the topography has been precisely mapped by NASA's Lunar Reconnaissance Orbiter (LRO) so the particular topographic configuration could be anticipated for each limb crossing.

Another unique challenge of the lunar orbital environment would be clouds of small dust particles produced mainly by meteoritic impacts and producing local optical scattering backgrounds with scale heights up to 20 km in lunar surface altitude. As viewed from 10 R_M in an elliptical DSG orbit, this background would be present at solar distances up to 1.2 R_S. The lunar dust environment has now been extensively measured by LRO and by the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. Background dust brightness, $\leq 10^{-12}$ of solar brightness B_S [9-11] is similar to maximum sensitivity of LASCO C3 [5] > 3 R_S as an upper limit on coronal brightness sensitivity that the DSG coronagraph might achieve, as compared to 10^{-9} B_S from ground eclipse telescopes.

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DEVELOPMENT OF A LUNAR SURFACE ARCHITECTURE USING THE DEEP SPACE GATEWAY.

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Before sending crews to Mars – a journey of unprecedented autonomy – the capability to perform activities and use technology intended for Martian missions must be thoroughly tested and successfully demonstrated in a similar environment. The Earth's moon provides a great deep-space analog where unanticipated risks and challenges can be identified and best practices and recommendations established.

NASA's NextStep-2 program is an incremental approach to the Journey to Mars, which includes the Moon as a proving-ground and utilizes both a Moon-orbiting Deep-Space Gateway (DSG) habitat, and a Mars-bound Deep-Space Transit (DST) spaceship. As part of this architecture, a Lunar Lander descending from the DSG to the surface of the Moon, carrying crew and equipment, presents a renewed opportunity to test surface technologies and operations in support of deep-space exploration. [1]

The rationale justifying this addition to the NextStep-2 program lies in the comparison of current strategic knowledge gaps (SKG's) and technology area (TA) roadmaps for both Lunar and Martian surface operations. [2, 3, 4, 5, 6,] The comparison shows that similar knowledge gaps exist for both the Moon and Mars. If the same questions exists for two destinations, why not begin with attempting to answer them in the closer of the two? Upon identifying overlapping items for both environments, our team produced a concept of operations for a lunar surface mission addressing these topics and other key research areas applicable to Moon and Mars. By generalizing lunar lessons to the Martian environment, this surface mission fits within the scope of the "proving ground" objective of NextStep-2.

Under the constraints of three total landings, four crewmembers, thirteen metric tons per cargo module, and a six-week mission duration including one lunar night, our team analyzed the logistics and feasibility of a DSG-enabled, lunar surface mission, and optimized a base layout design in order to accommodate all identified surface objectives. The proposed timeline is shown in Figure 1. During this mission, the DSG will provide support for:

a) Communications
b) Telerobotics
c) Advanced scientific research
d) Contingency operations

This paper explains our architectural approach and trade studies for several design factors, including the utilized equipment, mass, volume, power, and mobility hardware required for such a long-duration Deep-space surface mission. The integration of lunar landings with the NextStep-2 architecture, and the logistical interface between the lunar surface facilities and the Deep-Space Gateway are discussed. A mission schedule plan detailing weekly tasks and activities is provided in order to demonstrate the types of data and results that could be harvested from this effort.

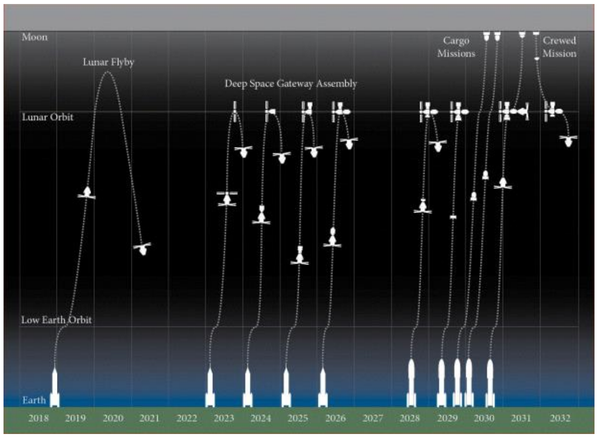

Figure-1. Mission Sequence

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DEEP-SPACE ENVIRONMENTAL EFFECTS ON IMMUNE, OXIDATIVE STRESS AND DAMAGE, AND HEALTH AND BEHAVIORAL BIOMARKERS IN HUMANS.

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Introduction:

Cell-mediated immunity has been demonstrated to be reduced in human subjects during long-duration spaceflight [1], and a relationship between the observed immune changes and reactivation of latent viruses has been confirmed. Postflight human testing has revealed severely depressed T-cell function after 6 months of flight but unaltered function after short-duration flight. Altered cytokine production patterns and potentially a shift to the Th2 pattern have been observed after spaceflight. Natural killer cell, monocyte, and neutrophil functions have all been found to be reduced after spaceflight. Latent herpes viruses reactivate to a high level during short-duration spaceflight, and new preliminary data indicate that this phenomenon also persists during long-duration flight. Long-duration flight has also recently been shown to result in elevations in an array of plasma cytokines, indicating that in vivo immune alterations associated with various physiological adaptations persist during flight. In addition, stress hormone levels have been found to be elevated during and after flight and to be heavily dependent on mission duration as well as biomarkers for oxidative stress and damage [2].

The question is, therefore, whether the immune system, oxidative stress and damage, and changes in antioxidant status may affect behavioral stress and other systems to a larger extent in deep space than in low Earth orbit because of synergistic or additive effects of deep space radiation with the other spaceflight environmental factors (e.g., 0*g* and isolation). Such synergistic effects on physiology may increase specific health risks for exploration crewmembers. Since the deep space radiation effects cannot be simulated on the ground in humans, Gateway research in astronauts is needed to answer this question.

Methods: The methods will be based on biomarker detection in biological samples (stabilized or dry saliva, blood, urine, and feces) that will be returned to Earth at various intervals, mirroring (where feasible) collection timepoints such as those currently used when collecting such samples from crewmembers on the International Space Station (ISS). For these purposes, collection devices will be needed in the Gateway habitat. Current assays on the returned samples include (1) stress hormones, (2) cytokine concentration, and (3) latent viral DNA. This affords an assessment of stress, immune status, inflammation, and latent viral reactivation (an adverse clinical outcome that can be measured).

Alternatively, to minimize sample return, an option could be to conduct some onboard analysis of blood cell distribution, leukocyte subsets, various soluble proteins, cytokines, and stress hormones.

Collection of longitudinal physiological and behavioral metrics (such as cognition, fine motor skills, task monitoring, and others) and monitoring of in-mission clinical events will enable an assessment of whether inflight changes in the proposed biomarkers can be used as early predictive measures.

Resources Required: In order for blood to be collected (for serum or whole-blood assays), a blood collection kit containing items such as skin-disinfecting wipes, gauze, band-aids, butterfly needles, blood tubes, and gloves (total mass 0.266 kg, total volume 3071 cm^3), and a sharps container (0.125 kg, 1742 cm^3) of some sort would also be needed. Serum separator tubes (SST) would be required (minimum tube size available is 3.5 mL, 13 x 75 mm plastic with clot activator/polymer gel), as well as a centrifuge. Portable centrifuge models currently available are in the range of 27.94 cm x 27.94 cm x 25.4 cm (19828 cm^3) and weigh about 10 lb. A freezer capable of cooling to at least -20ºC would be required. Whole ambient blood samples collected in a preservative may be returned to enable leukocyte distribution assays to be done. The preserved samples could be stored for 7 to 14 days.

For urine collection, a urine collection kit containing single-void urine collection devices, wipes, adapters, tubes, and a urine containment bag would need to be flown to collect single-void urine samples (mass ~ 1.5 kg, volume 17749 cm^3).

Fluid saliva collection requires salivette bags and salivette tubes (0.019 kg, 258 cm^3) and would be done using passive salivation into a salivette, centrifuging the sample, and then freezing at -20ºC.

Alternatively, dry saliva collection hardware is already flight certified for ISS, and used as part of the "Functional Immune" study. Dry saliva books measure 4″ x 1.25″ and are paper thin. Assay development would be required to expand this technology for additional analytes.

Fecal collection for microbiome analyses requires a fecal collection kit containing fecal swab tubes, swabs, outer fecal container bags (total mass 0.826 kg and volume 1524 cm^3).

For in-flight analysis of fluid-based biomarkers, in-vehicle imaging cytometry and immunoassay techniques will be required.

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CRAFT: Collaborative Rover and Astronauts Future Technology

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Introduction: As the ISS will be de-orbited in the next few years, we need to think beyond. The future step in the space exploration are missions to the Moon or to Mars, astronauts and engineers have to be ready for it. To accomplish these new missions, telerobotics are essential. Robots have already demonstrated their potential for the space exploration and they are likely to play an important role alongside Humans for future extra-terrestrial missions. Therefore, improving the Human/Robot collaboration is a challenging field of work that is complicated by the special environment in which astronauts have to progress through. A special effort has to be made in order to make interfaces as intuitive as possible. In the context of space exploration, space agencies and companies are currently researching and developing projects on Human-Machine Interfaces (HMI). This is the way humans and machines interact and work together to accomplish different tasks. This is vital as machines perform better and better, and men will need to interact with them and often rely on them during future space exploration missions.

The space exploration has become a reality for several decades and is now looking forward extra-terrestrial colonization. Our closer neighbours, the Moon and Mars are at the centre of attention. The European Space Agency (ESA) is developing its “Moon village” concept that aims to establish the first manned base on the Moon. To achieve this goal, robots will be firstly sent to begin the constructions, before the arrival of the first lunar inhabitants. Moreover, the private sector also wishes to take part into space exploration: Elon Musk, SpaceX founder and CEO, wants to send humans on Mars by 2024. These projects reflect the new approach of space exploration activities.

Objectives: In all these new projects, it appears undeniable that robots will play a major role alongside Humans. Astronauts will constantly have to deal with high workloads, high-risk, technology-dominated environment, and the effects of the environmental condition. Even simple tasks, as carrying tools, walking, are very constraining. Using robots will save time and ensure the astronauts a greater safety.

Our project, CRAFT, is focusing on the relationship between astronauts and rovers to best work together during surface explorations. The exploration of planetary surfaces (Mars, Moon…) will require not only astronauts but also robots to achieve some tasks during their mission. Robots will help and assist astronauts, and will also carry out tasks outdoors autonomously. In order to simulate this type of missions, and to give the astronauts the best preparation, our project is to develop a rover doing all these tasks.

A robot system brings a lot of challenges such as weight and size constraints, sensors and actuators suitable for extraterrestrial environnement conditions, communication delay. In this work we present the CRAFT rover that we designed for the challenges of HMI exploration missions.

Equipment facilities required: Our CRAFT rover will not only be an autonomous rover but also the astronauts partner. CRAFT will be able to navigate in rough terrain and explore areas to work on relevant sites.

The delay between a ground station on Earth and a rover on Moon is limited to 100 Mbit/s and delayed by two seconds in each way. Nevertheless during exploration missions, monitoring and intervention on robot’s task execution is primordial. Sevevre delays and periods of blackouts between the Earth and the Moon during high level tasks, will be partly solved by using the METERON technology developed by ESA. The rover could be monitored from different control centres : Earth control centre, DSG orbital centre, Moon base control room.

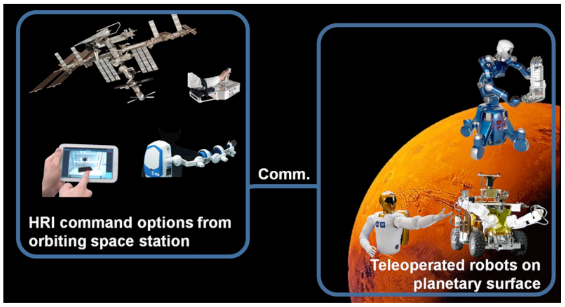

Figure 1: Space telerobotics with the Meteron experiment

The CRAFT rover would have two operations modes : the autonomous mode and the collaborative one. Morover it will be equipped by:

Locomotion system: It will be equipped by a high maneuverable locomotion system (using individually steered wheels), stereo cameras, inertial measurement unit, GPS, self-localization system, environment mapping, robotic arm, and also by human linked systems.

EVA operations system: On autonomous mode, during EVAs, the rover will be able to dig and take sample thanks to his six degree-of-freedom robotic arm (while recording each location and time of sampling tasks). His perception of the environment will be purely vision-based thanks to stereo-cameras.

The rover will also be able to send astronauts datas (hearth rate, temperature, etc) to the control centres (Earth control centre, DSG control centre and Moon Surface control base).

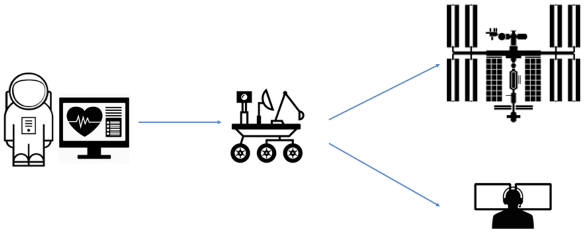

Figure 2: CRAFT communications scheme

In case of any malaise, the rover will be extended in a medical stretcher and will go automatically to the moon base.

We designed this CRAFT rover to operate both in autonomous mode and in monitoring mode in order to assist the astronaut and to rescue him if necessary. This is essential to conduct efficient and safe exploration space missions.

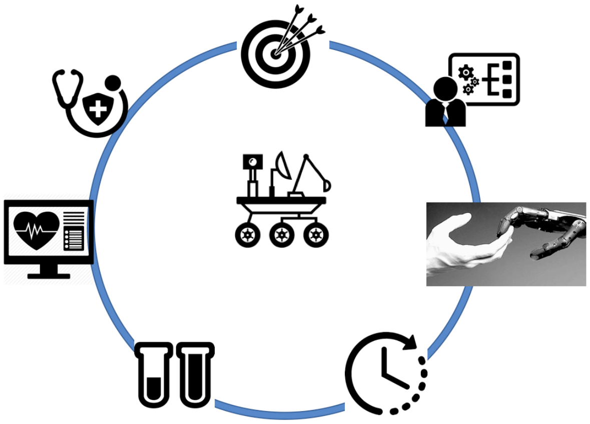

Figure 3: Main advantages of CRAFT utilisation

To conclude, CRAFT project will enable many step forwards for space exploration. Not only its autonomous mode will enable the astronauts to optimize their time, but also its collaborative mode will make EVAs safer. Indeed, the collaborative work between CRAFT rover and the astronauts will rise effectiveness and success of EVA's operations. Moreover these dangerous activities will be monitored by the rover and it will bring back the astronauts to the habitat in case of emergency.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Neal Y. Lii , Daniel Leidner et all (2015) *Simulating an extraterrestrial environment for robotics explration : the meteron supvis-justin telerobotic experiment and the solex proving ground.*[2] A. Schiele (2011) *METERON- vqlidqting orbit-to-ground telerobotics operations technologies,* Symposium on Advanced Space Technologies for Robotics and Automation.

COMPLEX CLOUD AND RADIATIVE PROCESSES UNFOLDING AT THE EARTH'S TERMINATOR: A UNIQUE PERSPECTIVE FROM THE PROPOSED DEEP SPACE GATEWAY.

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Introduction: The dynamical, microphysical, and radiative properties of clouds are not understood well enough for the purposes of accurate predictive climate science based on Global Climate Models (GCMs). Major roadblocks to progress are presently inadequate answers to questions such as: How do clouds change in a warmer climate? I.e., the "cloud feedback" issue. What will storms, including extreme weather events (hurricanes, tornadoes, etc.) be like in the future climate? How do clouds interact with anthropogenically- or even naturally-generated particulates? I.e., the so-called "indirect" aerosol effect on climate—also a key question in a number of global warming mitigation proposals based on geoengineering.

The root cause of this inadequacy is the daunting complexity of cloud physics and dynamics, and extending to cloud particle optics, and to the associated radiative properties across the entire electromagnetic spectrum, as required for both radiation budget estimation in weather and climate forecasting and remote sensing purposes. Clouds are indeed manifestations of the highly nonlinear physics and dynamics of the Earth's atmosphere where deep and shallow convection play key roles, as does fluid dynamical instability and the ensuing turbulence (ranging from huge geostrophic scales down to tiny dissipation scales). This multi-phase flow generates and entrains cloud particles that range in size from diminutive condensation nuclei to massive hydrometeors that can wreck havoc when hitting the Earth's surface.

Survey of state-of-the-art passive cloud remote sensing: In support of cloud-related weather and climate science, the global satellite remote sensing communit—at NASA and elsewhere—is heavily invested in maintaining and improving observations of clouds at wavelengths ranging from the UV to microwaves, with much of the heavy lifting in terms of global coverage coming from the reflected solar spectrum, and especially the visible (VIS), near-IR (NIR, VNIR for both), and shortwave-IR (SWIR) regions. Indeed, observations at VNIR wavelengths not selectively absorbed by water (condensed into cloud particles or not), nor by major or minor gases, inform us about overall cloud structure and opacity. Liquid and ice particles absorb somewhat differently in the SWIR region, hence phase discrimination capability arises, as well as an inherent sensitivity to cloud particle size. Polarized VIS light has also been used to infer cloud particle size from cloudbow phenomena. The spectral absorption features of water vapor at VNIR, SWIR and thermal-IR (TIR) wavelengths are of course paramount to comprehensive cloud studies. Finally, the vertical distribution of clouds has been probed passively using stereography and oxygen absorption in the VNIR, as well as cloud top brightness temperature in the TIR "windows" provided there is ancillary knowledge of the atmosphere's thermal stratification—itself affected by clouds.

Multi-channel passive microwave remote sensing is not of immediate interest here but, for the record, it provides at coarser spatial resolution the total and condensed water columns, including precipitation.

Again for the record, large precipitating hydrometeors can be detected with conventional (cm-wavelength) weather radar systems in space. With new sophistications in Doppler and polarization decomposition, fall speeds and crystal habit can be assessed. Other active methods, lidar in VNIR and mm-wave radar, are not of immediate interest in the present context either, except as benchmarks for validation of passive methodologies. They are currently used extensively in that capacity, and will continue to be in the foreseeable future, including the new techniques described further on. Morever, although extremely valuable, active sensing of clouds only delivers a sub-satellite "curtain" of information. Over time, this limited spatio-temporal sampling can deliver cloud climatologies that may challenge the status-quo but to improve the representation of clouds in GCMs one needs global coverage from passive imaging sensors.

The fundamental shortcoming of current passive cloud remote sensing. To retrieve inherent cloud properties from VNIR-SWIR-TIR radiances measured by spaced-based sensors, one needs a physics-based forward model for the observed signals from every pixel, at every wavelength and, as needed, at in every measured state of polarization. Current operational retrievals of the inherent cloud properties of interest to cloud and weather/climate modelers are predicated on radical assumptions about cloud geometry: flat top, flat bottom, and horizontal uniformity inbetween. This representation blatantly contradicts everyday observations of clouds, including satellite imagery. However, operational satellite data processing has to be very fast in view of the data volume. Therefore it is performed on a pixel-by-pixel basis and that simplistic assumption about cloud geometry enables retrieval algorithm developers to invoke so-called "one-dimensional" (1D) radiative transfer (RT) models that have been computationally tractable since the beginning of NASA's Earth Observing System (EOS) era in the late 20th century.[1] Ensuing biases have been documented abundantly in the so-called "three-dimensional" (3D) RT literature.

Summary: The cloud science community is struggling with the limitations of its own capabilities in (in-situ) observations, in fluid-dynamical computation (although this is a moving target), and in the theoretical understanding of cloud-scale processes that is required to formulate the next generation of cloud parameterizations in GCMs. At the same time, the cloud remote sensing community is confronted with the ramifications of the so-called "plane-parallel/1D" cloud assumption that is hard-coded into operational retrievals of the very cloud properties of interest to the above.

At the core, cloud physics and dynamics modelers need global remote sensing retrievals of inherent cloud properties even in the presence of strong horizontal variability. From the above discussion, it is clear that this science-driven requirement challenges the cloud remote sensing community at its own core.

What can an Earth-observing sensor on the Deep Space Gateway (DSG) do to overcome this conundrum? There is one region on Earth were 3D RT effects in cloud scenes are at their most spectacular across the solar spectrum (i.e., NVIR+SWIR), namely, the day/night and night/day transitions, a.k.a. "terminators." By definition, incoming solar radiation at terminators is at grazing angles. One only needs to think about watching from the Earth's surface a cloud-graced sunrise or sunset. At that special time-of-day, and thanks to the Earth's curvature, clouds can be illuminated from below rather than above, and with naturally-filtered light that favors red versus blue wavelengths. At these extreme incidence angles, clouds can cast such long shadows that anticipated "reflections" of sunset or sunrise light toward the ground or space may not occur.

From the DSG's vantage point, these terminators take a couple of weeks to move across the Earth's disc. This is an unprecedented opportunity to observe and investigate clouds crossing both day-to-night and night-to-day transitions, which are obviously key events in their diurnal cycle, with the turning on and off of solar heating. Such observations can be collected from the DSG at high spatial and temporal resolutions, enough to advance the science providing that the forward signal modeling follows suit.

At present, regions with the grazing solar incidence that defines terminators are of course known to be liabilities in operational cloud remote sensing, and are therefore either avoided altogether or flagged and filtered. That down-selection seems reasonable. In radiation budget estimation studies, however, it isn't that simple. On the one hand, little solar radiation is involved due to the near-horizontal solar incidence. On the other hand, excluding from consideration (or accepting large errors in) an annulus of finite size that runs all around the planet isn't a viable option either from the standpoint of planet energetics. This is especially true in the Arctic and Antarctic, which are highly sensitive to global warming, with potentially dire consequences via ice melting and ensuing sea-level rise.

We therefore percieve detailed observations from the DSG of regions of the Earth with very low solar incidence, either daily or annually, as a challenge in cloud remote sensing that can be met with the proper resources. Theoretical and computational 3D RT has indeed made huge progress over the past couple of decades and, combined with concurrent progress in computer science and technology (e.g., Moore's law), it is now poised to become the basis of operational cloud remote sensing.

Recommended DSG instrumentation: To rise to the challenge posed by cloud studies in the "low sun" zone, and elsewhere, we need a multi-spectral sensor not unlike the Enhanced Polychromatic Imaging Camera (EPIC) on the Deep Space Climate Observatory (DSCOVR) that orbits the Earth–Sun "Lagrange 1" point, at about four times the distance to the Moon. Replicating EPIC on DSG would thus increase its spatial resolution from ~8 to ~2 km pixels. But EPIC was designed and built with technology from the 90s. Current CMOS focal plane arrays (FPAs) are far more efficient than EPIC's CCD, with ~25% QE. We can thus gain another factor of 3 to 4 without sacrificing SNR. Advanced data compression and denoising will also contribute another net gain in spatial resolution, say, down to ~0.5 km scales at which most clouds can be detected. All that with a sensor that weighs ~60 kg and consumes ~60 W. EPIC has 10 spectral channels, ranging from UV to NIR, on a filter wheel. At the cost of more weight, say, up to 100 kg, one can extend the spectral coverage into the key SWIR and TIR regions (at somewhat lesser spatial resolution) by splitting the beam from the telescope and directing light into two other FPAs with SWIR- and TIR-sensitive materials. Astronaut-enabled calibration/upgrades are welcome.

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[1] Recent releases of cloud properties derived from satellite sensors such as MODIS-Terra and –Aqua consider the pixel's spatial context. However, this extra effort is only to address retrieval quality control. In essence, the more homogeneous the surrounding area, the better the retrieval that ignores spatial variability will perform.

Instruments for Deep Space Weather Prediction and Science.

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Introduction: We discuss remote space weather monitoring system concepts that could mount on the Deep Space Gateway and provide predictive capability for space weather events including SEP events and CME crossings, and advance heliophysics of the solar wind. Accurate predictions of space weather are of critical importance for deep-space missions, because particle storms and related events can induce harmful or even lethal ionizing doses in unprotected astronauts, and feasible mitigation strategies all involve at least partial suspension of mission operations while astronauts retreat to a small, massy radiation shelter within the spacecraft. Storm predictions with high false-positive rates waste valuable astronaut time, and storm predictions with significant false-negative rates could harm astronauts through excessive radiation exposure.

The monitoring/prediction system comprises a polarizing coronagraph and a wide-field heliospheric imager, mounted on the Gateway to provide "nowcast" images to the Gateway and/or the ground. The system could be mounted on a Sun-pointed portion of the Platform, such as a solar array mount; or could be body-mounted with an included gimbal to achieve Sun pointing from a variety of Gateway attitudes. Polarization enables 3-D measurement of the position and trajectory of solar wind features (including CMEs) enroute from the Sun, to predict event arrival at the Gateway or at Earth. Mass, power, and telemetry requirements vary greatly depending on desired additional benefits. A compact dual-channel platform (DAMASC form) could operate with under 10kg of mass, a few watts of required power, and a few kbps of telemetry, but with applicability limited to basic space weather prediction; while a larger platform (DELPHI form) might require 40-50kg, 30W of power, and up to 1Mbps ot telemetry, but would yield discovery science of the poorly mapped large-scale structure of the solar wind far from the Sun.

Space Weather Prediction

The most important space weather events are caused by passage of coronal mass ejections (CMEs) and, more commonly but less vigorously, solar wind stream interaction regions (SIRs, also corotating interaction regions or CIRs). These events involve propagating density fronts or shocks that are caused by fast-moving, dense bodies of solar wind material ejected from the Sun at high speed. Shocks, in particular, can produce delayed solar energetic particles (SEPs) and other sources of ionizing radiation, cause spacecraft charging events, and/or cause geomagnetic storms at Earth. CMEs are impulsive ejection events caused by magnetic instabilities at the Sun, and are difficult to predict based on direct solar observation alone – but can be identified in image sequences from coronagraphs. The very largest CMEs are associated with large geomagnetic storms and with near-lethal ionizing radiation pulses in deep space. SIRs are caused by interaction of quasi-stationary wind streams leaving the Sun at different rates, and can give rise to stationary shocks with similar symptoms to mid-sized CMEs. Tracking CMEs and SIRs improves strength and arrival time predictions by factors of 2-3 with current technology, and coronagraph measurements are considered critical assets by NOAA's Space Weather Prediction Center.

CMEs and SIRs can be detected and tracked using ordinary visible sunlight, scattered from free electrons in interplanetary space. The degree of polarization of the scattered light is an indicator of 3-D location of the feature. The scattered light is faint and, more than about a solar radius above the Sun, cannot normally be detected from within Earth's atmosphere. However, probes in Earth orbit or deep space (e.g. *Skylab, SMM, SOHO, STEREO*) can image features quite far from the Sun in the sky. *SOHO*, in particular, has been operated for over two decades because its coronagraph (*SOHO*/LASCO) has become important for identification and early tracking of CMEs departing the Sun, to predict terrestrial space weather.

Currently, *SOHO* is the only operating coronagraph in deep space. Deploying additional space-weather-capable imaging instruments is a critical part of any viable long-term manned exploration strategy.

Instrument concepts

We will describe three principal concepts, in increasing order of instrument quality and resource requirements. A basic space weather prediction capability would be satisfied by the DAMASC concept, a dual-acquisition, minimal-resource instrument that affords tracking of space weather events from Sun through the inner heliosphere. Improved tracking and imaging are afforded by the DELPHI concept, a steerable high quality imaging system that can be scanned around the inner heliosphere to track events of import, or in a regular pattern to capture space weather fronts as they propagate. To capture both space weather prediction and advance understanding of the currently not-well-explored cross-scale physics of the inner heliosphere, SP4CE, a quad-camera system with fully annular wide-field imaging, would provide high resolution imagery of the entire inner heliosphere on a 1-2 minute cadence.

Using DSG to build the capability of space weather forecasting in deep space. Edward E. DeLuca[1], L. Golub[1], K. Korreck[1]; S. Savage[2], D. D. McKenzie[2], L. Rachmeler[2], A. Winebarger[2], P. Martens[3] [1]Harvard-Smithsonian Center for Astrophysics; MS 58; 60 Garden Street; Cambridge MA 02138 edeluca@cfa.harvard.edu. [2]NASA MSFC, NSSTC ST13, 320 Sparkman, Dr. Huntsville, AL 35805; [3]Georgia State University
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Introduction: The prospect of astronaut missions to deep space and off the sun-earth line raises new challenges for space weather awareness and forecasting. Combined efforts of the science and human flight communities are needed to identify the requirements and identify pathways that will allow us to address the requirements for protecting human life and equipment, on a timescale consistent with the deep space exploration program.

Role of Deep Space Gateway: The DSG provides a platform where we can develop, test and validate a combined space weather instrumentation, analysis and forecasting system that can be used when out of routine contact with near earth based assets. This presentation will attempt to outline the bounds of the problem and start the discussion about how to build an independent space weather program.

- Develop the requirements – is it only SEPs? Do we need to track CMEs? Do we need to forecast flare radiation? How about cosmic rays?
- Understand the communication issues – on what time frame can we expect data transfer from near earth assets? Is it feasible to construct a system that also includes direct communication between observing stations?
- Understand our current forecasting capabilities – esp SEP forecasts.
- What do we need to improve in the forecasting capabilities? What are the required measurements/observations? Can these be made on board?

Requirements for Deep Space Gateway: Instrument testing and validation requires a DSG orbit with substantial solar viewing (NHRO, EMDRO, or EML2). The availability of a test platform like the The CisLunar Interchangeable Observatory for Heliophysics (CLIOH) will facilitate a competitive appraisal of different instrument packages.

Solar X-ray and Gamma-ray Imaging Spectroscopy.

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Scientific Rationale: X-ray and gamma-ray observations of the Sun over a broad energy range from <1 keV to >10 MeV provide unique information on both the thermal and nonthermal processes occurring in the solar atmosphere. EUV and energetic neutral atom imaging spectroscopy from the lunar surface would greatly augment the scientific value of these observations. While there have been significant advances in our understanding of impulsive energy release at the Sun since the advent of RHESSI observations, there is a clear need for new X-ray observations that can capture the full range of emission in flares (e.g., faint coronal sources near bright chromospheric sources), follow the intricate evolution of energy release and changes in morphology, and search for the signatures of impulsive energy release in even the quiescent Sun.

The science that would be addressed by new instruments on the Moon extends over a very broad range of activity from the smallest nanoflares that may well be the driver of coronal heating to the largest solar eruptive events that produce the most extreme space weather. The Earth's atmosphere makes ground-based observations of this radiation impossible, and observations from spacecraft in low-Earth orbit are generally limited in scope by the ~95-minute day-night cycle and by passages through the van Allen radiation belts. In contrast, observations using X-ray and gamma-ray telescopes on the lunar surface would not suffer from such limitations and thus could provide continuous imaging spectroscopy over the full energy range for periods of up to the length of a lunar day, ~14 Earth days.

These observations would provide key information about a wide variety of solar phenomena including coronal heating, and energy release and particle acceleration in solar flares and in the often-associated coronal mass ejections.

Operational Parameters: The array of instruments that would best address the scientific goals is given in the white paper provided to the Heliophysics Decadal Survey committee on the Solar Eruptive Events (SEE) 2020 Mission Concept [1]. The instruments include EUV, X-ray, and gamma-ray imaging spectrometers, a white-light coronagraph, and an energetic neutral atom imaging spectrometer. Any one of these instruments operating alone on the Moon would make important breakthrough observations but the scientific return would be greatly enhanced by coordinated observations with other lunar instruments in this set and with the many instruments that will likely be in Earth orbit and in ground-based observatories. All of these instruments would require a lunar facility to provide continuous solar pointing to within the ~half-degree solar disk. They would each have their own fine pointing control to achieve the desired arcsecond-class imaging capability.

The expected weight, volume, power, and telemetry requirements vary between the different instruments with the soft X-ray and ENA spectrometers being the least demanding and the gamma-ray instrument the most demanding. Representative values can be estimated by considering the relevant parameters of the Focusing Optics X-ray Solar Imager (FOXSI), a Small Explorer (SMEX) Heliophysics mission that is currently undergoing a Phase A concept study. It uses a 14-m boom to separate the grazing-incidence focusing optics from the pixelated detectors to produce X-ray images with 8 arcsecond angular resolution. FOXSI will be able to observe the largest flares without saturation while still maintaining the sensitivity to detect X-ray emission from weak flares, escaping electrons, and hot active regions. It has an estimated mass of ~100 kg and a volume of 1 x 1 x 15 m; it requires ~100 watts of continuous power and generates up to 10 GB per day depending on the level of solar activity.

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The Moon: A 100% isolation barrier for Earth during exobiological examination of solar system sample return missions. *Barry E. DiGregorio, Buckingham Centre for Astrobiology, University of Buckingham, Buckingham MK18 1EG, United Kingdom*

Introduction: In the coming decades NASA and all other capable space faring nations will want to return samples of Mars, samples of ice from Jupiter's moon Europa and samples of the plumes of water emanating into space from Saturn's Moon Enceladus to look for any evidence of extraterrestrial biology. As exciting as these sample return missions are to astrobiologists, lingering questions on how best to safely examine these samples without accidental contamination of the Earth's biosphere remain problematic. For example, robotic sample return missions that are sent to the surface of the Earth or Earth orbit for laboratory analysis do not offer a 100% guarantee that some technological or other errors would not lead to an eventual exposure of these materials to Earth's biosphere. Even if examined in an Earth orbiting space station, a contamination event might render it uninhabitable, ultimately to reenter the Earth's atmosphere where sections of the spacecraft could survive intact and spread out over vast distances of our planet.

The only 100% guarantee of protecting Earth's biosphere from a hazardous back contamination event is to use the Moon as a sample return examination facility to qualify samples for eventual return to Earth. A well planned lunar quarantine laboratory as part of a larger lunar base would be perceived by the public and scientific community as another legitimate reason to reinvest in a return to the Moon.

Pros: The size of sample return payloads could be much larger because of the Moons 1/3 gravity. Aside from the Moon offering a 100% back contamination barrier to Earth, it also has enough gravity that would make working with extraterrestrial materials less difficult than working in a microgravity environment of an orbital space station or other orbiting module designed for such a purpose. The Moon's lack of an atmosphere with near vacuum conditions greatly reduces the possibility of the spread of a back contamination event to other areas of a lunar scientific outpost.

If putative extraterrestrial microorganisms are found in samples, a lunar planetary quarantine facility could be used to test a wide variety of terrestrial ecosystems in enclosed modules simulating various Earth environments.

Finally, other advantages would be experiments on the mutation rates of terrestrial microorganisms in the lunar radiation environment that might help how humans could best survive radiation exposure on Mars.

Cons: Cost. Obviously the establishment of a lunar quarantine facility as part of large scientific outpost would require the commitment and resources from a number of space faring partners.

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LONG-TERM STABILITY OF SPACEFLIGHT FOOD FOR MULTI-YEAR EXPLORATION MISSIONS

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Introduction: Food is one of the most basic needs for sustaining life and is a major factor in human health and well being. To enable optimal performance of crewmembers on multi-year exploration missions the food needs to supply an adequate amount of calories, provide all required macro- and micro-nutrients, be palatable for an extended period of time, and remain safe for consumption and free from microbial or chemical spoilage. While food intended for terrestrial consumption has a limited shelf life of between 6-24 months, foods packaged for deep-space exploration missions will need to maintain shelf life for at least 5 years, based on plans to send food supplies ahead of the crew in an unmanned vehicle, pre-positioning it on the surface of the intended planet or in orbit around it [1]. Foods that are stored for prolonged periods of time undergo chemical transformations including degradation and loss of vitamin content, oxidation of fats resulting in rancidity, and undesirable changes to texture and taste [2][3]. Such reactions may be accelerated when foods are exposed to the higher levels of radiation found in deep space. A study conducetd on the International Space Station (ISS) evaluated stability of low-moisture food items that were maintained in orbit for a period of 880 days [4]. Although no significant decrease was found in the 30 nutrients measured, the levels of radiation found in deep space are very different from those found in low-Earth orbit and high-moisture foods, which are more radiation sensitive, were not adequately evaluated.

Methods: Food items will be sent to the Deep Space Gateway for storage, and samples will be brought back to Earth for periodic analysis. Food items will include meat products (preferably both fish [high in omega-3 fatty acids] and pork [high in B vitamins]), a vegetable, a fruit, a starch (preferably a vitamin fortified bread product that can be evaluated for stability of B vitamins in a second matrix), and a nut item. Items sent would be mostly high moisture products, which are expected to be more susceptible to raditation effects. Preferably, food items would be kept at 3 conditions onboard the Deep Space Gateway: ambient (21º C), refrigerated (4º C), and frozen (-20º C) to ascertain the best storage parameters for preserving and stabilizing the food items for long durations. Samples of the stored food will be brought back to Earth after 1, 3, and 5 years and the returned food samples will be evaluated for changes that include vitamin content (especially vitamins that are known to be labile such as thiamin), oxidation of fats and fatty acids, evaluation of amino acids, and quality impacts to texture, color or taste. A control set of identical food items will be kept on the ground under the same storage conditions (ambient, refrigerated and frozen).

Resources Required: Ideally, all foods in the space food system would be evaluated to validate stability of individual matrices under deep space storage conditions. However, given resource constraints, the minimum number of foods evaluated should include a wide range of foods and matrices. Assuming 6 different categories of food items are flown (fish, meat, vegetable, fruit, bread, and nuts), initial upmass is anticipated to be between 35 kg and 70 kg, depending on the number of storage temperatures tested. This would equate to a volume of about 0.086 m^3 to 0.171 m^3.

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LUNAR SAMPLE RETURN MISSIONS USING A TELE-ROBOTIC LANDER H. Downes[1,2,3], I.A. Crawford[1,2], Alexander L[1,2]. [1]Department of Earth and Planetary Sciences, Birkbeck University of London, Malet Street, London WC1E 7HX, United Kingdom; [2]Centre for Planetary Sciences at UCL-Birkbeck; [3]Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD, UK

Introduction: The Deep Space Gateway has the potential to engage in acquisition of samples from sites on the lunar surface, and to return them to Earth. Specifically, operation of tele-robotic landers and rovers from the DSG enables more complicated surface operations than can be achieved with purely automated vehicles. Such tele-robotic landers could be developed which can examine different parts of the lunar surface, collect specific targeted samples, and return these samples to the DSG for preliminary examination before return to Earth for analysis. This will pave the way for similar tele-robotic rovers to operate on the surface of Mars in future missions, but will also enable lunar scientists to obtain samples of specific rock-types from previously unsampled parts of the lunar surface, including the lunar farside. This presentation will discuss several possible areas of lunar science in which scientific questions have been posed which could be answered by such targeted sampling.

Farside lunar basalts: Basaltic volcanism on the Moon is mainly found on the nearside and only limited amounts occurred on the lunar farside. All Apollo and Luna returned samples are from the nearside regions. Thus there are many unanswered questions regarding the ages and compositions of basaltic volcanic activity on the farside. There are suggestions that farside volcanism continued to 2.5 Ga [1], which have implications for the heat flow of the lunar interior. Sample return from any of the regions of farside basaltic volcanism would provide many more constraints on models of lunar volcanic activity, as both age and composition could be determined with very high precision on such samples in terrestrial laboratories.

Young lava flow regions: Most lunar lava flows erupted in a narrow time window between 3.9 and 3.1 Ga. Evidence from crater counting suggests that some volcanic activity continued until 2.5 Ga, and even perhaps 1 Ga [2], but the age determined for the youngest sampled lava is only 2.9 Ga. Recently it has been suggested that basaltic activity may have continued until 100 Ma in some regions [3]. Geochronological dating of samples returned from specific regions of the lunar surface in which young volcanic rocks may be present is the only way to determine whether any of these suggestions of young volcanism are correct. If confirmed, these young ages would require significant modification of our models of the lunar interior and its heat production, and would greatly increase our understanding of the processes which caused the volcanic activity.

Silica-rich volcanic units: Silicic volcanism is extremely rare on the Moon, but there is evidence for occurences in isolated regions such as at Compton-Belkovich on the farside and at the Gruithuisen Domes on the nearside [4, 5]. The origin of silicic magma on a planetary body dominated by basaltic magmatism is as yet unresolved. Geochemical analyses of samples from any of the regions in which the products of silicic volcanism have been found would be of immense value in understanding the formation of such magmas, and hence extend our understanding of magmatic processes on the Moon.

Olivine-rich regions: Unlike on the Earth, where samples of mantle and lower crustal material are often brought to the surface as xenoliths in volcanic eruptions, we currently have no samples of the lunar mantle or lower crust. Nevertheless, several localities on the lunar surface have been found to be rich in the mineral olivine, which is thought to be a dominant component of both the lunar mantle and lunar lower crust [6]. Sample return from these sites would allow us to investigate these hitherto uninvestigated regions of the Moon’s interior, and would provide new constraints on models of the origin of lunar basalts and the nature of the lunar crust.

Palaeoregolith deposits: Lunar regolith deposits have been exposed to billions of years of Solar System history, and can provide a record of the solar wind (via ion implantation) and the passage of the Solar System through the Galaxy (via retention of cosmogenic nuclei from Galactic Cosmic Rays (GCRs)) [7,8,9]. Apollo regolith samples were collected from the surface of the Moon, where the regolith has been gardened by meteorite impacts over geological time, resulting in time-averaged records of Solar System evolution. In order to obtain undisturbed records of the ancient cosmic environment, we require samples that have been exposed to the space environment at known times and for known durations [10]. Such records should be retained by regolith deposits which have been covered by younger lava flows. These “palaeoregolith” deposits would contain a record of the solar wind and GCRs which impinged on them while the deposits were at the surface. The record would be terminated when the lava flow buried the deposit. Returned samples of the strata underlying and overlying the palaeoregolith deposit would be amenable to standard radiometric dating, thus providing a precise age and duration of exposure to the intervening regolith. Samples of the palaeoregolith would be analysed to determine their exposure to GCRs and solar wind, using mass spectromentry in terrestrial laboratories.

Mission requirements: All of the sample return missions described above would require similar elements, including (1) precision landing of a spacecraft at locations where specific rock-types are known to outcrop (located via high-resolution cameras); (2) ability of the craft to roam around the lunar surface to locate the precise position for sample collection (via telerobotics by astronauts operating from the DSG); (3) sample collection via boom arms or drilling. The latter would be specifically required for the palaeoregolith deposits which, by definition, are situated beneath the surface of the Moon; (4) extraction of samples or drillcore; (5) examination of samples by camera from the DSG; (6) transfer samples to a return vehicle; (7) return samples to DSG for further examination by astronauts; (8) return samples to Earth for curation and analysis.

Some of these elements are currently undertaken either by Mars Rovers or by submarine Remotely Operated Vehicles (ROVs) operating in scientific missions beneath Earth's oceans. Other elements (precision landing system; extra-terrestrial drilling technologies) are currently being invested in by ESA. Real-time telerobotic operations from the DSG on the lunar surface would provide a wealth of experience which could be transferred to similar operations on other planets, specifically Mars, if future missions included orbiting manned spacecraft.

There is a significant requirement for DSG crew interaction in this project. The astronauts would need to be in contact with the rover whenever the rover was active on the lunar surface. Rover-lander activity could only take place during the lunar day, and when the DSG was in direct communication with the lander.

Facilities for storage of samples in an inert atmosphere (or in vacuum) on the DSG would also be required, to keep the rock samples as pristine as possible before shipment to Earth.

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EXPLORATION OF NEAR-EARTH OBJECTS FROM THE DEEP SPACE GATEWAY.

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Introduction: This is not about specific scientific goals or instruments, but about how clever use of orbital dynamics can lower delta-V costs to go to scientifically interesting destinations. High-energy orbits relative to the Moon, as envisioned for the Deep Space Gateway (DSG), are excellent locations for reaching near-Earth objects (NEOs, either asteroids or comets). Our previous work [1] has explained the advantages of Earth-Moon 2nd libration-point (EM-L2) halo orbits as staging locations for exploration of NEOs and Mars, but other high-energy orbits near the Moon, such as nearly-rectilinear halo orbits (NRHOs; they are large-amplitude EM-L2 halo orbits) or lunar distant retrograde orbits, can also be used [2].

Learning the structure and composition of NEO's is important not only for understanding the formation of the Solar System, but also for planetary defense and for assessing their value for providing fuel and other resourses that could facilitate human exploration of the Solar System. Small satellites (possibly cubesats) kept at or near the DSG could be sent quickly to NEOs, especially newly-discovered objects that will be found in increasing numbers with LSST and other surveys. These robotic science missions could serve as precursor missions for later human missions, first a test mission (6 to 12 months) to an NEO before the longer missions to Mars. This paper will present some trajectories to NEOs with especially low delta-V requirements from an EM-L2 orbit like ones that might be used by payloads deployed from the DSG.

1994 XL1: The The asteroid, (480808) 1994 XL1, about 200m across, is unusual because it has one of the smallest semi-major axes of any asteroid, less than that of Venus and with a perihelion just inside Mercury's orbit. Its aphelion is near Earth's orbit, giving easy close flyby opportunities approximately every six years. One of these will occur in 2022. The trajectory shown in Figures 1-3, from [3], needs only 432 m/s of deltaV, including departure from, and return to, an EM-L2 halo orbit.

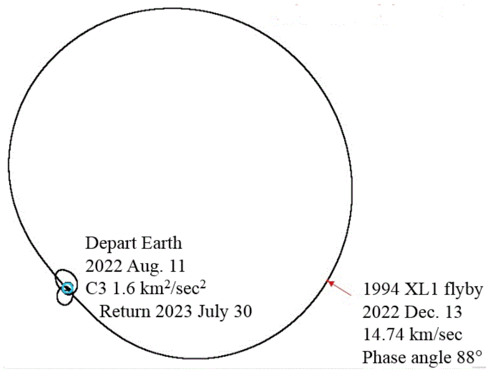

Figure 1: *Ecliptic-plane view of the heliocentric trajectory to 1994 XL. The turquoise circle is the Moon's orbit, showing the scale of both Fig. 1 and Fig. 2.*

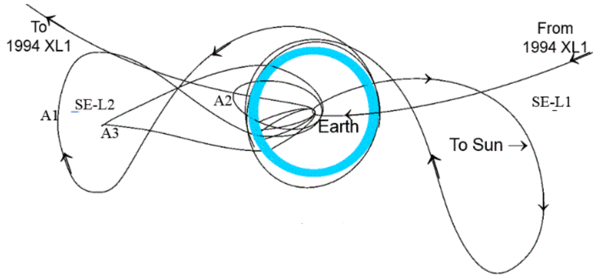

Figure 2: *Solar rotating ecliptic-plane view of the trajectory with the departure and return (from and back to the EM-L2 halo orbit) parts of the trajectory near the Earth.*

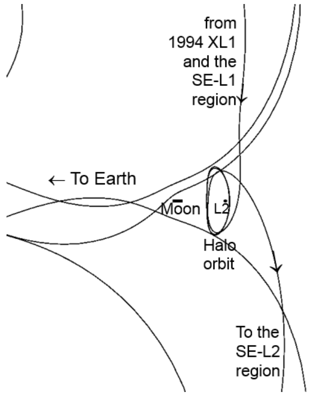

Figure 3: *Earth-Moon rotating lunar orbit-plane view of the trajectory with the departure and return (from and back to the EM-L2 halo orbit), as well as 3 lunar swingbys.*

Comet Wirtanen: This interesting comet, the original target of ESA's Rosetta mission, will pass only 0.08 AU from Earth in Dec. 2018. It provided a low-energy opportunity to visit both this comet, and the split Comet Schwassmann-Wachmann-3, as shown in Figure 4 [4]. It would have been a good opportunity for multiple cubesats, to study the complex environment of the active comet [5]. Although missed, there will be other future near-Earth comet apparitions.

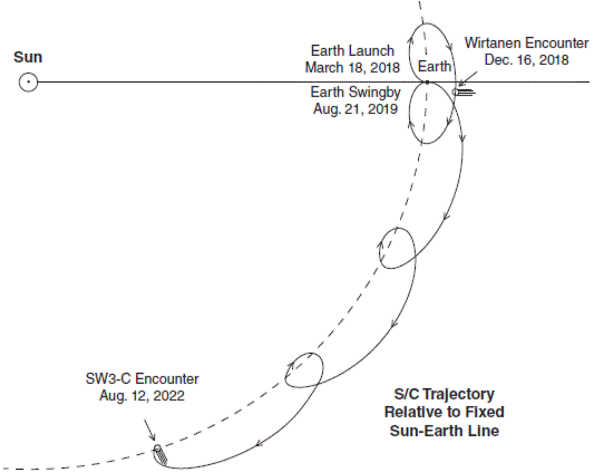

Figure 4: *Solar rotating ecliptic-plane view of the trajectory to Comets Wirtanen and Schwassmann-Wachmann-3.*

2000 SG344: This is one of the most accessible NEOs with a great opportunity in 2029, illustrated in Figures 5 and 6, needing only 1890 m/sec of deltaV and 7 months to and from an EM-L2 halo orbit for a 5-day rendezvous with the asteroid. With a month longer flight time, the stay time at 2000 SG344 can be increased to 30 days with only 60m/s more deltaV. There is a 1-year opportunity to 2000 SG344 in 2027 with several hundred m/s less deltaV.

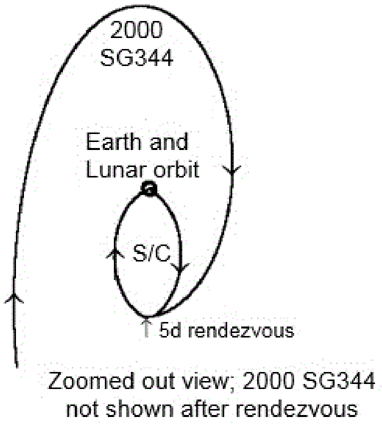

Figure 5: *Ecliptic-plane view of the heliocentric trajectory to 1994 XL.*

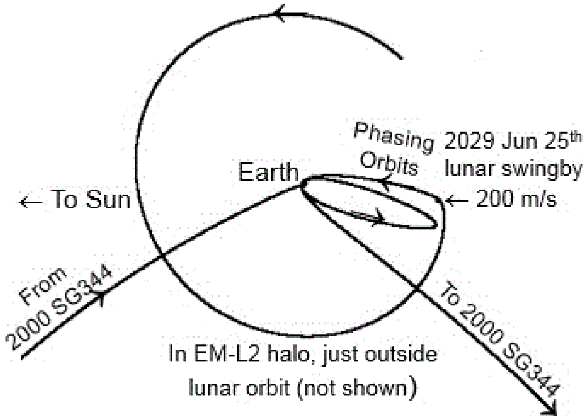

Figure 6: *The part of the trajectory to 2000 SG344 near the Earth is shown in a solar rotating ecliptic-plane projection with a fixed horizontal Sun-Earth line*

Low-thrust trajectories. The trajectories above were computed with impulsive deltaVs. We have optimized the heliocentric part of the trajectory to 2000 SG 344 with both impulsive and hybrid (with low- and high-thrust maneuvers), assuming a crewed vehicle with a dry mass of 58 mt (metric tons) using 150kW Hall-effect thrusters, similar to those assumed in [6]. The calculations indicate that the hybrid mission offers a net reduction of initial mass in Earth orbit of about 6 mt. It is interesting to note that the excess speeds at Earth actually increase over those of the ballistic mission, but this is more than made up by the substantial reductions in high-thrust propellant

Lunar Science: From an EM-L2 halo orbit, any point on the lunar surface can be reached in less than two weeks for a one-way delta-V cost of about 2.5 km/sec. Other trajectory ideas that facilitate achieving lunar science goals are given in another paper [7]. The departure and return Earth orbits are highly elliptical orbits, similar to the phasing orbits shown in Figure 6, so there are extra deltaVs amounting to a few hundred m/sec to transfer from these orbits to an EM-L2 halo.

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EXTERNAL LONG-DURATION MATERIALS INSTRUMENT RESEARCH OBSERVATORY,

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Introduction: The External Long-duration Materials and Instrument Research Observatory (ELMIRO) is a commercial facility that will allow for continuous and repeatable external testing on the Deep Space Gateway of materials, electronics and instruments for future deep space spacecraft. The ELMIRO Facility will be designed and built by Alpha Space Test and Research Alliance, LLC (Alpha Space), to enable scientific testing of new or existing materials in the cislunar environment for periods in excess of 1 year on orbit. This is a follow-on testbed to the Materials ISS Experiment (MISSE) being flown on the ISS in LEO.

The original testing of materials in the LEO environment consisted of the Long Duration Exposure Facility (LDEF), which required two dedicated Space Shuttle missions for deployment and retrieval. Cost for the LDEF program was in excess of $1.0 Billion, including deployment and retrieval flights. The MISSE testing systems were developed as part of a Risk Mitigation Experiment on the Russian Space Station Mir as the Mir Environmental Effects Payload (MEEP). The MISSE program initially developed by the NASA Langley Research Center, was integrated to the ISS by the USAF Space Test Program as part of the Space Experiment Review Board Process within the Department of Defense (DoD).

Since then there have been eight MISSE Missions flown with over 4,000 experiments. Alpha Space signed a cooperative agreement with NASA in 2014 to manage the next generation facility - the MISSE Flight Facility (MISSE-FF) on the ISS. Building off accomplishments and heritage of the previous MISSE flights and the MISSE-FF the ELMIRO would be a natural extension of the MISSE-FF program offering materials testing in cislunar to increase TRL levels for spacecraft components in the deep space environment. Both facilities will benefit NASA and the Aerospace community by pre-screening components at LEO on MISSE-FF, then testing at cislunar for final TRL determination on ELMIRO.

The Alpha Space philosophical approach to the flight of experiments on the ELMIRO is simple. Alpha Space is the hardware development and integration knowledgeable entity required to enable a scientist to do research. The scientist is the knowledgeable person on the research that needs to be conducted. With Alpha Space performing the Integration, Safety and Flight activities, the scientist only needs to focus on the research, thus producing a much better experiment.

The ELMIRO: Alpha Space has developed the MISSE-FF to assist an experiment developer who does not fully understand the methods, engineering, requirements, or environments of space flight vehicles to be able to fly their experiments in space. Without a complete understanding of the flight vehicles, safety process and testing requirements, a scientist will end up devoting most their time to hardware development and not be able to devote any time to experiment development. Furthering the MISSE-FF concept to extend to the cislunar environment, Alpha space will develop the external interface hardware (based on the current MISSE-FF design) for flight on the Deep Space Gateway. Up-grading the MISSE-FF design to the ELMIRO is the most cost-effective method for implementing external testing on the Deep Space Gateway because the majority of the Non-Recurring Engineering has already been developed.

The ELMIRO will consist of four major components. The four components are the Power & Data Box, the Switch Box, the Material Sample Carriers and the facility structure. The Alpha Space MISSE program developed the four components to allow for external testing on the ISS. The system architecture allows for replacement of the components for up-grades or hardware failure.

The Power & Data Box controls the Material Sample Carrier locations so that external testing can be completed in a safe manner. Furthermore, the data transmission and commanding between the Material Sample Carrier and the Gateway will be controlled by the Power & Data Box. It also prevents the waste of power by disabling the converters that do not have Materials Sample Carriers installed.

The Switch Box allows for proper control of all the switches in the Power & Data Box as well as the Experiment power switches in the Material Sample Carriers. The Switch Box provides total control of the ELMIRO on the Gateway, preventing wasted power and data bandwidth. It also provides automated control of the entire system.

The Material Sample Carriers provide the interface between the Gateway and the experiments. The Material Sample Carrier can provide for passive experiments and active experiments. This allows for a common interface platform to the Gateway to lessen the cost of sample integration.

The Facility Structure will be tailored to the launch vehicle or the Gateway itself. The structure will consist of all interconnect cabling and mechanical interfaces to the Gateway for robotic installation and removal of the boxes.

Flying the ELMIRO program on the DSG can be supported in two possible scenarios, 1) Mount the ELMIRO to an ESPA type adapter ring and place between DSG Modules. 2) Mount individual sample carriers outside of the habitat accessible by robotic arm. This approach would require minor modifications to data/power systems.

ELMIRO Required Resources: The ELMIRO will require the following resources from the Gateway:

MASS – Launch Mass of the Power & Data Box will be less than 40 pounds. Launch Mass of the Switch Box will be less than 40 pounds. Launch Mass of the Materials Sample Carriers will be less than 45 pounds each. (If the Gateway is launch mass limited, the Material Sample Carriers can be flown on the next servicing mission, reducing the mass requirement.) The interface hardware to the launch vehicle should be less than 300 pounds delta to the spacecraft.

POWER – ELMIRO power can be controlled by experiment activation and de-activation for the duration of the testing time on the Gateway. The minimum power required for basic operations is less than 150 Watts, with the maximum power draw of 650 Watts. The ELMIRO experiment configuration will determine the power requirements, with operations of the experiments being controlled by the Switch Box to prevent exceeding the power allowed for the current mission.

COST – Development cost of the ELMIRO will be in the realm of $6 Million, with $1 Million going toward the hardware upgrades from the MISSE-FF design, $3 Million going to hardware purchases to implement the design changes, and the final $2 Million going to software and data interface parameters for communication between the ELMIRO and the Gateway. $6M does not include costs for the ESPA Ring or vehicle integration as this is assumed to be GFE.

VOLUME – Internal volume will be limited to the volume required to launch and return the Material Sample Carriers to/from the Gateway. This will be equivalent of 8 components measuring 10 x 14 x 20 inches (less than an ISS Single Cargo Transfer Bag). External Volume will be approximately 20 cubic feet (that can be broken down into ten separate 2 cubic feet volumes).

AMMOUNT OF CREW INTERACTION – Transfer of the MISSE Hardware is currently completely robotic. If the Gateway and/or servicing vehicle has a robotic capability, then the crew interaction would be required for transfer through an airlock if one is available. If not, then the transfer would be totally external and would require no crew time.

DESIRED DEEP SPACE GATEWAY ORBIT – Any orbit outside the LEO orbit will work for the science performed on the ELMIRO. The requirement for deep space testing is outside the Van Allen Radiation Belts, so any orbit between cislunar or GEO.

OTHER RESOURCES NEEDS – The ELMIRO, being external, will only require a penetration through the bulkhead for power and data, or inclusion of pins in an existing penetration.

References:

Space Flight Utilization of the Materials ISS Experiment Facility, J. Engelhardt, Applied Space Environment Conference Abstract.

LIGHTSHEET METEOROID DETECTOR. Christoph. R. Englert[1], Andrew C. Nicholas[2], Diego Janches[3] and Petr Pokorny[3,4], [1]U.S. Naval Research Laboratory, Space Science Division, Code 7630, 4555 Overlook Ave SW, Washington, DC 20375, christoph.englert@nrl.navy.mil, [2]U.S. Naval Research Laboratory, Space Science Division, Code 7634, 4555 Overlook Ave SW, Washington, DC 20375, andy.nicholas@nrl.navy.mil, [3]NASA Goddard Space Flight Center, Mail Code: 674, Greenbelt, MD, 20771, diego.janches@nasa.gov, [4]Catholic University of America, Washington, DC, 20064, petr.pokorny@nasa.gov.

Introduction: The possibility of flying an externally mounted instrument on the Deep Space Gateway (DSG) to measure small particles in a halo orbit close to the Moon presents a unique opportunity for both scientific investiagtions and spaceflight safety and engineering. Small objects around the Moon are mainly meteoroids, rather than space debris, which is concentrated closer to Earth. Thus, concerning small particles, the environment for the DSG is more instructive with repect to the environment that will be encountered on the way to Mars, as opposed to the environment closer to Earth. Measuring meteoroids with sufficient statistics requires a large area-time product for the sensor. The time aspect is well covered by the DSG, as it provides a persistent platform in space. Achieving a large sensitive area generally requires large physical structures and is thus resource intensive. However, a novel instrument concept that uses a lightsheet to create a “virtual witness plate” allows large sensitive areas without requiring a physical structure to support it.

In the following we briefly discuss the science opportunities for a Lightsheet Meteoroid Detector and outline the sensor concept, including the expected spacecraft resources for the sensor.

Science Opportunity: The solar system contains a thick circumsolar disk of dust and meteoroids (interplanetary bound particles with diameters between 30 μm and 5 cm) known as the Zodiacal Cloud (ZC). Current dynamical models suggest that the ZC is mainly formed from products of asteroid break-up events (ecliptic dust bands [1]), cometary activity and disintegration [2, 3, 4]. Solar radiation effects, specifically radiation pressure and Poynting-Robertson drag [5], and the gravitational effects of planets act as sinks for the ZC meteoroids and dust particles on timescales of hundreds of thousands or millions of years. The existence of the present ZC suggests that a balance between the sources and sinks in the solar system is maintained and the currently observed ZC contains relatively young material that is formed in a significantly evolved system, posing a contrast to recently observed circumstellar disks around young stars such as Beta Pictoris [6]. Understanding the nature of the ZC sheds light onto the history and evolution of our Solar System as well as extra-solar planetary environments [7, 8, 3, 9, 10].

Planetary bodies and satellites sweep through the ZC while they move along their orbital path experiencing a constant bombardment of particles. For the case of bodies with atmospheres, these particles heat up as they interact with an increasingly dense atmosphere, decelerate, and ablate most of their material in the atmospheric aerobraking region, and introduce species such as magnesium, sodium, and iron [11, 12, 13]. For airless bodies, such as the Moon, meteoroids impact their surfaces with all their kinetic energy producing secondary ejecta and ionized and neutral vapor clouds, which are the sources of their exospheres [14, 15]. And thus, besides understanding the origins and formation of the Solar System, studying meteoroids provide insight on planetary atmospheres and exospheres.

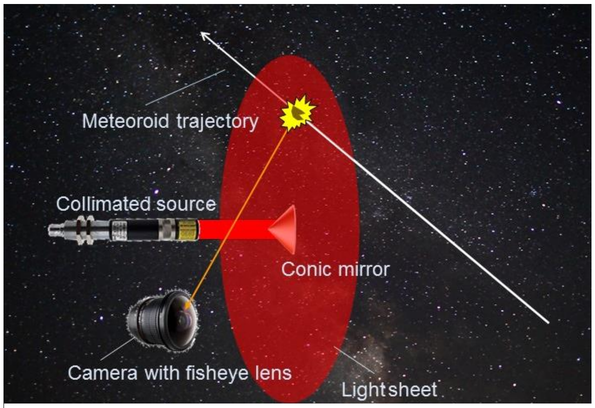

Figure 1: Basic concept of the Lightsheet Meteoroid Detector

Finally, for airless bodies, missions like the Lunar Atmosphere and Dust Environment Explorer (LADEE) and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) have shown recently that meteoroids play a major role in space weathering and material removal from airless bodies [14, 15, 16].

Despite the recent development of dynamical models and new results brought by space missions, many properties of the ZC are not yet understood. The flux and density of meteoroids with a diameter of >10 μm at different places in the solar system is virtually unknown. This information is a critical part of any dynamical model of the ZC, which enables an absolute calibration for the solar system as a whole. This critical gap in our knowledge results from a lack of observations and prevents us from accurately estimating fluxes of meteoroids of a wide range of sizes at any place in the solar system and ultimately developing predictive capabilities. New observations, specifically in the mass range above 1 μg (>100 μm in diameter), will directly contribute to new predictive capabilities for possible hazards for all space missions in the solar system, modeling of impacts of meteoroids on surfaces of airless bodies in the solar system like Mercury, the Moon, and the icy moons of giant planets, and assessing the contribution of meteoroids to metal layers in planetary atmospheres.

To improve over Pioneer data which has the largest area interplanetary particle detector flown to date, we have to achieve a sensitive detection area of more than about 0.57 m^2, corresponding to an effective lightsheet disk of about 0.44 m radius. According to Grün et al. [17], a 1 m^2 collecting area would allow the detection of about 30 particles with a mass of >1 μg (diameter of >100 μm) per year at 1 au.

Instrument Concept: A lightsheet is created using a collimated light source and a conic mirror, as shown in Figure 1. When a particle penetrates the lightsheet, it scatters light and a portion of that scattered light is detected using a camera and wide-angle (fisheye) lens [18]. The camera continuously views the scene and can be read out at a slow cadence, e.g. every second (1 Hz). The detected signal is then used to count and locate the objects. To be counted, the detected signal has to be large enough to be identified over the instrumental noise sources, such as read noise, and dark current shot noise. The lower size limit of the detectable particles is determined by the brightness of the light source, the distance of the scattering event to the center of the lightsheet, the distance to the detector, the particle albedo, the trajectory angle, and the particle speed. The viewing direction information from the recorded image, together with the known light sheet geometry is used to determine the location of the particle. For larger objects and smaller distances to the camera, the detected signal also provides information on the particle size and shape. The lightsheet can be viewed as a virtual witness plate that does not need any mechanical structure to support it.

To avoid false detections due to high energy particles or cosmic rays, which can create similar signals within the detector, one can, e.g., form two redundant images on the detector. Variations of this concept can be implemented depending on the science focus. For example, one can use two lightsheets to reconstruct the particle trajectory direction from the two scattering events.

Spacecraft Resources: The Lightsheet Meteoroid Detector can be implemented with different performance parameters, tailored to the specific science focus. For this abstract we baseline a 1 m^2 sensitive area for particles of 100 μm in size and above. Note that closer to the center of the lightsheet, smaller particles can also be detected. Using these assumptions we estimate an instrument power of about 40W, a payload mass of about 3 kg and a total payload size of about 10 cm x 10 cm x 30 cm. The lightsheet generation does not have to be at the same location as the camera. The data rate depends on how much image processing is performed on orbit. Ideally, only images with a potential detections are downlinked, which would limit the data rate to about thirty CCD images (~2 Mbytes each) per year, but realistically, more data is desired to allow for verification of on-orbit algorithms and, at least at first, the ground analysis of all potential particle detections.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

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TIME, METROLOGY AND FUNDAMENTAL PHYSICS WITH THE DEEP SPACE GATEWAY

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Introduction: The Deep Space Gateway (DSG) proposed for cis-lunar space offers an opportunity to both improve tests of fundamental physics and to develop chronometric navigation techniques for the human exploration of Mars and beyond. Here we outline how the DSG, equipped with highly accurate optical atomic clocks and optical phase coherent links with the Earth and other spacecraft, can used to develop and apply the science of chronometric geodesy and navigation, where the clock-spacecraft system is used to both position the spacecraft and measure adjacent gravitational fields.

It appears likely that the DSG will be placed in a lunar Near Rectilinear Halo Orbit (NRHO), which offers many advantages for access to the lunar surface and the Earth, while minimizing or even eliminating both solar eclipses and terrestrial communications blackouts [1, 2, 3]. For definitiveness, we assume a 4:1 synodic resonant Halo orbit with a perilune radius of 5600 km and an apolune radius of ~75,000 km.

Development of Optical Communication and Navigation: Optical communications is becoming increasingly important in space exploration [4], to provide the increasing bandwidth needed to support the high data production rates of modern instrumentation; a Deep Space Optical Communication (DSOC) optical communications system is under active development at NASA [5]. Optical communications will also drive the development of Deep Space Optical Navigation (DSON), so that positioning can use the DSOC infrastructure. Recent developments in atomic clocks, and in particular the development of optical atomic clocks with fractional frequency stabilities at the 10^{-18} level [6, 7] and time transfer at the femtosecond level [8] will lead to the development of chronometric geodesy and navigation, causing profound changes in spacecraft operation. The DSG offers a near ideal installation for the development of these new technologies, offering in addition tests of fundamental physical laws and improvements in our knowledge of the solar system.

The ability to establish phase coherence between terrestrial clocks at a level of a few parts in 10^{-19} with fiber optics [9] allows for phase coherent arrays of optical transmitters, and thus for an optical navigation system analogous to the terrestrial Global Positioning System (GPS). A coherent laser array can send out interleaved timing pulses kept in synchronization at the 10^{-18} fractional frequency stability (ffs) level allowing the receiving spacecraft to infer the relative time of arrival of the different pulse trains at that level. Over cis-lunar distances, small telescopes and lasers (10 cm and 1 W, respectively), should be sufficient to allow phase coherence between the DSG clock and each element in the transmitting array. With a picosecond relative delay accuracy a continental laser array extending over 4000 km would allow a DSON receiver to position itself to within a formal error < 0.1 nanoradians, or better than 5 cm accuracy over a cis-lunar distance of 5×10^5 km.

Quantum Entanglement across Cis-Lunar Distances: At present, quantum-entangled photons have been distributed over Earth to space round trip distances of ~2400 km [10]. With the lasers and optics needed for DSG DSOC and DSON, this range could be extended to cis-lunar distances, an increase of over two orders of magnitude. This is important for more than just establishing a new distance record. Current optical clock technology is approaching the classical limits for clock stability , and quantum clock-synchronization techniques have been proposed to improve the accuracy of time transfer beyond the classical limits [11, 12]. The DSG can be used to extend these techniques to cis-Lunar distances as a step towards their use in deep space, for example to establish a common quantum clock between the Earth and Mars. In addition, the large one-way travel time to the DSG and Earth will enable a new Earth-Moon test of Bell's Theorem and the foundations of quantum mechanics by expanding these tests to include human decision making across space-like separations, a test of quantum mechanics only possible with a crewed vehicle such as the DSG [13]

Solar, Lunar and Planetary Redshifts and Other Tests of Relativity: The basic relativity tests enabled by a highly accurate spacecraft clock are described in [14] for the ACES experiment on the ISS; it should be possible to improve these tests by orders of magnitude with the DSG. In particular, the DSG solar potential change (see Table 1) is large enough that the second Post-Newtonian (PN) order change should be observable. The DSG thus could be the first platform able to access second order PN effects in the solar system, enabling a new class of tests of relativity. The redshifts from the Earth, Moon and Jupiter could be determined to a part per million (for the Moon) to a part per thousand (for Jupiter), allowing for improved redshift tests with a variety of compositions. Redshift changes of these magnitudes will be noise for any chronomet-

Body	δPotential	Notes
Sun	5.7×10^{-11}	Full to New Moon
	1.4×10^{-18}	Second PN Order
Moon	9×10^{-12}	Apo- to Perilune
Earth	6×10^{-13}	Apo- to Perigee
Jupiter	2×10^{-15}	At opposition
Venus	9×10^{-16}	At opposition
Saturn	10^{-16}	At opposition
Other planets	$< 10^{-16}$	

Table 1: Gravitational redshifts in the default DSG orbit.

ric navigation system, which will rely on its ability to separate target potential changes from the time-varying background. The DSG will offer the opportunity to develop techniques to account for the gravitational background, and thus to actually make it possible to deliver chronometric navigation using a 10^{-18} ffs clock.

Chronometric Observation of Gravitational Radiation with frequencies $\sim$1 Hz: Highly accurate optical clocks in space, together with phase coherent optical laser links between spacecraft, will enable the detection of gravitational waves with metric amplitudes comparable to the clock stability and wavelengths comparable to the clock separation [15, 16]. The chronometric detection of gravitational radiation offers advantages over the interferometric gravitational wave detectors, such as LIGO and the planned eLISA, which look for changes in the light travel time between end-points, instead of changes in clock phase. Modeling of the long-period gravitational wave background will also become important for chronometric navigations at distances $\gg$ 1 AU, where gravitational radiation is likely to become a significant source of clock, and thus navigation, errors.

An extended gravitational wave instrument is most sensitive for waves with wavelengths twice the projected length of the size of the instruments (or $\lesssim$ 2.56 light seconds for the DSG-Earth combination). It happens that this wavelength is too long for effective detection by LIGO and will be too short for eLISA; the DSG with a good clock could thus help to fill in a hole in the gravitational wave frequency spectrum. A DSG chronometric gravitational wave detector would thus be a valuable addition to the Earth and space based gravitational wave detection instruments, capable of sensing large binary masses with orbital periods of a few seconds (for the larger masses, shortly before they merge into a single black hole). Figure 1 shows the detection range as a function of mass for orbital periods of 1 seconds assume a clock fractional frequency stability of 10^{-18}. For total masses of order 3000 solar masses (M_{Sun}), where the merger happens at an orbital period $\sim$1 second, the DSG could be competitive with both eLISA and LIGO.

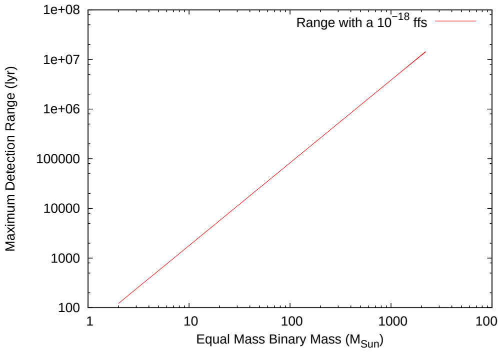

Figure 1: Maximum Detection Range using the DSG for an equal mass binary with a 1 second orbital period.

Basic Tests of Existing Positioning Techniques: The DSG will be at the lunar distance, and thus can be ranged by existing Lunar Laser Ranging (LLR) facilities. New technology corner cubes [17] could thus be tested on the DSG before deployment on the lunar surface; this would assist future LLR work and provide an auxiliary source of navigation data. The DSG will also be within range of the GPS satellites (either the main-lobe or side lobes) and should be equipped with a sensitive GNSS receiver capable of operation in cis-lunar space [18] to allow for tests of GPS / GNSS performance in a cis-lunar Space Service Volume.

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Developing Science Procedures for Deep Space Gateway Habitat Mockup Ground Testing.

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Overview: The Deep Space Gateway (DSG) is a possible NASA program to place a habitat in cis-lunar orbit for periodic visits by crews delivered on the spacecraft Orion. NASA has contracted with private companies to develop concepts for the design of the habitat, and mockups will be provided for evaluation beginning in FY2019. In order to train NASA Subject Matter Experts (SMEs) for the upcoming evaluations, a series of ground tests are being conducted with available resources at JSC. The first test was conducted on 9/28/17 – 9/29/17 at JSC Building 29 in the Integrated Power, Avionics, and Propulsion (iPAS) facility using the habitat mockup named “Phoebe”. A second test was conducted at JSC Building 9 in the Habitable Airlock (HAL) mockup on 12/13/17. For both tests, science procedures were developed for crew to demonstrate the use of possible equipment and instruments that might be available in a DSG habitat. Execution of the procedures may help inform science requirements for future DSG development, and can also evaluate whatever science opportunities are available with the delivered NextStep contractor habitat mockups.

Procedures: For the Sept. 2017 test, five procedures were developed and successfully executed in the iPAS Phoebe habitat mockup.

1. **Telerobotics:** The crew successfully operated a simulated rover on the lunar surface from a workstation within the habitat. The simulation software was developed at JSC to measure latency impacts on crew telepresence operations (which was tested in a separate procedure). For the science procedure, the objective was to identify a specific rock for the crew to collect and deliver to a Lunar Ascent Vehicle (LAV). An “Execution Note (EN),” modeled after the ISS daily communication message, was developed to inform the crew of the desired rock with a suggested ground traverse path for the crew to drive the simulated rover. The simulation software was modified to provide boundary markers (to prevent driving off the simulation course) and colored identification marks for the desired rock. Crew successfully navigated the rock field, found the targeted rock, photographed the rock from multiple angles (using screen capture on the workstation), and simulated delivery of the sample to the LAV (see Figure 1). The simulation allowed the rover to become trapped on rocks (from “high centering”), and real-time monitoring required occasional removal of the rock from the simulation to allow the crew to progress. The test generated a list of desired future enhancements for the simulation software, including the need for countup/countdown timers, multiple camera angle views from the rover, and changeable rocks with a more realistic lunar landscape. It is also hoped that the EN will provide a variety of rocks of different priorities for collection to allow the crew to test alternate traverse planning for optimum efficiency.

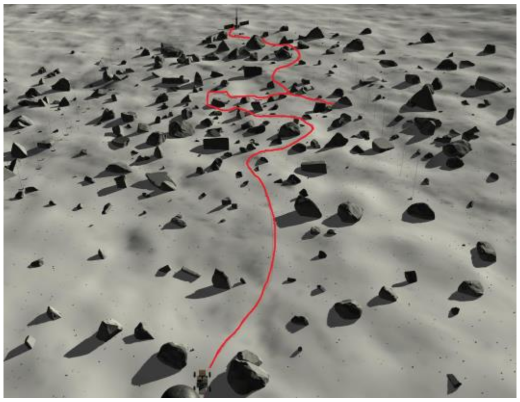

Figure 1: Example crew traverse path

2. **Remote Manipulator System (RMS) Sample Return:** The crew successfully operated a simulated robotic arm from within the habitat to retrieve a sample return canister from the simulated LAV, which had completed a rendezvous with the DSG and was free flying nearby. The simulation software was developed for the HAL and included a science airlock with two external doors that can be assessed by the arm. The procedure was mostly automated with crew monitoring the arm for clearances and range of motion limits. The test revealed this procedure benefitted from two crew working together for execution and monitoring of the arm.

3. **Telescope observations:** The crew successfully operated a simulated external telescope to observe lunar, celestial, and Earth targets defined in an EN. The HAL simulation software was modified to include this instrument, and the crew manually commanded slew and elevation parameters from the habitat workstation for observations. A new feature was added to insert and observe a lunar "flash" on the surface from a meteorite impact. The predefined orbit for the Sept. 2017 test placed the DSG low over the lunar surface, so future tests will test observations at different points of the planned, highly elliptical DSG orbit.

4. **Camera observations:** The crew successfully operated a retired ISS flight hardware Nikon camera to capture images from the simulated "window" on the habitat. Following directions from an EN, celestial, Earth, and lunar observations were conducted (although the designated targets were not all available for the simulated time period). For the Sept. 2017 test, the "window" was a television screen near the robotic workstation. The crew requested a neck strap for future tests.

5. **Sample Return Canister Transfer:** For the Sept. 2017 test, the crew successfully gathered the sample return canister from the science airlock (simulated as a prepackaged suitcase), inspected, cleaned, and repackaged the canister in a sealed bag within the habitat glove box, and then delivered the package to the Orion storage (simulated as a file cabinet). This procedure was developed to evaluate initial concepts of crew processing for lunar samples at the DSG, including consideration of planetary protection and curation protocols. The processing of possible asteroid or martian samples would be much more extensive (if even possible within the DSG habitat). The crew noted the need for velcro straps or storage shelves to anchor the electronic tablet with the procedure while working inside the glove box (a limitation of simulations in the 1g environment). Future discussions will address the need for a dedicated or inflatable glove box, or other sample processing hardware within the DSG, as evaluated from the NextStep contractor mockups.

Summary: The ground test of the HAL mockup (scheduled 12/13/17) included the procedures for telerobotics, RMS canister capture, and telescope observations. Results from this test will be integrated with the results of the Sept. 2017 test in iPAS, to modify the science procedures for more extensive ground tests scheduled for 2018. The science procedures provide an effective tool for evaluating upcoming NextStep contractor habitat mockups, and open discussion for the development of science requirements on the DSG. The assembled science team is working to write efficient procedures and create meaningful metrics to evaluate crew performance. These skills are valuable for whatever science instruments ultimately reside at DSG or other cis-lunar habitats.

LONG DURATION EXPOSURE PLATFORM (LDEP).

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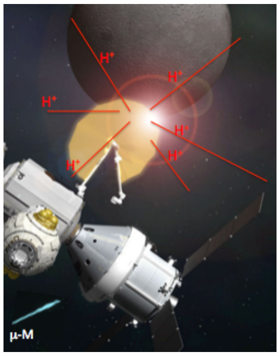
Introduction. In the early 2020s, NASA will build the Deep Space Gateway (DSG) for extended human occupation in cis-lunar orbit. The DSG provides a new unique platform to carry out science investigations on a number of high priority topics in planetary science. The DSG will be immersed for long periods of time in this harsh space environment (see figure of DSG below), where it is constantly being bombarded by H^+ from the solar wind and by micrometeoroids μ-M). We describe here an experiment to test for possible hydrogenation of material exposed to this environment.



We propose the placement of a long duration exposure platform (LDEP) on the *outside* of the DSG that would contain a patch-plate of various materials, exposing them to the space environment for months-long periods. Portions of the LDEP would then be brought into the habitat and would be examined by mission specialists to determine the chemical makeup of implanted solar wind and micrometeoroid species. Inside the DSG, mission specialists would use an oven and mass spectrometer (MS) system to measure the outgassed species and an IR spectrometer system to examine altered surface composition from exposure.

Specifically the investigation would target the efficiency of the solar wind hydroxylation of exposed mineral and rock surfaces, providing space-truth experiments to compliment shorter-term simulations in terrestrial laboratories. The experiments would also address whether methane is created from this process, via a mechanism that causes hydrocarbon to be formed by implantation of solar wind hydrogen and carbon. We hope to gain an understanding of how these geological substrates become chemical conversion surfaces that are capable of creating H_2, OH, water, and methane in the space environment.

Surfaces being considered include porous silica, sapphire, and slabs of common rock types on planetary surfaces, and single mineral crystals to test the effect of crystal structure and binding on hydrogenation potential. We also will design our own a porous activated surfaces to determine if we can create more vigorous hydroxyl forming substrate. These experiments will test our own understanding of the solar wind implantation, diffusion and loitering solid-state process. Creation of OH and water from exposed material, albeit in small amounts, would test the resource potential of the solar environment itself- literally getting water from minerals exposed to a proton beam and hyper velocity impacts.

The LDEP system would also be the start of an onboard laboratory sample analysis facility that can be used by mission specialists later when new samples are returned from the lunar surface.

Motivation. In the Apollo era, Housley [1] suggested that solar wind protons could create OH^- and water at the lunar surface via the proton interactions with iron oxide. In 2009, various IR reflectance observations [2-4] showed a lunar surface absorption feature at 2.8 μm arising from an OH vibrational mode. This OH signature appears to decrease with increasing surface temperature [2-4] and possesses a diurnal variation that suggests relatively weak bonding between the O and H on surface glass and minerals.

Solar wind proton implantation and 'hindered' H atom diffusion [5] in the weathered regolith was identified as a possible source of the weakly bound hydrogen [2]. Vacancies, interstitial atoms, unsatisfied chemical bonds, and other crystal defects that result from space weathering can act to slow interstitial hydrogen diffusion [6] creating 'loitering' hydrogen interstitial atoms that possibly form the OH [7].

H Diffusion and Molecular H emission. Diffusion of implanted hydrogen atoms is a sensitive function of temperature, with H concentrations apparently dropping to undetectable levels in the IR near the warm subsolar point [8]. Warming of the surface enhances diffusion and desorption, leading to vigorous loss of H in the top 10's of nm. The various surface-emitted forms could include thermal atomic H, molecular H_2 [9, 10] and methane [11], the latter two, which have been observed in the lunar exosphere.

Methane. Hodges et al. [11] recently reported the observation of methane emitted in large quantities at dawn. He surmised that this hydrocarbon was produced by interactions of the implanted and diffusing solar wind hydrogen with the solar wind implanted carbon. The observation stunningly points to evidence that the lunar soils are acting as a catalyst for new surface chemistry – collecting, confining, and enhancing collisions between implanted H and C atoms. This new surface-induced chemistry could be operating at all exposed airless bodies. The LDEP can investigate this plasma-surface interaction in detail.

Role of Micrometeorites. In addition to the solar wind, meteors also deliver surface molecular species. These high-speed particulates may deliver more complex carbons and hydroxyl groups depending on their sources. Any exposed area on the LDEP will be intercepted by smaller micrometeoroids; it is also anticipated that hydrocarbons could be implanted onto the surface as a result. The LADEE methane observations [11] might also result from carbon delivered by micrometeoroids rather than solar wind. The actual source of this methane-bound carbon has yet to be identified and will be investigated in the course of this proposed study.

LDEP Investigation. We propose to build an analog system to the old LDEF system flown in low Earth orbit that will now be exposed to a space environment more comparable to the Moon. Our new facility will enable specific examination of the implantation, diffusion, and end-state of atomic and molecular species that can give rise to new hydrogen and carbon volatiles species, like molecular hydrogen and methane, on airless bodies.

We propose to place a plate on the exterior of the DSG body where it will be directly exposed to all elements of the space environment. The plate will carry mineral and rock samples along with porous oxide-rich activated surfaces specifically designed to absorb and trap solar wind hydrogen (to form hydroxyl). Lunar and meteoritic samples as examples of previously space-weathered material could also be considered in the set. After prolonged exposures, exposed sample elements can be exchanged for fresh surfaces and brought in to the DSG by mission specialists. Samples will first be studied by a VNIR-IR spectrometer to examine the alterations in the surficial chemistry and mineralogy. They can then be placed in an oven to undergo gas emission and sampling via an onboard lightweight mass spectrometer. We also can consider an **alternate sample analysis process**: performing this same analysis in the exterior environment using sample handling techniques similar to Curiosity. There is a set of trades to consider in either approach including the risk and cost of mission specialists' EVAs.

Of special interest will be hydroxyl and water absorption features in the IR and the emission of volatiles in the mass spectrometer. We will calibrate the patch plate in the IR before it is exposed to allow for comparison of pre-and post exposure spectra.

LDEP Scientific Goals and Objectives. The goal of these experiments will be to examine the creation of volatile species like neutral hydrogen, molecular hydrogen, methane, and other more complex hydrocarbons by the interaction of the space environment with oxide-rich porous plasma-activated materials.

LDEP Measurement Objectives. Atomic and molecular hydrogen and hydrocarbons including methane will be measured by the MS and IR systems pre- and post-exposure. Solar wind-implanted helium and neon, both typically observed in the lunar exosphere [12], will also be measured as a baseline calibrating species for the samples.

DSG Mission Requirements. To spend long periods of time (many months) in the solar wind to expose the samples to the ~1 keV ion beams and micrometeoroids. This requirement is easily met, given the long-term plans for the deep hab. Laboratory analysis [5] indicates detectable implanted H levels in ~100 days of equivalent solar wind exposure.

Instrument requirements. Instruments for this experiment are not taxing; the required MS and IR spectrometers could be similar to those used in previous space flight science missions (e.g., LADEE NMS, O-Rex IR). Runs with and without the sample can help derive the MS signal from the lab water contamination at AMU = 18.

Science relevance. The solar wind and meteoric creation of hydrogen- and carbon- based volatiles at airless bodies like the Moon connects back to the highest-ranking themes of the Vision and Voyages Planetary Decadal Study (see Table S.1).

Exploration relevance. The possible extraction of water from exposed H-implanted geological material, even in small amounts, could represent a new and unique ISRU capability for harvesting H on larger scales from regolith-rich surfaces like the Moon. The proposed new DSG laboratory facility with spectrometers will also be needed for immediate volatile analysis of newly returned samples. The analytical role to be played by mission specialists will be challenging but very necessary.

LDEP as a Facility. Because the platform with removable plates is modular, we can consider other experiments as well, including studies of the cratering characteristics of micrometeoroids on patches, the radiation dose, high-energy particle damage (tracks), and deep dielectric discharge on surfaces, and the collection of nanograins emitted from the lunar surface during meteor showers. We focus herein on the volatile manufacturing because volatile creation is a high profile science objective in the Vision and Voyages Planetary Decadal Study. However, the system can be treated as a facility, and can be creatively reconfigured, with new test patches built here and sent up on successive missions.

Acknowledgments: This work was supported by NASA's SSERVI consortium.

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SPACE LIFE AND PHYSICAL SCIENCES IN DEEP SPACE: PERSPECTIVE FROM AN OBSERVER OF THE CURRENT DECADAL.

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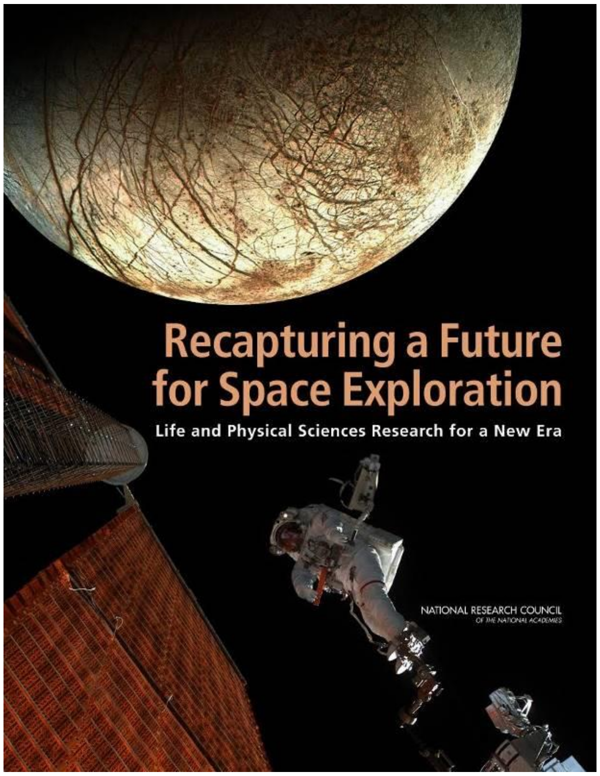
Introduction: The science portfolio described in the 2011 National Research Council (NRC) decadal survey on biological and physical sciences in space, *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era* [1] was written during the critical period near the beginning of the ISS era. That decadal is now in its midterm assessment by committees of the National Academies. That decadal is unique among decadal studies in that it directly addresses science that is enabled by and that enables human spaceflight activity. As such it remains an important tool for the discussion of space life and physical sciences currently and in the coming years.

The Committee on Biological and Physical Sciences in Space (CBPSS) of the National Academies interacts with the Space Life and Physical Sciences Research and Applications Division of NASA to regularly discuss progress within this decadal study and the implementation of decadal priorities within the program. Therefore, there is an ongoing and very useful dialog between NASA program planners and the substance and science of the decadal portfolio.

It will be useful to consider this decadal and its science recommendations during the discussion of science that can and should be planned for the Deep Space Gateway. In addition the midterm assessment of the progress against this decadal will be published by the time of this meeting, and will likely provide additional guidance regarding the trajectory of this portfolio as the focus of exploration leaves LEO for deeper space.

References: [1] National Research Council, 2011, *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era*, The National Academies Press, Washington, D.C., https://doi.org/10.17226/13048.



UTILIZING THE DEEP SPACE GATEWAY AS A PLATFORM FOR DEPLOYING CUBESATS INTO LUNAR ORBIT.

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Introduction: The capability to deploy CubeSats from the Deep Space Gateway (DSG) may significantly increase access to the Moon for lower-cost science missions. CubeSats are beginning to demonstrate high science return for reduced cost. The DSG could utilize an existing ISS deployment method, assuming certain capabilities that are present at the ISS are also available at the DSG.

Science and Technology Applications: There are many interesting potential applications for lunar CubeSat missions. A constellation of CubeSats could provide a lunar GPS system for support of surface exploration missions. CubeSats could be used to provide communications relays for missions to the lunar far side. Potential science applications include using a CubeSat to produce mapping of the magnetic fields of lunar swirls or to further map lunar surface volatiles.

International Space Station CubeSats: The International Space Station (ISS) has been a major platform for deploying CubeSats in recent years. A commercial organization supporting the ISS, Nanoracks, has been providing checkout and deployment services since 2011 [4]. CubeSats are brought to the ISS on cargo missions as a small subset of the total payload, allowing for significantly reduced launch costs for each CubeSat experiment. CubeSats deployed from the ISS enter a low-Earth orbit (LEO) with an orbital life of 8-to-12 months and, to date, do not have propulsion systems [4].

ISS CubeSat Deployment: The International Space Station has a well-documented process with a high-technology readiness level (TRL) system for deploying CubeSats that could be leveraged for the DSG. CubeSats are packaged and loaded as internal payloads on cargo re-supply missions to the ISS. After being unpacked from the pressurized capsule, each CubeSat is loaded into a Nanoracks CubeSat Deployer (NRCSD) by the astronaut crew. The NRCSD is then loaded into the Japanese Experiment Module (JEM) airlock and grappled by the Japanese Remote Manipulator System (JRMS). The JRMS then positions the NRCSD to deploy the CubeSats. Each NRCSD can deploy up to 6U of CubeSats and each JEM airlock cycle holds 8 NRCSDs which allows for a total of 48U deployment capability [4]. See Figure 1 for an image of an NRCSD being positioned by the JRMS.

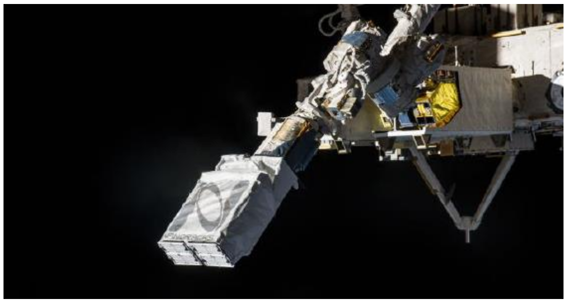

Figure 1: Nanoracks CubeSat Deployer (NRCSD) being positioned by the Japanese Remote Manipulator System (JRMS) for deployment on ISS [4].

Present Lunar CubeSat Architecture: While there are many opportunities for deploying CubeSats into Earth orbits, the current options for deployment to lunar orbits are limited. Propulsive requirements for trans-lunar injection (TLI) from Earth-orbit and lunar orbital insertion (LOI) significantly increase the cost, mass, and complexity of a CubeSat while also reducing the size of potential science payloads. Various propulsion systems have been in development for CubeSats but few have been tested and demonstrated on a lunar transfer. In 2015, NASA initiated the Cube Quest Challenge which resulted in thirteen CubeSats being chosen for launch as secondary payloads on the SLS Exploration Mission 1 (EM-1) [2]. These CubeSats will be put on a cis-lunar trajectory and will need to utilize their on-board propulsion capabilities to transfer into their final science orbits.

Building a CubeSat that can perform a TLI and LOI requires a propulsion system that can meet significant delta-v requirements (ranging from ~1300 m/s for weak stability boundary transfers and up to ~4000 m/s for direct transfers) [1]. Chemical engines that can produce this delta-v require large (relative to CubeSat dimensions) propellant tanks which reduce the volume and mass that can be utilized by the science payload. Low-thrust engines are being developed that can fit within some 3U and larger CubeSat designs while providing the delta-v required to reach lunar orbit, however the alternative use of a low-thrust engine significantly increases the transfer time. The Lunar Icecube mission, one of the EM-1 secondary CubeSats, will utilize an ion-propulsion system which will require a ~247 day transfer to reach lunar capture [3].

Deep Space Gateway Capabilities: A CubeSat deployment system, such as the one used on the ISS, could be implemented at the DSG. The key capabilities for the system would be:

- Robotic arm of similar capability to the JRMS
- Airlock of similar volume to the JEM airlock
- Minimal crew time to load NRCSD and load/unload from airlock.

Assuming these capabilities are available, a deployer would be simple to integrate within a wide range of potential DSG architectures.

Access to Science Orbits from Deep Space Gateway: Near-rectilinear halo orbits (NRHO) are currently being proposed for the Deep Space Gateway [5] and are shown in Figure 2. The NRHOs being considered are highly eccentric with perilunes below 6000 km, apolunes above 70000 km, and orbital periods of 8 days or less [5].

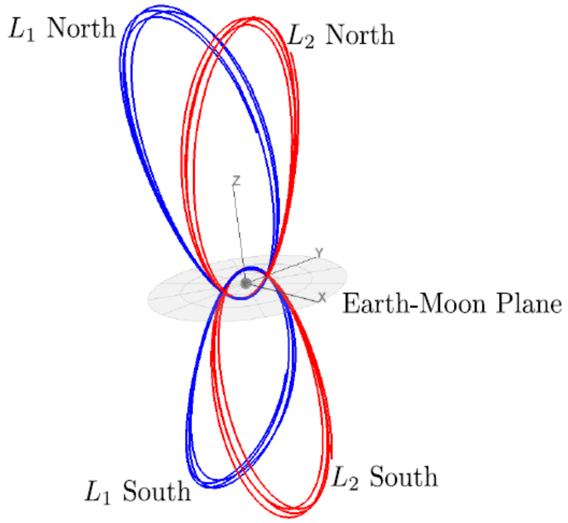

Figure 2: Sample NRHOs with r_p = 4500 km. Figure from Whitley et al [6].

These orbits are not desirable for most CubeSat missions and therefore introduces the need for on-board propulsion. The delta-*v* needed to access various lunar polar orbits from a sample polar near-rectilinear halo orbit is shown in Table 1. Access to low lunar orbits (LLO) and elliptical lunar orbits (ELO) from an NRHO requires significantly less delta-*v* than required for TLI.

CubeSat Thruster Systems: Various thruster systems for CubeSats are in development. Many of these propulsions systems are being designed to fit in a 1U volume to be easily integrated within any CubeSat design. A few of the numerous propulsion systems in development include radio-frequency ion, pulsed plasma, and green monopropellant thrusters. As these systems improve, the potential applications for CubeSats within planetary science missions will increase significantly.

Sample DSG Orbit	
Perilune	2000 km
Apolune	75000 km
Period	8.4 days
Inclination	Polar
Transfer to ELO	
Perilune	110 km
Apolune	310 km
Inclination	Polar
Delta-*v*	~630 m/s
Transfer to LLO	
Radius	100 km
Inclination	Polar
Delta-*v*	~670 m/s

Table 1: Delta-v estimates for transfers from sample NRHO to polar ELO and LLO. No inclination change included in this example. Sample DSG orbit from [5].

Conclusion: The Deep Space Gateway could serve as an important platform for deploying CubeSat missions to the Moon. The DSG would be leveraging existing technologies developed for the ISS to provide deployment services. The required DSG capabilities (robotic arm, airlocks) are common across the many proposed DSG architectures.

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LASER-ASSISTED WIRE ADDITIVE MANUFACTURING SYSTEM FOR THE DEEP SPACE GATEWAY.

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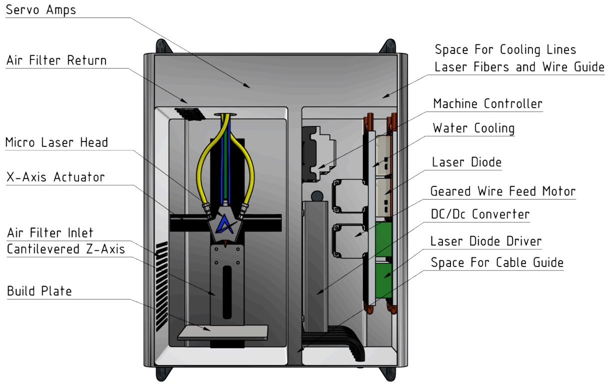
Introduction: Scientific investigation on the Deep Space Gateway will involve experiments and operations inside pressurized modules. Cross-discipline support for those experiments and operations may necessitate a means to fabricate and repair required articles and configurations. This capability can be provided through an additive manufacturing (AM) system. This system provides for experiment continuity and adds flexibility for in situ changes and variations across the science area disciplines accessing the Deep Space Gateway.

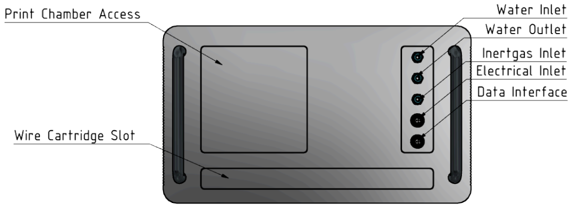
AddiTec proposes to utilize its commercially available TriAx 3D laser-assisted metal wire deposition technology to re-engineer a complete prototype system optimized for operation in a microgravity, confined environment. This system will provide operators with a means to fabricate and repair metal and polycarbonate parts in real-time. The complete system will fit within a user-specified envelope down to minimum dimensions of 440 mm (w) x 515 mm (d) x 250 mm (h). The system will be powered by diode laser technology with a user-specified build volume comparable to system dimensions (e.g., the build volume would be 150 mm x 150 mm x 150 mm for a system with the minimum dimensions identified above). See below for a system schematic.



Base System Configuration

Machine Access: All system interface functions will be addressed via the front panel to ensure ease of access in a rack mounted spacecraft environment. See below for access description. Gateway resources required for operation include water, power, and inert gas along with a data interface.

The metal wire feed will be provided by a cartridge consisting of a custom spool with a large diameter and shallow depth. The spool size is selected such that the wire has the lowest amount of curvature as it is fed into the system. This approach is preferred since wiree straightening cannot be easily automated within the volume constraints of the design, and manual straightening is undesirable since it introduces accessibility, time, and resource challenges.



Access Ports

For Earth-based testing, the system can be oriented with the front panel facing downwards. The top panel includes a large laser-safe window so that the operator has full view of the process. The laser-safe window will be replaced by a windowless panel for use in space.

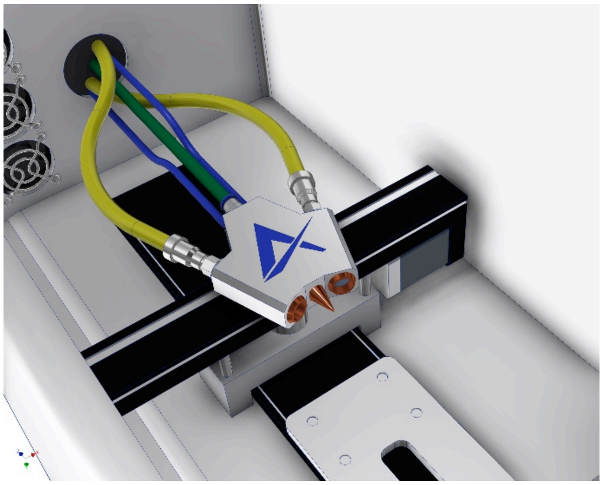
When operating in a micro-gravity environment such as in space, the operator removes the printed part via the access port positioned within the front panel at the base of the Z-axis. Part removal utilizes the extended travel range of the Z-axis (more than twice the print envelope) to completely retract the printed part from the system.

Motion System: The motion system will utilize clean-room certified slide bearings and leadscrews driven by small servo motors. The deposition head will be actuated in the X and Y axes, with the build substrate manoeuvred along the Z-axis.

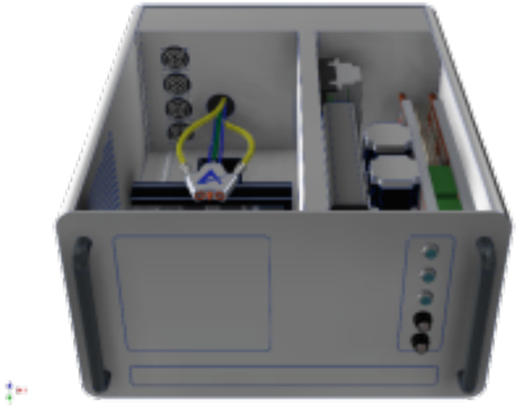
Filtration System: The system will include a custom filter to collect welding fumes and protect the optics of the deposition head from contamination.

Deposition Head: The dimensional constraints imposed on the system design necessitates a low-profile deposition head that is highly compact in one-axis, as illustrated in below. This constraint favors an approach of using two lasers as opposed to the four lasers usually employed in the AddiTec TRIAX 3D system. Testing previously conducted by AddiTec has shown that using two lasers is sufficient to achieve a direction independent welding process of sufficient power for most applications.

Adjustment of the deposition head will be automated by integrating a photodiode as a sensor target and two piezo actuators for lens angle adjustments. The deposition head will use the proven spring-loaded wire nozzles employed in the AddiTec TRIAX 3D product line, ensuring firm wire guidance even under varying feedstock diameters. Allowing for integrated water-cooling components, the deposition head will have dimensions less than 95 x 70 x 20 mm.



Diode Laser



Low Profile Configuration

Process Control: The proposed prototype system will incorporate standard AddiTec inline process control technologies for wire feed, including feed-pressure sensing and deposition layer height detection and regulation via laser power and material feed modulation. These controls will enhance system stability.

Pre-Programed Parts Configuration: Experiments and operations to be conducted within the pressurized modules will be screened to identify material and parts requirements. The AM system will be preloaded with programs and prequalified print settings that can be used to reproduce the identified parts. These pre-loaded programs will significantly reduce time and material requirements for part reproduction.

Commercially Technology Basis: System development will be based on AddiTec's TriAx 3D proven direct energy deposition technology shown below.

TriAx 3D Deposition Head

The TriAx 3D dual mode deposition head which allows the use of both metal powders and metal wire as infeed material, will be modified for wire feed only. Metal powder deposition in an microgravity environment introduces significant challenges and is therefore, unsuitable for this applcation. This technology allows the production of parts with functional material gradients and has the potential for very broad applicability.

DIRECT CHARACTERIZATION OF COMETS AND ASTEROIDS VIA COSMIC DUST ANALYSIS FROM THE DEEP SPACE GATEWAY.

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Introduction: The Deep Space Gateway (DSG) may provide a platform for direct sampling of a large number of comets and asteroids, through employment of an instrument for characterizing dust from these bodies. Every year, the Earth traverses through debris streams of dust and small particles from comets and asteroids in Earth-crossing orbits, generating short-lived outbursts of meteor activity commonly known as "meteor showers" (Figure 1)[1]. The material in each debris stream originates from a distinct parent body, many of which have been identified. By sampling this material, it is possible to quantitatively analyze the composition of a dozen or more comets and asteroids (See Figure 2, following page) without leaving cislunar space.

The DSG would be well suited to this task, because the flux of material from these bodies is low. DSG could employ the instrument for the long time (several years) necessary to collect a statistically significant amount of material.

For the purposes of this abstract, the instrument will be referred to as Dust Analyzer (DA).

Science Description: The purpose of a DA in this concept is to analyze the elemental composition, and potentially isotopic composition, of comets and asteroids which generate significant meteor showers on Earth by analyzing dust from those bodies. The dust environment in cislunar space consists of a "sporadic" background with relatively steady flux and no clear parent body, periodic meteor shower-generating dust/debris originating from specific parent bodies, and possibly a small component of lunar-origin dust in the Moon's vicinity (which was the target of the LDEX instrument on LADEE[2]). Since the parent bodies of most debris streams are identified, analyzing the composition of dust in those streams is a direct measure of the composition of the parent asteroid/comet, and analyzing this dust will give us valuable new data on the composition of a large number of comets and asteroids with Earth-proximity orbits.

The measurements this instrument would produce would be of significant scientific interest to the meteoritics, planetary astronomy, and planetary science communities. First off, the data will give valuable insight on the nature of previously unvisited comets and asteroids. Secondly, NASA maintains a Cosmic Dust collection composed of material collected using high-altitude aircraft, but the parent bodies of that material are poorly constrained. DA measurements collected from DSG would substantially improve the scientific value of the NASA Cosmic Dust collection by identifying the composition of the various bodies that contribute to Earth's cosmic dust inventory, allowing correlation between individual dust particles and comets and asteroids.

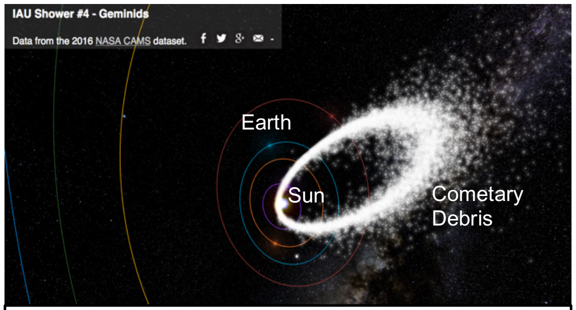

Figure 1: Still image from an animation showing the motion of cometary debris. The white material represents dust and small debris from asteroid 3200 Phaeton, the parent body for the Geminid meteor shower. These debris cross Earth's orbit and can be sampled directly, allowing analysis of the composition of 3200 Phaeton without leaving cislunar space. Similarly, the composition of all cometary and asteroidal parent bodies that cause meteor showers on Earth can be analyzed. Source: American Meteor Society, using NASA CAMS data.

Instrument Operations: The DA would need to 1) measure elemental, and possibly isotopic, composition of dust from periodic meteor showers, 2) discern periodic dust from the sporadic background, and 3) collect a statistically useful number of dust measurements. The former will require collecting material from a given debris stream, which probably necessitates the capability to gimbal the instrument so it is pointed into the radiant of an active shower. Meeting the latter requirement will necessitate collection over a long time, probably a period of several years.

Dust analyzer instruments have very high heritage. Previous missions that have included a dust analysis capability include Cassini-Huygens[3], Stardust [4], Rosetta[5], LADEE[2], New Horizons[6], Ulysses[7], and Galileo[8].

Dust from these debris streams enters cislunar space at velocities between ~30-80 km/s. This is too high for collection with current methods, but actually facilitates analysis by a DA instrument. Dust strikes the DA's target plate at high velocity and to produce an ionized gas. The ions travel to a charged detector, producing a time-of-flight detection of the mass and relative abundance of the particles. This allows measurement of the bulk composition of the particles from an identified parent body.

Resources Needed: If we assume DA is similar to the Cassini Dust Analyzer (CDA) [3], the instrument will require approximately 0.5 kbits/s data rate, a peak operating power of 20 W, and average power of 12 W. Dimensions of CDA are 81x67x45 cm with a mass of ~17 kg. DA will be placed on the outside of the spacecraft with a view of the sky that is preferentially unobstructed by hardware. This is offered as an example; actual requirements and parameters of the necessary instrument should follow from a more detailed study.

Meteor Shower	**Parent Body**
Quadrantids	C/1490 Y1, 2003 EH_1
Lyrids	Comet Thatcher
Pi Puppids	Comet 26P/Grigg-Skjellerup
Eta Aquariids	Comet 1P/Halley
Arietids	Comet 96P/Machholz
June Bootids	Comet 7P/Pons-Winnecke
Southern Delta Aquariids	Comet 96P/Machholz
Alpha Capricornids	Comet 169P/NEAT
Perseids	Comet 109P/Swift-Tuttle
Kappa Cygnids	Asteroid 2008 ED69
Draconids	Comet 21P/Giacobini-Zinner
Orionids	Comet 1P/Halley
Southern Taurids	Comet 2P/Encke
Northern Taurids	Minor planet 2004 TG_{10}
Andromedids	Comet 3D/Biela
Alpha Monocerotids	unknown
Leonids	Comet 55P/Tempel-Tuttle
Phoenicids	Comet 289P/Blanpain
Geminids	Asteroid 3200 Phaeton
Ursids	Comet 8P/Tuttle

Figure 2: List of major meteor showers on Earth and their parent bodies. Material from all of these comets intersects Earth's orbit to produce meteor showers, and may be captured and analyzed to study the list of comets and asteroids on the right. Truncated from Wikipedia, "Meteor Shower".

References:[1] Jackson, A. A., and H. A. Zook. *Icarus* 97.1 (1992): 70-84. [2] Horányi, M., et al. *Space Science Reviews* 185.1-4 (2014): 93-113. [3] Srama, Ralf, et al. *The Cassini-Huygens Mission*. Springer Netherlands, 2004. 465-518. [4] Kissel, J., et al. *Science* 304.5678 (2004): 1774-1776. [5] Kissel, Jochen, et al. *Space Science Reviews* 128.1 (2007): 823-867. [6] Horanyi, M., et al. *New Horizons*. Springer, New York, NY, 2009. 387-402. [7] Grün, E., et al. *Astronomy and Astrophysics Supplement Series* 92 (1992): 411-423. [8] Grün, Eberhard, et al. *The Galileo Mission*. Springer Netherlands, 1992. 317-340.

THE GATEWAY GARDEN, A PROTOTYPE FOOD PRODUCTION FACILITY FOR DEEP SPACE EXPLORATION.

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Introduction: CIS-lunar space provides a unique opportunity to perform deep space microgravity crop science research while also addressing and advancing food production technologies that will be deployed on the Deep Space Transport (DST). Incorporating crew-grown fresh food on long duration exploration missions will be an important complement to the pre-packaged food system and provide crews with produce selected specifically to address nutritional deficiencies in the pre-packaged diet, serving as a risk mitigation to crew performance and health. The Gateway Garden will be the first space-based plant growth system designed primarily for sustained food production activities.

What is the Gateway Garden: Table 1 provides an overview of the hardware. In understanding the concept for the Gateway Garden it will be helpful to consider it from two perspectives.

What the Garden will be. The Gateway Garden will serve as a prototype science and technology platform to test plant systems for eventual selection and incorporation on the DST. Key to its mission will be the evaluation of the deep space performance of plants selected on the basis of micronutrient content not adequately provided by the pre-packaged diet. It will also be imperative to observe plant-associated microbial community successional changes. The Garden will also provide an opportunity to incorporate automation, teleoperations and plant health monitoring in order to ensure successful, reliable and sustainable supplemental food production. Crew involvement in the plant growth processes will be studied. This will provide insight into which tasks associated with raising plants that the crew finds enjoyable while also refining the system to minimize crew time on less desirable tasks.

What the Garden will not be. The fresh food generated by the Garden will not be designed or scaled to provide a significant contribution to the daily caloric intake of the crew. Similarly, the garden will not provide a significant contribution to the ECLSS system (i.e.. CO_2 scrubbing, O_2 generation, H_2O purification.)

Table 1: Notional Hardware Overview

Mass:	150 - 200Kg
Volume:	0.5-1.0m3
Power:	0.2 - 1.0kW
Data Volume:	Periodic Images and data files
Crew time:	Minimal setup and operation
Cost:	$4.0-$6.0M

Figure 1: astronauts enjoying a harvest of red romaine lettuce on the ISS.

Why a Garden on the Gateway: The Human Research Program (HRP) has determined that the quality of many shelf-stable foods becomes unacceptable and critical nutrients degrade as a result of long term storage [1]. Incorporating a reliable food production system that provides key nutritional supplementation will reduce this risk for long duration missions. A garden on the DSG will provide researchers with a key tool to identify and study the technological, biological, operational and behavioral challenges associated with the implementation of long duration food production systems in deep space.

Technology. While NASA has been successful in growing plants in space for several decades, current plant research systems on the ISS (Veggie, APH) are not designed for sustained and reliable food production. The incorporation of a Garden on the DSG will enable continued development in key areas such as water and fertilizer delivery in microgravity, lighting efficiency and mechanization and control. In addition, application of new sensor technologies in the area of plant health and microbiome monitoring will enable increased harvest index and crop success. Automation will liberate crew members from obligatory plant care tasks should a higher priority task take precedence over food production.

Innovative hardware concepts will focus on volume, resource and mass efficiency, allowing for maximized productivity in the spacecraft environment. Long term seed storage concepts that ensure viability in the deep space environment will be developed and validated. All concepts and architectures based on actual performance metrics will be scalable for potential future applications.

Biology. Advances in food production systems also require continued development of the biological component. For missions lasting beyond three years, the pre-packaged food system can meet caloric needs, but specific nutrients (Vitamins B_1, C, K and potassium) have been demonstrated to degrade and fall below minimum required dietary levels [1]. Additional beneficial nutrients able to counteract adverse physiological problems such as macular degeneration can also be readily provided by fresh grown produce. The Human Research Program (HRP) recognizes the benefits of supplementing the pre-packaged food system with fresh foods that would enhance the crew diet with nutrients identified to be deficient or to degrade over time. HRP's goal is to provide these nutrients from a whole food diet rather than from supplements that are less well absorbed and used by the body. Initial investigations have been accomplished on the ground and in LEO. The long-term impacts of the deep space radiation environment on seed viability, plant performance and changes to the plant and spacecraft microbiomes represent a knowledge gap that can only be accurately assessed beyond the Earth's magnetic field [2]. The importance of studying the successional changes of microbial communities of plants and the overall spacecraft in a confined deep space environment cannot be overstated. Advanced understanding of deep space microboimes will ensure the maintenance of a healthy spacecraft microbiome for the crew while also producing numerous benefits to plant growth and health.

Operations. The inclusion of systems automation and teleoperation will enable remote systems start up, ensuring a supply of fresh produce is available when the crew arrives, maximizing the amount of supplemental nutrition available for the crew during their stay. It is also understood based on experience with the Veggie payload that the crew enjoys a certain amount of interaction with the plants during the growth cycle. This interaction is benefical to the crew. Consideration should be given to strategically incorporate automation to ensure the most psychologically beneficial aspects of plant growth and care are not taken away.

Behavioral Science. Incorporation of a Garden on the DSG would allow for continued study of the potential psychosocial benefits associated with plant/crew interaction. Terrestrial studies have shown that plant-related activites are associated with positive mood, increased recovery from stress and increased relaxation in subjects [3]. Plants have been considered as a potential countermeasure for the stresses of living in space, and anecdotal evidence from astronauts indicates that crew members enjoy plant experiments [4,5]. Tests with the Veggie plant growth hardware on the ISS have demonstrated that astronauts enjoy growing and eating crops, often voluntarily committing their time to Veggie experiments (figure 1). Harvests of fresh produce in space can be festive occasions which lead to new combinations of foods which may help prevent dietary fatigue.

Conclusion: As astronauts continue to venture further away from earth for longer durations of time, the food system will still need to meet both their caloric and nutritional needs to maintain optimal health. The inclusion of a Garden on the DSG will provide an important capability towards the development of an operational food production system that can reliably meet the nutritional supplementation needs of future crews operating in the unique environment of deep space.

References: [1] Cooper, M., Perchonok, M., Douglas, G. (2017) *Microgravity* 3, 17 [2] Anderson, M. S., Barta, D., Douglas G., Fritsche, R., Massa, G., Wheeler, R. et al. (2017) *AIAA Space and Astronautics Forum and Exposition* (p.5142) [3] Faulk, J., Whitmire, A., Otto, C. (2010) *NASA Behavioral Health and Performance Working Group* [4] Bates, S., Gushin, V., Bingham, G., Vinokhodova, A., Marquit, J., Sychev, V. (2009) *Habitation* 12: 33-40 [5] Odeh, R., Guy, C. (2017) *Open Agriculture* 2(1), pp. 1-13.

Remote In-Space Manufacturing applied with the Science of Interplanetary Supply Chain modeling for Deep Space Gateway Application

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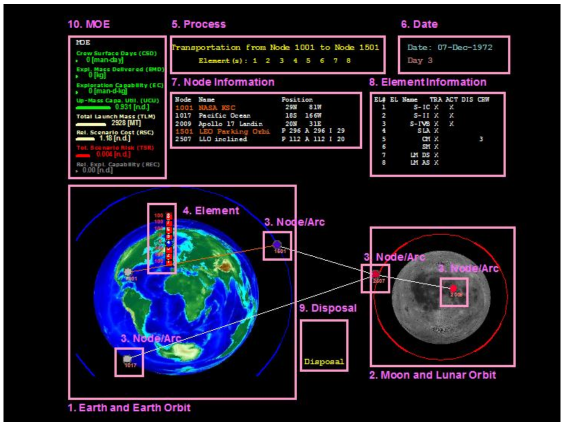
The Deep Space Gateway initiative will create new applications for a combination of existing systems and new flight and ground elements to include In Situ Resource Utilization (ISRU) technologies. To fully understand and act on the implications of such opportunity it is necessary to understand what, how, when and where such opportunities occur and more importantly, how all these interact with commercial space partners. This paper presents Human Space Flight, with an emphasis on the Kennedy Space Center's (KSC) Vehicle ground processing operations, as advances in 3D Printing with ISRU feedstock and interplanetary Supply Chain Management (iSCM) will improve the support posture of remote deep space systems while minimizing the logistics footprint and launch costs. A joint National Aeronautics and Space Administration (NASA) and Massachusetts Institute of Technology Earth-to-Orbit (E2O) supply chain model designed to simulate the logistics nodal positioning of critical materials is presented (screenshot below).



MOE
Crew Surface Days (CSD) 0 [man-day]
Expl. Mass Delivered (EMD) 0 [kg]
Exploration Capability (EC) 0 [man-d-kg]
Up-Mass Capa. Util. (UCU) 0.931 [n.d.]
Total Launch Mass (TLM) 2928 [MT]
Rel. Scenario Cost (RSC) 1.18 [n.d.]
Tot. Scenario Risk (TSR) 0.004 [n.d.]
Rel. Expl. Capability (REC) 0.00 [n.d.]

Transportation from Node 1001 to Node 1501
Element(s): 1 2 3 4 5 6 7 8

Date: 07-Dec-1972
Day 3

```
Node  Name                Position
1001  NASA KSC             29N   81W
1017  Pacific Ocean        18S  166W
2009  Apollo 17 Landin     20N   31E
1501  LEO Parking Orbi    P 296 A 296 I 29
2507  LLO inclined        P 112 A 112 I 20
```

```
EL# EL Name   TRA ACT DIS CRW
 1    S-IC  X    X
 2    S-II  X    X
 3   S-IVB  X    X
 4     SLA  X
 5      CM  X          3
 6      SM  X
 7   LM DS  X
 8   LM AS  X
```

Further, a supply chain economic model, funded in 2007 by the U.S. Air Force Research Lab (AFRL) and the Space Shuttle Program Office, to measure the NASA space industrial base risks will be utilized to assess 3D printing opportunities for on-demand in-space component production. The art, science and perspective of 3D Printing is not only applicable to such a government & contractor operations, it is an invaluable approach for understanding and improving on the long term Product Lifecycle Management (PLM) of deep space hardware.

Applying aspects of the high-volume, market demand driven SCM disciplines of the commercial industry to a low-volume, schedule driven aerospace environment is not only possible but vital to accurately estimate, plan, control and manage the non-recurring and recurring costs associated with long-term operations and vehicle processing of space flight and ground support equipment. "Applying these disciplines is especially crucial during the early design, development, test and engineering (DDT&E) phase of a new program. Upwards of 70% of the operational recurring costs, which include 90% of the indirect processing costs associated with Launch and Landing core activities, are influenced as a result of the initial phase of DDT&E"[1]. Breakthroughs in the field of 3D Printing, specifically using Regolith-based raw material feedstock will provide the capability needed to create an on-demand rapid mobilization of manufacturing of critically needed replacement parts or support other vital lunar surface hardware requirements.

Deploying the tactical and strategic iSCM disciplines described in this document will take a significant amount of time, however by leveraging other agency programs, resources and tools, costs to deploy can be kept to a minimum but more importantly; a single portfolio of in-space 3D printing capabilities and iSCM processes that support NPD 7120 and NPD 7500 will have been established. Ultimately 3 simple goals can be achieved by 2030;

1. NASA will have the capability for rapid on-demand 3d printing of critically needed hardware using lunar regolith material as feedstock.
2. Logistics ground operations footprint and costs will be reduced by 35%.
3. Remote Deep Space Gateway logistics efforts will become 75% self-sustaining and minimize Earth-based hardware sourcing.

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[1] M. Galluzzi, O. de Weck, E. Zapata, M. Steele, (2006) *"Foundations of Supply Chain Management for Space Application,"* AIAA 2006-7234 Space 2006, 19-21 September, San Jose, California URL: http://strategic.mit.edu/docs/3_84-AIAA-2006-7234.pdf

Advanced Manufacturing and iSCM is a key piece of the framework for America's space technology investments as the NASA the aerospace industry, and international partners embark on a bold new vision of human and robotic space exploration beyond Low-Earth-Orbit (LEO). This type of investment is driven by the Agency's need for cost efficient operational support associated with, processing and operating space vehicles and address many of the biggest operational challenges including extremely tight funding profiles, seamless Government-to-Commercial program inter-activities and the reduction of the time gap with human spaceflight capabilities in the post-Shuttle era. An investment of this magnitude is a multiyear task and must include new patterns of thought within the engineering community to expand on the importance of PLM, iSCM and advanced manufacturing, in particular understanding the physics, information flow and modeling needs of remote in-space 3D printing. Proven history within the Department of Defense and commercial sectors has shown that logistics cost reductions and or cost avoidances of upwards to 35% over business as usual are achievable. It is iSCM, advanced manufacturing modeling and in-space 3D printing that will ultimately bring the solar system within the economic sphere of our society.

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[1] M. Galluzzi, O. de Weck, E. Zapata, M. Steele, (2006) *"Foundations of Supply Chain Management for Space Application,"* AIAA 2006-7234 Space 2006, 19-21 September, San Jose, California URL: http://strategic.mit.edu/docs/3_84-AIAA-2006-7234.pdf

MATROSHKA ASTRORAD RADIATION EXPERIMENT (MARE) ON THE DEEP SPACE GATEWAY.

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Risks of human exploration of the solar system include detrimental effects of exposure to the space ionizing radiation environment. While the risk of acute effects to astronauts inhabiting exploration-class spacecraft such as Orion is controlled by design and operational strategies to enhance shielding, risks of long term radiation exposure require additional efforts to fully characterize and mitigate. Some of these risks, including radiation-induced Central Nervous System (CNS) effects, cardiovascular disease, and other tissue degenerative effects, are prioritized as having potential in-mission consequences. The Deep Space Gateway (DSG) provides opportunities for radiation studies previously unfeasible. DSG operates in cis-lunar space, in the harsh radiation environment beyond the protection of Earth's magnetosphere, and representative of that experienced by astronaut crews during a Mars-class mission, including effects of spacecraft shielding. As some biological endpoints are dose rate dependent, radiation biology experiments performed in the actual flight environment may provide more accurate results than those performed in ground facilities (charged particle accelerators) and typically at fluxes significantly higher than the natural space environment. The projected DSG operational lifetime allows for long duration radiation dosimetry studies accounting for the variability of the radiation environment due to Galactic Cosmic Rays (GCR) modulation by the solar cycle and transient increases due to Solar Particle Events (SPE).

This paper focuses on the Matroshka AstroRad Radiation Experiment (MARE) as a candidate radiation measurement platform aboard DSG. MARE is currently planned to fly as a self-contained payload aboard Orion's Exploration Mission 1 (EM-1) flight. In this configuration as shown in Figure 1, MARE consists of two radiotherapy phantoms, i.e., anatomically correct analogs of human torsos manufactured from tissue-equivalent materials of variable realistic density spanning the entire range of bone, soft tissue and lungs. The torsos are fitted with a large number of passive dosimeters and active radiation detectors of various types, including the DLR-developed M-42 Silicon detector. One torso is also fitted with the AstroRad radiation shield. AstroRad is state-of-the art personal protective equipment (PPE) developed in collaboration by Lockheed Martin and StemRad specifically to protect astronauts from space radiation exposure. AstroRad is designed to provide preferential protection to stem cell rich-, and other organs at increased risk from radiation exposure. In addition to heritage Matroshka experiments performed on ISS, MARE not only measures internal body radiation exposure but also the effectivity of the mitigation strategy. A future DSG version of MARE will further advance the scope of the experiment. Instead of a one-time experiment, DSG MARE is envisioned as a science and operational radiation platform that can be leveraged by multiple investigators. MARE would serve a dual purpose. The first is to provide long term operational radiation measurements from baseline DSG detectors. Second, MARE would provide capability for individual tasks such as characterization of novel radiation detectors, or outreach initiatives. For example, academic institutions would leverage MARE to perform radiation dosimetry measurements in the actual flight environment using passive dosimeters in standard packaging. Improvements to the Orion EM-1 MARE needed to achieve the increased scope envisioned for DSG consist of integration with the power and data/telemetry systems of the spacecraft and development of a standard dosimeter interface, and are considered feasible.

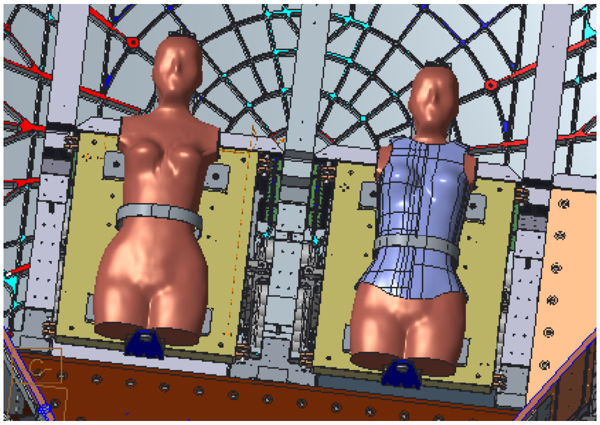

Figure 1. MARE configuration as baselined for Orion consists of two radiotherapy phantoms located at seat positions 3 and 4 in the spacecraft. The phantom at position 4 is fitted with the AstroRad astronaut radiation shield.

In order to maximize the science potential of DSG, it is critical for the DSG architecture to address science payload integration features from the initial conceptual design phases. DSG power and data systems must allow for autonomous data collection and reporting from various sensors such as radiation detectors while unoccupied. Lockheed Martin invites input from the science community helpful for identifying science critical design features of the DSG, and toward formulation of design goals to implement them.

Estimated experiment properties	Description
Mass of hardware	125 kg (includes two radiation phantoms, AstroRad vest, bracketry and radiation detector complement)
Volume of hardware	0.125 m^3 (TBR)
Accommodation (e.g. internal/external)	Internal
Power required	<30W (TBR)
Data generated	Dose rate @ multiple body internal locations, intravehicular charged particle spectra
Communications needed	Ground, command and status telemetry through the DSG data system
Duration of experiment	Onboard platform for radiation measurements: • Long term for baseline / reference detectors • Short term for novel dosimeters and academia • AstroRad can be leveraged for crew protection while DSG is occupied
Crew tasks (if needed)	Option for crew to wear vest for periods of time Access and servicing (integration of short term dosimeters in MARE via standard interfaces) Radiation biology experiments require crew time
Need for retrieval and return to Earth	Short term detectors only
Specific orbit needs (if any)	None
Operations without crew (if any)	Autonomous data transmission from baseline / reference detectors. Remote command and status

SUPPORTING A DEEP SPACE GATEWAY WITH FREE-RETURN EARTH-MOON PERIODIC ORBITS

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Introduction: Earth-Moon periodic/cycler orbits constantly travel between the Earth and Moon via free-return, figure-8 circumlunar segments. Such cycler orbits can host a space station that can be utilized in a flexible manner with regard to providing support (e.g., propellant, crew supplies, robotic spacecraft, etc.) to other stations/nodes near or on the Moon, to near-Earth asteroids and Mars.

If an Earth-Moon cycling station acts a propellant depot, then the braking delta-V (ΔV) needed to enter lunar orbit, land on the lunar surface, and ascend back to lunar orbit to eventually reach the Earth can be provided by the cycling station thus minimizing the mass needed for human launches. Propellant can also be transported to and from lunar orbit (including a deep space gateway station at/near and Earth-Moon Lagrange point) via Earth-Moon cycling trajectories. Figure-8 cyclers can also provide abort-friendly trajectory plans for crew to execute in case of an emergency.

Connections to and from Earth-Moon cycler orbits and associated science applications are detailed in this abstract.

Cycler Orbit Properties and Connections: One type of Earth-Moon cycler orbit originally theorized by Dr. Buzz Aldrin and proven by the author is detailed in Figure 1. This cycler orbit is in 3:1 resonance with the Moon with figure-8 segments occurring ~26 days apart, separated by elliptical Earth orbits used for phasing.

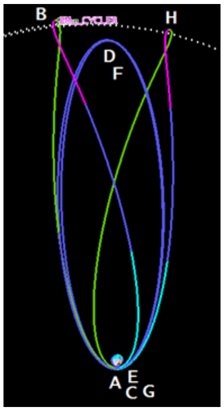

Figure 1: *Earth-Moon Cycler Orbit in 3:1 resonance with the Moon, from [1].*

Station-keeping ΔV requirements for Earth-Moon cycler orbits with monthly lunar encounters average as low as ~18 m/s per month [1].

Transfer from Cycler to Earth-Moon Halo Orbit: It appears that a strong candidate orbit for NASA's deep space gateway is that of a halo orbit around the Earth-Moon L2 Lagrange point [2]. Although this abstract focuses on Earth-Moon cycler orbits, cyclers can work together with nearly any orbit in cislunar space, especially a halo orbit. This connection is detailed in [1] with an image of the solution shown in Figure 2. A halo orbit generally requires a lunar flyby for orbit insertion and since a cycler orbit makes repetitive close-approaches to the Moon, little ΔV is required to alter the cycler orbit to set up the halo orbit insertion. Furthermore, this halo orbit can reach any point on the lunar surface within two weeks with a soft-landing ΔV cost of 2.5 km/s; transfers to three lunar sites of scientific interest (Tsiolkovsky on the far side, Reiner Gamma on the near side, and Shackleton near the south pole) are shown in Fig. 3 (left).

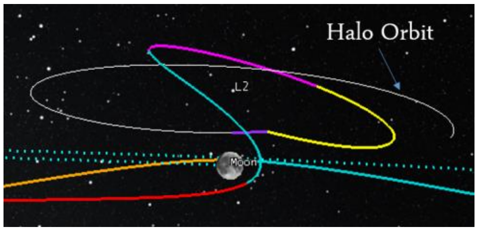

Figure 2: *Transfer from Earth-Moon Cycler Orbit to Earth-Moon L2 Halo Orbit, from [1].*

Transfer from Cycler to Mars: An Earth-Moon cycler orbit contains an orbit energy very near that of Earth-escape, meaning that little ΔV is required from the cycler (or halo orbit) to reach near-Earth asteroids (NEAs) and Mars. Both are similar orbit geometry problems as NEAs and Mars are heliocentric targets that require attainment of a hyperbolic asymptote. Connecting a halo orbit to NEAs is detailed in [3] while a connection from a cycler orbit to Mars is detailed in [1] and shown in Fig. 3; both are point solutions that can be optimized with further study.

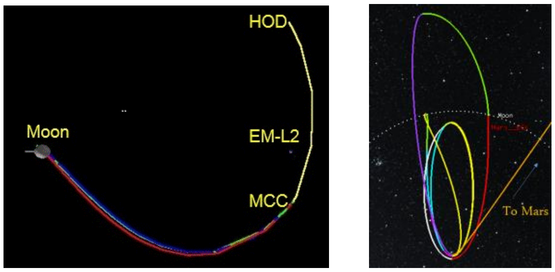

Figure 3: Transfer from Earth-Moon L2 Halo Orbit to 3 lunar surface sites: Tsiolkovsky, Reiner Gamma, and Shackleton (left); *Transfer from Earth-Moon Cycler to Mars hyperbolic asymptote (right), from [1].*

Science & Technology Applications via Earth-Moon Cycler Orbits: Science that can be gained directly from an Earth-Moon cycler orbit pertains to the field of astrophysics. NASA Ames Research Center recently won a Medium Explorer Phase A award for a mission concept named *Arcus* that utilizes an orbit very similar to an Earth-Moon cycler. *Arcus* science goals include (from [4]): *1) to measure the effects of structure formation imprinted upon the hot baryons that are predicted to lie in extended halos around galaxies, groups, and clusters, 2) to trace the propagation of outflowing mass, energy, and momentum from the vicinity of the black hole to extragalactic scales as a measure of their feedback and 3) to explore how stars, circumstellar disks and exoplanet atmospheres form and evolve.* Figure 4 (left, from [5]) details a cycler-like orbit considered by the *Arcus* mission concept; it can be seen that this orbit is periodic in cislunar space.

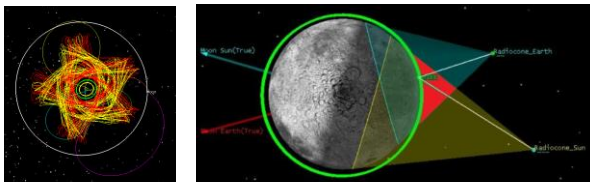

Figure 4: *High-Earth Orbit considered the ARCUS spacecraft, which will carry an x-ray grating spectrometer (left), from [5]. Lunar Orbit passing through Earth and Sun shadow cones to collect radio science data (right), from [8].*

Indirect science data that can be attained via an Earth-Moon cycler orbit (or halo orbit) relate to the Moon. LunaH-Map is a cubesat mission that is scheduled to fly with SLS on EM-1. The LunaH-Map cubesat mission [6, 7] plans to map the hydrogen distribution on/near the lunar south pole (Figure 6, left). Deployment of cubesats from a cycler orbit, which is very similar to EM-1's starting orbit, can yield a variety of science return from the Moon including mapping of important elements, minerals, and volatile species. Additional observations pertain to radio science (e.g., Dark Ages, see Fig. 4 and [8, 9]) and lunar magnetic anomalies such as Reiner Gamma (Fig. 3 and [3, 10]).

Finally, it is noted that technology applications from cycler orbits exist, such as testing of critical exploration systems including communication relays which can be deployed from the cycler (Fig. 6, right).

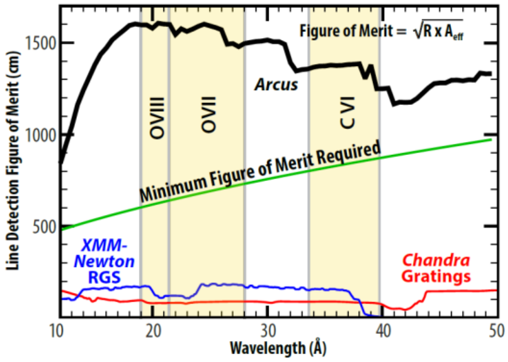

Figure 5: *Arcus has the unique ability to detect weak absorption features that reveal the "mission baryons" at redshifts <0.3 (yellow bands), from [4].*

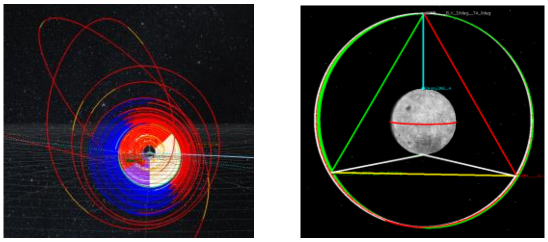

Figure 6: *Low-Thrust transfer (left) to low perilune orbit for the LunaH-Map cubesat, from [6]. Lunar Orbit Communications Relay (right), from [11].*

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UTILIZING THE HABITABLE AIRLOCK TRANSFER PORT AS A MODULAR, LOW VOLUME SCIENCE AIRLOCK.

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Introduction:

The habitable airlock (HAL) is one of several options being considered to provide airlock capability for the Deep Space Gateway (DSG). The HAL consists of a core cabin with ECLSS, avionics and habitation systems (e.g. waste collection system (WCS), a potable water/food preparation system, sleep stations, exercise equipment accommodations), work stations for controlling various robotic operations, and all of the interfaces necessary to support EVA prep and return (e.g. umbilical interface panel that is compatible with the advanced EMU).

The core cabin is outfitted with a hemispherical end cap on the nose that includes a docking port/ hatch. The aft bulkhead contains functional prototypes of two transfer ports, which will be fitted with a logistics stowage module and a science airlock. The science airlock serves as a low volume airlock capable of bringing in samples, ORUs and other hardware into and out of the vehicle with minimal gas losses. This science airlock can also be configured as a glove box for sample handling and processing, negating the need for transfer to a dedicated glove box in the habitat. This results in lower gas losses than an ISS-style science airlock, lower risk of contamination due to fewer intra-habitat transfers, and utilizes less of the interior volume of the habitation system.

BREAKTHROUGH SCIENCE ENABLED BY REGULAR ACCESS TO ORBITS BEYOND EARTH

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Introduction: Smaller satellites are becoming more and more capable of carrying out significant and vital scientific research [1]. One of their main advantages is their lower cost, especially the CubeSat format, but since their orbits are always determined by launches they ride-along on, their main numbers and influence has been primarily in low earth orbit (LEO), as those launches are the most common. The launches envisioned for the Deep Space Gateway (DSG), both initially to build it, and then to transfer astronauts, should similarly open up the potential for smallsats to access orbits beyond the Earth.

Once a rocket has reached the velocity to obtain lunar orbit, it opens up a slew of interesting other orbits, each with its own unique scientific advantage ranging from Heliophysics to Lunar and Planetary Science to Astrophysics. Below I document some of the main orbits achievable with lunar orbit achieving velocities, give examples of other, larger missions that have needed and benefitted from those orbits, and list some of the basic science advantages for those orbits.

Earth Leading/Trailing Orbits: Examples: Kepler Space Telescope, Spitzer Space Telescope, and STEREO A and B.

Potential Types of Science:

1. Long duration time series monitoring e.g. exoplanet transits or movies of the changing Sun.
2. Very cold and stable thermal environment for imaging and spectroscopy at longer infrared wavelengths.
3. 3D movies of the Sun.

Sun-Earth L1: Examples: Advanced Composition Explorer (ACE), Solar and Heliosphere Observatory (SOHO).

Potential Types of Science:

1. Solar particle and radiation monitoring
2. Solar atmospheric monitoring

Near Earth Orbits: Examples: Near Earth Asteroid Rendezvous (NEAR), Hayabusa

Potential Types of Science:

1. Asteroid surface mapping
2. Asteroid sample return

Impact on DSG: To achieve these orbits some additional Δv and trajectory alteration by the smallsat will be required as lunar orbit does not require full Earth escape velocity. How much Δv and alteration depends on the final orbit of the DSG. There may be a class of orbits for the DSG which will be very advantageous to helping achieve these smallsat orbits without significantly impacting the main objectives of the DSG. So those DSG orbits should be given additional weight in the final orbit determination.

Use of DSG as Communications Hub: Once these orbits are achieved, the science return will be based primarily on the rate of data return. Recent developments of compact optical communications will allow for a large amount of data to be returned by these small satellites without having to carry large radio transmitters. By using the DSG as an optical receiving station from which the data can then be relayed down to the Earth via radio, we would gain the advantages of both those communications techniques. Optical comm's high bandwidth would allow large data files to be transferred, while the radio downlink from the DSG will be less susceptible to weather conditions on the Earth and can have large dishes and high power to make very fast radio downlinks.

Conclusion: The DSG will require regular launches of lunar orbit achieving rockets which can carry one or more smallsats outside of Earth orbit as ride-along cargo. Depending on the final orbit of the DSG, with relatively small additional Δv and trajectory alteration by the smallsats, multiple different and scientifically advantageous orbits can be achieved. These orbits currently require a dedicated rocket launch or waiting for the rare outer planets mission for a ride-along. Much like the greater access to LEO for smallsats has led to a great increase of Earth science and heliophysics smallsats, access to orbits which are advantageous to solar, planetary, and astrophysics can lead to a significant increase in breakthrough space based science return in each of those categories.

Once these orbits are achieved, the science return for these missions will be dependent on their rate of data return. By using the DSG as an optical receiving station, large amounts of data can be downlinked from small satellites without requiring large radio dishes on those small satellites. The DSG can then downlink the data at radio wavelengths which are less susceptible to weather and at a much higher bandwidth than possible for smallsats.

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Earth-from-Luna Limb Imager (ELLI) for Deep Space Gateway.

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The new type of limb imager, operating at two wavelengths (353 and 674 nm) with a high-frequency imaging (2 min), proposed for DSG. Each day this CubSat' scale imager will generate the global 3D model of the aerosol component of the Earth's atmosphere along with the distribution of Polar Mesospheric Clouds (PMC). Subpixel image processing technology will allow up to 1 km of resolution of vertical atmospheric profiles. The required downlink is only <50 kilobits/sec. This high-frequency limb imaging mode can be implemented on other sensor or camera that makes images of the Earth (like DSCOVR or VOLCAM).

Introduction: Aerosol component of the Earth's atmosphere and stratospheric and mesospheric clouds (PSC and PMC) represent a less well-studied element of the Earth's system and an important indicator of many atmospheric processes. The contribution of atmospheric aerosols to the Earth's energy budget is a significant, yet relatively uncertain, factor. Comprehensive measurements of aerosol vertical profiles with dense spatial sampling are needed in order to compute climate impacts. The most effective source of stratospheric aerosol data comes from satellite limb scattering measurements.

The primary goal of the Limb Profiler (LP) on the OMPS/NPP "Suomi" is to assess the 3-D distribution of ozone and stratospheric aerosol in the Earth's mid-atmosphere. The OMPS/LP measures limb-scattered light at high vertical resolution 1.5–2 km, high sampling rate at one measurement per degree latitude, 14 orbits per day, and on a 5 day repetition rate [1]. The NPP operates in a near-circular, sun-synchronous orbit with a 1:30 P.M. ascending node. LP is very sensitive and easily records volcanic clouds and plumes from rockets [2] and even clouds left by fireballs [3]. LP provides reliable information on the height of aerosol layers and clouds. – see Fig.1 from [2].

OMPS LP viewing geometry (backwards along orbit track) produces high scattering angles in SH, low scattering angles in NH. When combined with typical aerosol phase function, this yields a factor of 30 difference in sensitivity over the latitude range of the orbit.

Other limitation of all current aerosol measurements is that data are collected only along the orbit track, so that large areas are not sampled each day. Although OMPS LP does have three viewing slits, their separation of 250 km is still relatively small compared to the orbital separation.

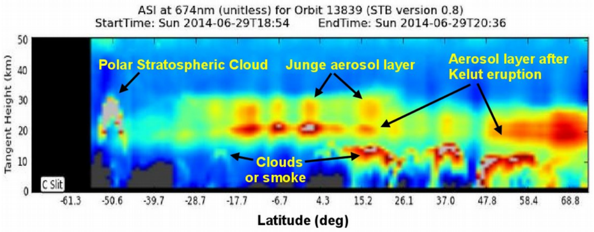

Fig.1. Aerosol Scattering Index from Limb Profiler (OMPS/NPP). Fig from [2].

The Earth is constantly impacted by meteors, and meteoric debris are known to contribute to high-altitude atmospheric physics (such as condensation nuclei for stratospheric and mesospheric clouds). These effects are still not well characterized, and it is hoped that further observations will help in better understanding these effects.

The Chelyabinsk meteor about 18 m in diameter and weighing about 11,000 t exploded near Chelyabinsk on 15 February 2013 at 03:20 UT, at an altitude of 30 km. The OMPS/LP instrument first observed the meteor plume on 15 February 2013 at altitudes above 40 km near Novosibirsk. On 18 February, the plume was observed from North America West Coast to the middle of the Atlantic Ocean. By the end of February, the meteoric dust plume had formed a quasicontinuous midlatitude belt located a few kilometers above the Junge layer. While the extinction in this belt is about 10 times smaller than the lower altitude Junge layer value, it can nevertheless be detected by limb viewing sensors such as OMPS/LP sensor [3].

Limb observation from geostationary orbit: Several pictures of the Chelyabinsk bolide trajectory were made from the MTSAT-2 satellite (2013) with a time step of 30 min. Figure 2 shows four pictures after computer processing and subtraction of a frame made before the burst, which increased the plume contrast. The MTSAT-2 satellite successfully tracked the bolide plume at a small (~3°) slope of the line of sight to the direction of motion of the body (in projection on the ground).

New type of a limb sensor: A promising method of limb observations is photographing the Earth from cislunar orbits, when the image can cover the entire illuminated limb. We suggest placing a limb imager on the DSG for imaging the Earth's limb at two wavelengths 674 and 353 nm. Through the downlink, not the whole image will be forwarded to the Earth, but only the edge of the planetary disk, corresponding to altitudes 1-100 km (Fig. 3).

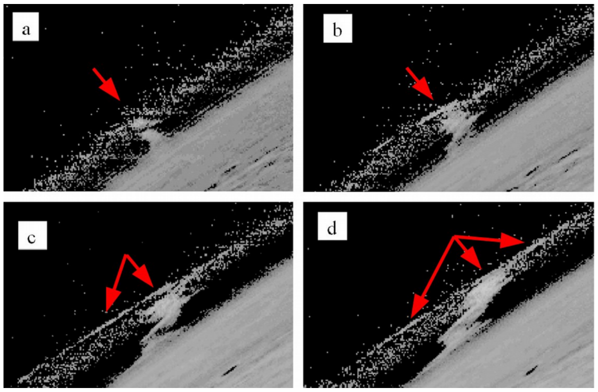

Fig. 2. Limb images of plume of Chelyabinsk bolide (Feb 15, 2013) from geostationary satellite MTSAT-2. a. 12 min after blast; b. 41 min; c. 72 min; d. 101 min. Figure from [4].

Lunar orbits provide nice opportunity to study of light scattering on aerosol particles from different phase angles that provide information about phase function and size of particles. Algorithms for observations of aerosol clumps from different phase angles will be developed for MASTAR satellite [5].

If we use 2K*2K matrices, then each pixel will correspond to 7-10 km of the altitude of the atmosphere, if 4K*4K - 3.5-5 km. This is not a very high resolution, which we propose to compensate for by the high frequency of the imaging (every 2 min). We can use well-developed approach for obtaining a sub-pixel resolution from drift-scanning mode [6]. Together with anti-aliasing algorithms that take into account the spherical geometry of the aerosol layers on the limb, we can obtain a resolution of 1/2-1/3 of the pixel. This allows the creation of a global 3D model of the aerosol component and PMC/PSC every 24 hours with the following characteristics (Table 1). Filter choices include 670 nm for aerosol science and 350 nm for altitude registration and better PMC/PSC extraction. ELLI can used on any orbit types (e.g., LLO, Earth-Moon L2 Halo Orbit or Near Rectilinear Halo Orbit) or on lunar surface (anywhere with a condition for Earth visibility).

The limb imager will make it possible to study the distribution of small asteroids near the Earth, using the Earth's atmosphere as a huge detector. This will provide important information for developing methods to protect the planet from dangerous asteroids. The limb imager can work at any phase of the Earth during the entire lunar month.

Table 1.

Matrix	Z/pixel (km)	Z-resolution (km)	Lat. resolution (deg)	Long. resolution (deg)	Down-link (kbit/sec)
4K*4K	3.5-5	~1-1.5	<0.1	<1.0	50
2K*2K	7-10	~2-3	<0.2	<1.0	13

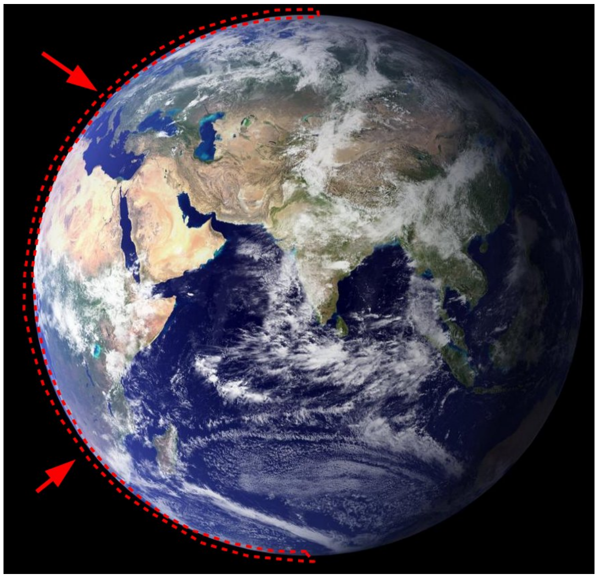

Fig.3. The limb area for study in the ELLI sensor.

Conclusion: From ELLI observations we can generate 3D tomography for aerosol component and high clouds (above dense cloud layers) for whole atmosphere and renew this 3D model each day. Synergy between ELLI and other sensors (NPP; JPSS; MASTAR [5]) is possible for developing better 3D model.

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COMPACT EXPERIMENTAL HIGH ENERGY TELESCOPE ON DEEP SPACE GATEWAY.

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Introduction: An advantage of high energy spectrum data collecting system with additional X-ray and Gamma ray acquisition sensors on Deep Space Gateway; a spaceship in lunar vicinity, would be a considered as a giant leap in aspects of radio astronomy and astrophysics topics using native celestial and orbital characteristics of Moon. When we consider the Earth's atmosphere which absorbs the incoming ultraviolet (UV), X-ray and Gamma spectrum, we may clearly state that it is impossible to conduct a research on UV astronomy without going outer space, so the observations at this spectrum must be performed by the spacecrafts/space telescopes or may be a remote lander/rover Infrared, UV/X-ray/Gamma telescope, robotic high energetic particle missions on Moon which would have been beneficial for the high energy research and mankind' knowledge about our solar system, our galaxy and universe.

Within this opportunity of a space gateway which will be orbiting around the Moon, the data obtained from the distant space objects will not be exposed to the atmospheric effects like pollutants, aerosols, and like any other noise generating obstacles which diminish the astronomic observations just like on the Earth's surface. The general purpose of high energy particle astronomy is that the observation and understanding the phenomena and the mysteries behind of celestial objects like energetic deep universe objects: supernovas, binary stars, black holes, our Sun, upper atmospheric research for observation of interactions between exosphere and solar activity and so on to those which emit radiation on UV and X-ray spectrum. In addition, the observation process could also be maintained continuously through communication with command and data uplink – downlink via Earth orbiting data relay satellites or direct receiving data terminals on Earth in near-real time with some signal delay in such systems, which are corrected by telemetry & tracking algorithms.

The equipments and electronic devices that are required on telescope system to work properly according to the mission are defined as initially data acquisition (telescope aperture and structure) system which includes IR, UV, X-rays & Gamma rays sensors & instruments compartment and primary telescope mirror assembly with proper RF filters and RF switches, what is more, the internal pointing, orientation and aperture alignment system including fixed star sensors for focusing proper astronomical objects is needed too for operations to avoid traditional azimuth-elevation correction by crew and not to interrupt spacecraft operations that will be hold on while the Deep Space Gateway is in operation. Also after data acquisition, a data management system is required to store and archive observation data, it may be added or programmed lately on spacecraft computers to process, generate and prepare the enhanced levels of science data from raw data acquisitions and conduct initial tests and signal processing. After the system integration procedure, the crew may calibrate the instruments on/board for general mission, do maintenance checks to achieve better scientific results and make improvements according to mission procedures. Also the telescope autonomy on the spacecraft interface which may set-up and control the instruments autonomously, which could be developed will prevent and reduce the additional crew/ground segment operations to cover times while observing variety of high energy sources across the celestial sky frame. The distant sky objects will take long time to observe since the more distant the object is the more faint signal received by the detectors.

Instruments on/board the Deep Space Gateway should be radiation resistant to protect the crew members and instruments. For the main mission phase, the thermal ranges of the electronics may vary between 210 to 350 K for minimum and maximum space environment limits for operation and non-operation constraints to work properly so that the scientific instruments & passive RF filters on/board should be cooled and/or heated accordingly for better accuracy and stability considerations, moreover, the localisation of the telescope may be considered to look forward from the dark side of the Moon where we can not see from the Earth, since the radio-free side would be the best position to prevent UV interference from the Earth's atmosphere & surface due to the Sun rays reflection, then according to this, the spacecraft attitude and orbital specifications of the mission phase would be classified. If we consider Low Lunar Orbit (LLO) station keeping, in order to maintain this configuration, it will be needed that the energy generating solar panels would be switched off to the batteries for an approximately 2 weeks for a month since the synodic period of the Moon equals 29.53059 days and half of this period will be dark while the other half will be sunlit. However, the operation orbit of the telescope can possibly be the most effectively conducted on Earth – Moon L2 Halo Orbit and Near Rectilinear Halo Orbit (NRHO) to have continuous Earth and Moon surface communication coverage & easier for spacecraft tracking, a hundred percent Earth visibility is also provided with having less eclipse time intervals generated by the shadow of the Earth and also have lesser ΔV velocity increments for Deep Space Gateway thruster firings and to configure orbits and attitude orientation easily by low energy manoeuvres for station keeping. General operation procedures of detector compartment will include cooldown periods of the HE detectors, initialization of the system for observation period, the observation, then regeneration to cooldown to initial states of electronics & standby mode between the other mission modes. During those mission intervals, the data obtained from the observation will be calibrated in terms of orbital attitude of the Gateway and ephemeris of the target object, then modulated & encoded to achieve better signal energy per bit over noise density values, then transferred to Earth terminals via high data rate (HDR) telemetry downlink since the data obtained from the observations are stored on a limited disk space in Gbits, after these standart procedures the observation data of high energy environment will be ready to use by researchers and engineers.

We may expect the data collected from such reliable observations will contribute on the researches and technological development on upper atmospheric research, detection of deep space objects which radiates IR/UV/Gamma/X-ray radiation properties, galaxy and star systems evolution, our Sun and solar system topics and a lot more so on, in the end, the flight model will revolutionize our understanding about hot & energetic background of our universe.

Estimated experiment/mission properties

Mass of hardware

70-100 kg. for max. mass budget allocated

Volume of hardware

0.6 m3 for predicted size (using between 85-90 cm aperture diameter) 0.85 m x 0.85 m x 0.85 m

Accommodation (e.g. internal/external)

External hardware which will be operated independently from the Lunar Gateway module, spacecraft body itself

Power required

- Power drawn for tracking, focusing and communication is 75 Watts nominally.
- Power drawn for cooling/radiating the UV receiver system for reducing system noise is 20 Watts to cool down the detector sub-system. (no power requirement if passive foil shielding with thermal blankets is used)
- Power drawn for operations is 25 Watts/max.
- Total power needed 120 W max.

Data generated

- Data generation rate may rise up to Gbits/day
- An approximation for data generation: for 2000 x 2000 sensor resolution, 16 bits radiometric resolution, and 3 different channels of UV spectrum including between near UV & far UV will result in:

= (2000*2000*16*3) = 192 Mbits per image/frame

- Same calculation procedure may be considered for the X-ray and Gamma Ray radiometry

Pointing/viewing/line of sight needs

- Localisation and pointing of the telescope may be set on dark side (radio-free side) of the Moon or directed away from the Earth for better data quality for lower noise reception and performance of sensor and telescope operations

Communications needed

Optional communication links may be established between Earth/Lunar Stations or data relays/orbiters for considering further Moon missions.

Duration of experiment

May differ for properties of the target space objects (minutes-hours) or relies on better sensitive sensors.

Crew tasks (if needed)

Mounting, calibration, maintenance operations will & may be held by the crew including EVA's for these purposes.

Access and servicing by crew (if needed)

Access and servicing is needed for telescope operating tasks by relay communication.

Need for retrieval and return to Earth

Not needed, may be upgraded later for further lunar gateway terminal enhancements

Specific orbit needs (if any)

L2, NRHO (not to set constraint on the operations) or LLO (lower performance)

Operations without crew (if any)

Remote command operations from ground station, telescope orientation and programming, spacecraft payload housekeeping, data acquisition and telemetry downlink.

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Deep Space Gateway Asteroid "Recycler" Mission, L. Graham[1], M. Fries[1], J. Hamilton[1], R. Landis[1], K. John[2], W. O'hara[3], [1]ARES NASA Johnson Space Center, Houston, TX 77058 (marc.d.fries@nasa.gov), [2]Jacobs Technology ESCG, Houston, TX 77058, [3]Wyle Laboratories, 2400 NASA Parkway, Houston, TX 77058..

Introduction: A cislunar platform at the Earth Moon Lagrangian point 2 (EML2) near rectilinear halo orbit (NRHO) around the Moon provides an opportunity for an economically viable, reusable planetary science-based sample return program. By utilizing the Weak Stability Boundaries (WSB), as well as the latest advancements in smallsat technologies, a reusable, reconfigurable "recycler" sample return platform can be developed and implemented. Planetary science sample returns have the benefit of providing contextual information for the specific source, as well as identifying in-situ esources available for future Solar System mining.

Concept of Operations: While not in an optimum location, a platform at NRHO can be utilized as either a receiving point for inbound or an outbound originating point for planetary science sample return missions.

A location at EML1 or EML2 itself would represent an origination/return point that would require less delta-V to accomplish these missions. Missions similar to OSIRIS-REX, Hayabusa 2, the ESA Asteroid Impactor Mission (AIM) or even a Mars moon sample return, could follow the low energy transfer trajectories available at the WSB and thus be able to affect a ballistic capture or departure. Use of this approach could require approximately 5-7 km/s delta-V propulsion from the spacecraft. Similarly, outbound trajectories would also be a low energy transfer exercise and would provide opportunities for multiple sampling targets for Near Earth Objects (NEOs), main belt asteroids, Mars moons and the Moon itself. [1]

Secondary Experiments: In addition, both because of the extensive mission time in-transit and the wide volumes of space traversed by these spacecraft, an externally-mounted "stardust" collector could also be incorporated into each and every mission. This has the advantage of adding a passive experiment to obtain additional interstellar material samples with no additional mission costs beyond the initial design, development and fabrication. In the same vein of passive experiments, a Materials International Space Station Experiment (MISSE)-type experiment could also be employed to test long term exposures of various materials and computing elements to the environment of deep space over the mission transit time of an interplanetary mission.

Spacecraft Concept Conceptually, the spacecraft would be a 300-600 kg-class vehicle, powered by solar arrays and propelled by redundant low power iodine-fed electric propulsion units. The spacecraft would be designed to be highly radiation resistant so as to not require the removal and replacement of avionics or other sensitive components after every mission. For those components that might need replacement after a 5+ year mission, such as imagers and solar arrays, they would be designed to be able to be rapidly removed and replaced by simple robotics or humans. For those components that need to be replaced to address a specific mission (such as a sample canister for a Mars moon sample versus a C-type carbonaceaous main belt asteroid sample), they can be designed to be incorporated into a mission specific "cartridge" also allowing rapid robotic removal and replacement. In terms of spacecraft design, the primary structural frame of the recycler could allow a pre-planned component improvement program so each refit, as it is needed, incorporates better, more modern technology. This applies to spacecraft systems as well as improved, miniaturized science instruments. Additional benefits from such a vehicle and mission include improved protection of samples from thermal effects of re-entry and implementation of stringent Planetary Protection requirements (through crewed interaction with samples prior to Earth return).

Science Benefit As one example of the benefits, the main asteroid belt consists of 26 "classes" of asteroids, as defined by the Small Main-Belt Asteroid Spectroscopic Survey (SMASS). This is material left over from the early assembly of the Solar System but it was spared incorporation into planetary bodies and so retains much of the chemical, mineralogical, morphological, and isotopic signatures of the young Solar System. The asteroids range from silicate-rich "S" type bodies in the inner Solar System to carbonaceous "C"-type bodies which predominate at the reaches of the Belt closes to Jupiter. While inferred matches can be surmised between asteroid spectral classes and meteorite types, only sample return can establish definitive ground truth that a given asteroid spectral class is appropriately assigned to a meteorite type.

Example Mission An illustration of one example "recycler" mission is a rendezvous and sample return mission to a potential Near Earth Asteroid (NEA). The most recent near-Earth pass for 2012 TC4 occurred on October 12, 2017 at 1:42 AM EDT at an altitude of 42000 kilometers over Antarctica. With a known closest approach orbit and a relative velocity of 7.65 km/s it represents a rendezvous challenge, but a still credible possibility, to match this velocity for the rendezvous and sample gathering and return to cislunar space. Other asteroids, such as the asteroid 2000

SG344 (at 20-89 m in size) and with a relative velocity of 3.56 km/s represent a more interesting mission possibility. Finally, objects with slower relative velocities, or objects closer to the inner solar system or objects in the main asteroid belt may offer more credible opportunities for sampling if a platform is already standing by, waiting in orbit and able to begin an intercept mission on short notice. Of interest in this category might be the main belt “active” asteroid 7968 Elst-Pizarro that also exhibits comet-like dust activity (such as the development of a coma or tail). With the advent of multiple “on-call” sampling and sample return mission capability, asteroids such as the main belt asteroid 253 Mathilde also become credible targets. With a 52.8 km diameter and a C-type asteroid with a bulk density of 1.3 g/cm^3 and a porosity > 50%, and with craters larger than its radius, it represents an interesting investigation into the formation of the early solar system.

Summary: The recycler is a mission concept that capitalizes upon a crewed presence in cislunar space to comprehensively sample multiple locations in the Solar System, using robotic sample return spacecraft, and thus significantly expanding the understanding of the young Solar System.

TESTING SURVIVABILITY OF LIFE FORMS IN OPEN SPACE BEYOND LEO.

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Introduction: Observations that certain microorganisms can survive in the stratosphere (i.e., Near Space) and recently-completed external ISS exposure experiments show that terrestrial microbes can endure extreme conditions [1, 2, 3]. However, it remains uncertain whether microbes can survive in deep space beyond low Earth orbit. One Apollo-era study suggested that *Streptococus mitis* bacteria survived almost one year on the lunar surface [4]. A variety of dryable microbes (bacteria, fungi, algae, and tardigrades) could be exposed to the deep space environment outside of the Gateway habitat, allowing researchers to understand how resilient terrestrial life forms respond to the combined conditions of vacuum, temperature variations, micrograviity and space radiation. Such experiments would not only inform fundamental space biology research, but also be relevant to astrobiology and the topic of habitability, specifically how microbes might move (naturally or artificially) between planets. It is reasonable to consider that life in solar system, once initiated, was transferred by meteorites and asteroids based on unique ability of bacterial spores and primitive organisms to reduce metabolic functions and survive in harsh space environment [5, 6]. Equally compelling is that knowledge that hitchhiking microbes can ride on spacecraft sent to pristine worlds; so-called forward contamination monitored by NASA's Planetary Protection Office. Survivability experiments of microorganisms on exterior portions of the ISS cannot provide answers to these important space biology and astrobiology questions because conditions in LEO and deep space are substantially different. This includes the protective geomagnetic factors of Earth and radiation protective belts which may be important factors for bio-survivability of life forms in open space within LEO. The Deep Space Gateway can provide a unique opportunity for long–term microbial exposures for a variety of proposed experiments. We propose a tray-like structure that would accommodate biological samples in separated compartments with multiple wells, similar to that used onboard the ISS the EXPOSE-E and LIFE experiments that were installed and initiated through ISS extravehicular activities. A similar concept of operations mounted outside of the Deep Space Gateway would be a simple and powerful way of testing the survival of terrestrial microorganisms in outer space. Externally mounted exopure hardware could accommodate more than 470 samples of microorganisms and be minimally resource-demanding (i.e., low mass, no power, low cost, and with little involvement of crew members after installation & removal) Nominally, exposure experiments would run comparative assays of exposed and unexposed strains of microorganisms, spores or simple animals previously tested in the ISS experiments in order to establish how deep space conditions are uniquely influential. The comparative survivability and genomic response assays will provide insight about the role of the Earth's geomagnetic factors on terrestrial life. Sequencing and functional analyses (e.g., proteomics, transcriptomics, metabolomics) could be performed to identify space induced changes in deep space exposed organisms.

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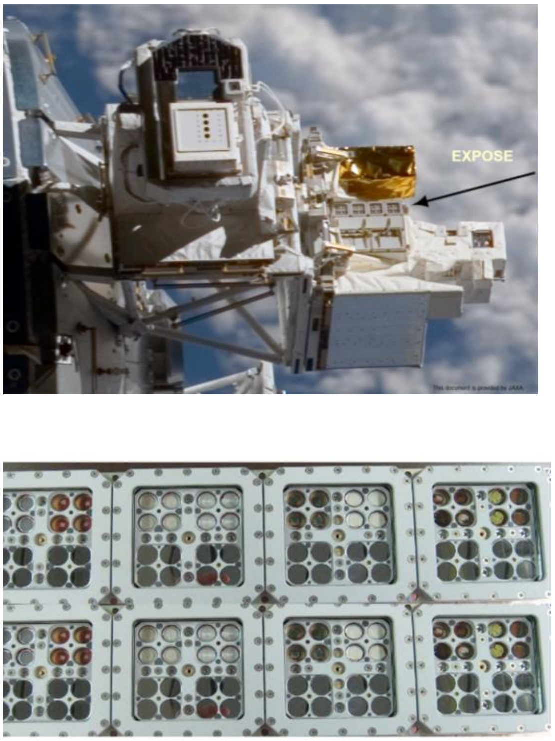
Sample trays used in the EXPOSE-E experiments



Starshade Assembly Enabled by the Deep Space Gateway Architecture.

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Introduction: A starshade is essentially an external coronagraph which nulls the bright light from a distant star to reveal an otherwise hidden planetary system. With a starshade, it may be possible to obtain the spectrum of an earth-sized planet in the habitable zone around a nearby star in emission, even with a relatively small telescope. The technical challenge is to produce a device which can reduce the 'glare' from the host star by a factor of 10^{10}. Recent progress has shown that unique flower-like shapes can perform this function, but for large future telescopes they must be constructed at a scale nearing 100 m with micron-thick edges. All current designs are examining the engineering of highly complex deployment mechanisms to attain these requirements and fit in a conventional rocket fairing.

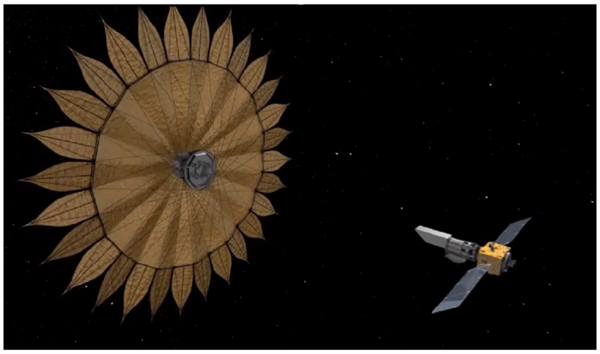

Figure 1. Starshade with notional telescope

Gateway Assembly: We present an alternative approach: assembling a starshade with support from the Deep Space Gateway (DSG) architecture. The DSG will have the benefit of a robust cis-lunar transportation system, an orbit which is favorable to sending spacecraft to deep space, robotics, and spacewalking crews. In the time frame of the DSG, NASA is planning to launch a "starshade-ready" Wide Field Infrared Survey Telescope (WFIRST), which requires an ~30m starshade. Assembling a starshade at the DSG from large pre-fabricated solid parts provides a major simplification of the design and may reduce the cost, resulting in achieving the WFIRST starshade science sooner. We present the concept of how a starshade might be assembled and deployed to deep space as a partner to enhance the science of future space telescopes.

"Smart" Vehicle Management System: A Necessity for Future Endeavors

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Introduction: As NASA reaches into deep space with manned exploration, delayed communication and the inability to rapidly return home drive the need for smarter spacecraft capable of assisting the crew in routine and off nominal operations. Systems that plan and operate themselves based on nominal events and system failures will be essential partners where crew time, skill, and vehicle knowledge may be spread thin and earth assistance is 5 to 40 minutes or more in the future. NASA's eventual Deep Space Gateway (DSG), Deep Space Transport (DST), and surface habitats will require proven "smart vehicle" functionality including onboard autonomous planning to achieve reduced ground support while providing a minimal flight crew with optimal utilization of both time and resources. A "Smart" Vehicle Management System (VMS) that enhances scientific return, crew survival, vehicle operational viability, minimizes crew work load, and ensures safe crew return will be an essential function to the future success of these missions. In order to achieve these goals Marshall Space Flight Center (MSFC) engineers plan to leverage previous work that has yielded proven success in this area of autonomy while outlining a roadmap for future requirements and concepts. Building on the success of prior projects such as "Habitat Ground Based Demonstrator", the man rated Higher Active Logic (HAL) for ISS, the ground based Autonomous Fluid Transfer System (AFTS) demonstration, and the ISS based Autonomous Mission Operations (AMO) rack activation experiments. As an example, the AFTS demonstrated automated procedures with autonomously executing Fault Detection, Isolation and Recovery (FDIR), and the onboard AMO rack activation demonstration simplified ISS crew involvement to a single button functionality while providing notification of faults and advisories. MSFC engineers will continue to include expanded autonomous planning and plan execution capabilities that will be a great benefit and fill a vital requirement of any deep space mission. Current work is being performed to prove the feasibility of a vehicle with multiple systems operating without ground planning support as the current VMS system under development at MSFC will prove an existing capability to perform the following activities: 1) Autonomously plans and executes vehicle system activities based on resource and operational constraints and 2) All systems reconcile each other system's plan to converge on a vehicle level plan that is then executed based on resources and the negotiated constraints and timing. Given NASA's goal to move beyond Low Earth Orbit and endeavor to explore further into deep space, it is becoming more evident that smart VMS will be an essential corner stone to the success of these missions. The VMS could potentially greatly reduce the need for ground based planning, mitigating the loss of crew time due to inefficient planning or time and resources. A robust VMS would enable experiments to be conducted on the spacecraft in both manned and unmanned states increasing the scientific usefulness of any cis-lunar or deep space infrastructure.

MICROARCSECOND ASTROMETRY TELESCOPE ON THE DSG

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Introduction: The Microarcsecond Astrometry Telescope (*MAT*) is a relatively small size (~0.5m) astrometric telescope on the Deep Space Gateway (DSG), which extends astrometric accuracy beyond that of the current space telescopes to a microarcsecond (μas) level, by measuring and correcting systematic errors in the telescope optics and the focal plane. The key technologies in this *MAT* instrument concept have been matured in ground testbeds and other flight systems, and will enable the μas-level astrometric measurements in a ~1-2 hours of integration on bright stars.

The primary science objectives of the *MAT*, are to conduct a set of unique astrophysics, and fundamental physics investigations relying on precision astrometric measurements. Through its ultra-precise, relative astrometry, the *MAT* can address many prime open questions in astrophysics and fundamental physics, namely:

1. *MAT* will be able to find a ~1$M_\oplus$ planet at 1AU (scaled to solar luminosity) orbiting one of the nearest ~60 FGK stars. This census of habitable exoplanets is crucial for future exobiology missions. The current estimate is ~20% of solar-like stars could have an Earth-like planet in or near the habitable zone. *MAT* can inform future direct exo-Earth imaging and spectroscopy missions, Habex or Luvoir, what stars to avoid because they do not host Earth like planets, and, equally important, to inform those missions to "keep looking" if the first few attempts at imaging fails because the planet is inside the inner working angle of the coronagraph, starshade or interferometer. *MAT* will measure the inclinations of ~10^3 RV planets and remove the *sin(i)* mass ambiguity, as well as find ~10^3 new Jupiters.
2. *MAT* will advance cosmology by determining the small-scale properties of the dark matter (DM) in the local Universe. It will be the first space observatory designed to test for signatures of models beyond the Standard Model of particle physics, and either confirm or invalidate Cold Dark Matter (CDM) and various theories of primordial inflation. *MAT* will: (i) examine whether DM in the inner part of faint dwarf spheroidal galaxies is cuspy or more homogeneously distributed; (ii) determine whether the outer halo of the Milky Way is prolate; (iii) detect small DM halos by finding the gravitational perturbations they have left on the Milky Way disc; and (iv) test inflationary models by detecting ultra-compact mini-halos of DM.
3. The instrument will serve as a pathfinder for a future stand-alone astrometric satellite to conduct a set of investigations recommended by the recent Decadal Surveys including the search and study of exoplanets, and investigations in cosmology, astrophysics, and fundamental physics.

Instrument description: *MAT* will conduct a set of unique investigations relying on a precision astrometry. It will use a stable telescope with in-orbit calibratable focal plane to perform differential astrometric measurements of nearby stars. It will also perform targeted astrometric observations of extragalactic sources. The *MAT* payload concept includes i) a single 3-mirror anastigmatic telescope with a ~0.5-m primary mirror and laser metrology subsystems, and ii) a camera. The camera focal plane array (FPA) consists of a multiple detector array, providing a Nyquist sampled FOV of 0.4°. The laser metrology subsystems will perform detector's position, QE, dark level calibrations, to ensure that *MAT* instrument can achieve ~1 μas astrometric precision in a couple of hours, which is needed to detect habitable exoplanets in our stellar neighborhood.

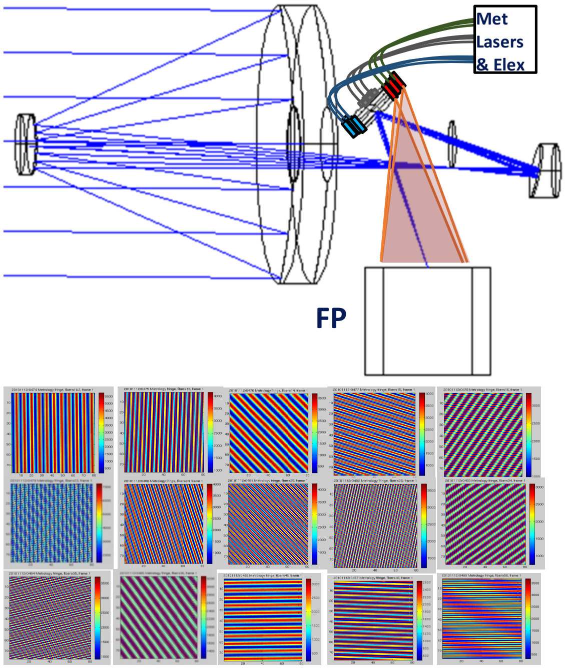

Figure 1. A concept demonstrating the on-orbit FP calibration laser metrology system with a TMA telescope (top) and an example image from our laser metrology testbed showing laser fringes of multiple spatial frequencies (bottom).

The *MAT* instrument would be a ~0.5 m telescope with a large focal plane, 0.4° field of view (FOV) with the point-spread function (PSF) being Nyquist-sampled, and with the metrology systems that will calibrate out the instrumental errors in the focal plane and the telescope optics at the μas level. It will be located on the exterior surface of the DSG, and will have a thermal system for good stability. High precision observations can be performed within the estimated mission life time of 3 years. The conceptual drawing for the *MAT* instrument is shown in Fig.2.

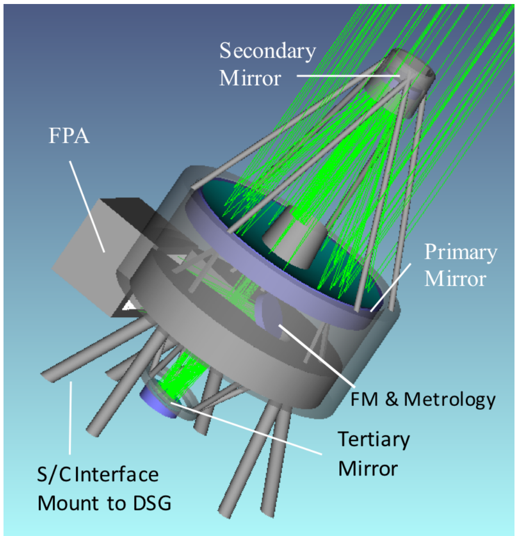

Figure 2. A conceptual drawing of the *MAT* instrument. A shun-shield, light baffles, and thermal radiator are not shown.

The instrument will weigh 65-90 kg, including a gimbal and ~30-50 kg for thermal radiator. *MAT* will occupy an estimated volume of <1.0 m^3 and will require ~70W electrical power. The *MAT* will generate a total estimated data volume of ~100 GB for the entire 3 years of its anticipated operational time. The instrument will be thermally insulated from extremal mounting fixtures. In general, very stable temperature environment is desired for observations. An ideal orbit would allow to observe sources with the Sun-exclusion angle of ~45°.

The cost of the robotic *MAT* mission would be in the range ~$75-90M, including technology maturation and data analysis. The astronaut involvement and potential servicing may allow for cost reduction.

Technology Readiness: Most of the required technologies for *MAT* are mature. For example, a large number of even larger, 1-m telescopes have been flown in space. There are three technology areas where flight qualification should be addressed. One is the on-board metrology system to measure the geometry of the FPA. All of the components, such as lasers, modulators, fibers have been flown in space, but the system was not flown. The second technology is the diffractive pupil, should we decide to use it as a primary mean for a field distortion calibration. A diffractive mask on the primary optics is passive, hence there should be no major issues with respect to flight qualification. The main technology challenge is putting it on a large optic (~0.5m). A potential third technology is a laser metrology system to measure changes in the alignment of the telescope/focal plane. Again, all individual components have flight heritage, but a *MAT*-like system is not yet flight qualified.

Conclusion: Unlike the Doppler and transit methods, only *astrometry* can determine the true mass and three-dimensional orbital geometry of an exoplanet reliably and precisely, which are the fundamental inputs to models of planetary evolution, bio signature identification, and habitability. With recent advances in detector calibration techniques, newly-developed flight metrology techniques, availability of the highly-precise astrometric catalogues, and existence of various mission concepts, a space astrometry mission is an ideal candidate for the future standalone mission.

1-µas astrometry in general and with *MAT* in particular, has the potential to bring major advances in many fields of modern astrophysics, namely: 1) discover most of the potentially habitable planets around the nearest ~100 stars to the Sun, 2) directly measure their masses and system architectures, and 3) provide the most complete target list and vastly improve the efficiency of detecting potential habitats of complex exo-Life with the next generation space and ground-based telescopes.

The µas-level astrometry will be a new tool for precision cosmology. By studying the gravitational perturbations in the local Universe, *MAT* can determine the small-scale properties of the DM. This space-based observatory will provide unique opportunities to study the signatures of models beyond the Standard Model of particle physics and fields, not available otherwise; it will either confirm or invalidate CDM and various theories of primordial inflation.

MAT will also push high-precision tests of gravity into a new regime. It will explore the physics of the universe by measuring the curvature of space-time around the Sun, represented by the parameterized-post Newtonian Eddington's parameter γ, reaching the accuracy of 1×10^{-6} (today's best is 2.3×10^{-5}).

MONITORING THE OUTFLOW OF MATTER FROM THE EARTH AND THE MOON FROM THE DEEP SPACE GATEWAY.

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Introduction: The Deep Space Gateway provides an ideal vantage point from which to monitor the outflow of matter from the Earth and the Moon. Material is continually lost from both the Earth and the Moon, in the form of neutral and charged particles and dust. The Deep Space Gateway provides a unique opportunity to comprehensively measure and characterize the structure and variability of both lunar and terrestrial outflow over long time scales, utilizing both in situ and imaging techniques.

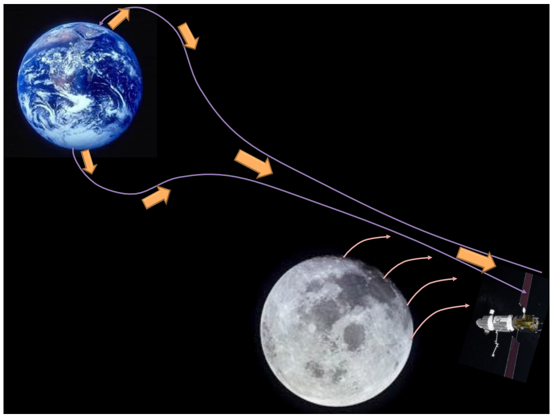

Figure 1: The Deep Space Gateway is optimally located to monitor outflowing matter from both the Earth and the Moon.

Outflow from the Moon: The tenuous lunar exosphere has been explored by both remote and in situ techniques since the Apollo era [1], most recently by the ARTEMIS, LRO, and LADEE missions [2, 3, 4, 5, 6, 7, 8]. Thanks to these previous observations, we have learned that the exosphere has both endogenic and exogenic sources and sinks. Some species, such as neon and helium, appear to be delivered primarily by the solar wind. Others, such as argon, are derived primarily from the interior. Still others, such as alkalis and molecular species, may be primarily delivered by micrometeoritic bombardment. Outflow from the Earth provides an additional source for atomic oxygen and some molecular species (see below). The Moon is therefore a witness plate that bears imprints of physical processes in the lunar interior and surface, the terrestrial environment, and the greater solar system.

We have also learned that the many atomic and molecular species in the lunar exosphere, as well as the dust component, respond differently to solar and micrometeoritic inputs and as a result have very different spatial and temporal dynamics. However, our knowledge of the composition, structure, and variability of the exosphere unfortunately still remains fragmentary, due to the short duration of most observations to date and the low abundances of most species.

To understand the long-term behavior of the exosphere and the interconnections between the exosphere, the surface, and the surrounding space environment, we require long-baseline measurements with high sensitivity. Though many exospheric constituents interact repeatedly with the surface and may reside in the lunar environment for extended durations (particularly in cold traps), the ultimate sink for material of both endogenic and exogenic origin is the surrounding space environment. Therefore, a spaceborne platform near the Moon affords an ideal opportunity to monitor the outflow of matter from the lunar environment.

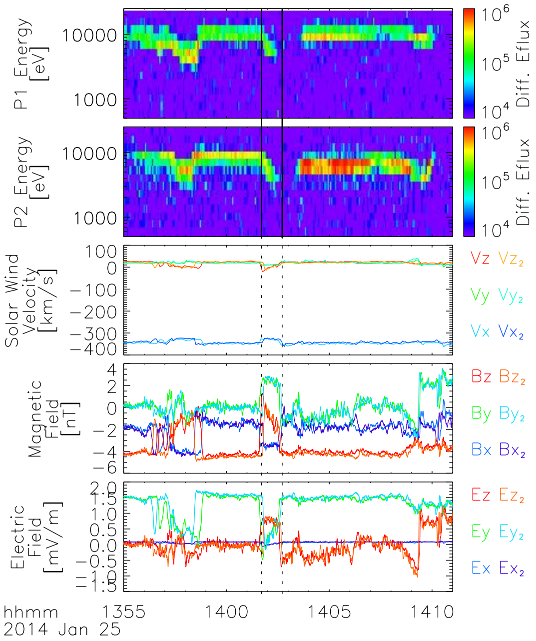

Figure 2: Ion outflow from the Moon observed by ARTEMIS, used to infer the presence of an extended population of massive species in the exosphere [8].

Elliptical selenocentric orbits and halo or Lissajous orbits in the vicinity of one of the Earth-Moon Lagrange points would both provide ideal vantages from which to monitor the outflow from the Moon. Outflowing neutral and charged atoms and molecules as well as small particulates are transported primarily antisunward from the Moon by radiation pressure and solar wind pickup, while larger particulates follow more Keplerian trajectories. Any orbit in the near-lunar environment will therefore intercept escaping matter from the Moon for a portion of the lunar cycle.

For this objective, we recommend as the highest priority measurement a sensitive ion composition sensor housed on the Gateway or a nearby platform. As proven by previous missions, ion composition sensors are capable of detecting all known lunar species [7], and provide the highest signal to noise measurement of many species. Ion composition measurements would be augmented by (but do not require) coordination with energetic neutral atom and UV observations to provide remote imaging of outflow from the Moon, as well as dust measurements to provide in situ monitoring of the particulate component of the outflow.

Coordination with other assets at the Earth-Sun L1 point and in lunar orbits, while not required, would provide additional value, allowing better separation of lunar and extralunar sources, as well as correlation of lunar responses to external drivers.

Outflow from the Earth: Recent measurements from Kaguya and ARTEMIS [9, 10] have demonstrated that atomic and molecular ions from the terrestrial ionosphere flow downstream through the magnetotail and intercept the lunar environment. This material represents not only a portion of the outflow from the terrestrial system, but also an additional source of material to the lunar system, with implications for the evolution of the lunar regolith and exosphere.

At present, we have only a few direct observations of outflow at lunar distance, and we have limited understanding of the frequency and spatial extent of the outflow and its variability with solar inputs or terrestrial seasons. By monitoring the outflow over a long time scale and correlating to other assets in the solar wind and near the Earth, we would learn about the response of the terrestrial environment to solar influences.

Any orbit around or near the Moon would provide an ideal vantage from which to monitor outflow from the Earth. Any such orbit will intercept escaping matter from the Earth as the Moon passes through the Earth's magnetotail (during full Moon).

For this objective, we recommend as the highest priority measurement a sensitive ion mass composition sensor mounted on the Gateway or on a nearby platform. An ion composition instrument would provide direct measurements of terrestrial outflow. Ion composition measurements would be augmented by (but do not require) coordination with energetic neutral atom and UV measurements to provide remote imaging of terrestrial neutral and charged particle outflow.

Coordination with other assets at the Earth-Sun L1 point and in terrestrial orbits, while not required, would provide additional value, allowing correlation of terrestrial outflow to external drivers.

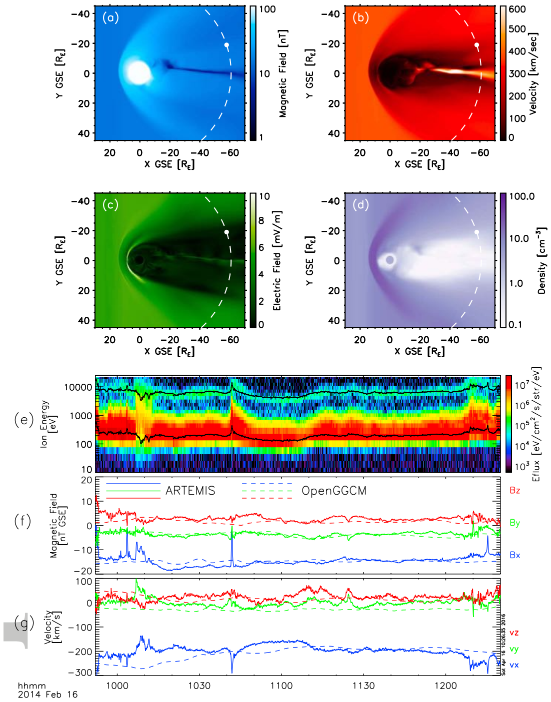

Figure 3: *Molecular ion outflow from the Earth observed by ARTEMIS [10].*

Conclusions: Long-term measurements by a sensitive ion mass composition sensor mounted on the Deep Space Gateway or a nearby platform would return important data that would answer critical questions about both the lunar and terrestrial environments. Both objectives would benefit from, but do not require, supporting measurements and/or coordination with assets at other locations

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BIOLOGICAL OBSERVATORY AT THE DEEP SPACE GATEWAY.

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Introduction: The NASA Life Sciences Research Capabilities Team (LSRCT) has been discussing deep space research needs for the last two years. The LSRCT supports a large number of abstracts in addition this one, reflecting a full range of desirable life science research. NASA's programs conducting life sciences studies – the Human Research Program, Space Biology, Astrobiology, and Planetary Protection – see the Deep Space Gateway (DSG) as enabling opportunities to investigate biological organisms in a unique environment that cannot be replicated in Earth-based laboratories or on Low Earth Orbit science platforms.

The LSRCT discussions have estimated that the life sciences' needs for deep space exposure greatly exceed that expected capacity of the DSG. This paper describes an innovative idea that has been under discussion by LSRCT members for addressing these needs, an approach that appears to be compatible with a commercial business model.

The DSG Life Sciences Capacity Problem: The entirety of what humanity knows about the effects of deep space exposure on living systems comes from the very few men who spent a very few day there during the Apollo program. The many unknowns that remain certainly contain keys to ensuring crew health and safety during extended exploration missions and may uncover entirely new science. The details of research needs are described in other LSRCT member abstracts but are summarized below to underscore the volume and importance of deep space, life science investigations.

There is no way on the ground or in LEO to simulate the effect of long duration, low dose deep space radiation combined with microgravity. Issues of microbial and microbiome evolution in an isolated system under deep space conditions are entirely unknown. There is no information whatsoever on plant growth in deep space nor how habitable ecosystems including plants might react to the deep space stress. There is no information on the stability of food and pharmaceuticals in the deep space environment. Hypothesis-driven studies of radiation and microgravity effects may help scientists understand them in enough depth to develop countermeasures with low system impact, like pharmaceuticals. Observational studies beyond the Earth's magnetosphere may reveal entirely new biological responses and mechanisms. Deep space provides an opportunity to expand understanding of the possibility of extraterrestrial life and the implications for planetary protection. Exposure of living specimens to the deep space environment offers an enormous potential for discovery, understanding, and exploration risk reduction.

Unfortunately, realizing this potential requires far more capacity than the DSG can provide. DSG was envisioned from the start as a platform for testing systems, operations, and human accommodation for deep space, with science utilization taking opportunistic advantage of any capability that might be available in meeting those challenges. It was never envisioned as a robust laboratory like ISS.

Hypothesis-driven studies typically require a large number of organisms. A minimum of twenty specimens are needed just to distinguish an observed phenomenon from random chance. Countermeasures for human use typically require scores or even hundreds of individual specimen exposures to demonstrate their safety and effectiveness above chance. Furthermore, human countermeasures and investigations of the effects of deep space on complex behaviors require complex animal models, typically rodents, which place a great demand on experiment volume, power, upmass, downmass, consumables, and upkeep.

DSG's life sciences research capacity is subject to two main constraints.

First, crew access will be limited to a month or two every year or two, and ISS experience suggests that crew time devoted to utilization is likely to be highly restricted even then. Second, the locker volume available to all utilization, biological and otherwise, will be modest compared with the needs for it.

The DSG can make many years of exposure time available for experiments that do not need crew attention. Some additional research could be enabled by relatively simple robotic support. High-value research with complex animal models and plants would need more advanced robotic technology, which could emerge through innovation and commercial spin-in if a need for it is established. However, justifying the investment in such technology and equipment would require far more utilization than could be accommodated by the few DSG lockers that might be allocated to life sciences.

A Biological Observatory: The solution to the utilization volume problem could involve docking a separate, special-purpose module, specially outfitted for life science research, to one of the docking ports to serve as a dedicated biological observatory. Three potential scenarios for the Biological Observatory are offered here.

The module could be configured as a visiting vehicle, perhaps based on a vehicle designed to serve as a logistics module. While the crew and their logistical support vehicle are not at the DSG, an observatory module outfitted with experiments and specimens could dock on the logistics module's port. DSG would provide communication, power and cooling, GN&C, and an environment compatible with life. The Biological Observatory would provide the resources needed for transit, experiment locker accommodations, robot interfaces, and supplemental ECLSS. Expensive or heavy multi-purpose equipment for robotic tending of the module experiments would be permanently based on the DSG. Before a new crew's logistics vehicle arrived, specimens could be robotically sacrificed, preserved, and off-loaded as appropriate. The module would be detached then reentered, destroyed, or sent to a station-keeping position for redocking after the logistics module departs. The crew could prepare the samples for return or do any delicate manual work (e.g. harvesting organs, sectioning) needed to capture the experimental information remotely.

Alternatively, the Biological Observatory could be permanently attached to a port in the node and equipped to accommodate lockers and the robotic equipment needed for individual experiments. Experiment lockers would come up on the logistics module, either on a dedicated flight during the quiescent (unmanned) period, to be offloaded and installed robotically, or as part of the crew's logistics for manual installation. This permanent module would allow the multi-year exposures that are key to several critical research questions associated with deep space exploration.

It is possible that an untended, isolated vehicle with living specimens could produce a contaminated environment unsuitable for human occupation. If this proves to be a concern, the observatory could be a separate vehicle attached to but isolated from the habitable DSG modules. The vehicle would have its own environment and ECLSS but rely on the DSG for power, communication, GN&C, etc. Crewmembers, appropriately protected, would gain access to it for experiment change-out or data collection via a tunnel, perhaps an inflatable one, attached to the EVA airlock, which would be suitably configured to provide isolation by, for example, purging with sterile air after crew access.

The exact conops and design of the Biological Observatory would be a matter for studies and trades. The central idea, however, would be a module that supplements the capacity of the baseline DSG specifically to support biological specimens for long-duration exposure and robotic tending in the absence of crew. It would have the flexibility to accommodate a variety of experiments and both plant and animal specimens.

A Commercial Business Model: It is entirely feasible that the Biological Observatory could be provided on a commercial business model, with its space leased to NASA investigators. In the 1990s, SpaceHab pioneered a commercial research business model aboard its Shuttle-based research module. It not only offered locker volume with access to space, but also provided integration services and leased some equipment, for example protein crystal growth chambers. The same kind of business model could provide a Biological Observatory on DSG to minimize the need for NASA to invest in expensive facilities while its resources are committed to developing the exploration gateway.

Commercial logistics transport to ISS already has the ability to accommodate living specimens and return cargo intact; commercial crew transport will provide a human-compatible environment that could be used on the Biological Observatory. The DSG architecture anticipates the availability of commercial logistics transport. These vehicles, modified to accommodate experimental lockers and robotic tending, could minimize the commercial investment needed provide the Biological Observatory while providing companies a new revenue stream from previous investments.

Because of the technology risk, NASA may be required to provide the robotic tending or at least underwrite the development and validation of the technology. The commercial business model will provide the vendor with an incentive to transition NASA's technology to improve the capabilities of the module and to work on simplifying the integration timeline and documentation.

Conclusion: The needs of living specimens are sufficiently unique, and the opportunities for breakthrough life science research are sufficiently abundant that the baseline capabilities of the human-tended DSG will never meet them. Something like the Biological Observatory described here would be necessary to take full advantage of the deep space exposure opportunities that the DSG provides to life scientists.

NEXT GENERATION FAST NEUTRON DETECTOR FOR SPACE EXPLORATION (Mini-FND).

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Introduction: One major hazard for human space exploration is that humans receive radiation doses that are much higher than on Earth [1], where we are protected from highenergy Galactic Cosmic Rays (GCRs) by our thick atmosphere. On bodies with no or only very thin atmospheres (e.g., the moon or Mars), interactions of these GCRs with the nuclei of the soil create secondary particles, such as neutrons, yielding an intense radiation environment of energetic particles. Similarly, inside a spacecraft, GCRs will create such a radiation field by interacting with the spacecraft material [2]. These energetic particles can cause severe health effects, such as cataracts or cancer.

Neutrons, in particular, are a major concern because shielding against them is hard to accomplish. Thus, measuring and understanding the neutron environment in interplanetary space and on extraterrestrial bodies is of high importance for future space exploration missions. The energy range of the neutron fluxes spans orders of magnitude, from below 1 eV (so-called 'thermal' neutrons) up to several hundred MeV. Of special interest for human space flight are neutrons in the range of a few hundred keV to a few MeV (called 'fast' neutrons). These have the highest biological relevance and are the potentially most hazardous neutrons for humans. This is expressed in their high radiation weighting factor [3].

Mini-FND: SwRI has developed a miniature Fast Neutron Detector (mini-FND), based on MSL/RAD [4] and ISS/RAD heritage, for use in the Deep Space Gateway, as well as other future lunar, near-Earth asteroid and near-Mars space missions to characterize the neutron albedo radiation in these environments. Mini-FND is directly related to the science areas of human health and performance, and will provide full coverage of the biologically highly relevant neutrons at energies of 500 keV and greater, with a mass of only ~1-2 kg.

Instrument Description: The mini-FND consists of a boron-loaded plastic scintillator (BLP) cube readout by a small-size Avalanche photo diode. Fast neutrons are detected via double-pulse capture gating as employed in the ISS/RAD. Neutrons interact with the BLP material, creating recoil pulses and losing energy. Once the neutron energy is in the thermal range, it can be captured by a boron, creating a second distinct light pulse with well-known timing distribution.

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DETECTION AND MAPPING OF LUNAR ICE WITH ACTIVE ILLUMINATION FROM THE DEEP SPACE GATEWAY.

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Introduction: Water and other volatiles are fundamental tracers of the formation and evolution of the Solar System, including the Earth and Moon. Water is also a critical resource for future human and robotic exploration. The need for better understanding of lunar water is evident in both the Planetary Science Decadal Survey [1] and in NASA's Strategic Knowledge Gaps [2]. In particular, SKG Theme 1 is to "understand the lunar resource potential," by quantifying and understanding the form and distribution of hydrogen species and other volatiles within the Moon's polar regions (SKG 1-D).

Ice deposits may also provide a record of delivery of exogenous materials by comets and asteroids [3]. Within at least one cold trap, inside Cabeus crater near the lunar south pole, this record strongly suggests a cometary source [4]. However, models indicate extremely heterogeneous volatile concentrations due to impact gardening [5]. So far, inside the Moon's permanently shadowed regions (PSRs), it has been exceedingly difficult to: 1) definitively identify water and other volatiles, and 2) map their distribution and concentrations at useful spatial scales.

Recently, NASA's Lunar Flashlight mission has presented a novel approach: using active illumination to measure surface reflectance spectra and search for features diagnostic of water and other volatiles [6]. This system is implemented onboard a low-cost CubeSat platform, which has inherent limitations. Here, we propose an active illumination system that leverages the potential capabilities of NASA's Deep Space Gateway to vastly improve knowledge of lunar volatiles.

Measurement Approach: Reflectance spectroscopy is a standard technique for determining the composition of planetary surfaces and atmospheres. Traditionally, reflected sunlight (or starlight) is used to measure the positions and depths of diagnostic absorption bands in the ultraviolet [7,8] to near infrared [9]. In the PSRs, this technique is challenging if not impossible, due to the low sunlight levels (from radiation scattered by surrounding terrain). Instead, we propose to use a light source onboard the Gateway (Fig. 1). A similar technique has already been successfully demonstrated using the Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter (LRO) at a single wavelength of 1064 nm [10].

For a collimated light source enclosed by the receiving telescope's field of view, emitted from the spacecraft with power P_T, the received power is

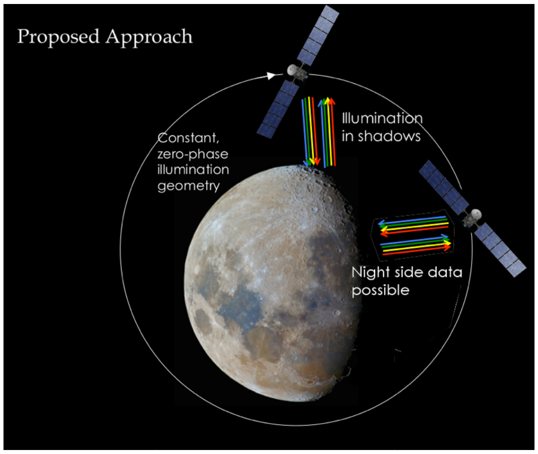

Figure 1: The proposed active illumination approach to measuring lunar surface reflectance and detecting water and other volatiles. Passes over the poles are required, but the DSG does not necessarily need to be positioned in lunar orbit.

$$P_{\mathrm{R}} \sim \left(\frac{r}{z}\right)^2 \alpha P_{\mathrm{T}}$$

where r is the receiver/telescope radius, z is altitude above the lunar surface, and α is the wavelength-dependent Lambert albedo of the surface. Therefore, the signal scales linearly with output power, and quadratically with both telescope aperture and distance to the surface.

Requirements for the Gateway: A trajectory with opportunities for line-of-sight views into the PSRs is required. Scaling from Lunar Flashlight's (LF) predicted performance provides useful estimates of required power, altitude, and aperture. From an altitude of ~30 km and ~8 cm aperture, LF has a detection limit and precision of ~1 wt% H_2O, using four lasers each with optical output power ~25 W, requiring peak delivered power of ~100 W to the laser subsystem. The electric power system includes super-capacitors, which charge between science passes in order to minimize the instantaneous power draw from the spacecraft. Thus, the relevant resource is energy. LF pulses its lasers during several minutes of a flyby, requiring ~10 Wh (36 kJ) per pass. If the Gateway were instead measuring from 300 km altitude, 1 kW peak power (~100 Wh for 5 min discharge) could accomplish the same measurements with this very small telescope. Alternatively, the telescope aperture could be increased to ~25 cm (10") diameter for the same boost in received signal.

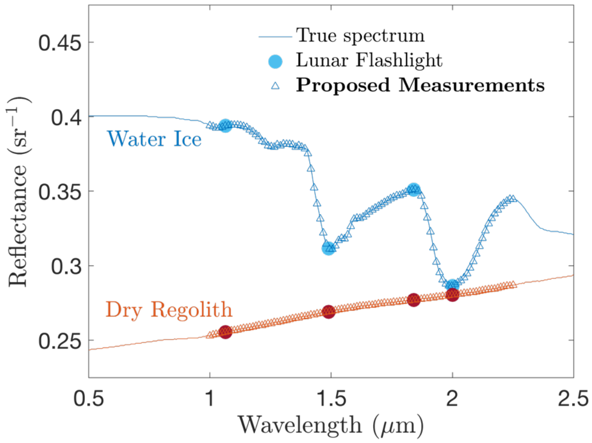

Figure 2: Example spectra for water ice and dry regolith, using two different spectral resolutions: a four-band measurement similar to Lunar Flashlight, and a 100-band measurement achievable by the proposed active illumination system with a simple grating spectrometer. The higher spectral resolution and/or signal-to-noise ratio would enable better discrimination of water and other condensed volatiles on the lunar surface.

Further enhancements in capability are possible. For example, with a 50-cm diameter telescope aperture and 1 kW peak power (discharging for ~1-5 min), SNR ~250x that of LF could be achieved from moderately low altitude (~30 km). In this case, a broadband "searchlight" could be used in combination with a grating spectrometer to achieve high spectral and spatial resolution. With enough power or lower altitude, high-resolution camera images could also be taken using a flashbulb approach during passes over the PSRs. Limited crew interaction would be necessary for instrument operations.

One of the challenges faced by the active illumination technique is heat dissipation; most light sources, including lasers, have optical efficiencies of < 50%. Therefore, the Gateway would need to be capable of removing at least ~100 W during laser operation. Temperature stability of < 5 K is necessary if lasers are used, in order to minimize wavelength shifts.

Anticipated Results: The proposed technique could yield high-resolution detections of water and other volatiles in the PSRs. Spectral resolution is limited by telescope aperture and optical power of the illumination source, as well as altitude above the lunar surface. Spatial resolution is limited by collimation of the light source and altitude of the platform. For anticipated capabilities, it may be reasonable to achieve ~100 m resolution on the lunar surface with ~10-100 spectral bands. Such data could quantify H_2O concentrations, and discriminate other volatiles, including CO_2 and methane. Multiple passes over both poles could build coverage to produce maps of volatile concentrations. Measurements on the lunar night side are also possible, which would constrain the mobility of water and also the mineralogy of the lunar surface without the complications of variable lighting and viewing geometries.

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Deep Space Gateway Facilitates Exploration of Planetary Crusts: A Human/Robotic Exploration Design Reference Campaign to the Lunar Orientale Basin.

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The Deep Space Gateway can serve as the International Science Operations Center (DSG-ISOC) in Cis-Lunar Space (akin to McMurdo in Antarctica) for addressing fundamental scientific problems about the Moon and planets, and preparing for the human/robotic exploration of Mars and beyond. We envision the DSG to be a hub for facilitating the activities necessary to explore fundamental scientific problems in an integrated fashion, utilizing a broad strategy for the systematic exploration of the Solar System, calling on a wide range of technologies and accomplishing fundamental goals through potential international cooperation. Microsymposium 56, "Crust of the Moon: Insights Into Early Planetary Processes", (http://www.planetary.brown.edu/html_pages/micro56.htm) identified a series of outstanding problems for future international human/robotic exploration of the Moon centered on: 1. Crustal geometry-physical structure; 2. Crustal Chemistry-mineralogy-petrology; 3. Exogenic crustal modification by impacts; 4. Chronology of crustal formation-evolution. Furthermore, the nature of mantle uplift and the possibility of sampling mantle in the uplifted material as well as determining the nature of basin impact melt processes (differentiated or undifferentiated) is critically important. Direct dating of impact melt and placing Orientale in the firm context of lunar chronology is also achievable. To illustrate the potential utility of the Deep Space Gateway ISOC, we are formulating a human/robotic exploration design reference campaign (DRC) to the 930 km Orientale impact basin (1,2), the most well preserved basin on the Moon. This DRC provides insight into all aspects of these fundamental questions.

The Deep Space Gateway ISOC can 1) ensure human exploration of the lunar surface to meet national and international goals, 2) facilitate complementary robotic missions to optimize the science and exploration return, 3) provide communications infrastructure that can be shared internationally, 4) engage a renge of commercial entities, and 4) help train current and future astronauts in orbital science operations and surface landing, roving, essential for future human scientific expeditions and operation on Mars.

Our design reference mission is a model for the exploration of the Moon and planets in the coming decades, and combines robotic exploration geophysics traverses operated radially from the basin interior, together with human exploration missions to the key sites that will provide data to address these questions. We outline six human exploration mission landing site targets: 1) Base of the Cordillera ring/Montes Rook Formation; 2) Base of the Outer Rook ring/Lacus Veris maria; 3) Inner Rook peak-ring massifs/Maunder Formation impact melt rough facies 1; 4) Maunder Formation impact melt sheet smooth facies; 5) Central melt sheet craters/Mare Orientale/Kopff crater; and 6) Maunder crater interior/ejecta. Our strategy for human/robotic exploration optimization from the DSG-ISOC centers on seven mission concept themes and is totally flexible relative to the important new results and significant discoveries that will be made from early DSG-ISOC-enabled science return in the next few years:

Robotic Precursor Phase:

I) *Precursor* Robotic Missions (What do we need to know before we send humans?);

II) *Context* Robotic Missions (What are the robotic mission requirements for final landing site selection and regional context for landing site results?);

Human Surface Exploration Phase:

III) *Infrastructure/Operations* (What specific robotic capabilities are required to optimize human scientific exploration performance? How can the DSG-ISOC implement/complement robotic cabilities);

IV) *Human Surface Exploration Phase* (Sorties to the key scientific exploration sites in the Orientale Basin for intensive scientific exploration with stay times up to 10-12 days and sample and data return back to the DSG-ISOC; practice feed-forward Mars exploration concepts);

V) *Interpolation* Robotic Missions (How do we use robotic missions to interpolate between human traverses?);

VI) *Extrapolation* Robotic Missions (How do we use robotic missions to extrapolate beyond the human exploration radius?);

VII) *Progeny* Robotic Missions (What targeted robotic successor missions might be sent to the region to follow up on discoveries during exploration and from post-campaign analysis?).

We use the targeted human exploration sites to illustrate how human exploration, complemented and assisted by robotic exploration, can provide insights into early planetary processes by exploring and characterizing the crust of the Moon. Our architecture provides insight into human/robotic exploration strategies for other lunar regions and other destinations on other planetary bodies such as Mars, all from DSG.

This international design reference mission approach will assist in identifying the key technologies, including laboratory, remote sensing and in situ that will be necessary to accomplish these fundamental and broad scientific goals in the DSG-ISOC time frame. It will also serve to form the partnerships and identify the opportunities and obstacles to international synergism. Human-Robotic partnerships in science and engineering synergism (SES), such as that exemplified by the NASA Solar System Exploration Virtual Institute (SSERVI), are absolutely essential to formulating and achieving these goals.

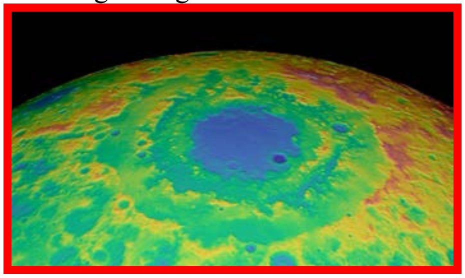

Fig. 1. Perspective view of topography of Orientale Basin. LRO LOLA data.

References: (1) Zuber, Maria T. et al, (2016) Gravity field of the Orientale basin from the Gravity Recovery and Interior Laboratory Mission. *Science*, 354, 438-441DOI: 10.1126/ science.aag0519. (2) Johnson, B. et al. (2016) Formation of the Orientale multiring basin, *Science*, 354, 441-444, DOI: 10.1126/science.aag0518.

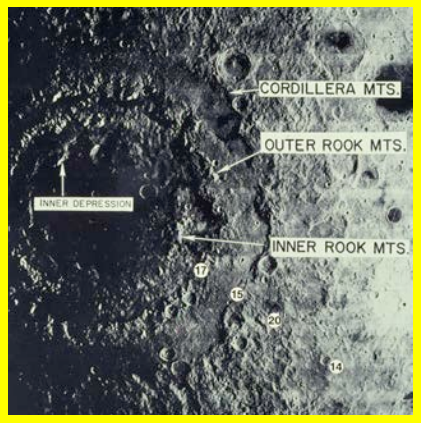

Fig. 2. The Orientale Basin from Lunar Orbiter, showing the rings and the Apollo and Luna equivalent landing site locations for the Orientale Basin.

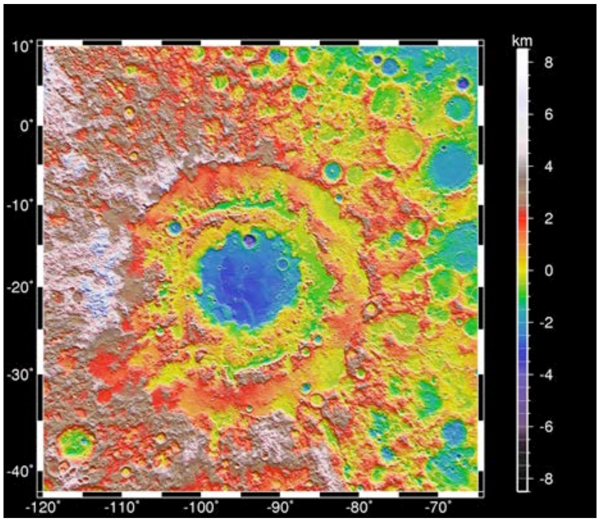

Fig. 3. LRO LOLA Topography of the Orientale Basin.

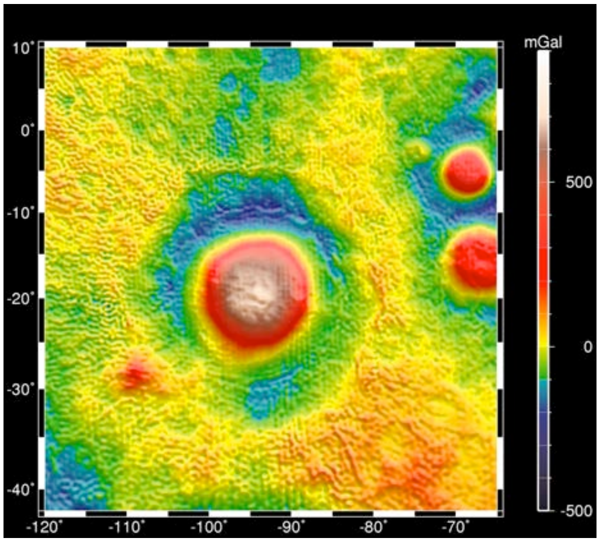

Fig. 4. GRAIL Bouguer gravity map of Orientale Basin.

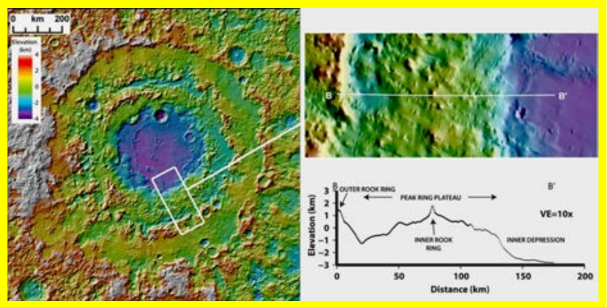

Fig. 5. Exploration Region of Interest 3 (ROI-3) for the origin of Inner Rock Mountains and Maunder Formation impact melt.

THE DEEP SPACE GATEWAY OPPORTUNITY FOR NEXT GENERATION SPACE WEATHER MEASUREMENTS

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Introduction: The NASA Heliophysics Living With a Star program focuses on the science necessary to understand aspects of the sun and Earth's space environment that affect life and society. The goal is to provide the comprehensive research needed to understand the many factors affecting the sun-Earth system and thus provide the information necessary for improved forecasting of space weather. Over the space age, we have accumulated extensive knowledge of the regions of space surrounding the Earth and the Sun, and the governing physical processes operating in these regions. However, this knowledge, with few exceptions, has not fully translated into a systematic operational forecast capability that informs the users of space weather data on timescales sufficient to take appropriate actions, whether for day-to-day operations or to protect against catastrophic events. This is particularly an issue for the Deep Space Gateway (DSG) and Orion crews and potential lunar surface crews. Addressing these needs will require a fundamental shift in the strategic approach to space-based missions.

Approachs: In the past, in situ heliophysics observations have been obtained from flagship missions carrying comprehensive instrument suites and significant budgets; however, these high-cost missions still supply only localized measurement sets that are difficult to use to characterize the global response of the system. Because of this, the promise of small satellites as an affordable option for in situ measurements of relevant space plasma parameters makes these platforms an ideal candidate to obtain the outstanding observations necessary to advance space weather operations. The near-Earth vicinity of the Deep Space Gateway could represent the first step in formulation of the next-generation space weather system concept, potentially providing a broad range of infrastructure (e.g., telemetry, launch capabilities) to enable a paradigm-shifting, more systemic approach to how space-based measurements are made. The location is ideal to launch small satellites (< 6U) that carry both remote sensing and in-situ sensors to cover the near Earth environment from the magnetosphere to upstream of the Earth's bow shock. In addition, the DSG can also provide a data relay function to pass real-time space weather measurement down to Earth or the Orion crew.

Payload: The Johns Hopkins University Applied Physics Laboratory (APL) has been developing field and particle instruments that can be accommodated on small spacecraft such as those that proposed here. *Korth et al.* [1] have also developed at APL a miniature atomic scalar magnetometer for space that is based on the rubidium isotope. The entire sensor (excluding the harness) is less than 150 g and development is currently underway to incorporate this scalar sensor into an existing APL fluxgate magnetometer. The new combined sensor will be able to measure the vector magnetic field and self-calibrate, which is ideal for a small spacecraft mission. The APL's many particle and dosemeter designs that have been successfully flown on previous NASA missions can also be accommodated in a small spacecraft such as those we propose here.

Spacecraft: APL collectively continues to explore, and invest in R&D for new architectures for Civil and National Security Space (NSS) missions uniquely enabled by small satellites in the 4 kg (3U CubeSat) to ~180kg (ESPA-class) range. Notably, the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat Mission that is funded by NASA's Earth Science Technology Office was launched on Nov. 11, 2016. The payload was designed and built at APL and L-1 Standards and Technology; the 3U CubeSat bus was designed and built by Blue Canyon Technologies, who also performed integration and testing. RAVAN is a pathfinder for a constellation to measure the Earth's radiation imbalance, the single most important quantity for predicting the course of climate change over the next century. Prior to RAVAN, APL flew Multi-Mission Bus Demonstration (MBD) 3U CubeSats. Launched in Nov. 2013, these CubeSats, including payload, were entirely developed, built, and operated by APL. The technologies demonstrated and lessons learned through RAVAN, MBD, and other NSS missions will guide this study's investigation into planetary small satellite applications.

References: [1] Korth, H., Strohbehn, K, Tejada, F. et al. (2016), Miniature atomic scalar magnetometer for space based on the Rubidium Isotope 87Rb. *J. Geophys. Res. Space Physics, 121,* doi:10.1002/2016JA022389.

LUNAR VOLATILE SYSTEM DYNAMICS: OBSERVATIONS ENABLED BY THE DEEP SPACE GATEWAY.

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Introduction: A decade of observations from many spacecraft has shown that the Moon possesses a dynamic volatile system that includes interaction with the solar wind and coronal mass ejections, micrometeorites and larger objects, and outgassing from the lunar interior with time-varying signals present in the atmosphere and on the surface. While low altitude orbital measurements are invaluable, several of the proposed Deep Space Gateway orbits offer a unique vantage point for long duration remote sensing monitoring of the lunar volatile system. In addition, the potential for higher power and mass instruments are enabling of measurements impractical for smaller spacecraft. We present a notional science and technical case for dedicated long duration remote sensing of the Moon to understand the dynamics of its volatile system.

Science Case: In the present epoch it appears that the principal sources of volatiles to the Moon are the solar wind (including solar storms) and meteorite impact, with lesser contributions from outgassing or sputtering (K, Na, Rd [1]). Redistribution of ancient volatiles by moderate impacts capable of reaching depths of several meters may also be a source of volatiles into the lunar volatile system. Solar wind principally supplies hydrogen in the form of moderate energy protons; reactions with the surface appear to supply H_2 to the atmosphere [2]. The time-variable 3 micron surface absorption [3] may also be due to solar wind input producing time-variable hydroxyl or possibly water. Formation of carbon compounds from solar wind C and H in surface chemical reactions is also proposed to explain methane detected in the atmosphere [4].

Meteorite impact can stimulate mobile volatile production in several ways. Common meteorite types contain water in various forms that can be released on impact. Some laboratory experiments indicate molecular water is not produced from proton irradiation under typical lunar conditions [5]. However, the temperatures achieved in meteorite impact may be high enough to enable production of water from a hydrogen enriched silicate surface.

Both the solar wind source and meteoritic sources are dynamic. Solar wind is variable on the solar cycle timescale, and if coronal mass ejections are included the energy and flux of solar particles vary by orders of magnitude. The solar wind flux to the surface is also modulated by the Moon's passage through the Earth's magnetotail and this passage is known to strongly affect the flux of He in the lunar atmosphere [6].

An important result of the LADEE mission was that meteor streams had a strong effect on atmospheric species including water [7,8].

While these observations have been invaluable, there are numerous unanswered questions. Among these are whether water is produced on the lunar surface and propagates to the poles, charging polar cold traps, or is the time variable surface signal an artifact or due to hydrogen and hydroxyl chemistry occurring within surface grains producing no mobile species other than H_2? The hydrogen budget itself is not fully accounted for and it is unknown whether hydrogen is in accumulation, equilibrium or loss from the Moon. Observations from the Deep Space Gateway may provide a means to answers to these questions.

The Gateway Vantage Point: While the orbit of the Deep Space Gateway is as yet undetermined, studies suggest an extremely eccentric orbit with apolune tens of thousands of kilometers above the lunar surface is likely [9]. From many of these candidate orbits the Moon would subtend only a few degrees for most of the orbit, enabling a synoptic view of the Moon for remote sensing, and enabling simultaneous imaging of the entire lunar atmosphere nearly continuously. For higher resolution observations, the final orbit may not include very low perlunes, but even a few thousand km range offers the potential for relatively high resolution observations with modest telescopes.

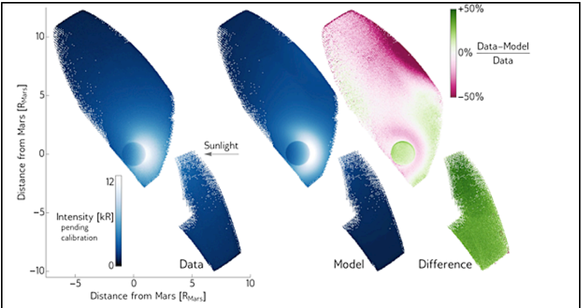

Figure 1. Images of atomic hydrogen corona around Mars obtained by the MAVEN mission.

The Gateway Resource Advantage: A remote sensing package on a crewed spacecraft is offered several advantages not typically present in dedicated science mission satellites: mass, power, thermal control and serviceability. As we will see below, a key water-related infrared observation is probably impractical on a Discovery class mission owing to its mass, power consumption, and heat dissipation.

Proposed Experiment: The MAVEN spacecraft provided dramatic imagery of the entire extended Mars atmosphere during its approach to that planet (Figure 1), synoptic observations that could not be repeated once in orbit [10]. Lunar column densities are far lower [11], so a similar result would require longer integration times, nevertheless, a sensitive UV spectrometer or imager would enjoy long counting times at long ranges for many of the proposed Gateway orbits and provide long duration monitoring of the lunar atmosphere, and detailed correlations of its composition and dynamics with volatile inputs and their variations.

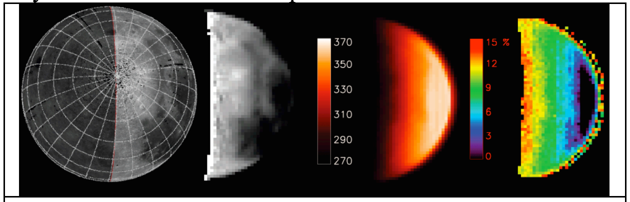

Figure 2. Deep Impact IR view of the lunar North Pole showing the depth of the 3 micron water feature (right). A similar map at 6 microns would definitively show the abundance of molecular water, day and night.

An outstanding question regarding lunar surface volatiles is the nature of the time variable 3 micron absorption feature reported by Sunshine et al. [3]. It has long been hypothesized that solar wind hydrogen can cause production of hydroxyl by reaction with lunar surface oxygen [eg. 12], and that formation may include water and that this water may migrate to the lunar poles and be trapped in regions of permanent shadow[13]. However, the relative abundance of water and hydoxyl is unknown [3] and there have been doubts cast on the time variability of the spectral feature owing to disagreements surrounding correction for thermal emission contamination of the reflectance signal [14].

Table 1. Gateway resource requirements

Instrument Analog	Mass	Power	Volume m^3	Special requirements	Orbit
MAVEN IUVS	30 kg	30W	0.1	Pointing system	Apolune > 50,000 km
GHAPS Cross-dispersed IR spectrograph	100 kg	100W	0.1	Access to Gateway thermal control	Perilune <1000 km

Molecular water exhibits a narrow emission feature near 6 microns due a fundamental vibration, and at these long wavelengths, solar reflected flux is minimal, so detection and mapping of a 6 micron feature provides definitive characterization of molecular water. Emitted fluxes are strongly dependent on temperature, and within the limitations of a modest spacecraft detection and mapping is likely limited to temperatures above 220K (about 70 degrees of latitude). However, the potential for power in the 100W range on the Gateway would enable a fully cryogenic instrument that could map the extent of water on the lunar nightside as well as dayside at a resolution of 1 km. This capability would enable direct detection of lunar surface water variations in the 10s of ppm range.

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DUST MEASUREMENTS ONBOARD THE DEEP SPACE GATEWAY: INTERPLANETARY AND INTERSTELLAR DUST; SOLAR WIND ENTRAINED NANODUST; AND THE LUNAR DUST EXOSPHERE

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Introduction: Placing a dust instrument onboard the Deep Space Gateway (DSG) will revolutionize our understanding of the interstellar and interplanetary dust environment at 1 AU, contributing to our fundamental understanding of the evolution of our solar system, and improve our dust hazard models for the safety of crewed and robotic missions to Mars, and other destinations.

Interstellar Dust and Solar Wind Entrained Nanodust Particles: The observations of the inward transport of interstellar dust and the outflow of near-solar dust provide a unique opportunity to explore dusty plasma processes throughout the heliosphere. The flux, direction, and size-distribution of interstellar dust can be used to test our models about the large-scale structure of the heliospheric magnetic field, and its temporal variability with solar cycle. The measurements of the speed, composition and size distribution of the recently discovered, solar wind-entrained nanodust particles hold the key to understanding their effects on the dynamics and composition of the solar wind plasma.

Interplanetary Dust Particles: The orbital elements of dust particles that are generated by active comets, by dust impacts onto the surfaces of airless bodies, or by collisions between asteroids, for example, are initially similar to their parent bodies. Collections of such particles form meteoroid streams. Depending on the size of these grains, their initial orbital elements will change and randomize over timescales of centuries or longer, and they become part of the sporadic background of meteoroids. In general, long period Halley-type comets likely come from the Oort Cloud (Tisserand invariant $T < 2$), and short period Jupiter family comets likely originate from the Kuiper Belt ($T > 2$). Main belt asteroids have low inclination, nearly circular orbits. Hence, the orbital elements of the offspring dust particles from comets and asteroids can be used to identify their parents. Interstellar dust particles are entrained in the flow of interstellar gas across our solar system and can be identified by their narrow speed distribution and directionality.

The Lunar Dust Exosphere: While orbiting the Moon, the Lunar Dust Experiment (LDEX) onboard NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission discovered a permanently present ejecta dust cloud engulfing the Moon, sustained by meteoroid bombardment. The lunar dust cloud in the Moon's equatorial plane is dominantly produced by impacts from three known sporadic meteoroid sources: apex, helion, and antihelion, listed in order of their contribution to ejecta production. The cloud density is also modulated by the Moon's orbital motion about the Earth, peaking during its waning gibbous phase. However, due to its short mission, LADEE could not observe the lunar dust environment through the year. The DSG will provide an opportunity to expand dust measurement in a lunar orbit to characterize the temporal variability of the lunar dust exosphere, and the meteoroid environment at 1 AU.

The Dust Experiment (DEX) Instrument: DEX (Figure 1.) is an in situ, high-resolution compositional dust analyzer developed specifically for the detection and analysis of interstellar dust (ISD) an interplanetary dust particles (IDP). It measures the speed and mass distributions, as well as the elemental and chemical composition. It is based on the proven measurement method of Cassini's Cosmic Dust Analyzer (CDA) instrument. Compared to CDA, however, it provides a larger effective target area (700 cm^2) to collect a statistically significant number of dust impacts, and provides a drastically higher mass resolution due to its of its unique ion-optics design. Individual dust particles entering the instrument pass through a set of grid electrodes and impact a 0.5 μm thick layer of high-purity rhodium target. A charge sensitive amplifier (CSA) attached to the target measures the impact- generated charge that is a function of the particle's mass and speed. A mass spectrum is obtained for each particle from the time-of-flight (TOF) analysis of the impact generated atomic and molecular ions. The target is biased at +3 kV to provide positive ion acceleration, and reflectron type ion optics is used to enable resolving powers in excess of m/dm > 200. The electrostatic field is shaped by a set of biased rings and one curved grid electrode to provide spatial and temporal focusing of the accelerated ions. The centrally located ion detector is a single plate, 40 mm diameter, small pore-size microchannel plate detector with a high dynamic range and sensitivity even for minor species. DEX records a wide mass range of 1 – 500 u to identify elemental and molecular ions and to reveal the chemical and mineralogical makeup of impacting particles. DEX may also be implemented with a negative ion detection mode that could deliver critical new information of the makeup of ISD/IDP particles.

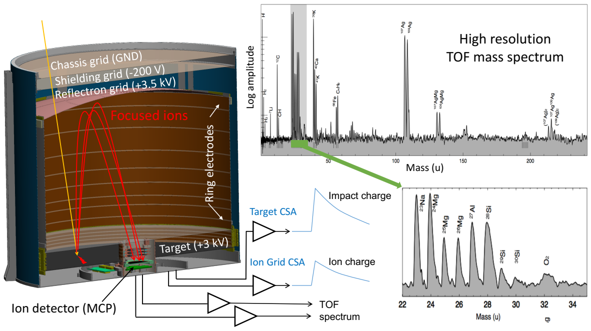

Figure 1. The operation principle of the DEX instrument and the signals measured. DEX has been developed specifically for the detection and analysis of ISD/IDP particles. Electronics box not shown. The inserts demonstrate the capability of the instrument to capture time-of-flight spectra with a ion mass resolution m/dm > 200.

DEX is an event-driven instrument. A trigger for data acquisition is derived from the impact charge signals detected on the target, the ion grid, or the ion detector. The TOF spectra are recorded at a rate of 250 MS/s on two analog channels from an unevenly split anode behind the MCP detector achieving a high dynamic range. The impact charge and auxiliary signals are sampled at 12.5 MHz. Each trigger event is time-stamped, post-processed, and checked for validity before data compression. The IDEX low-mass mechanical design consists of a simple aluminum shell structure that provides support for the biased electrodes of the TOF analyzer and the grids over its aperture. The centrally located ion detector, along with the front-end CSAs are integrated into the bottom of the instrument. The electronics box (not shown), housing the high- and low- voltage power supplies, the digital and processing boards, is mounted near the instrument.

The interpretation of the measured impact spectra is supported by laboratory calibration measurements using analog dust sample materials and the IDEX engineering prototype. DEX derives heritage from the CDA instrument on Cassini, and the LDEX instrument on LADEE. On a subsystem level, DEX also derives heritage from a number of space instruments developed at LASP. Based on flight heritage as well as existing functional laboratory models, the current TRL of IDEX is 6. The instrument preliminary specifications are summarized in the table below.

Instrument Resource	CBE	Notes
Mass	10.1 kg	Based on MEL
Power	9.8 W	Based on MEL
Survival heater	5 W	Estimate
Data rate	200 bits/sec	Science + Housekeeping
Volume	48x48x45 cm^3	Instrument
	20x20x11 cm^3	Electronics box

A concept for differential absorption lidar and radar remote sensing of the Earth's Atmosphere and ocean from NRHO Orbit

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Absstract: We propose a concept that will put a few microwave and beam steering laser transmitters on the Deep space gateway platform for active sensing of the Earth's atmosphere and ocean. Receivers will be placed on the ground and installed on Buoys and Argo floats, as well as cube satellites. The amount of receivers will be scalable to the resources available.

The wavelengths of the microwave and laser transmitters include the ones used for differential absorption lidar and radar techniques for measuring optical depths of aerosols and clouds, surface atmospheric pressure, atmospheric trace gases, and ocean biogeochemistry.

This study introduces the concept and gives an overview of the techniques and scientific applications.

WHAT COULD BE LEARNED FROM PHASE CONTRAST X-RAY NANOTOMOGRAPHY ANALYSIS OF COSMIC DUST POTENTIALLY COLLECTED IN DEEP SPACE?

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A gateway in cislunar space for next-step human exploration of the solar system will provide new opportunities for science research, including enabling unbiased collections of primitive cosmic dust particles for laboratory study. Cosmic dust particles, also known as interplanetary dust particles (IDPs), derive primarily from comets and asteroids [1]. They provide samples of primitive or the least altered fine-grained materials from the early solar system, some of which were either not incorporated or not preserved in common meteorites [2-3]. Cosmic dust particles studied to date are collected in the stratosphere as well as in polar regions and deep-sea sediments [1, 4-6]. These collected particles are the samples of primitive solar system bodies that have survived atmospheric entry (hence biased samples). They experienced varying degrees of heating during atmospheric entry, which complicates analysis (atmospheric entry heating and terrestrial contamination or weathering have been a limiting factor in realizing full scientific potential of the collected cosmic dust). Collecting cosmic dust in cislunar space would eradicate the drawbacks to collection in the terrestrial environment. Moreover, with a long-duration collector in the pristine space environment, pristine primitive cosmic dust particles from known sources could be harvested with a great size range, say, from submicrons to one hundred microns or larger. By using state-of-the-art and new laboratory instruments with unparalleled resolution and sensitivity, analyses of the pristine primitive cosmic dust particles collected in deep space would allow challenging questions to be uniquely answered about the early solar system and beyond. In this presentation, I will explore what could be learned from phase contrast X-ray nanotomography (PCXNT) study of cosmic dust to be potentially collected in cislunar space, based on new results obtained from porous IDPs [7].

Knowledge of the morphology and structures of the most primitive fine-grained cosmic dust particles at the 3-D nanoscale is key to understanding properties of the most fine-grained dust aggregates and grain aggregation in the protoplanetary disk (the crucial first step towards the formation of planetesimals and/or planets [8-9]) as we come to appreciate that cosmic dust contains samples of primitive or the least altered dust of the outer solar nebula. PCXNT enables bulk porous particles to be noninvasively visualized and analyzed morphologically and microstructurally in 3-D ~ 10 nm detail, which has resulted in new findings, including revealing an inherently fragile and intricately porous aggregate of submicron grains or clusters that are delicately bound together frequently with little grain-to-grain contact in 3-D space in CP IDP U2015-M-1 [7]. PCXNT study of the most primitive cosmic dust particles collected in deep space would enable the 3-D structures of protoplanetary fine-grained particles to be determined qualitatively or quantitatively, including 3-D pore structure and porosity, 3-D morphologies of pristine grains and their parent particles, grain size distributions, the spatial arrangements of grains, and grain-to-grain contacts. The new information would advance our understanding of the properties of the most primitive fine-grained solar system materials and yield in-depth insight into grain or cluster aggregation, the evolution of dust morphology, and early accretional processes. It would shed light on the properties of the protoplanetary disk. Our initial nondestructive 3-D mapping of pore structure of CP IDPs has demonstrated a viable new approach to probing dust and ice agglomeration at a fundamental level [7]. Pristine collections in cislunar space would provide an invaluable resource to address such questions as the sizes of icy or ice grains, the ratio of dust/ices [10], and the role of ices in growing larger aggregate particles [11].

In conclusion, collecting cosmic dust in deep space would provide unbiased samples of primitive solar system materials for laboratory study. Nondestructive analysis of 3-D structures and morphology of the most primitive fine-grained aggregates with PCXNT would advance our understanding of the properties of protoplanetary fine-grained particles and provide direct information about the formation of our solar system that may be unobtainable otherwise.

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DEEP SPACE GATEWAY AS A DEPLOYMENT STAGING PLATFORM AND COMMUNICATION HUB OF LUNAR HEAT FLOW EXPERIMENT.

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Background: Planetary heat flow density (or heat flow in short) is a measure of the conductive heat flux from the interior of a planet. It is a fundamental parameter in understanding the internal physical state, chemical composition, and near surface thermal environment of a celestial body. The Moon is the only planetary body (except for Earth) from which its heat flow density has ever been measured with instruments emplaced in situ by humans. However, while there are heat flow measurements from tens of thousands of sites on the Earth [1], there are only two on the Moon [2]. Moreover, the two lunar heat flow measurements, respectively from the Apollo 15 and Apollo 17 landing sites, might not be of global representativeness [3,4,5]. Heat flow experiment remains as a high priority task in lunar science and exploration [6].

Apollo Heat Flow Experiment: Lunar Heat Flow Experiment is an integral component of the Apollo Lunar Surface Experiments Package (ALSEP). The Experiment was planned for Apollo 13, 15, 16, and 17 missions. Apollo 13 did not land on the Moon due to a malfunction caused by an explosion and rupture of an oxygen tank in the service module. The experiment on Apollo 16 failed, unfortunately, due to a broken cable connection. So far only two heat flow values have been obtained on the Moon – 21 mW/m^2 from the Apollo 15 landing site in Hadley Rille and 14 mW/m^2 from the Apollo 17 landing site in Taurus Littrow [2]. These two lunar heat flow values are less than a quarter of the global terrestrial mean of 87 mW/m^2 [1]. However, they are significantly higher than the prediction with respect to the small size and commonly accepted chemistry of the Moon [4]. There are concerns that the existing measurements are biased because they are located at geographical/geological boundaries [7]. The Apollo 15 is located within the confines of the Procellarum KREEP Terrane which possesses high abundances of heat producing elements as determined from the Lunar Prospector gamma-ray spectrometer. In contrast, Apollo 17 is located in the Feldspathic Highlands Terrance which possesses much lower crustal abundances of heat producing elements.

Three Deployment Options: Heat flow is measured as the product of the thermal conductivity and vertical temperature gradient in the subsurface. Therefor, a lunar heat flow measurement requires penetration into the regolith layer. There are three possible deployment options [8].

Manned Onsite Drilling. This conventional and most reliable approach was taken by the Apollo 15-17 missions. It involves astronaut operation of drilling at least 1.5 meters into the lunar regolith near the landing site.

*Lander-Attached Deployment***.** This would use either a drill or a telescopic injection system attached to the main lander. The prospective Mars mission InSight would use this approach with a self-penetrating mole to deploy the Heat Flow and Physical Properties Probe (HP^3) down to a depth of 5m [9].

Gravitational Penetration. A lunar heat flow probe can be deployed by gravitational force via free-fall from a high altitude. This approach was designed for the canceled Japanese mission Lunar-A [10]. It would allow the heat flow experiment to be deployed over a greater range without the constraints of a lander.

This Proposal: The idea of this proposal is to use the Deep Space Gateway (DSG) as a staging platform for the deployment of lunar heat flow experiment, and consequentially as a communication hub of the installed heat flow experiment. A mini-spacecraft loaded with multiple instrumented penetrators will be inserted by the DSG into a low lunar orbit. The spacecraft will later release the penetrators to let them freely fall to the lunar surface and penetrate vertically into the regolith at least 1m deep with appropriate impact speeds. The instruments of the penetrators will measure the temperatures and thermal physical properties of the regolith for the determination of lunar heat flow density. The following are some advantages of such an approach for lunar heat flow experiment.

Rich Knowledge Base of Lunar-A. The design and development of the deployment mechanism and instrumentation of such a DSG enabled lunar heat flow experiment can be based on the lessons and rich experimental data of the canceled Lunar-A, from which this concept is derived. The well-tested missile-shaped Lunar-A penetrators are 75 cm in length, 14 cm in diameter, and 13 kg in weight. They were designed to penetrate 1-3m into the regolith [10].

Lower Risk and Cost Effective. The deployment has no dependency on astronaut or robot on the Moon. No landing module is required.

Reduced Artificial Perturbation. Subsurface temperature at shallow depths of the regolith layer is sensitive to the physical properties of the surface [11]. Any changes in the regolith compactness related to human/robot exploration activity, or shading of any artificial object such as a lander will introduce transient perturbation to the subsurface temperature field and, hence, heat flow measurement. Such perturbation can be avoided with astronaut/robot free deployment, although there might be some perturbation due to penetration impact.

Global Coverage. With the DSG as the staging platform and communication hub, in principle there would be no limitation on the target of deployment. Heat flow experiment can be deployed to various geological areas including those on the far side of the Moon. This is of great importance to the characterization of the lunar heat flow distribution and the assessment of its global energy budget.

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Deep Space Gateway Ecosystem Observatory (DSGEO). K. F. Huemmrich[1] , P. E. Campbell[2] and E. M. Middleton[3], [1]Joint Center for Earth Systems Technology, University of Maryland Baltimore County, Code 618, NASA Goddard Space flight Center, Greenbelt, MD 20771, karl.f.huemmrich@nasa.gov, [2]Joint Center for Earth Systems Technology, University of Maryland Baltimore County, Code 618, NASA Goddard Space flight Center, Greenbelt, MD 20771, petya.k.campbell@nasa.gov, [3]Code 618, NASA Goddard Space flight Center, Greenbelt, MD 20771, elizabeth.m.middleton@nasa.gov

Objectives: To advance global understanding of the dynamics in terrestrial ecosystem function, photosynthesis and environmental stress responses using vegetation spectral reflectance, thermal, and fluorescence signals. This requires global observations collected throughout the year to describe the two key temporal variables: seasonal change and diurnal variability. Observations would be at spatial scales relevant to global ecosystem models (1-10 km).

To accurately quantify plant photosynthesis and stress responses, DSGEO would provide a full description of the energy pathways of sunlight absorbed by chlorophyll (Chl) in ecosystems. The absorbed sunlight by Chl can be determined from reflectance wavelengths across the visible through shortwave infrared spectra, as the fraction of photosynthetically active ration absorbed by chlorophyll (fAPARchl). The energized Chl molecules release energy as they return to the ground state, and this energy is either used for photochemistry (leading to carbon fixation); or is actively discarded for photoprotection as heat in the form of non-photochemical quenching (NPQ) or as chlorophyll fluorescence emissions. Chlorophyll fluorescence (such as Solar Induced Fluorescence, SIF) can be directly measured in atmospheric windows (e.g., O2-A &B, Fraunhofer lines), while the energy dissipated by NPQ can be inferred from changes in spectral reflectance.

Measurements of Chl and other pigments from spectral reflectance can provide information about the photoprotective processes that plants use to mange longer-term (days to weeks) stress conditions while estimations of vegetation nutrients (e.g. nitrogen) and water content describe physical constraints on canopy/ecosystem photosynthesis. Thermal infrared (TIR) measurements of surface temperature provide further information on vegetation stress responses and evapotranspiration, linking ecosystem water and carbon cycles, as well as improving cloud detection and screening.

Instruments: 1) an imaging spectrometer with 5-10 nm spectral resolution covering from 400-2400 nm to measure plant pigments, nutrients, water content, and structural materials, 2) a second imaging spectrometer with high spectral resolution of 0.1-0.3 nm over 650-800 nm to measure red and far-red chlorophyll fluorescence necessary for describing activity in both Photosystems II and I., and 3) a thermal sensor imaging at multiple wavelengths in the 4-12 µm region for measurements of surface temperature and emissivity.

Instrument characteristics. Similar existing instruments include the Hyperion imaging spectrometer on Earth Observing 1 (EO-1), GOES (Geostationalry Operational Sattelite) and EPIC (Earth Polychromatic Imaging Camera) on DSCOVR (Deep Space Climate Observatory). Information on these instruments are included below to provide a sense of expected mass, size, and power requirements for DSGEO:

Hyperion
Volume (L x W x H, cm) 39x75x66
Weight (Kg) 49
Avg Power (W) 51
Peak Power (W) 126
Aperture (cm) 12 (we would need a larger aperture telescope)

EPIC Telescope:
Aperture, effective focal length
FOV, wavefront error
Cassegrain type with adjustable secondary for on-orbit focus
30.5 cm diameter, 282 cm
0.61°, 0.054 waves rms at 633 nm on-axis
Instrument power; total mass: 32 W (electronics), 30 W (operational heaters); 63.2 kg

GOES (12-15) imager:
5 channels covering VIS, MWIR and TIR
Mass (kg) 140, Power (W) 130,

Operations: From the vantage point of an orbit near the moon, each month the instruments would be able to collect multiple days of Earth views under a range of solar phase angles. In a two week period Earth views would go from surface dawn, through midday, into the afternoon, and finally sunset under consistent view angles. This differs from missions in geosynchronous orbit, by enabling observation of the entire Earth with a single set of instruments to produce a new consistent diurnal-seasonal dataset. Further, by being in an orbit near the ecliptic, a lunar Earth observatory views farther poleward during the high latitude summers when ecological activity in those regions are at their highest.

Secondary Activities: Along with the primary mission there are a number of secondary activities for the DSGEO:

1) Support exobiology studies by providing full Earth reflectance spectra collected at a range of phase angles and throughout the seasons. These spectra will provide a baseline of Earth's spectral characteristics to compare with observations from future exoplanet observatories in the search for Earth-like planets.

2) Many Earth viewing remote sensing satellites use lunar views for instrument calibration. The DSGEO instruments could be turned toward the moon for detailed descriptions of lunar spectral characteristics. The DSGEO hyperspectral measurements can be convolved to match the spectral bands of other instruments providing improved standards for calibration of other Earth-observing missions.

3) DSGEO observations of total solar eclipses on the Earth provide natural experiments in the Kautsky Effect. The Kautsky Effect occurs following illumination of a dark-adapted leaf, when there is a rapid rise in fluorescence from Photosystem II (PSII), followed by a slow decline. Such observations from various ecosystems would provide the first large-area canopy-level evaluation of this effect leading to improved understanding of photosynthetic processes at this global modeling scale.

4) From an observatory located near the moon, during the period of the full moon most of the Earth will be in darkness and not suitable for reflectance or fluorescence observations. The DSGEO spectrometer could be equipped with a high-gain mode where observations of nighttime Earth lights could be observed in a few broad spectral bands. Further, the TIR sensor would continue to be usable during Earth nighttime detecting fire and volcanic activity. The nighttime lights and fire information can be merged with the ecosystem observations in a consistent dataset to study human and disturbance effects on ecosystems.

5) While DSGEO would mostly be autonomous, there are benefits for it to be deployed on a human-tended station. Sensors on satellites often have solar diffusers, calibration standard panels, and/or calibration lamps, to describe changes in instrument response over time. Unfortunately, on unmanned satellites these calibration standards can change over time with no way to describe that change, creating uncertainties in instrument calibration. On the DSG, crew could periodically swap out instrument calibration standards (e.g. solar diffusers), returning the old one to Earth for evaluation of change over time and replacing it with a new well-characterised standard, thus providing a significant improvement in data quality, and aid in the development of accurate measurement time series.

MoonBEAM: A Beyond-LEO Gamma-ray Burst Detector for Gravitational-Wave Astronomy.

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Introduction: Moon Burst Energetics All-sky Monitor (MoonBEAM) is a free-flying CubeSat concept of deploying gamma-ray detectors in cislunar space to increase our gamma-ray sky coverage and improve localization precision for gamma-ray bursts by utilizing the light travel time difference between spacecrafts in Earth and cislunar orbit.

Gamma-ray bursts are among the most energetic and brightest events in the Universe. The flash of gamma rays can last from < 0.1s to > 100s, occurring about once a day, and are distributed isotropically across the sky. Emission from radio to X-ray has been observed after the prompt gamma-ray flash, and fade within hours or up to months past the initial burst of gamma rays. The electromagnetic radiation is created by violent interactions such as the merging of two compact objects (neutron star or black hole). Recently, an association between a gravitational wave and a gamma-ray burst was established during the first observation of two neutron stars merging by the Laser Interferometer Gravitational Wave Observatory, the Virgo interferometer, and the Fermi Gamma-ray Burst Monitor. The joint detection triggered electromagnetic follow-up observations by 70 observatories and resulted in a kilonova detection visible from radio to X-ray [1].

Current all-sky monitoring instruments have localization precision no better than a few degrees in radius. Follow-up observations require instruments to tile over a sky area that is many times larger than their field-of-view in order to detect and observe the source. This mode of follow-up observations risk missing the afterglow emission which may fade quickly. The Interplanetary Gamma-Ray Burst Timing Network has demonstrated that with an additional detection from a distant spacecraft, the localization uncertainties can be improved on average by a factor of 180 over localizations done by the *Fermi*-GBM in low Earth orbit alone [2]. The delay in data downlinks for instruments outside the Tracking and Data Relay Satellite network, however, prevents rapid follow-up observations.

Instrument: MoonBEAM will be capable of rapid response given its closer orbit, but far enough to provide a timing baseline for localization improvement when partnered with an Earth-orbit instrument. The preliminary design is a 12U CubeSat, with gamma-ray detectors placed on 5 sides to maximize sky coverage and solar panels to be deployed on the 6th side for power. Its 12U size is driven mainly by propellant needed to achieve the desired orbit. A deep space gateway in the lunar vicinity can potentially allow us to shrink down the mass and volume through a closer approach to our desired orbit, provide additional orbit or mount options, and rapid communication to trigger timely follow-up observations. The desired data downlink is 20kbps continuous transmission, with ~100kB per event trigger and up to 10 triggers per day to be transmitted to ground within minutes. Depending on the deep space gateway orbit in relation to the gamma-ray background of the Moon, it may be possible to mount the MoonBEAM gamma-ray detectors externally instead of on a free-flying CubeSat. The baseline gamma-ray detector module is a 160cm^2 scintillation crystal coupled to an array of silicon photomultipliers, each weighing 1kg and requiring 1W of power. There is no pointing requirement as each detector module is statically mounted. At least 4 detectors are needed to cover the entire sky, optimally there would be more detectors with overlapping fields of view to enable independent or on-board localization of gamma-ray bursts.

MoonBEAM would probe the extreme processes in the cosmic collision of compact objects and facilitate multi-messenger time-domain astronomy to explore the end of stellar life cycles and black hole formations.

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Manned Mission Space Exploration Utilizing a Flexible Universal Module.

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Introduction: The proposed Flexible Universal Module is in support of NASA's Deep Space Gateway Project. The Flexible Universal Module provides a possible Habitation or Manufacturing environment in support of Manned Mission for Space Exploration.

The ASMS Flexible Universal Module is in the form of a cylindrical vessel equipped to accommodate the members of a manned mission for thirty plus days within the module with the basic necessities while creating an environment for on-demand manufacturing of space structures and components to allow fabrication of parts in case of an emergency [1]. The Flexible Universal Module System consists of two modules where one unit is used as a dedicated habitation unit while the second could be used as the 'Space Fab Workshop.' The modules could be used as in logistics purposes [2].

The ASMS self-contained modular unit's designs, are of the size to fit in the cargo bay of X Type Space Vehicles utilizing available technologies. These modular units for space exploration applications will provide a safe environment against the harsh conditions of the outer space [3][4]. This Deep Space Gateway module, or modules could be tested on Earth in a remote location to demonstrate the upgradability and reconfigurability. Then tested on ISS, before going onto Deep Space Gateway.

Two such Universal Modules are connected through a docking mechanism to allow the crew to transfer between the two modules if needed. Parts could be manufactured using an advanced tracked robotic system and to move raw materials from storage bins to the fabrication stations equipped with various manufacturing processes. The CIM manufacturing operation option is monitored using, infrared, high definition cameras, and communication protocols to send command to various enabling manufacturing pieces of equipment not only from the second module, but also from Earth if needed [5]. The fabrication of large structures such as 'truss' members to be connected to create a platform for the logistics of loading and unloading of cargo as well as to allow the crew to have the opportunity to exit the modules to perform a EVA.

These ASMS Flexible Universal Modular Units are designed to provide a tracked robotic manufacturing facility to allow fabrication of various components using laser cutting and welding, wire feed laser 3D additive manufacturing, and robotic assembly of various components to form space structures for the purpose of repair of space vehicles. Multi-material additive manufacturing method using advanced imaging technology based on neutron radiography and tomography could provide extremely valuable components [6]. Investigations by various science community would enable them to do test materials, methods to fabricate components in development of space platforms and other structures.

The ASMS Flexible Universal Modules are designed to be upgradable-reconfigurable due to the, slidable platform with rollers such that various 'environments' could be set up for different operations and applications [7][8]. This would provide a major benefit for the science community as these modules could also be placed on Earth-Moon or other planets as a permanent 'habitation' or 'research lab' including a possible 'medical' facility in support of long duration space exploration missions [9]. Thus, it would meet NASA's requirement to leave something behind as resource for future space missions [10].

The ASMS Flexible Universal Modular Units can be configured for various applications including health care, manufacturing of exotic materials, engineered plants and other medical biological research in-situ, or on Earth prior to launch.

The expected impact of this will enable NASA's Deep Space Gateway platform the opportunity to have established not only a habitation environment, but also a manufacturing capability in support of exploration.

The specific benefit for NASA and its Deep Space Gateway Platform to establish itself as an enabling community in support of long duration crewed mission utilizing a flexible upgradable habitation environment as well as a demonstrated manufacturing capability needed for any long exploration mission. As well as an emergency backup if needed.

These modules would enable the private sector of the space community for commercial applications due to the flexibility and upgradability such as space hotels [11].

Expected Equipment, & Operational Requirements.

Estimated experiment properties	Description
Mass of hardware	16,000kg Module + 200kg manufacturing equipment + 500kg miscellaneous interior
Volume of hardware	4.6 m diameter x 7.6 m long for 126 cubic meters
Accommodation (e.g. internal/external)	Internal Habitation requirements and manufacturing hardware
Power required	10 Kw
Power required when no Astronaut in Habitation Module	4 Kw
Power required, for wire feed laser 3D printer	0.8kW- 2Kw
Data generated	Testing & evaluation of results 20GB approximately per day.
Pointing/viewing/line of sight needs	Hatch windows 120-degree angle view.
Birthing Docking Mechanism incorporating the Double Doors.	Upgradability and reconfigurability of slidable platform on rollers into habitation module.
Communications needed	SN, & Deep Space Communication Network
Duration of experiment	1st phase, 24 -36 months.
Crew tasks (if needed)	Controlling the manufacturing while in the Astronaut unit. Gathering CIM/CAD/CAE/CAM data from engineers on Earth.
Access and servicing by crew (if needed)	Utilizing a hybrid docking mechanism
Need for retrieval and return to Earth	30 Days plus, can stay in space for a longer period. Up to 1,100 days if required for Mars application.
Specific orbit needs (if any)	Currently studied for LEO. Could put in NRO, HALO.
Operations without crew (if any)	Yes, tracked robot-controlled manufacturing

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DEEP SPACE RADIATION EFFECTS ON PHARMACEUTICALS.

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Introduction: Space radiation may induce chemical changes in the active pharmacological ingredient (API) or the inactive excipients in a given drug formulation rendering parts of the spaceflight pharmacy ineffective or potentially toxic. There is a paucity of data, particularly from controlled studies, regarding pharmaceutical stability in the spaceflight environment. Data from limited non-controlled opportunistic research has suggested that some medications exposed to conditions on the International Space Station may degrade faster than ground controls[1], [2]; however, non-controlled study designs have limited analysis of contributing cofactors, including radiation.Terrestrial-based radiation beam exposures fail to effectively emulate the deep space environment[3], [4], limiting efforts to translate ground-based studies for space radiation risk characterization[5].

This proposal seeks to identify detrimental effects on pharmaceutical stability imposed by the deep space radiation environment over time. Because deep space radiation effects cannot be effectively simulated on ground, Deep Space Gateway (DSG) research is necessary to investigate space radiation-induced decrements to a deep space pharmaceutical formulary. Raman Spectroscopy analysis is a validated, mature technology for the assessment of API and first degradants in various drug formulations. We propose to use this technique for the investigation of exploration pharmaceuticals on DSG to provide much-needed data regarding drug stability, appropriate drug choice and packaging, and radiation-induced risk for long-duration exploration spaceflight.

Methods: A suite of pharmaceuticals, identified as likely for inclusion for a human exploration mission, will be flown aboard DSG missions. Raman Spectroscopy analyzers will be used to analyze the chemical structure and related physical or biopharmaceutical properties of each medication. Spectroscopy will occur weekly during DSG flights, for drug on-board exposure times ranging from 0-1100d. A matched ground-based control group of medications will be maintained in a closed environment similar to the DSG mission, but without the microgravity or deep space radiation exposures, and will be subject to similar analyses over the same time period. A subset of these ground controls will undergo proton and heavy ion beam irradiation for correlation of space and terrestrial radiation effects. Raman results will be down-linked in near-real time for rapid comparison to controls and correlation of data, enabling longitudinal analysis and time-sensitive decision-making guidance for future formulary composition. After pre-determined exposure times, flown medications would also be returned to earth for paired analysis using liquid chromatography and mass spectrometry.

Resources Required: This project will require on-orbit standard integration (power, thermal, structural, data) and minimal payload mass consisting of the spectrometer and drug formulary. Soft stowage during launch with subsequent installation will reduce payload development costs and will require only crew time to install in its DSG location.On-orbit DSG operations are considered to be minimal due to payload automation. Commercial-off-the-shelf Raman Spectroscopy, power supplies, servo motors and drivers will be used for maximal automation. The protoflight payload, which will consist of an indexing scheme to position/align each individual drug for in-flight analysis with the Raman spectroscopy sensor, requires full exposure to the radiation environment. Thus, the experimental platform is ideally mounted internal to the vehicle and without additional shielding, simplifying vehicle and payload interfaces and crew installation. Transmitting Raman data to ground can be limited to transmission only when the crew is not present on DSG, removing some burden on the communications subsystem.Results will be provided to the JSC Pharmacy, Space Medicine Operations Division, and Exploration Medical Capabilities Element for consideration in future formulary development.

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EXPLORING THE ROLE OF PIWI/piRNA PATHWAY IN EPIGENETIC DYSREGULATION IN LOW DOSE RADIATION INDUCED CARDIOVASCULAR DISEASE.

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Introduction: Human explorers will experience similar flux of interplanetary solar and cosmic radiation in a cislunar space as on a trip to Mars. There is a need to ensure healthy crews operating at peak performance during long-duration space exploration to cislunar and beyond. Exposure to ionizing radiation constitute a change from the normal cell environment and can result in dysfunctions to almost all organs of the body depending on the total dose and site of irradiation.

Opportunity: For example, exposure to radiation hazards could cause cardiovascular disease and other degenerative tissue effects (Degen) [1]. To identify and understand the risks of Degen due to radiation exposure and design countermeasures to mitigate these risks, we must understand the underlying cellular responses. We need to identify biomarkers specific to space radiation, investigate the regulatory switches of inflammation and identify cross-risk biomarkers. Information will aid development of countermeasures to regulate the low dose radiation inflammatory response in astronauts. The cumulative biological effects of low dose space radiation responsible for atherosclerosis and heart attack include chronic inflammation and endothelial cell alterations. Both hypo- and hyper- methylations occur in major inflammatory biomarkers of radiation. We seek to further understand the mechanism for epigenetic switches and modifiable risk factors. The Piwi-interacting RNAs (piRNAs) a class of 26- to 32- nt non-coding RNAs are thought to play a role in the inflammatory processes. The piRNAs typically form RNA-protein complexes, by partnering with PIWI proteins. These RNA-protein complexes then silence the transposable elements (TEs). The Piwi-piRNA pathway is also linked to somatic functions such as, genome rearrangement, epigenetic programming, stem cell function, whole-body regeneration, memory and possibly cancer. The epigenetic programming function could involve transcriptional repressions, via establishment of a repressive chromatin state; or DNA methylation of promoter region of the target gene. Methylation is the major regulatory mechanism in most inflammatory response genes and chronic inflammation is important in many diseases, including neurodegenerative diseases, cancer, autoimmunity and infections. To understand the regulatory switches of inflammation, identify cross-risk biomarkers and design countermeasures to mitigate these risks, we will study freshly irradiated and archived irradiated tissue samples provided by NASA. Specifically, we will study the effects of radiation on epigenome and targeted proteome of inflammatory pathways relative to CVD at the cell, tissue and organismal levels. We will identify cross-risk biomarkers for cardiovascular disease and other degenerative tissue effects caused by radiation exposure as well as surrogate endpoints that could be used to access the efficacy of radio-protective countermeasures. Characterizing epigenetic and genome wide epigenomic profiles provides the capability to modulate epigenetic factors. Thus, they represent novel powerful paradigms for identifying and monitoring the development of cardiovascular disease in real time, while providing opportunities for halting, preventing and possibly reversing the condition. Given that CVDs constitute the number one cause of death globally, information on applicable gene-regulatory functions is valuable to humans during space exploration missions and on earth.

Our discussion will focus on four main Thrusts:

I. **Epigenetic changes:** Identify entire set of differentially expressed piRNAs, DNA methylation and histone modification patterns of irradiated murine blood vessel and heart tissues.
II. **Biomarkers of inflammation:** Identify target proteins for dysregulated piRNAs by informatics.
III. **Signaling molecules and pathways:** Elucidate and characterize signaling molecules and pathways regulating inflammation by utilizing piRNAs as epigenetic switch in cardiovascular disease using primary endothelial cells culture system.
IV. **Countermeasures**: Identify countermeasures to reverse epigenetic effects.

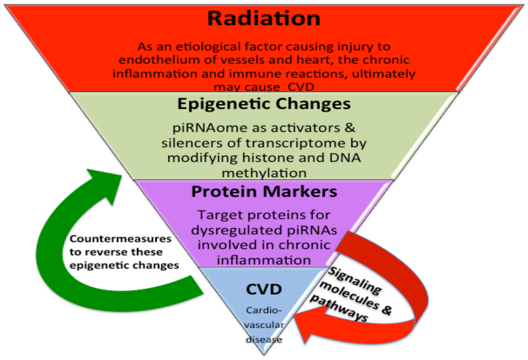

Figure 1: Research Areas.

Methods:

Epigenetics: Radiation exposures present serious risks to astronauts. There is a need to understand the pathophysiology of CVD and other degenerative diseases due to space radiation exposure..

Objective 1.1. To Investigate differential Expression of piRNA and transcriptome by Next Generation Sequencing (NGS). Cells and murines subjected to radiation will be monitored for altered piRNA and whole transcriptome epigenetic changes.

Objective 1.2. ***To Study Differential Expression of DNA and Histone Methylation Patterns.*** We will examine cells and murines subjected to radiation for epigenetic changes including DNA and histone methylation patterns, and accumulation of DNA damage.

Biomarkers: Biomarkers are important assessment tools for prediction, diagnosis and monitoring of diseases.

Objective 2.1. ***Use informatics to identify the proteins targets which dysregulated piRNAs use in epigenetic regulation.*** We will use existing statistical methods and when applicable develop new methods for modeling data that enable identification of protein targets of dysregulated piRNAs.

Objective 2.2. ***Use informatics to identify the proteins targets which dysregulated piRNAs use in epigenetic regulation.*** Statistics will also be used to obtain epigenetic regulation signatures of piRNA protein targets.

Objective 2.3. ***To establish theoretical basis for selecting biomarkers of inflammation during radiation exposures***. Chemical and biochemical protocols for detecting and quantitatively evaluating radiation stress damage and inflammation will be integrated. We will use genomics, transcriptomics and proteomics tools to select biomarkers of inflammation for *in vitro/in vivo* testing. The theoretical basis for inferences will also be explained using available literature.

Signaling Molecules and Pathways: High energy particle radiation causes cellular damage, and the resulting inflammation is thought to be involved in the pathophysiology and prognosis of CVD. However, we have limited knowledge of the mechanisms involved**.**

Methods (Research Design)

Objective 3.1. To examine expression of target proteins of piRNAs in vitro. We will examine differential expression of target piRNAs in Human Umbilical Vein Endothelial cells (HUVECs) model. We will then perform mimics and antagomir assays to examine accuracy of predicted target proteins for respective piRNAs from Biomarkers Thrust above.

Objective 3.2. To identify epigenetic changes due to methylation in vitro. We will identify changes in promoter methylation status of target genes, using methylation-specific polymerase chain reaction.

Objective 4. To develop countermeasures for the effects of radiation.
We will test a variety of compounds, including antixodants, curcumin, resveratrol, and various other natural products in an attempt to prevent the damage caused by radiation,. The assays developed in Objective 1 to 3 above will be utilized to determine if these treatments prevent such damage.

Conclusion: Cells inherently respond to changes in their environment by working to maintain genomic integrity through initiation of complex responses that rely on changes in gene expression. Advances in genomics, has opened windows into inner workings of the cell, how cells interact with other cells and respond to changing environments. Additional single 'omic fields are advancing rapidly, and mechanistic studies reveal high integration at both intra and inter-cellular levels. We are learning more about cellular functions through transcriptomics, proteomics, metabolomics and the processes that regulate them, including methylation, acetylations, phosphorylation, ubuiquitination, miRNAs, piRNAs and other non-coding RNAs as well as diet and physiological processes within the human body. It is imperative that we take advantage of these advances to identify robust biomarkers and utilize knowledge to understand diseases, adverse environmental effects and develop countermeasures. Information obtained will enhance development of capabilities to monitor health in real time and for mitigation of risks. Our efforts will not only enhance productive human space exploration, but will also improve the quality of life here on earth.

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A LUNAR ORBITER FOR EARTH AND EXOPLANET STUDIES.

Jonathan H. Jiang[1], Vijay Natraj[1], Jay Herman[2], Chengxing Zhai[1], Hui Su[1], Yuk Yung[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California (Jonathan.H.Jiang@jpl.nasa.gov), [2]NASA Goddard Space Flight Center, Greenbelt, Maryland, [3]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California

The December 5, 2014 NASA test launch of the newly developed Orion spacecraft into deep space is a strong indication of NASA's unwavering commitment to future space exploration targeting asteroids and Mars. In 2019, the James Webb Space Telescope will be launched and placed at the Lagrangian point L2 on the night side of the Earth, 1.5 million kilometers away from Earth. One of its prime science objectives is to study exoplanets, especially those that are Earth-like. These developments provide a compelling case to explore the science and technology of building an Earth observatory in the Moon's orbit to deliver:

(1) Long-term, global, continuous full spectral view of the Earth from the UV to IR. This will enable a range of measurements from which the trends in the atmosphere, lithosphere, cryosphere, hydrosphere, and biosphere can be analyzed, and important science can be addressed. This includes tracking climate variability, air pollution sources and transport, natural hazards (e.g., extreme weather, volcanic plumes, hurricanes, lightning), seasonal and secular variations in polar ice, and vegetation health (e.g., spring greening).

(2) A testing and validation tool for Earth-like exoplanet observational studies. The real-time day /night, full disk, phase-changing Earth view can help us design and implement future exoplanet observational studies as they are in the form suitable for studying a planet around a distant star. There is a strong need to demonstrate that we can correctly interpret the data from an exoplanet in order to search for signs of habitability and life on that planet. In exoplanet studies, a planet is viewed as a single pixel with spectral information. The orbiter can make similar measurements of the Earth as a single pixel and then use the spatially resolved observations to properly interpret the single pixel data. The benefit of the lunar orbiter for exoplanet studies is that a several-year time-series of disk-integrated photometry of the Earth, in several wavelengths bands, will help us interpret future exoplanet observations in those same bands, to understand if we can detect oceans, continents, seasons, and vegetation on an Earth-twin candidate around a nearby star. In other words, the lunar orbiter is ideal for using the Earth as a proxy exoplanet to test the models developed for exoplanet studies, enabling better understanding of the range of uncertainties in the interpretation of observed exoplanet data. Data from the DSCOVR mission has been used for such a study (see, e.g. Jiang et al. 2017; Figure 1 below); however, the DSCOVR data has some limitations such as limited phase angle variation. Exoplanet observations will typically be at the stellar terminator line; we will not be able to see the full starlit planet. The lunar orbiter will solve this problem to give us a more useful Earth view. Furthermore, lessons learned from the lunar orbiter can also be used to build a future observatory in Mars orbit to further help exoplanet studies using the Earth as a proxy.

Key science elements of the lunar orbiter are to:

(1) Conduct full Earth-view multi-spectral observations at multiple incidence, emission, and phase angles, and provide more precise radiative balance calculations for climate studies that go beyond what is currently available from Earth orbiting satellites. The multispectral sensors can range from the UV to the Far IR for Earth atmospheric composition and climate studies, or monitor Earth's "hot spots" – thermally elevated features (e.g. volcanic, fire, military, and other anthropogenic activity) with high temporal frequency.

(2) Observe the dynamic spectral variation of Earth as a proxy exoplanet harboring life, and thus enable us to test spectral models in exoplanet studies.

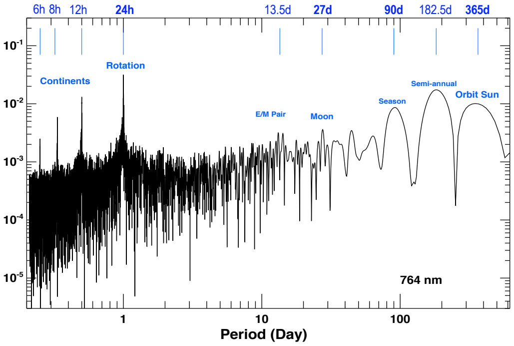

Figure 1: Fourier series power spectra of DSCOVR EPIC L1B 764 nm radiances after averaging to a single point. This technique yields information about the planet's rotation, its orbit around the Sun, and possible periodic variations due to weather (clouds) patterns, surface type (ocean, land, vegetation), and the moon.

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Heliophysics radio observations enabled by the Deep Space Gateway.

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Introduction: The brightest emission in the heliosphere is due to nearly coherent radio waves produced by non-thermal plasmas including the solar atmosphere and corona, solar wind, planetary magnetospheres and aurora, and the termination shock and heliopause. Since the emission mechanisms are tied to local plasma properties such as the cyclotron and plasma frequencies, beam densities, and plasma beta, the spectral, temporal, and spatial evolution of this radiation encodes information related to the characteristics of the local emitting plasma, making radio observations a powerful technique for remotely characterizing energetic processes and environments. This presentation reviews the scientific potential of low frequency radio imaging from space, the SunRISE radio interferometer, which is an Explorer mission concept currently under study by NASA, and the scientific value of larger future arrays in deep space and how they would benefit from the deep space gateway (DSG).

Low frequency radio in space: For more than half a centry heliophysics missions have used single spacecraft with fixed antenna to measre the total power emitted by various non-thermal plasmas. The scientific value of these total power measurements is well documented and continues in anticipated upcoming missions such as the Parker Solar Probe (PSP) [1]. Antennas on spacecraft allow us to conduct unique radio heliophysics not possible on the Earth. The absorption and refraction of low frequency radio waves by the ionosphere limits ground-based heliospheric and astrophysical radio science: Below the ionospheric plasma frequency of 2-15 MHz, external radio waves are completely attenuated. Above the ionospheric cutoff variable refraction resulting from density fluctuations prevents high fidelity imaging.

SunRISE and imaging: Single antenna radio experients are limited to producing dynamic power spectra of radio emission as a function of time, and other data products generally related to the total emission. This is unfortunate because coherent low frequency radio emission should contain a great deal of information about energy flow and acceleration if it would be imaged. Radio emission from coronal mass ejections (CMEs) is a direct tracer of particle acceleration in the inner heliosphere and potential magnetic connections from the lower solar corona to the heliosphere. Energized electrons excite Langmuir waves, which convert into radio emission at the local plasma frequency, with the most intense acceleration thought to occur within 20 RS. The capability of ground based radio arrays to track this radio emission is limited by onospheric absorption (f > 15 MHz) to altitudes less than about 3RS. The state of the art for tracking such emission from space is defined by single antennas (Wind/WAVES, Stereo/SWAVES), in which the tracking is accomplished by assuming a frequency-to-density mapping; there has been some success in triangulating the emission between the spacecraft, but considerable uncertainties remain. The Sun Radio Imaging Space Experiment (SunRISE) mission is a NASA Explorer mssion currently under concept study. SunRISE would consist of a constellation of six small spacecraft near GEO, operating as an interferometer designed to localize and track radio emissions in the inner heliosphere. Each spacecraft would carry a receiving system for observations below 25 MHz, and SunRISE would be the first produce the first images of CMEs more than a few solar radii from the Sun.

Radio Observatories in Deep Space: There is clear value for more ambituous radio interferometer missons in deep space beyond SunRISE. Terrestrial RFI is the largest source of radio contamination for a space based radio array. While the GEO orbit reduces contamination enough to study solar radio bursts, an orbit in an Earth-moon Lagrange point or some other location near the moon would be thousands of times quieter, and would permit detection of queieter emission from objects such as Saturn, Neptune, and Uranus aurora, weak solar radio emission or even quiet Sun emission. SunRISE has six spacecraft, and the image quality (or dynamic range) scales as a the square of the number of antennas or spacecraft. An array with dozens of spacecraft would be able to make high resolution images of time varing sources. One exciting application is real time imaging of Earth's electron radiation belts.

Infrastrure Requirements: Here are several examples of how a DSG could assist the deployment and operation of a radio array.

Deployment of small satellites. The DSG could accept shipment of a series of small satellites and then inject them into the constellation, either to initially create the radio array or to replenish lost spacecraft over time.

A deep space time and navigation beacon. Many of the advances in location and signal processing on small spacecraft are made possible by the ability to determine local absolute time and location using GPS, even when the spacecraft are in orbits far beyond the nominal range of altitudes for GPS. SunRISE in GEO for example makes use of GPS timing for synchronizing data collection. The NASA Magnetospheric Multiscale (MMS) mission has demonstrated GPS receipt further from Earth, but with a larger set of electronics. The DSG could operate an atomic clock and transmit absolute time and location, acting as a supplement to GPS that would enable precision navigation and timekeeping in deep space.

High bandwidth communications and data processing. Future deep space radio arrays using higher bandwidth, time coverage, and number of antennas will produce significantly more data. The data volume scales as the square of the number of antennas for a radio interferometer, so data volumes for direct to Earth communication could quickly become prohibitive. The DSG could solve this issue by receiving data from the individual spacecraft and then either relay the data untouched to Earth, or perform data processing on a workstation at the DSG before sending down a further reduced data volume.

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Alamos: An International Collaboration to provide a Space Based Environmental Monitoring solution for the Deep Space Network.

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Introduction: The Alamos team is pleased to submit our response to the Call for Abstracts for the Deep Space Gateway Workshop to be held in Denver, CO this coming spring. This abstract proposes the advantages of an externally mounted instrument in support of the human physiology, space biology, and human health and performance key science area defined in the Call.

Providing the capability for rapid and responsive Space-Based Environmental Monitoring (SBEM) is critical to support space weather monitoring. Understanding the surrounding space environment is significant for human safety and technology hardening for deep space exploration.

The Alamos team is a dedicated, international group of subject matter experts (SME) and space-qualified component vendors that bring many decades of experience to support the Alamos sensor.

Alamos Team: The Alamos team is comprised of four major corporate entities, both domestic and international. Oakman Aerospace, Inc. (OAI), located in Littleton, Colorado, is the team lead responsible for systems engineering, integration, and the common interface unit development. Thales Alenia Space in Switzerland (TAS-CH), based in Zurich, Switzerland, is the provider of the Next Generation Radiation Monitor (NGRM) sub-system of the Alamos Sensor Suite. The Laboratory for Atmospheric and Space Physics (LASP), a University Affiliated Research Center (UARC) at the University of Colorado in Boulder, Colorado, serves as the subject matter expert (SME) on space weather, associated science, and components. Plasma Controlls, LLC is co-located and closely associated with the Center for Electric Propulsion and Plasma Engineering (CEPPE) at Colorado State University in Fort Collins, Colorado. Plasma Controls provides the Electro-static Analyzer Sensor (EAS) for the Alamos sensor suite. This team and its hardware is uniquely situated to support NASA's Human Exploration and Operations (HEOMD) and Science Mission Directorate (SMD) goals for the utilization of the Deep Space Gateway. Alamos also acts as a successful case study for international partnerships and collaborations and can help enable future opportunities through international collaboration.

Alamos Suite: The Alamos sensor suite is a Modular, Open-System Architecture (MOSA), rapidly reconfigurable Energized Charged Particle Sensor Suite. It is low-cost, -size, -mass, and -power, with high performance. It is also very robust in accommodating multiple satellite bus standard interfaces and reconfigurable for specific missions. For the Deep Space Gateway, it will be externally mounted and require minimum power. The system consists of a baselined, compact unit seen in Figure 1. The Alamos Sensor consists of three major sub-subsystems which include: a Common Interface Unit (CIU) for interfacing to the host spacecraft (s/c); NGRM Suite for in-situ measurement of internal charging (IC), single event effects (SEE), and event total dose (ETD); and, an Electro-static Analyzer Sensor (EAS) for measurement and reporting of surface charging (SC) effects on the Deep Space Gateway or other s/c.

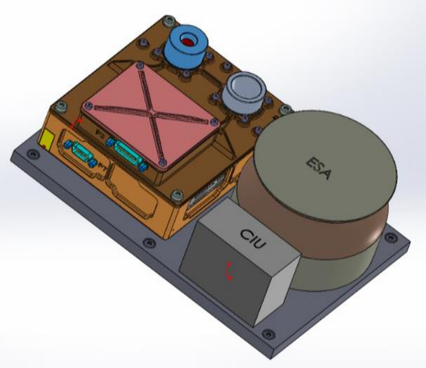

Figure-1 Alamos Sensor suite conceptual image

Integrating these three components into a common integrated ECP, Alamos leverages previous spending/development/flight heritage invested by the European Space Agency and TAS-CH without requiring a redesign or any significant non-recurring effort from the NGRM perspective. It also will bring in the Space Weather and Radiation expertise resident within the LASP space weather science team. Additionally, the CIU will allow the entire system to be modular and compatible with open standard interfaces, allowing for reduction in redesign, recurring cost savings and flexibility for future missions.

Next Generation Radiation Monitor: The NGRM instrument is highly-mature, fully integrated suite of sensors that perform all measurements related to IC, SEE, and ETD environments. *Table-1* outlines the measurement characteristics provided by NGRM. It provides a proven and low-risk solution to gain better understanding of the radiation environments surrounding the Deep Space Network. Not only will it detect burst anomalies for catastrophic prevention, it provides a longterm measurement and long exposure profile of the ambient environment. This data, analyzed by the space weather SMEs at LASP, is crucial to understanding the safety requirements for extra-vehicle human activities as well as the consequences of long-exposure, both from a human safety aspect and an electronics lifespan.

Table-1 NGRM Measurement Ranges

Electrons	
Minimum Energy	100 keV
Maximum Energy	7 MeV
Log Energy bins	8
Maximum Flux	$10^9 cm^{-2}s^{-1}$ (at 100 keV)
Protons	
Minimum Energy	2 MeV
Maximum Energy	200 MeV
Log Energy bins	8
Maximum Flux	$10^8 cm^{-2}s^{-1}$ (at 2 MeV)
Heavy Ions (Cosmic Rays and Solar Events Ions)	
Minimum LET	.1 MeV cm^2/mg
Maximum LET	10.0 MeV cm^2/mg
Log energy Bins	8
Identification	Particle discrimination between electrons, protons and heavy ions
Total Dose	Up to 100 krad (Si)
Non Ionizing Dose	Derive from particle spectra

Electro-static Analyzer Sensor: EAS designs are based on simple electrical physics concepts. Plasma Controls will scale the design of their terrestrial electro-static analyzer sensor in order to tune the design to meet any Deep Space Gateway or deep space orbit specific requirements. This sensor has a narrow field of view and high resolution detector ranges which will be aligned with the sources of electrons spacecraft typically experience in the GEO and polar LEO environments and will be adjusted for expected Lunar and deep-space orbit environments. Because of the low mass and volume, a number of these sensors could be deployed for multiple survey decks.

Another option provided by the Alamos team is an electro-static analyzer with an omnidirectional field of view. This sensor design, also developed by Plasma Controls, will inherently have a larger volume but will still allow the Alamos Sensor suite to remain a low mass, volume, and power option.

OAI will develop the EAS electronics and data interfaces into its CIU. This will eliminate redundancy of hardware but retain risk assurance through its modularity and easily replaceable instrumentation.

Common Interface Unit: The CIU functions include power services (switching, monitoring, and control) to the Alamos Sensor suite (NGRM, EAS(s)), data messaging services between the Deep Space Gateway and the Alamos Sensor suite, and communications. The CIU will receive power and send data to the ss/cc via any common military standard interface (MIL-STD 1553, RS422, CAN, Spacewire, etc.). The CIU will route power to the NGRM and EAS and receive data from the two sensors. The data will then be reconciled and distributed to the s/c via the common, selectable interface. The system is low Size, Weight and Power (SWaP) and modular, allowing for easy implementation and external sensor change/addition, increasing mission flexibility.

The CIU is an important function to the Alamos Sensor suite because it allows the flexibility to insert other scientific payloads, at users discretion, with minimal engineering and interface development. This is an important aspect as technological advancements are made and as Deep Space Gateway needs evolve.

Deep Space Gateway Impact: Alamos will have minimal impact on Deep Space Gateway resources while providing important knowledge on the surrounding cislunar environment. With a mass of less than 5kg, power consumption less than 10W, and a modular software and interface design, Alamos can be placed on any external surface of the Deep Space Gateway, or on multiple surfaces for additional space weather mapping, with minimal impact. Either a pre-launch configuration or a one time installation by an astronaut or external robotic arm is all that is needed for implementation. Should a unit need to be removed or replaced, on board support will be minimal.

In addition, these instruments can be stored on board for any amount of time, awaiting installation on spacecraft which may be deployed into lunar orbit from a Deep Space Gateway portal. This would allow a cost effective and low SWaP impact method to mapping lunar space weather.

Conclusions: The Alamos team proposed in this aspect will provide the Deep Space Gateway crucial data needed for space weather mapping and monitoring. Continuous monitoring of the space based environment will alert NASA of immediate anomalies that may disrupt operations or be dangerous to exposed humans, as well as evolve the understanding of long exposure for systems in new deep space environments. Also, the success of the Deep Space Gateway and beyond is dependent on successful, efficient international collaborations. The Alamos team is a leading example of such collaboration and will help to enable future opportunities of international teamwork.

USING THE DEEP SPACE GATEWAY TO MAP RESOURCES AND DEFEND EARTH.

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Introduction: A human-tended spaceport in cislunar space would be a valuable platform from which to conduct scientific observations supporting humankind's growth toward being a full-fledged space-faring species. The two ideas we emphasize here are (1) assessing resources for *in situ* resource utilization and (2) defending our home planet from near-Earth object (NEO) impacts.

Orbit Choice: The instrument suite we suggest can provide important scientific information from almost any orbit. However, the two science goals we focus on have different optimal orbits. Impact monitoring is best done from near the Earth-Moon L2 point because the observations would be complementary to those made from Earth. Detailed mapping of the lunar polar regions would be best accomplished from a low polar orbit. For this abstract, we focus on a near-rectilinear halo orbit.

Planetary Defense: The Deep Space Gateway (DSG) could improve planetary defense in two ways. The first is by observing new impacts on the surface of the Moon to refine our understanding of the flux of small impactors in the vicinity of the Earth. Such impacts create flashes that can be detected on the night side of the Moon using only visible wavelengths, but estimates of the energy (and thus impactor size) are improved by having follow-up infrared observations and high-resolution imaging of the crater.

The DSG could also be an important platform for characterizing NEOs, especially as they come close to Earth. The difference in viewing geometry from the DSG and Earth should assist in quickly pinning down the trajectory of the NEO and possibly help to disambiguate light curves used to calculate rotation rate. As with any space telescope, spectra collected from the DSG will not have to contend with atmospheric absorptions that block key infrared wavelength regions.

Resource Assessments: Observations from the DSG would be useful for both lunar and NEO resources. We consider hydrogen/water to be the primary resource of interest with regolith and free Fe-Ni alloy for construction as a secondary interest. In principle, observations from a DSG in low polar orbit around the Moon could complement, augment, and ultimately supplant data from robotic orbiters like LRO. Flying "next-generation" versions of the full suite of LRO instruments would be recommended in this scenario. The more challenging question, and the one we explore in this abstract, is what can be done from a range of thousands or even tens of thousands of kilometers that has not already been done by LRO and its robotic brethren.

We recommend focusing on infrared spectroscopy. The existing data sets (e.g., Kaguya Spectral Profiler, Moon Mineralogy Mapper, and DIVINER) have significant issues in the areas of greatest interest near the lunar poles. An instrument with the capacity to collect high quality spectra of the lunar polar regions would also be well suited to collect spectra of NEOs.

In addition to the classic passive remote sensing, a dedicated spectrometer on the DSG could allow repeats of the LCROSS experiment with carefully targeted impacts of spent boosters. Furthermore, human visits to the DSG are liable to produce volatile-rich waste that could be disposed by impacting the Moon. Observations of such impacts into volatile-poor parts of the Moon could provide critical calibration for using remote sensing to measure the volatiles liberated by impacts.

Required Instrumentation: Using remote sensing to characterize the lunar surface and NEOs is a mature science. We put our recommendations in three categories: threshold, baseline, and enhanced. Threshold requires resources of the same magnitude as a CubeSat. The baseline suite is comparable to a Discovery class mission and we briefly touch on potential enhancements if resources are more plentiful.

Threshold. The threshold system has two level-1 requirements: complement Earth-based tracking of (1) the number and energy of impacts on the Moon and (2) NEOs making close approaches to the Earth. While an orbit near the Earth-Moon L2 point would be optimal, useful data could be collected from any of the orbits discussed for the DSG.

A panchromatic visible imager with COTS hardware should be able to meet the requirements. Impact flashes are monitored by modest sized telescopes on Earth (<0.5 m diameter primary mirrors) [1,2] and a 6U CubeSat has been proposed to be adequate to make these measurements [3]. A standard 4Kx4K-pixel detector would allow the entire disk of the Moon to be monitored from close to L2 with better than 1 km/pixel ground sampling distance. Earth-based impact flash monitoring has used a 25 Hz image acquisition rate [1]. Meeting this same rate would require the ability to read and process, continually, at a rate of 400 Mpixels/s. This data rate is challenging to return to Earth from a CubeSat but should be straightforward from the DGS, especially after the data volume is reduced via onboard processing. A framing camera with a large FOV and short integration times has very benign pointing and stability requirements. NEO observations would have stricter pointing knowledge needs and require stacking many images to build up signal but no special modifications would be needed to the imager. Mass, volume, power, and cost should be similar to a CubeSat.

Baseline. The level-1 requirement driving the design of the baseline instrument suite is the ability to obtain robust characterization of the mineralogy and thermophysical parameters of even dark NEOs and the lunar polar regions. This means more than the classic 0.5-3.0 micron infrared spectra. The suite must also monitor the cooling of new impact sites, measure the temperature of shadowed regions of the Moon, and provide additional constraints on the size and surface properties of NEOs. We also require compositional information from the impact flashes. The most practical solution is to have two separate imaging systems: a staring multi-band imager and a scanning hyperspectral imager.

The staring imager would be used to obtain compositional information from emissions from the impact flash. The system would be similar to the threshold camera but would have 4 or more detectors, at least two to measure the color temperature of the flash and the others viewing selected UV-NIR wavelength bands tied to at least H and O emission lines. Na, S, C and Si emissions would be also be of interest. The narrower bandpasses will require additional light gathering capacity so the instrument would need to substantially larger than the threshold imager. To view the whole disk of the Moon over a wide range of distances, the optics must be also be able to adjust focus and focal length as in a zoom lens. While the imager would generally stare at the Moon, it would interrupt such observations to track any NEO that approached the Earth. A detailed trade study is needed to choose the optimal combination of (1) a system with separate slaved zoom telescopes for each detector, (2) a single telescope with a series of wavelength selective mirrors to send the desired light to each detector, and (3) a detector with a Bayer pattern of filters over pixels and reduced spatial resolution. The MSL Mastcam could be a starting point for the design [4].

The hyperspectral imager can leverage the extensive work put into designing the HyspIRI Earth observing mission. The 0.38 to 12 micron wavelength coverage and spectral resolution of HyspIRI [5] is very well suited to lunar and NEO compositional studies. The planned optics would provide an acceptable ground sampling distance of a few km/pixel on the Moon from the Earth-Moon L2 point. The possibility of integrating HyspIRI on the ISS has been examined, so many of the issues of operating on the DSG have already been investigated. The one major difference would be that in a high halo orbit the instrument may not be able to rely on the spacecraft's orbital motion alone to sweep the pushbroom sensors across the target. A scan platform may also be required to point at NEOs. Other benefits of a scan platform would be the ability to (1) use target motion compensation if the DSG makes high-speed close flybys of the Moon and (2) obtain super-resolution in multiple directions. Based on HyspIRI estimates, the hyperspectral imager is likely to have a mass of ~150kg and require ~700W of power. The HyspIRI mission was estimated to cost ~$500M but a derivative mounted on the DSG should be significantly cheaper.

Enhanced. There are numerous ways to enhance the proposed observations but the most valuable addition is likely to be radar. Radar can be used for altimetry, subsurface sounding, ice mapping in permanently shadowed regions, and classifying asteroids. However, a radar system that could provide such observations from a range of tens of thousands of km would be very large, complex, power-hungry, and expensive.

Note on Radiometric Calibration: Given that the instruments are expected to operate in space for many years, and the detectors may be swapped at various times, provisions for robust radiometric calibration must be included as part of the instrument suite. This is especially critical for the spectral observations used to infer the compositions of the Moon and NEOs. The current LANDSAT satellites are flying with onboard calibration targets that are good examples of the type of hardware and operations required to maintain accurate and precise radiometric calibration.

Note on Geometric Calibration: For precise tracking of NEOs, it is important to know the precise location of the gateway relative to Earth. A laser retroreflector attached to the DSG could prove invaluable for this. The ability to slew the hyperspectral imager introduces more sources of uncertainty in pointing knowledge. It may prove worthwhile to have metrology capability on the DSG – a capability that may prove useful for other activities such as docking of sample capsules.

Benefits of Using the DSG: These observations could be taken from any spacecraft in cislunar space. However, being on a human-tended platform means that the instruments can be upgraded in a manner similar to the Hubble Space Telescope. The baseline instrument suite is well suited for many investigations unconnected to resource assessments or planetary defense. For example, with appropriate optics, the hyperspectral imager could examine samples brought to but kept outside the DSG. Especially for asteroid samples, obtaining spectra of surfaces unaltered by the terrestrial environment may prove extremely useful.

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ENHANCED BENEFITS OF LUNAR ORBIT VIDEO ASTROPHOTOGRAPHY.

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Introduction: Video Astrophotography is capable of detecting transient events, which could be observe meteor impact flashes, light curves from approaching near Earth Asteroids, and various forms of Stellar Occultations. While currently employed from Earth and outer space, there are some specific advantages to observing from the lunar orbit. Benefits of implementing Video Astrophotography from a lunar orbit include: More accurate correlation between new craters discovered by the LRO to video captures from the earth, simultaneous light curve detections of near Earth Asteroids from two significantly different angles, and investigation of Earth's atmosphere on Stellar Occultation.

Monitoring Lunar Meteroid Strike Flashes: Meteoroid strikes generate flashes that have been successfully captured with video from the earth; and the resulting crater has been analyzed using before and after data from the Lunar Reconnaissance Orbiter (LRO). However, monitoring from the earth has many limiting factors, such as: 1) Low visibility in the night sky, 2) Day cloud cover; and, 3) A limited ground monitoring period restricted to a few hours each night within 3 days of the first and last quarter. These limitations have resulted in it being unfeasible to correlate the vast majority of new craters discovered by the LRO to video captures from the earth.

It is valuable to know when and where the strike occurs so that they can be potentially associated with meteor showers /streams. Having this information would provide data on the relative threats to astronauts and provide input to prediction models for larger than and equal to 1 meter class objects. Missions could be planned around increased threats. Furthermore, fresh craters could be the subject of: Ongoing measurements to analyze aging of new craters; Examination for potential landing sites for both man and probe missions; and Replacement of manmade impacts on the moon, which has been the subject of scientific study.

Initial studies could include a basing (orbital deployment) strategy for one or more monitoring satellites, and CubeSat technologies could be investigated for potential use. Eventually a fleet of small spacecraft could be deployed to provide continuous coverage on all sides of the moon.

In addition, spacecraft based monitoring could greatly increase the amount of monitoring time; and the could be accomplished using the Deep Space Gateway – where an initial capability could be installed.

Recording Light Curves from Near Earth Asteroids: Understanding the motion of an asteroid is necessary for both planetary protection - with respect to planning deflection, as well as safely and successfully mining an asteroid – a developing project supported by NASA. While most rotating bodies rotate around one axis, asteroids can tumble and rotate around multiple axes, making it difficult to determine the full range of motion. Furthermore, the surface of the asteroid can vary in reflectivity, further compounding the problem of accurately modeling the movement.

Traditionally, records of variation in light intensity over time have been used to create light curves, which in turn aid in modeling the motion produced by asteroids. This method can be significantly enhanced by recording light curves simultaneously from different angles. Obtaining light curve data from Earth and the lunar orbit simultaneously will provide significantly different viewing angles and offer a more complete understanding of a near Earth asteroid's motion.

Investigating the Affect of Earth's Atmosphere, on Stellar Occultation: Measurements of exoplanets, as they pass between stars and the observing telescope, have led to the development of theories that some exoplanets contain an atmosphere. While these measurements are in and of themselves useful data, they can be much better modeled and understood when compared to a known control. Amassing an extensive database of stellar occultation in Earth's atmosphere from various types of stars would not only broaden knowledge of Earth's atmosphere, but would also serve as a control to which atmospheric data from exoplanets can be compared. A lunar orbit provides various opportunities for Earth's atmosphere to be measured when a star is occulted by Earth.

Occasionally, the size of an asteroid can be determined through stellar occultation measurements that are timed for when the trajectory of an asteroid lines up with suitable stars. At present, being able to get this measurement is left to opportunity. Performing tests from a lunar orbit could provide information that will aid future missions in adjusting to the correct path of an occultation for specific measurements, as is currently done with NASA's airborne Sofia missions

Additional Information: The lunar meteoroid and asteroid measurements support astronaut and spacecraft safety. Furthermore, the proposed project is a low risk mission and represents an expansion of proven science and engineering. In addition, it capitalizes on the investment in LRO by utilizing an extensive, detailed historical archive - which has taken years to obtain. Finally, if done using the Deep Space Gateway, Astronauts could service instruments, install upgrades, and perform repairs. As such, the following additional resources would likely be required: 1) Remote operation is projected, thus crew interaction is only anticipated for initial setup and upgrades; 2) External Mounting is preferable to allow for extended duration of operation; 3) Mass of the system would be commensurate with that of a 200mm reflector telescope; 4) Consistent, low bandwidth communication will be required for control, while data downloads can be stored for larger bursts of results; and 5) Moderate power requirements will be necessary for continuous video capture and image processing.

References:

[1] Cudnik B., et al., (2003) *Earth, Moon, and Planets*, *93*, pp. 97-106 [2] Gural P. (2004) *WGN, IMO 32 #6*, pp. 159-160

Earth Observation and Science: Monitoring Vegetation Dynamics from Deep Space Gateway.

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Introduction: Vegetation plays an important role in the Earth's energy balance. Its monitoring is required to understand how ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change. The current state of art for mapping biophysical variables is limited to leaf area index (LAI) from passive sensors. Parameters of interest also include light use efficiency and diurnal courses of sunlit (SLAI) and shaded (ShLAI) leaf area indices, fraction of photosynthetically active radiation (PAR) absorbed by vegetation (FPAR), and Normalized Difference Vegetation Index (NDVI). Their retrieval from space measurements requires high temporal resolution of satellite data. Uniqueness of the Deep Space Gateway (DSG) observation strategy is its ability to provide frequent observations of the Earth that the existing Low-Earth-Orbiting and Geostationary satellites do not have. This feature therefore provides a strong basis for retrieving these variables, which are key paramters in most ecosystem productivity models and carbon/nitrogen cycle.

Ideal instrument: narrow band spectrometer that can register radiance in the spectral interval between 400 nm and 1000 nm at about 5-10 nm spectral resolution. Minimum requirements: spectrometer that register radiance at blue, green, red and near-infrared narrow spectral bands.

Below are prototyps of Earth' science products that can be derived from DSG data.

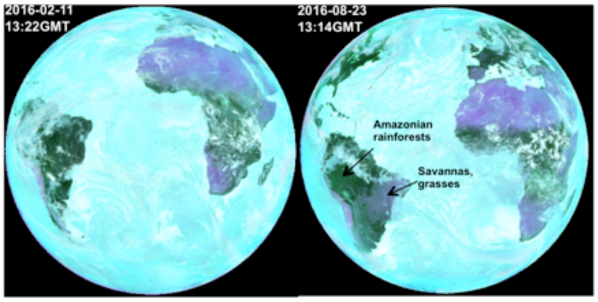

Figure 1. Vegetation dynamics. False color image (688-551-680) of the scattering coefficient derived from the NASA's Earth Polychromatic Imaging Camera (EPIC) onboared NOAA's Deep Space Climte Observatory (DSCOVR) images taken on Feb-11-2016 at 13:22GMT and Aug-23-2016 at 13:14GMT using a simple algorithm documented in [1]. The green color indicates green leaves that EPIC sees through the atmosphere. The images capture changes in savannas from wet (approximately June to September) and dry (October to May) seasons when area of green leaves increases during the wet season and decreases during the dry season.

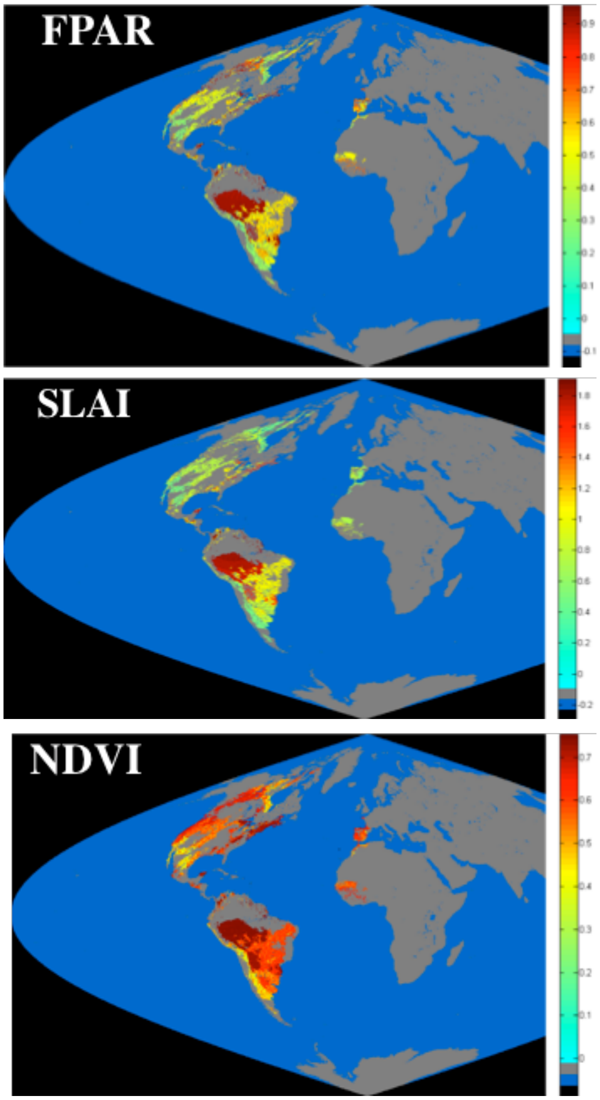

Figure 2. FPAR, Sunli Leaf Area Index (SLAI) and NDVI on Aug-23-2016 at 15:24:58 GMT [2].

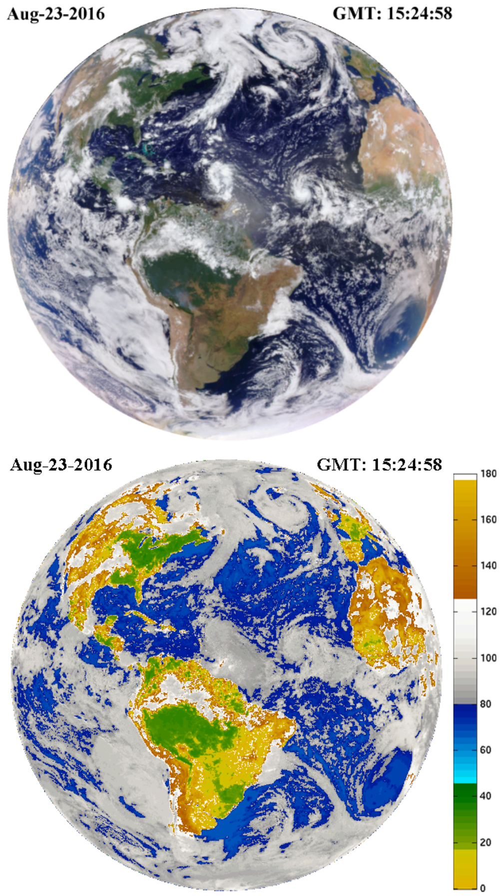

Figure 3. *Upper Panel*. An Enchance RGB DSCOVR EPIC image taken on Aug-23-2016 at 15:24:58 GMT. *Lower Panel*. Earth Surface Type Index (ESTI). This index can discriminate between signals originated from ocean, land, vegetation and clouds [3].

References:

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RADIO IMAGING SPECTROSCOPY OF PHYSICAL PROCESSES IN THE INNER HELIOSPHERE.

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Scientific Rationale: Radio observations below ~100 MHz provide unique insight into non-thermal processes in the outer solar corona and inner heliosphere. However, the intervening Earth ionosphere makes ground-based observations challenging and indeed impossible below 10 MHz. Observations from spacecraft are rather limited in scope (e.g., spectroscopy and occasional triangulation of sources) and in particular cannot provide imaging information. In contrast, observations using radio telescope arrays on the lunar surface would not suffer from such limitations and thus could provide radio interferometric imaging down to the solar wind cut-off at around 20 kHz. These observations would provide key information about a variety of energetic solar phenomena including energetic electron production, and shock and CME formation.

Operational Parameters: An angular resolution of half a degree (one solar diameter) at 1 MHz (wavelength 300 m) would require a baseline of about 30 km. Based on existing terrestrial arrays (e.g., VLA, EOVSA), a 16-32 element sun-pointed radio telescope array, with each antenna about half a meter across, would have a total mass of about 500 kg and require about 500 W to operate. Telemetry (to the Earth) would be of the order of 10 Mbps. Such an array could start with a relatively small number of antennas, which could still yield pioneering science discoveries, and augmented gradually over time, with the new antenna locations guided by the results from the existing array. Erection of such an array would require a number of rover-type sorties of up to 15 km from a central lunar base. Once erected, however, the array would require minimal astronaut involvement, with occasional servicing and repair sorties possible. The antennas and associated electronics would be fabricated on Earth and deployed upon arrival at the lunar base. Cost would be the same as for any other payload of similar mass.

INFLATE: INFlate Landing Apparatus Technology

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Introduction: « The objectives of the LM landing planning strategy are to anticipate the lunar environmental problems and to plan the landing approach so that the combined spacecraft systems, including the crew, will most effectively improve the probability of attaining a safe landing. » (From *Cheatham 1966*)

Space exploration missions are very complex scientific projects. One of the greatest challenges during such missions is the spacecraft's landing on the surface of the targeted planetary body. The vehicle has to be decelerated in a very short period of time from its orbital entry velocity to a complete rest on the surface. This mission phase is hardly fault tolerant. Moreover narrow targets for the vehicles position, velocity and attitude have to be met for a controlled landing within the vehicle's functional capabilities. Furthermore, each mission is highly constrained by the planetary environment, such as the gravity field, the atmosphere, the illumination conditions and also the surface properties. For instance, Viking (NASA ,1975) and Luna (Soviet Union, 1973) landings on the Moon relied on luck not to strike a large boulder or to be stuck into a large crater.

According to Adler et al (2012), "Entry, Descent and Landing (EDL) is defined to encompass the components, systems, qualification and operation to safely and usefully bring a vehicle from approach conditions to contact with the surface of a solar system body". Safely and Usefully are the main keywords of this definition. The scientific goals characterize not only the design of the spacecraft, but also the landing site in order to land in an area where the science objectives will be met. The site has to be « useful » to make the mission successful, and the landing must be « safe » to avoid fatal consequence in case of failure of such costly missions. The mission design deals with a high degree of uncertainty in the apriori knowledge of the environment.

Objectives: Our project, named INFLATE (INFlatable Landing Apparatus TEchnology) aims at reducing space landing risks and constraints and so optimizing space missions (reducing cost, mass and risk and in the same time improving performance). Inflatable braking systems are now the subjects of many researchers, but what about an inflatable landing system?

As the future space exploration projects are focusing on the installation of a Moon Village and then on an exploration of Mars, landing operations must be safe. In order to land on a celestial body surface, the lander's kinetic energy must be entirely safely removed, while traveling before the entry phase at high speeds (about 4 to 7 km/s). Re-entry friction with atmosphere is used to slow down from orbital speed (aerodynamic braking operations). For instance, with Earth's thick atmosphere, the only use of parachutes provides a gentle decent. The martian atmosphere is so thin that it cannot provide enough resistance to slow a spacecraft to a safe landing speed only thanks to a heat shield and parachutes. And on the Moon, as there is no atmosphere, only rockets are used all the way down to ensure a soft landing. Nevertheless, all these landings have ont thing in common: the touchdown which is also a very critical phase.

Mars exploration proved that it is not the fall that kills the mission but the landing. Remember the landing crashes of Mars Polar Lander, (NASA, 1999), Mars Express, (ESA, 2003, with Beagle 2 technology), and more recently ExoMars Schiaparelli lander, (ESA, 2017)

Nevertheless, in the last 50 years, landing technology has evolved and each generation of landing technology has attempted to resolve the challenges posed by the previous generation.

Equipment facilities required: Our INFLATE lander vehicle would be designed with inflatable lander system to avoid many of the previous landers uncertainty.

The INFLATE lander will be composed both by an inflatable landing structure and by a penetrator system based on the landing devices, it will be like an inflatable mattress with a reliable and safe anchorage system to avoid rebounds on the surface. As the first step of future lunar missions will be to build a safe and livable moon base, this considerable construction will need a great lander composed of inflatable braking device (IBD), system of inflation, shock absorption system, payloads, on-board equipment…

This lander will have the advantage to be composed of inflatable braking system with special thermal protection material that will absorb the heat flux when lander enters Moon vicinity or future Mars atmosphere. The advantage of this selected concept is that the lander physical size and the overall mass of the lander are much smaller than in case of the traditional landers with rigid heat shield and rigid landing system.

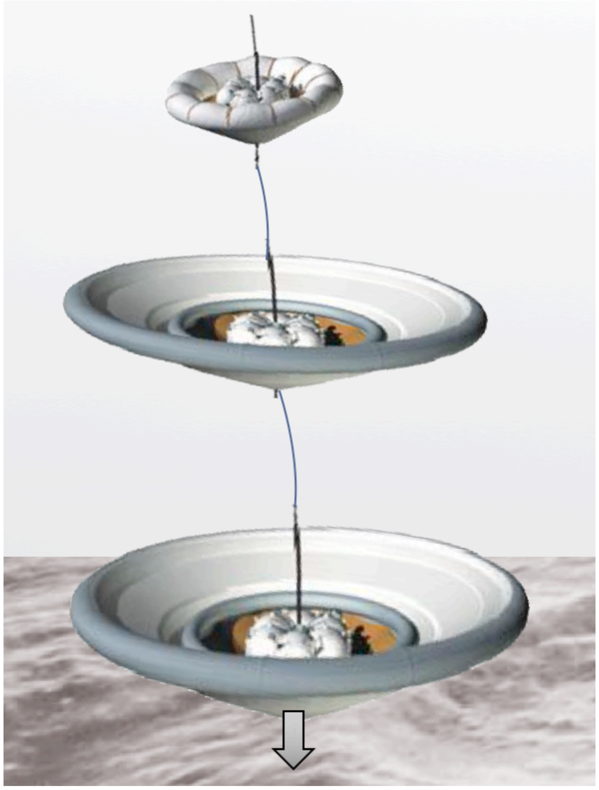

Figure 1: Inflatable structure deployment for Lunar landing

Moreover this innovative lander would also be equipped of various payload assuring science on the target surface (Mars, Moon, other celestial bodies…). This lander will :

- take panoramic pictures,
- perform observations of pressure, temperature, humidity, magnetism, wind speed and direction
- for bodies with atmosphere: atmospheric dynamics, interactions between the surface and the atmosphere, as well as atmospheric optical depth.
- analyze the surface (dust raising mechanisms, seismology seismometer)
- cycles of CO2, H20…

The main advantages of the inflatable lander concept, the compact size and mass compared to the conventional rigid heat shield landers, are even more significant when pursuing landing on other celestial body or planets (The Moon, Mars, Titan…). To conclude, INFLATE project aims to developing the safest landing system, using inflatable devices and anchorage system. Not only this project is a low cost and low mass project but also this is a simple construction that will revolutionize landing operations.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Mark Adler and Michael Wright (2010) *DRAFT Entry, Descent and Landing Roadmap.*

[2] Vsevolod V Koryanov and Victor P. Kazakovtsev (2017) *The technology applying of inflatable devices to access adaptation, movement and landing descent vehicle from Martian environment to the Earth conditions, AIP Conference Proceedings*.

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ACCESSING THE LUNAR FARSIDE AND FACILITATING HUMAN-ASSISTED SAMPLE RETURN WITH THE DEEP SPACE GATEWAY.

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Introduction: Twenty-seven missions have successfully reached the lunar nearside surface, while none have reached the lunar farside. If we are going to explore the unexplored, the lunar farside is our obvious target. It is the nearest, most accessible location to test scientific concepts, expand our technological horizons, and develop the type of integrated robotic and human exploration program that is needed to carry us successfully into deep space.

To address lunar science and exploration objectives, the best results will be obtained a well-trained crew on the surface. Crew on the surface will greatly accelerate scientific discovery while also testing methods for in situ resource utilization (ISRU) and sustainable exploration. Incremental progress can be made, however, with a human-assisted robotic architecture until the capability to land crew exists. In general, human and robotic assets will need to be integrated to maximize productivity and safety.

Human-assisted Sample Return: The Global Exploration Roadmap (GER) [1] includes a human-assisted lunar sample return mission. In this mission concept, a robotic rover is deployed to the lunar surface. It is tele-operated from Earth or by crew in the lunar vicinity. For farside operations, this requires a communications relay from Earth to the farside surface and/or crew in orbit above the farside surface. Both the Orion crew vehicle and Deep Space Gateway (DSG) can provide that capability.

In contrast to Mars robotic rover missions, the Moon favors real-time or virtually real-time rover operations. That capability was demonstrated by the USSR with the Lunokhod rovers in 1970 and 1973. More recently, tele-robotic control of rovers was tested at Meteor Crater, a realistic lunar-like field terrain (Fig. 1) [2]. Tele-operation by crew was also demonstrated by astronauts on the International Space Station controlling a rover on the ground at NASA Ames Research Center [3].

Landing Site: We conducted a global landing site study [4] of locations that address National Research Council recommendations [5] and found that the Schrödinger basin on the lunar farside is the highest-priority landing site. For that reason, detailed landing site and traverse studies have been conducted using all available orbital data, including 0.5 m resolution surface images. Landing sites, traverses, and sample stations have been identified for both a short-duration, 14-day-long mission [6] and a long-duration, 3-year-long mission [7].

Fig. 1. *(top) A Talon rover deployed at Meteor Crater, Arizona, for a field test of the human-assisted sample return concept. (bottom) A rock sample of impact ejecta recovered by the rover.*

The initial target in both cases is an immense pyroclastic vent deposit that may be the largest indigenous source of volatiles in the south polar region during the past ~2 billion years [8]. That material can be used to determine if farside interior water abundances are similar to that of nearside abundances. The pyroclastic vent was an ISRU target of the Exploration Systems Mission Directorate (ESMD) portion of the Lunar Reconnaissance Orbiter (LRO) mission. In that same area, a rover can also collect material to determine the age of the Schrödinger impact basin and, thus, help test the lunar cataclysm hypothesis, the highest priority goal of [5]. The rover will also be able to collect peak-ring lithologies that may be samples from deep within the lunar crust [9] and, thus, test the lunar magma ocean hypothesis. In a long-duration version of the traverse [7], samples of mare basalt lava flows can be collected from the center of the basin to assess the magmatic and thermal evolution of the Moon. Alternatively, samples of South Pole-Aitken impact melt can be collected from the basin walls to determine the age of the oldest, largest basin on the Moon [10]. Returned samples will include both rock and regolith components. Tele-operation of the rover along the traverses can occur from Earth, relayed through Orion. It can also be conducted by crew in Orion or the DSG (Fig. 2, top panel).

Orion and the Deep Space Gateway: Once samples have been recovered by a rover, they are transferred to an ascent vehicle (Fig. 2, middle panel). The ascent vehicle rendezvous with the Orion vehicle and, once it is installed, with the Deep Space Gateway (Fig. 2, bottom panel). This architecture has undergone a preliminary study [11] and is undergoing a more detailed science and engineering analysis by ESA, CSA, and JAXA for the GER.

Deep Space Gateway Requirements: Tele-ops and data download, including high-definition (HD) video from the rover, requires >1 Mbps bandwidth. A simple laptop or similar command and control interface in Orion or the DSG will allow crew to control the rover [12]. A sample transfer capability and method for securing sealed samples in Orion for return to Earth will also be needed. Based on initial traverse and sample studies [6, 7], sample masses of 15 to 20 kg per mission are reasonable. Studies of orbits and communication requirements [13] indicate a halo orbit around the Earth-Moon L2 point is ideal.

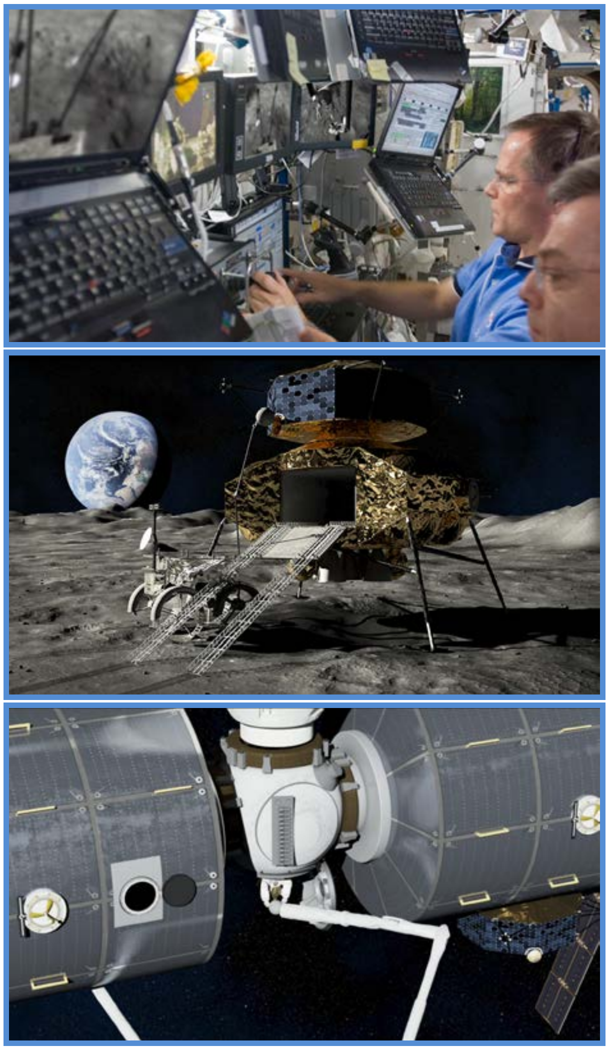

Fig. 2. *(top) Artistic rendering of astronauts tele-operating a lunar surface rover from the Deep Space Gateway. (middle) Transfer of sample container from rover to ascent vehicle. (bottom) Transfer of sample container to the DSG and Orion. Images courtesy of Markus Landgraf and ESA.*

References: [1] International Space Exploration Coordination Group (2013) *The Global Exploration Roadmap*, NASA NP-2013-06-945-HQ, 42p. [2] Kring D. A. et al. (2007) A rover-based strategy for the robotic and human phases of the lunar exploration initiative, Workshop on Science Associated with the Lunar Exploration Architecture. [3] Burns J. O. et al. (2017) This workshop. [4] Kring D. A. and Durda D. D., eds. (2012) *A Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon*, LPI Contrib. 1694, 688p. [5] National Research Council (2007) *The Scientific Context for Exploration of the Moon*, 107p. [6] Potts N. J. et al. (2015) *Adv. Space Res.*, *55*, 1241–1254. [7] Steenstra E. S. et al. (2016) *Adv. Space Res.*, *58*, 1050–1065. [8] Kring D. A. et al. (2014) *LEAG Mtg.*, Abstract #3057. [9] Kring D. A. et al. (2016) *Nature Communications*, *7*, 13161, 10 p., doi: 10.1038/ncomms13161. [10] Hurwitz D. and Kring D. A. (2015) *Earth Planet. Sci. Letters*, *427*, 31–36. [11] Landgraf M. et al. (2015) *LEAG Mtg.*, Abstract#2039. [12] Burns J. O. et al. (2017) Science and exploration at the Moon and Mars enabled by surface telerobotics, *10th IAA Symposium on the Future of Space Exploration*, 10p. [13] Pratt W. et al. (2014) *65th Internat'l. Astronaut. Congr.*, IAC-14-A5.1.7., 18 p.

DEEP SPACE GATEWAY SUPPORT OF LUNAR SURFACE OPS AND TELE-OPERATIONAL TRANSFER OF SURFACE ASSETS TO THE NEXT LANDING SITE.

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Introduction: A multi-agency team [1] introduced a design reference mission (DRM) that utilizes an exploration deep space habitat (eDSH) or Deep Space Gateway (DSG) in lunar orbit, along with the Space Launch System (SLS), Orion crew vehicle, a service module, two small pressurized rovers (SPRs), and a lunar surface lander with an ascent stage for crew. Two SPR are delivered to the lunar surface, followed by a crew of 4, which conducts a 14- to 42-day-long mission in the SPRs, before returning to Earth with lunar surface samples. The SPRs are then telerobotically driven to a second landing site, where a second crew lands. The cycle is repeated for a total of five missions. The landing sites in this scenario are Malapert massif, the South Pole, Schrödinger impact basin, Antoniadi impact crater, and the center of the South Pole-Aitken impact basin (Fig. 1). The surface ops associated with this DRM will put some demands on the DSG that are explored here.

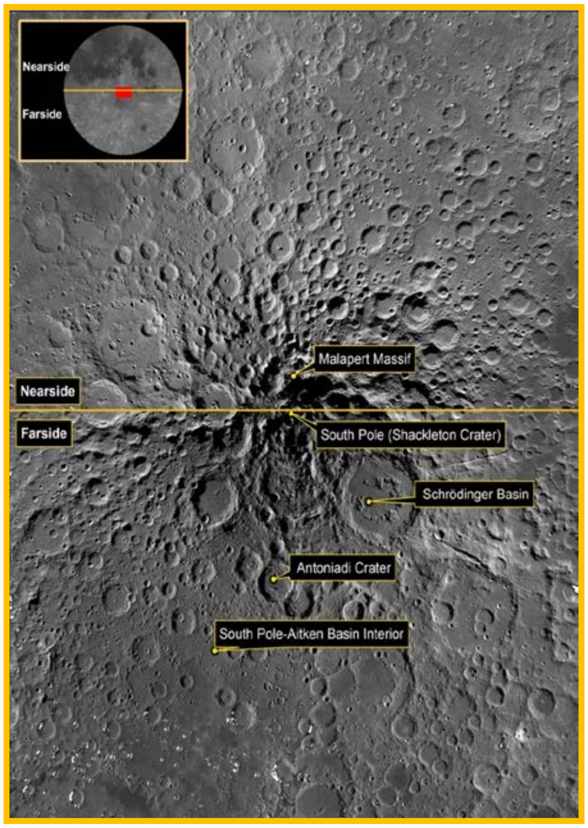

Fig. 1. *Human landing sites in the DRM [1, 2, 5].*

Surface Traverses with Crew: A study of traverses at each of the landing sites [2] indicate they will be feasible using a flight version of the Lunar Electric Rover (LER), which is a vehicle that has been tested in 1-, 3-, 14-, and 28-day-long mission simulations in the Moses Lake basaltic sand dune complex, Washington, and the San Francisco Volcanic Field, Arizona. The 28-day-long mission simulation involved two LER (Fig. 2) and is, thus, similar in concept to the use of SPRs in the DRM.

Fig. 2. *Dual LER in a simulation of a lunar mission involving a crew of 4 (2 in each vehicle).*

For crewed operations in the simulations, the LERs were outfitted with high-visibility windows, ForeCam, AftCam, port and starboard cameras, docking cameras, and GigaPan cameras to support both intravehicular and extravehicular activities (e.g., [3,4]). A high-definition (HD) video can be added. Ground-penetrating radar (GPR) was installed on an unpressurized version of the LER, called Chariot, during the Moses Lake test and successfully detected subsurface water. A more advanced unit was installed beneath the aft deck of the LER for an extended 14-day mission simulation at Black Point, demonstrating its application in rugged field conditions. A neutron spectrometer is another in situ resource utilization (ISRU)-related survey tool for volatiles (e.g., hydrogen) that could be installed on future LER (SPR). A compact device has been designed for NASA's Resource Prospector (RP). It produces optimum signal-to-noise when rover speeds are ≤10 cm/s (Richard C. Elphic, personal communication, 2017). While that speed is slower than the speed crew will likely use in most portions of their work, it is a speed perfectly suitable for portions of the tele-operated phase of rover operations.

Tele-operated Traverses: The SPRs can be tele-robotically driven between each of the landing sites from Earth via the DSG. A study of those traverses [5] indicate they are feasible, although descents into the Schrödinger basin and Antoniadi crater need to be verified. The traverse study revealed sufficient time exists for the rovers to prospect for volatile deposits that might be suitable for future resource recovery. Two specific survey locations were identified in Cabeus and Amundsen impact craters. The SPRs will be driven across diverse geological terrains between the landing sites, so if a robotic sampling capability was added to the vehicles, then selected sampling could expand the exploration potential of the tele-operational phase of an implemented DRM.

Data Rates: Communication with the SPRs between each landing site and with crew at each farside landing site needs to be relayed through the Orion, DSG, or some other orbiting asset (Fig. 3). Data rates will exceed 1 Mbps and should be studied in more detail to determine the bandwidth demands during each phase of the DRM. For the sequence of 5 landing sites outlined, a DSG in a large halo orbit about the Earth-Moon L2 point will provide a good communication relay [Lockheed Martin Space Systems Company, 2016, personal communication].

Sample Mass: Minimum sample masses collected by crew can be calculated for each landing site and traverse using CAPTEM recommendations [6] for the lithologies encountered. In the meantime, a notional average value can be calculated using the results of Apollo extravehicular activities (EVA). In Apollo missions 12 through 17, the sample recovery rate occurred at a nearly constant level of 2.3 kg/EVA hr/crew member [7]. If we assume 14 days of sample collection at each of the DRM landing sites, with only one of the SPR crews going EVA each day, and further assume 2 to 3 hours of EVA per day based on the previously described mission simulations, then ~130 to 200 kg of samples might be expected, not including sample containers, compared with the 110.5 kg of the Apollo 17 mission. This calculation is truly notional and needs to be refined after a rationale concept of operations (CoNOps) for the missions has been developed and landing site traverses reviewed. For example, more than 14 days may be spent collecting samples during a 42-day-long mission with 28 days of sunlight. The notional value is useful, however, because it shows human missions will likely recover an order of magnitude more mass than the human-assisted robotic missions being discussed for an earlier phase of Deep Space Gateway activities [8]. It is also important to note that well-trained crew will only collect the samples needed to meet science and exploration objectives, so any samples collected should be returned to Earth.

Those samples can either be launched with crew to lunar orbit or with a cargo ascent vehicle. The samples will then need to be stowed in Orion for return to Earth. Most samples will be composed of rock and regolith and will not need any special handling not already demonstrated by Apollo. If the tele-operated SPRs prospecting for ice are tasked to sample volatiles, then the return of those types of samples my require special cryogenic handling.

Fig. 3. *(top) Artistic rendering of a small pressurized rover on the lunar surface that uses (bottom) the Orion vehicle or Deep Space Gateway as a relay to Earth. Credit: NASA.*

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Volcanic Cloud and Aerosol Monitor (VOLCAM) for Deep Space Gateway

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Frequent (~15 min) imaging of reflected solar ultraviolet (UV) and thermal ifrared (TIR) radiation of the whole Earth from cislunar vantage point offer unique possibilities to answer NASA's Earth System Science (ESS) questions and further advance volcanic ash (VA) and sulfur dioxide (VSO2) aviation safety applications. We propose complementary ultraviolet (UV) and thermal Infrared (TIR) filter cameras for a dual-purpose whole Earth imaging with complementary natural hazards applications and Earth System science goals.

Our proposed UV imager is similar to the DSCOVR/EPIC filter camera currently observing Earth from the L1 vantage point[1], but with more rapid color sampling to mitigate scene motion artifacts. The baseline configiuration includes 4 narrow band (1-2nm) UV interference filters (317.5, 325, 340, and 388 nm) to obtain atmospheric composition retrievals: total column ozone O_3 and volcanic sulfur dioxide SO_2, UV scene reflectivity (cloud fraction), and UV absorbing aerosol properties (ash, smoke and dust). Visible filters near the oxygen absorption A band can be added to measure cloud and aerosol plume heights. The Earth disc image is projected onto 2048 x 2048 pixel CCD detector to produce a nadir ground resolution ~10x10 km^2 at nadir. Figure 1 shows Mt. Etna VSO_2 cloud measurd by the EPIC UV camera at ~20km resolution in 2 hours.

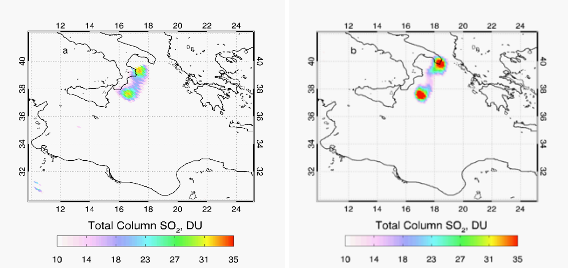

Figure 1. EPIC volcanic sulfur dioxide (VSO_2) map for the December 3 2015 eruption of Etna volcano (Sicily, Italy; triangle) in two consecutive EPIC exposures at (a) 08:16UTC; (b) 10:04 UTC. Total column SO_2 amount is measured in Dobson Units (1DU = 2.69x10^{16} molecules SO_2/cm^2). Background and anthropogenic SO_2 is far below EPIC detection limit of ~10 DU, while VSO2 is generally less than 1000 DU.

Large horizontally extended layers of smoke and desert dust are routinely generated by agriculture-related biomass burning and wild fires as well as by the wind lifting effect in the world deserts. These plumes are mobilized thousands of kilometers away from their original sources, often reaching densely populated centers and affecting air quality. Because of the known absorption properties of carbonaceous and desert dust aerosols, near UV observations will make possible the detection of smoke and desert dust plumes (Fig.2). The high temporal frequency of the observations will enable a predictive capability to minimize adverse effects on the population. Such whole disk UV measurements, including polar regions, will not be available from GEO satellites.

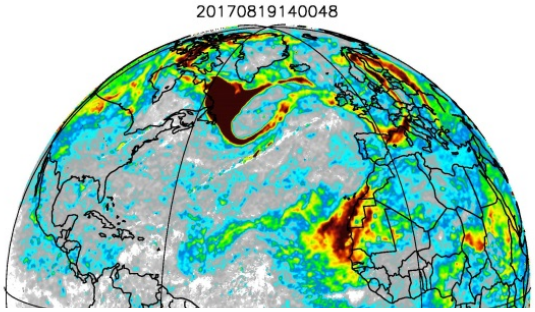

Figure 2. Spatial distribution of desert dust (over western Africa and Atlantic) and biomass burning aerosols (over Canada and north Atlantic) as shown by EPIC UV Aerosol Index (UVAI) measured on August 18, 2017. The UVAI is calculated from EPIC observations at 340 nm and 388 nm (red and black colors indicate high aerosol mass and height). TIR measurements will allow discriminating between ash (large particles), smoke (fine particles) and ash (using VSO2 as a proxy).

Nigttime observations of volcanic and aerosol plumes will be obtained with a TIR camera capable of ~20km spatial resolution. The baseline configuration is similar to the previously proposed geostationary VOLCAM TIR camera[2] with 4 spectral channels centered at 8.5, ~11,12 and 13.3 µm. This selection allows imaging of VSO2 (8.5µm)[3], meteorological cloud property retrievals[4], and ash mass and particle effective radius(11,12 µm) [5-6]. Adding 13.3µm (e.g., GOES-R/ABI channel 16) would allow retrieval of volcanic ash height[5]. The original VOLCAM TIR detector was a 640 x 480 noncooled microbolometer 2D array[2], which could be upgraded with an advanced microbolometer technology[7].

From cislunar orbit VOLCAM UV-TIR cameras will periodically observe movement of the large scale weather systems and transient volcanic and aerosol clouds over polar regions not visible from the equatorial GEO orbit.

Simultaneous, frequent measurements of cloud evolution (by O2-A band and TIR bands) and aerosol properties (by UV and TIR bands) will provide unique oppurtunites to study the interaction between cloud system and several important aerosol species (smoke, dust, and VSO2. This will help to better understand the indirect effects of aerosols on climate, as well as the invigoration/suppression of convective clouds by aerosols.

The TIR measuring capability will help to unambiguously differentiate volcanic sulfate aerosols from ash and desert dust plumes, and from smoke layers, providing accurate characterization of the optical depth and mass concentrations for hazard alert decisions. In addition TIR imaging will detect major “hot spots” due to forest fires and volcanic activity.

The combined use of UV and TIR cameras will allow volcanologists and atmospheric scientists to document the life cycle of volcanic sufur in the atmosphere and map radiative forcing (RF) of volcanic clouds and aerosols above land, water and meteorological clouds. The RF calculations would allow interpretation of the absolute whole Earth radiation measurements to quatify the input from clouds, volcanic events and aerosols (smoke and dust) to the Earth’s radiation balance.

Synergetic use of UV and TIR capabilities of VOLCAM will yield more accrate retrievals of SO_2 discharged from volcanic eruptions, by combining the greater SO_2 sensitivity afforded by UV measurements and information about SO_2 height provided by TIR emasurements. This will lead to more accurate quatification of volcanic input of sulfur (SO_2 and sulfate aerosols) into the atmosphere and their climate impacts.

The high-frequency, day-and-night monitoring capabilities of VOLCAM for volcanic ash will be crtical for aviation safety applications, particularly for airliners taking the polar routes over the Arctic that is not observed by GEO instruments.

Frequent measurements of volcanic ash size will also help to determine the sedimentation rate of voalnic ash, providing better constraints for numerical models.

DSG requirements:

1) External instrument stabilization platform for accurate Earth pointing;
2) External science data downlink antenna for high speed transmission of frequent measurements (e.g., ~10 wavelengths every 15 minutes from a 2048 x 2048 detector).

VOLCAM instrument characterisics

1) Mass (without pointing platform) ~30 kg
2) Power ~ 30 Wt
3) Volume < 0.5 m^3
4) Data rate (without compression) ~350 kb/sec
5) Independent thermal management

With the near autonomous operation of the VOLCAM instrument, the uplink commands are infrequent during normal operation and should not exceed a few kilobits per day.

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HABITABILITY STUDY FOR OPTIMAL HUMAN BEHAVIOR.

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Introduction: This project is built upon the research and studies done at SICSA and Boeing. The number of modules is fixed as is their diameter and length, based on heritage technology and current launcher technology. The general diameter of each module except for the power module is around 4.5 meters. The maximal length authorized for the habitat module is 8 meters, trade-studies were conducted.

The conclusion of those comparisons were that in order to provide the minimal private habitable space and accommodate some space for experiments, 8 meters long was the best choice. The conops were developed based on ISS standards and was adapted to the new configuration of this station. The habitable volume per crew is smaller than on the ISS, going from 60 cubic meters to 20. This new confined space requires new accommodations and new techniques. This paper will explore those techniques and the decisions required.

Design intent and approach: For the Boeing/SICSA DSG proposal, the goal was to come up with an alternative design for the interior of the space-station, to optimize habitability and functionality. To achieve these goals, it was important to learn about the different studies that have been conducted [1] on the same subject. After an analysis phase, the next step was to reconfigure the different elements in a more compact and pleasing way for the crew, the emphasis was put here on the notion of separation to increase the sensation of privacy and reduce the possibility of social exasperation which occurs in every long-term mission done so far. The technical aspects of the project for the storage of consumables or the way heat rejection and the recycling of the atmosphere will be dealt with actual knowledge based on the experience gained with the ISS [2].

The ISS was designed with modularity in mind, the rack system was designed to be removed and replaced on a regular basis, the renewal of equipment was not an important factor here as most of the scientific equipment will be already installed. Small changes and movement will probably occur but the conception of the station is based on fixed systems.

Vision mission, Goal and Objectives: As mentioned previously, the goal of separating inside the habitat module the different activities was done to induce a sensation of privacy to the crew. How can we provide a space built for efficiency while at the same time procuring a generous personal space for each crew during the day.

Separate each activity by physical and visual division and divide the experiment area by workstation instead of having one general common area.

The objectives of such a project is to achieve a visual division between each space while at the same time having a continuous seamless experience of impeccable interior design that is geared at the well-being of the crew based on simple lighting and perception principles.

Design Assumption & Requirements: A general clearway was built to guarantee the crew a way to escape danger and an easy circulation between different areas and modules. The diameter of that clearway along each module and at each intersection is slightly superior to the interior diameter of the international port standard, around 85cm wide. This first assumption will drive most of the organization of the module.

The quantity of consumables is expected to extend the duration of the mission to 300 days at max with 4 crew members, therefore the internal volume of the space-station is supposed to accommodate 11.3 cubic meters of consumables, assuming a 90% rate of water recycling (clothing=1.20m3, water=1.60m3, food=8.5m3). This space is not considered habitable and will need to be changed during the mission as some of these consumables will be changed to trash.

Inside pressure and air composition will be very similar to the ones on the ISS (14.7 psia / 75kpa, 21% 02 78% N 1% CO2).

This DSG will have to simulate and experiment with different scenarios that might happen during a long transit to Mars and during a possible orbit around this planet [3]. Radiation exposure will also be an issue, polyethylene tiles 2” thick will be considered for the crew quarters.

Power and avionics will be provided by other modules, the power module and the Node/Hab.

Overview of Research, Analysis, and Design: This project is slightly different as the inclusion of a RECLSS system was not possible since the delays in research & development could not permit such an installation. The study was then strictly focused on mechanical ECLSS systems and therefore, Molly Anderson’s presentation was extremely valuable. It brought precise sizing for the recycling mechanism and exact amount of storage for consumables, predictions based on her lecture assume a 90% recycling rate for water as mentioned previously. Food and water storage were also considered as was the preparation, the difference between dry-mass and the need to bring water to those portions was a valuable lesson for the availability of water dispensers and also the way exercises should be done and the logistic around it. The idea of having a unified and centrally located ECLSS system paired with the waste management system and in direct proximity of the exercise area came around after considering the amount of pipes and systems needed to convey water and human waste to the systems.

Therefore, a central donut-shaped system was devised to ensure the simplicity and centrality of the systems for the habitat module of the deep-space gateway.

Air circulation was also very important to the design of the sleep-pods, as Molly Anderson explained to us, the presence of dead zones (no air-flow) can be extremely dangerous for the crew and careful consideration was then taken to ensure a regular movement of air throughout the crew quarters.

Design parameters and details sufficient to convey the concept: Surfaces in the exercise area will be coated in a reflective material that also prevents the development of bacteria and fungi. Reflectivity will be important in the general design of the habitat as it allows the brain to imagine the space as being bigger.

The crew quarters will have a central space for gathering and handling of personal storage, each crew quarter's will be 4 cubic meters. These crew quarters will be divided, giving the crew a real sleep area free of visual reminders of their working schedule. The other area will serve a dual purpose, it will be used as an entertainment space with private gardens and spaces for laptops and tablets. The other use of that division will be for dressing and personal care with a wide mirror and a storage space. Each opening of for the crew quarter's will direct to a personal storage space instead of another door, increasing the sensation of personal space.

Personalization of one's quarter will also be important, the possibility to choose a coating for your front door will bring the crew satisfaction. The experiment area will feature 4 different areas with a central circulation space, allowing access to 2 out of 3 sides of the experiment racks. Enabling better configuration and better wiring, preventing clutter in the central area. The disposition of electric wiring will happen behind the experiment racks to prevent visual discomfort, rejection of the heat coming from the experiment will be handled by convection, preventing the quantity of pipe and the possible perforation of such pipes by incoming objects.

One of the design goal was to have access to the hull in case some reparation was necessary.

Conclusion: This study, after exploring new organizations, new secondary structure and a new heat transfer system, concludes that it is possible to divide the inside of a small module by using new systems and pre-installed components.

An optimal location of sleeping areas and sport equipment along the distribution lines of fresh and polluted air was the main factor for the way spaces are arranged, each area being almost independent in their settings and therefore their requirements. A division seemed the natural way to arrange the interior. Those two requirements, distribution of air and division of activities is the main factor for the general design of the station and ended up with a satisfying combination of rigid requirements with a pleasant livable space.

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Poor Man's Asteroid Sample Return Missions.

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Introduction: A cislunar platform at a Near-Rectilinear [Halo] Orbit (NRO)[1] in the vicinity of the Moon could provide an opportunity for a small near-Earth asteroid (NEA) sample return mission at relatively low cost. There are a couple potential small (0.1-1m) object target dynamical groups for this mission including:

1. small Earth orbiting, transient "mini moons" or quasi-satellites in temporarily captured orbits such as asteroids 2006 RH_{120}, 2016 HO_3, 2003 YN_{107}, etc. [1]
2. potential Earth Trojans in Sun-Earth Lagrangian point 4 (SEL_4) or Earth-Sun Lagrangian point 5 (SEL_5), such as 2010 TK_7. [2]

Concept of Operations: Utilizing telescopic assets to locate these low-Δv targets is the key essential first step., Once identified a small robotic spacecraft in NRO can perform rendezvous and proximity operations to examine, capture and return these small natural objects to the Deep Space Gateway (DSG) in NRO.

Mission Vehicle: The mission vehicle has a mass of (an estimated) 700 kg with a Δv capability of ~4 km/s) enabling RPO with either a minimoon, a retrograde, elliptical Earth orbiting object, or a Trojan at SEL_4. Sample return canisters would be limited to approximately 1kg sample mass. A limited sampling acquisition capability would also exist on the mission vehicle in the event that the orbiting object was too large to fit within the 1kg mass capability. In all three target family capture scenarios, the vehicle would use electric propulsion systems.

Detection and Rapid Response: A few of these objects have been detected from ground surveys. The key to finding these; however, is a space-based survey optimized in the infrared, away from the vicinity of the Earth, such as NEOCam [3]. Once such a relatively easily accessible NEA is detected, the existing DSG-based on-orbit asset is necessary to quickly respond to a mission opportunity due to the relatively transient nature of these objects in orbit and the potential mission duration timelines using electric propulsion.

Planetary Protection: Depending on the compositional type, the scientific consensus is that asteroids are not likely to support life and therefore do not present a risk to humans [4], and therefore no special handling or containment restrictions need be provided at the DSG for the returned samples. A few exceptions do exist and would warrant an appropriate curation process to ensure no contamination from the vehicle or to the crew of the DSG. [5]

Mini moons: Small asteroids may routinely be captured by the Earth's gravitational field for limited durations in time and thus become temporary natural satellites. Entering into dynamic Earth orbits (pulled by gravity from Earth, the Moon and the Sun), they may only stay for a month, a year, or decades and then depart Earth's vicinity. 2006 RH_{120}, 2016 HO_3, 2003 YN_{107} mentioned above are examples of such bodies and there are several others.[2]

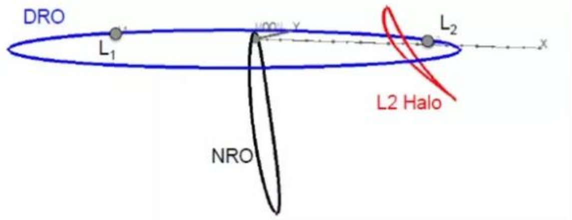

Figure 1: Depiction of NRO with respect to Deep Retrograde (DRO) and L_2 (EML_2) Halo orbits about the Moon

Earth Trojans: In 2011, the NEOWISE spacecraft identified the first (and, so far only) Earth Trojan, 2010 TK_7. [2] Such objects can be captured at Lagrangian points of stability where the gravitational effects from two larger objects (in this case, the Sun and the Earth) will hold a small object in a stable orbit. Two of these points (SEL_4 and SEL_5) are located either 60º ahead or behind the Earth in it's orbital plane, as shown in Figure 2. 2010 TK_7 precedes the Earth at the SEL_4 location and is approximately 300 meters in size, oscillating about SEL_4. At closest approach, 2010 TK_7

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[1] NROs are a subset of L_1 and L_2 halo orbit families. NRO is a possible candidate orbit for the DSG.

[2] Other quasi-satellites include: 2004 GU_9, 2006 FV_{35}, 2013 LX_{28}, 2014 OL_{339}. These bodies are not gravitationally bound to the Earth. There are also more bodies in horseshoe type orbits; again, loosely and temporarily semi-bound. These asteroids migrate from horeshoe orbits to quasi-satellites and back again.

is approximately 20 million kilometers from the Earth and at a high inclination of 20.9° to the ecliptic and thus requires 9.4 km/s Δv_{total} to reach it. This represents a difficult (but not impossible) sampling target to reach with existing propulsion systems.

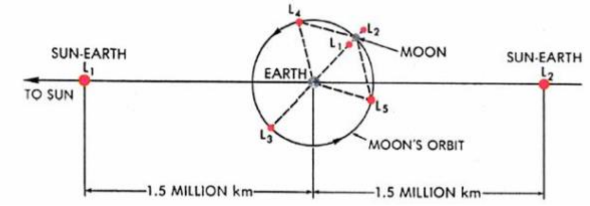

Figure 2: Earth-Moon Lagrange locations (with respect to SEL_1 and SEL_2 locations)

There may be other Trojans yet-to-be discovered. Several studies have been done to estimate the probability of finding more of these Earth Trojan asteroids [6, 7]. Dvorak *et al*. used analytical mapping and numerical methods in dynamical models. By taking into account clone orbits, the capture and escape of Trojans, and the stability region of the Lagrange points, they predict that other Trojan asteroids exist at Earth's stable Lagrange points [6]. Mikkola and Innanen (1990) performed numerical integrations to demonstrate that there exists stable, 1:1 resonance, asteroidal orbits for Earth [7]

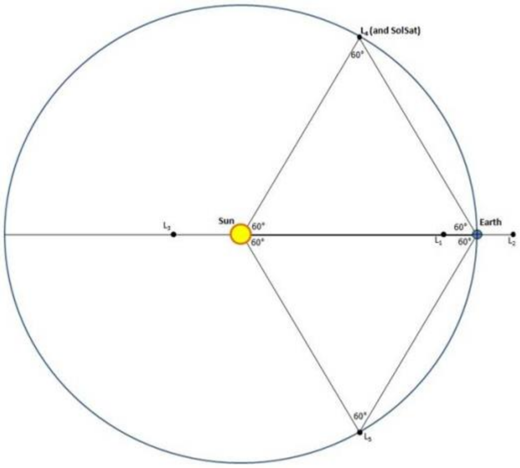

Figure 3: Sun-Earth Lagrange Locations

Conclusion: It is feasible that a small, relatively inexpensive sample gathering spacecraft can be based at the DSG and be able to transit to different locations to obtain NEA (or lunar ejecta samples). Searching for these objects in the course of regular NEA survey efforts (via ground- and space-based assets) might yield other opporotunties for sample return. *In situ* characterization of these samples could lead to cultivating immediate benefits in science, exploration, and resource utilization.

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The Deep Space Gateway Lightning Mapper (DLM) - Monitoring Global Change and Thunderstorm Processes through Observations of Earth's High-Latitude Lightning from Cis-Lunar Orbit.

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Background: The Deep Space Gateway (DSG) is a proposed manned mission to orbit near Earth's moon. It is anticipated that the DSG will be able to host science payloads of a variety of types, including Earth-observing instruments. While a lunar orbiter is not at first glance an obvious choice for performing dedicated Earth observations, in fact a previous workshop[1] found that a lunar-based mission would be able to fulfill important Earth science objectives, and would serve a useful complementary role to geostationary orbit (GEO) and low-Earth orbit (LEO) Earth-observing missions. One of the Earth science roles that received the highest grade in that workshop was to observe lightning occurring in the Earth's atmosphere.

Instrument Description and Justification: We propose the DSG Lightning Mapper (DLM) instrument. The primary goal of the DLM is to optically monitor Earth's high-latitude (50° and poleward) total lightning not observed by current and planned space-borne lightning mappers. While lightning is concentrated in the Earth's tropics, as the Earth warms, scientific studies[e.g., 2, 3] have found that thunderstorms will increase in frequency and severity at higher latitudes. This reflects the fact that a warming planet likely will see poleward shifts of mean frontal system positions, as well as an earlier onset to spring and a later onset to autumn. This has important implications for the distribution of global precipitation; for changes in vertical transport of heat, moisture, and pollutants from low-levels to the upper troposphere and lower stratosphere (UTLS); for the global distribution of lightning nitrogen oxide (LNO_x) production; and for the increasing risk of lightning-ignited wildfires in boreal forests. Moreover, lightning is under consideration as a new essential climate variable by the World Meteorological Organization, as it is related to changes in the frequency and distribution of temperature, humidity, and storminess.

Thus, there is a critical need to understand and monitor lightning and thunderstorms at higher latitudes of the Earth. Meanwhile, current GEO (e.g., the Geostationary Lightning Mapper - GLM[4]) and LEO (e.g., the Lightning Imaging Sensor - LIS[5]) lightning mappers do not provide sufficient coverage of higher latitudes to address this need. Furthermore, simply adding a lightning mapping instrument to a circular polar-orbiting Earth satellite cannot provide long-lived (i.e., multi-hour) continuous views of the same storm, limiting the ability to do process studies on poorly understood high-latitude thunderstorms. Highly elliptical orbits (HEO; e.g., Molniya, Tundra) do offer longer-lived, high-latitude coverage; however, field of view (FOV) and spatial resolution are highly variable during each orbit, which leads to difficulties in developing effective flash detection algorithms as well as difficulties in performing unbiased climatological and process study analyses. Finally, ground-based networks require unrealistic sensor densities to achieve comparable detection efficiency of total lightning relative to space-borne optical methods.

DLM will address all of these limitations and thus complement the existing lightning-observing constellation. It is expected that the carefully designed cis-lunar orbit options for DSG (e.g., Near Rectilinear Halo Orbit - NRHO) will offer periodic, long-lived views of the Earth's high latitudes (Fig. 1). This enables continuous sampling of individual thunderstorms throughout their lifetimes, similar to coverage provided at lower latitudes by GEO lightning mappers. This periodic sampling can be integrated in time to enable coherent monitoring of global changes in thunderstorms and lightning at higher latitudes, as well as to facilitate investigations into thunderstorm response to solar activity and other extremes in space weather.

Additional DLM science opportunities can be opened up by temporary sampling changes. These could include selective targeting of lower latitudes to assist with cross-validation with other lightning sensors, or occasional longer integration times to create a day/night band, which would be very helpful for high-latitude regions that experience long winter nights. DLM will thus provide multiple direct benefits to NASA's Earth Science Focus Areas in Weather, Climate, and Atmospheric Composition.

Design Requirements: We anticipate that DLM's design would be qualitatively similar to existing lightning mappers[4, 5], with a narrow band (777 nm) optical detector, operating at a frame rate of ~500 fps. The 777-nm frequency band enables high-detection efficiency (> 70%) of lightning during Earth's daytime or nighttime. DLM would connect externally to the DSG spacecraft. We expect that a gimbal system would be needed in the attachment to enable adaptive staring at Earth's high latitudes, thereby maximizing utility of the cis-lunar orbit. The DSG crew would need to mount the instrument to the hull. We anticipate that this process would be qualitatively similar to the mounting of LIS on the International Space Station (ISS), which took only a few hours. After that, DLM would run largely autonomously, with periodic commands and adjustments relayed remotely from Earth.

The ability to transmit data in near real-time to Earth would be highly desired. We anticipate that data rates could be significantly reduced (to ~1 mbps or less) relative to the current state of the art (GLM) with additional onboard processing for DLM, as well as a reduced FOV to focus mainly on higher latitudes. DLM would utilize new focal plane and field programmable gate array (FPGA) technology that has come of age since the development of GLM, as well as a recently acquired airborne optical validation dataset, to develop an upgraded approach to lightning detection that can account for the decreased lightning signal-to-noise ratio (SNR) expected from cis-lunar orbit.

Power requirements for the DLM instrument are anticipated to be significantly reduced compared to GLM, likely < 100 W, due to recent improvements in focal plane technology that have reduced power consumption. Relative to GLM, the DLM telescope size would need to be increased (to ~100 cm) in order to achieve the desired ~10-km instantaneous FOV. However, GLM required a large baffle to remove solar glint from nearby instruments. DLM would be designed to not require the extra baffle, and would have reduced electronics size, thereby keeping the instrument comparable in size (~150x60x60 cm^3) and mass (~100 kg) to GLM despite the longer telescope. Total cost of DLM is expected to be < $10M, due to recent technological improvements and lessons learned from GLM development.

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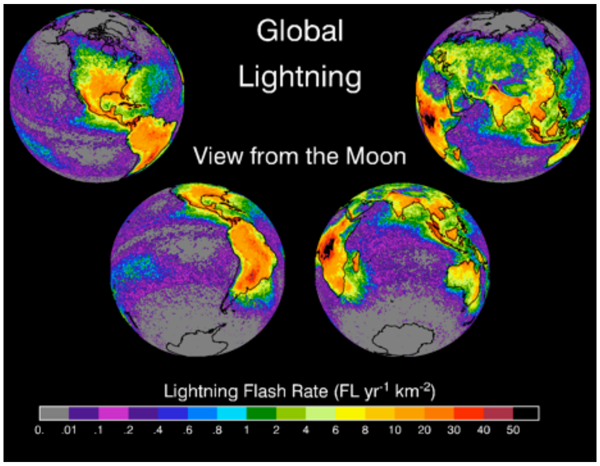

Figure 1. Global lightning climatology from LIS and the Optical Transient Detector (OTD), as viewable from a lunar-based orbit.

HIGH FIDELITY MEASUREMENT OF FREE SPACE SOLAR PARTICLE EVENT AND GALACTIC COSMIC RAY ENVRIONMENTS AT INTERMEDIATE ENERGIES.

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Introduction: The Deep Space Gateway opens up vast amounts of new opportunities for science measurements that can support the next steps for human space exploration. Radiation health impact in human space flight is identified in the NASA Human Research Project as one of the main risks for human space exploration requiring appropriate mitigations for habitation or planetary missions [1]. Mitigation of this risk can benefit from Deep Space Gateway enabled scientific measurements, in particular in the context of Solar Particle Events.

Background: NASA manages radiation exposure of astronauts by maintaining health risks below established safety limits. Different methods and mitigations are applied for different radiation fields and activities in free space.

Solar Particle Events (SPEs) represent transient radiation events where astronaut exposure can reach significant levels inside a spacecraft. The ability to accurately measure the flux energy spectrum of transient events can positively impact mission planning and health assessments. Astronaut health impact of SPEs is particularly driven by the intermediate energy flux spectrum shape above about 400 MeV proton kinetic energy. However, space radiation asset data currently used in operations is only available as integral fluxes for >10, >50 and >100 MeV [2], and SPE energy spectra vary from event to event.

Extra vehicular activities (EVAs) are expected to be a part of Deep Space Gateway operations. Astronaut radiation exposure management includes estimation of exposure received during EVAs using models of the radiation environment outside the vehicle. Simulations indicate that astronauts receive as much as 40% of total effective dose behind shielding corresponding to space suits from particles below 1 GeV [3]. This energy range of charged particles, however, is expected to be uniquely modulated by the presence of the Deep Space Gateway such that existing Low Earth Orbit measurements (e.g. [4]) will be of limited use.

Proposed Science Experiment: A charged particle measurement experiment mounted externally to the Deep Space Gateway is proposed. This experiment provides in-situ, free space flux energy spectrum information from about 1 MeV/n to 1 GeV/n particle energy directly relevant for characterizing the local Deep Space Gateway radiation environment. The experiment will achieve energy resolution for protons beyond 400 MeV to improve SPE radiation exposure hazard estimations for astronauts, and energy resolution for protons below 1 GeV to measure and monitor the local radiation environment for radiation exposure management in EVAs. Operational use of the device data is an expectable side-benefit of the experiment e.g. for in-situ space weather awareness and to complement Deep Space Gateway Caution & Warning systems. An additional system could be placed on the inside of the vehicle to quantify the radiation shielding impact of the Deep Space Gateway structural and payload materials on the exterior particle radiation spectra. Data collected with the experiment can be used to improve NASA radiation exposure management processes.

Expected Resources of Proposed Experiment: The experiment would utilize power and communications provided by the Deep Space Gateway and telemeter measured data back to Earth on a regular basis for science analysis. No need for astronaut operations or maintenance is expected.

System/Technology Candidates: The instrument to acquire the science data can be based on the AES Hybrid Radiation Environment Assessor (HERA) device developed for environmental radiation monitoring inside the Orion vehicle for Exploration Missions 1 and beyond. This technology path would provide a compact system with a small resource footprint and low cost through leveraging previous system integration and data analysis work.

Summary: The Deep Space Gateway offers opportunities for unique science measurements in a free space environment. An external radiation science experiment proposed in this abstract can measure charged particle data contributing to improvements in our scientific understanding of the immediate radiation environment around the Deep Space Gateway and has the additional potential to improve operational radiation exposure management of astronauts.

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HIGH FIDELITY MEASUREMENT OF DEEP SPACE GATEWAY INTRA-VEHICULAR NEUTRON ENVIRONMENT.

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Introduction: The Deep Space Gateway provides unique opportunities for new science measurements that also can support human exploration operations in the cislunar environment. The NASA Human Research Project has identified radiation exposure as one of the main risks for human space exploration requiring appropriate mitigations for habitation or planetary missions [1]. The contribution of neutron radiation to astronaut radiation exposure is of particular interest.

Background: NASA manages radiation exposure of astronauts by maintaining health risk metrics below established safety limits. The methods and mitigations applied differ for different radiation fields.

Neutron radiation inside spacecraft is created as secondary radiation through interaction of primary Galactic Cosmic Ray (GCR) and Solar Particle Event (SPE) particles with the spacecraft structure and payload material. Neutrons, due to their high potential for biological damage, are found to contribute up to 30-40% to astronaut dose equivalent in first dedicated continuous neutron flux measurements on the ISS [2]. However, predicted neutron fields underestimate measured flux spectra on the ISS by 30-50% [2], underlining that modeling of neutron production in spacecraft relies on assumptions on neutron production processes and shielding distributions with very limited experimental data for model development and verification.

Measuring the neutron flux energy spectrum inside the Deep Space Gateway with high resolution and a large energy range acceptance represents a novel and unique opportunity to both contribute to model improvement of neutron radiation simulations and characterize the Deep Space Gateway shielding distributions with high fidelity. Enhanced capabilities to simulate and measure the neutron radiation field will improve mission planning and astronaut health assessments for the Deep Space Gateway and all future human exploration mission.

Proposed Science Experiment: Free space GCR simulations indicate that 80% of the total neutron effective dose inside a model spacecraft is contributed from neutron energies between about 100 keV and 500 MeV [3]. Therefore, a neutron measurement experiment is proposed to measure the neutron energy flux distribution inside the Deep Space Gateway from energies of 100 keV to 500 MeV, with sufficiently fine energy resolution to capture flux spectrum shape and field variations at different locations inside the Deep Space Gateway.

An expected side-benefit of the data collected by the neutron experiment is the potential for operational use during crew occupations, complementing crew radiation monitoring for health assessments and improving radiation exposure management processes.

Expected Resources of Proposed Experiment: The neutron experiment can be designed as a standalone system (utilizing power and communication provided by the vehicle) to measure at various locations inside the Deep Space Gateway for obtaining a multi-point characterization of the neutron fields, and indirectly, of the shielding distribution of the vehicle and payloads. Relocations would require limited amounts of astronaut time. The experiment would telemeter measured data back to Earth on a regular basis for science analysis.

System/Technology Candidates: Due to the technological and physical challenges of measuring neutron radiation over wide ranges of neutron energy while satisfying size and mass constraints, novel technologies will need to be investigated, or combinations of known technologies will need to be employed. The AES Program develops and supports several compact neutron detection technologies that may provide resource-efficient stepping stones on the path to a wide-energy range system due to previous integration and existing analysis work.

Summary: With the Deep Space Gateway, new science measurements become possible that offer unique opportunities to significantly improve our understanding of astronaut radiation exposure in spacecraft. Advancing our scientific knowledge about neutron radiation generation in spacecraft will drive improvements in human space exploration operations and astronaut radiation protection.

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EXPLORATION TELEPRESENCE FOR SPACE SCIENCE, AND OPTIONS AT THE DEEP SPACE GATEWAY.

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Introduction: Exploration telepresence is the strategy of using low-latency telerobotic control to achieve a high level of human cognition for exploration. Most optimally, such latencies are small compared to the human reaction time, which is about 200 ms, allowing real-time human involvement. The speed of light requires that such activity take place in the vicinity of the region to be explored, perhaps in orbit overhead. This bears on the use of a Deep Space Gateway (DSG) for science on the Moon. Low latencies promote a sense of real human presence. Whether the telerobotics are implemented with direct or semi-autonomous control they would offer not only awareness but improved performance for dexterity and mobility.

This contribution is not aimed at any particular flavor of space science, but rather to call out a strategy that can economically bring real-time human presence to many kinds of scientific pursuits in space.

The Promise of Exploration Telepresence: Exploration telepresence (otherwise known as low-latency telerobotics) has been an acknowledged strategic asset for space exploration for many years, taking an important role in the decades-old Paine and Stafford reports. But advances in telerobotic control now make the strategy wholly credible. While the advantage for the Moon is notable, since the two-way control latency from the Earth is at least 2.6 seconds, the advantage for Mars is enormous. In this respect, while low-latency telerobotics on the surface of the Moon controlled from a DSG can be scientifically advantageous, such efforts are especially promising in that they exercise protocols for doing science in this way at Mars.

It is clear that modern imagers provide vastly more resolution, sensitivity, spectral and pixel information than does an in situ human eye behind a helmet visor. It is also clear that modern dexterous tele-manipulators provide better control than an EVA-gloved human hand. While EVA-suited astronauts may currently have an advantage in mobility, telerobots that can reach, climb, jump, and even fly are becoming realizable.

To the extent that high quality human presence can be electronically mediated, exploration telepresence on the Moon can allow astronauts to explore from the comfort, safety, and convenience of the DSG. We currently do telerobotics across the solar system from the Earth, but the latencies involved produce a very low quality sense of presence. Astronauts in orbit in one habitat overhead can explore many different sites on the planet below, including those that might be considered risky for human visits, with exploration not limited by EVA times for suited humans. The prospect of doing biological space exploration in this way shows great potential by avoiding forward contamination. [1]

Low latency telepresence is a strategy that is well exercised on the Earth, with military UAVs, mining and agricultural telerobots, hazardous environment telerobots, and telerobotic surgery. In fact, it is the enormous investment in such commercial effort that makes this a powerful space exploration strategy.

This Isn't Humans Versus Robots: Exploration telepresence requires astronauts travelling to distant sites in order to mediate light-time latencies, and is an excellent example of the spirit of human-robotic partnership that now guides exploration policy. In principle, it can be used to scout sites for eventual human visits, and even develop on-site infrastructure for those visits. This is about using robots to put human presence and real-time awareness on other worlds. Programmatically, comparison with human spaceflight is more appropriate than comparison with high latency robotic spaceflight because the latter cannot put high quality human presence anywhere. The question is whether low latency telerobotics is a more opportunistic way of doing it than putting boots on the ground.

New Thinking About Exploration Telepresence: In 2013, we organized a symposium at GSFC about opportunities presented by exploration telepresence (http://spacenews.com/exploration-telerobotics-symposium/). We have managed a Keck Institute for Space Studies study on *"Space Science Opportunities Augmented by Exploration Telepresence"*. (http://kiss.caltech.edu/programs.html#telepresence) A study report is now being developed. These efforts have attempted to develop modern perspective on low latency telerobotics, and its value for space science. For the latter study, field geology was considered with some care. A short review of the conclusions has been recently published [2].

The Problem With Latency: The importance of low latency control to human accomplishment can be assessed in a number of ways. Even very early work by Sheridan and Ferrell [3] considered the impact of transmission delay on manipulative control. They found that completion times of tasks scaled with command latency, with each component of an iterative task taking of order a human reaction time. Reaching out to pick up a rock can be a multi-step procedure, in which the hand and fingers are iteratively positioned. Each iteration suffers the same command latency. Simple manipulation tasks with Earth-Moon latency (2.6 s) required 6-8 s to complete. Clearly, the tasks whose completion times will suffer most from control latency are dexterous tasks that require fine control and iteration. It is well understood that surgical telerobotics, with incisions and stitching in a compliant medium, is completely intolerant of control latencies over 500 ms [4]. Telerobotic surgery on the Moon will not be done from the Earth.

To the extent that science is an iterative process, control latency is a serious handicap. That a human in situ could accomplish more in a day than a MER could accomplish on Mars in a month is largely the result of Earth-Mars control latency.

What We Don't Know:

In the case of, for example, doing field geology with low latency telerobotics, it is easy to make presumptions about efficiency and opportunity. In fact, we have no idea how to do it. We don't do field geology on the Earth telerobotically, because it is cheaper to send people. In order to make the best use of this strategy, analog studies are required that will better define protocols and requirements, and establish the penalties of latency for this kind of work. We need to assess which scientific tasks are most latency intolerant, and to what extent real-time human presence is necessary to do them. That being said, we're actually pretty good at doing high latency field geology on Mars.

Current Work on Low-Latency Space Telerobotics:

Current work, in which ISS astronauts control telerobots on the Earth with low latency, are being carried out by NASA [5], and by ESA [6]. These tests are important for establishing communication functionality from orbit to ground, and provide information about procedural and design requirements for operations with the DSG, as well as future Mars operations from orbit.

The DSG As a Control Node for Lunar Exploration Telepresence:

Of principal importance for doing exploration telepresence from a DSG is the surface-to-control node communication link. The attributes of this link are highly dependent on the orbit. High quality imaging will require of order 1 Mb/s for the link, and engineering it will determine the power and antenna configurations needed. Simple link budgets suggest that for an EM Lagrange point orbit, a pointed meter scale antenna on the DSG will serve a telerobot on the lunar surface with a MSL-type transmitter and HGA. The orbit will also determine the two way latency that the operators must cope with. A Lagrange point orbit will result in a fixed 400 ms latency, which is probably not uncomfortably large for what can be considered real-time operation. A proximal distant retrograde orbit (PSDRO) could be much better in this regard [7]. A Lagrange point or DRO orbit may not, however, be optimal for polar exploration. A high inclination near-rectilinear halo orbit (NRHO) can offer much smaller latencies at perigee, but the control latency will vary enormously, which could complicate operations.

The scientific methodology of field geology has been articulated in detail [8]. It requires systematic observations, and the process is a progressive one, where on-the-fly interpretive synthesis of an ensemble of observations generates results. This methodology is strongly enhanced with real-time human presence, whether achieved with in situ humans or electronically mediated by nearby humans. Certainly mobility is an asset, and telerobotic systems can achieve that mobility over great distances, and over extended periods of time, unlike an astronaut in an EVA suit. The ability to climb and reach is something that astronauts may have an advantage with, however. The process requires high quality pointable imaging, ideally with telescopic and microscopic capabilities, and even with spectroscopic discrimination. These capabilities are easily achieved with contemporary imaging systems, and not so easily achieved with the human eye inside a space helmet. Regolith will need to be manipulated – cleaved, scraped, as well as sampled. This requires some measure of dexterity that can be achieved with modern telerobotic systems which, as noted, can be done with a precision exceeding that of a hand in an EVA glove.

An important factor for science by exploration telepresence or by in situ humans will be the extent to which operations can be shared and supported with a larger population of scientists on Earth. The "science backroom" used by high latency telerobotic science, as well as for the Apollo lunar program, was critical for providing scientific perspectives above and beyond what a semi-autonomous telerobot or a limited number of scientist-astronauts are able to provide. Exploration telepresence should allow sharing of observations over a higher latency link, and can even allow telerobotic control over that link during astronaut down-time.

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PACKING A PUNCH: ENABLING CUTTING EDGE SCIENCE AND RESEARCH ON THE DEEP SPACE GATEWAY – DESPITE CONSTRAINTS.

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Introduction: Planners' and investigators' apprehension about facilitating science and research on human-occupied space vehicles have historically been rooted in constraints involving mass, volume, and energy. These concerns may be allayed for future missions based on the success of compact and modular accommodations and instruments utilized by a variety of space vehicles.

In fact, significant science return is not dependent on payload size. Many sophisticated investigations in a multitude of research, engineering and technology fields have generated breakthroughs over the decades of human space exploration involving investigators from government, academia, and industry. Examples include [1, 2, 3]:

- Apollo service module Science Instrument Module bay instruments that included cameras, spectrometers, and sensors
- Spacelab experiments in astronomy, earth observation, life sciences, material science, solar physics, biotechnology, combustion science, fluid physics, and space plasma physics
- Space Shuttle Hitchhiker and Get-Away Special external payloads and small satellite launchers enveloping research and technology areas such as heliophysics, plasma, environmental science, optics, contamination, materials science, fluid transfer, and cryogenics
- Shuttle middeck experiments studying space effects on everthing from plant growth to industrial manufacturing
- Space Experiment Module (SEM) satchel investigations in life science, material science, astrophysics, etc., and deployed cubesats hosted by the International Space Station.

Techniques such as incorporation of standard and modular interfaces are key to resource management, spacecraft payload manifest flexibility, and serving science and research needs. Functions for internal and external investigations, shared resources, fixed, deployable, and extractable compact capabilities are also advantageous to science/research communities [3].

As spacecraft accommodations and operations serve science and research, science and research synergistically assist the development and advancement of spacecraft through improvements in supporting systems, technologies, processes, utilities, and operations. Thus, it is critical that NASA's Deep Space Gateway (DSG) *facilitate* and *be facilitated by* science and research investigations and functions throughout its lifecycle. The DSG is expected to be resource-limited, based on a minimalist design and functionality approach. The ability for the DSG to accommodate emerging and varying research may be enabled and guided by several successful, relevant precedents and legacy design solutions despite its resource limitations [3, 4, 5, 6, 7, 8].

Techniques, systems, and processes employed to enable, enhance, produce, and deliver significant, breakthrough science and research results under mass-volume-energy constraints, as with the DSG, are discussed.

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SOLVENT – SIMULTANEOUS OBSERVATIONS OF THE LUNAR VOLATILE ENVIRONMENT.

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SOLVENT is a package to accomplish Simultaneous Observations of the Lunar Volatile EnviornmeNT by targeting the Moon with remote spectroscopy in complementary wavelength regimes, to measure the abundance of water and hydroxyl ions in the illuminated lunar surface and in the free space above it. Numerous measurements have demonstrated that the circumstances under which water is present at the Moon are more complex than cold trapping within permanently shadowed regions (PSRs), including present-day horizontal transport of neutral or ionized molecules. An accurate assessment of water abundance, distribution, and replenishment is essential to support access to this important resource for human activity in space. We envision the Deep Space Gateway (DSG) can enable these measurements using more than one implementation strategy. Externally mounted instruments can support some of the stated science goals. A free-flying spacecraft could be deployed and relay data through the DSG, or component instruments could be distributed across independent CubeSat/SmallSat spacecraft deployed from the DSG, enabling operations at low altitude with DSG as a communications hub.

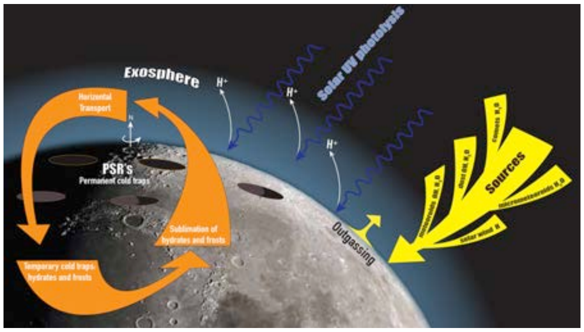

Fig. 1: Life cycle of water molecules at and above the lunar surface. Delivery to the surface is from multiple sources. Thermal desorption frees molecules from the surface to be exposed to photolysis by solar UV radiation and probable loss of hydrogen to space, or horizontal transport into cold traps on the lunar nightside or near the poles. SOLVENT instruments will enable tracking water and OH from surface to space to destruction or delivery back to the surface.

SOLVENT will consist of the instruments HOHM (H_2O-OH-Mineralogy), SOLVE (Sub-mm Observation of Lunar Volatiles Environment), and LOUVE (Lunar OH Ultraviolet Emission). Each instrument captures a particular phase in the life cycle of lunar water:

HOHM will be a single-point or imaging spectrometer at 1-5 μm, R~300–1000, to map mineral hydration in the lunar surface, identify its mineral context, and measure its diurnal variability. Hydration previously was detected at low spatial resolution from Deep Impact [1] and Cassini, and mapped incompletely by the Moon Mineralogy Mapper instrument on Chandrayaan-1 [2]. HOHM will complete the mapping of the Moon at NIR wavelengths to quantify the distribution and diurnal variability of mineral hydration and determine whether these properties vary according to mineral context, as well as completing the mineralogical mapping of the Moon. There has been no previous lunar instrument operating in the range 3–5 μm that is required to accurately characterize the shape of the mineral hydration feature at ~3 μm, so HOHM will have the opportunity to detect other trace volatiles in the gas phase [3].

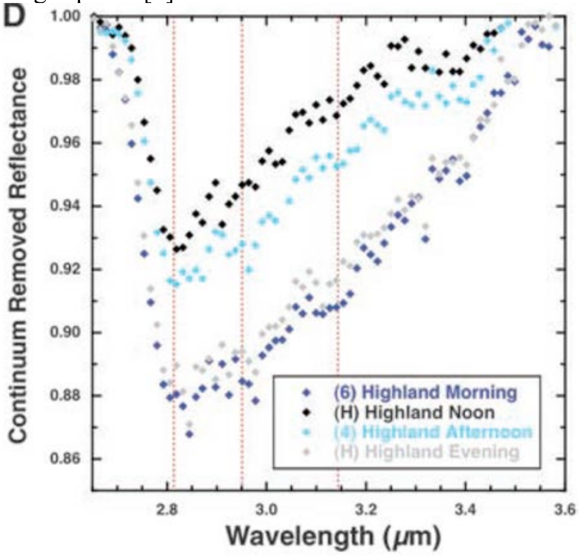

Fig. 2: HOHM will characterize the hydration spectroscopic feature across the lunar surface, to establish its chemical state (H_2O vs. OH) and magnitude of the hydration. HOHM will enable detailed mapping of hydration signature variation with local time and mineral context, by capturing the full width of the hydration feature as well as diagnostic transitions for lunar minerals. Figure from Sunshine *et al.* [1].

SOLVE will be a single-point sub-millimeter spectrometer (557 GHz) to unambiguously identify and measure the total column abundance of neutral water vapor above the lunar surface during horizontal transport. The anticipated sensitivity for sub-mm detection will enable measuring quantities as small as 1% of an exospheric column of water within two minutes, smaller quantities with greater total integration time. One year of data can sense quantities comparable to what is expected for water supplied solely by micrometeorite impact or solar wind delivery in steady-state competition with the anticipated photolysis rate. There has been no previous lunar instrument at sub-mm. SOLVE will include broadband continuum channels to accurately measure surface temperatures in even the coldest permanently shadowed regions on the Moon with temperatures less than 25K, and measure the near-surface temperature gradient to characterize properties of the highly insulating lunar soil.

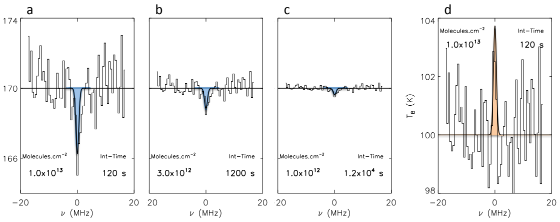

Fig. 3: SOLVE will detect even small columns of water above the lunar surface. Water will appear as a narrow absorption feature against surface thermal emission at submm wavelength on the lunar dayside. Over the nightside, for example due to migration across the dawn terminator, water will appear in emission.

LOUVE will be a single-point or imaging ultraviolet spectrometer at 200-350 nm (2000–3500 Å), to investigate the distribution of OH radicals above the lunar surface resulting from the photolysis of water in free space. The mid-UV wavelength range has been largely unexploited at the Moon, with only the LADEE UV spectrometer operating in this range previously [4]. LOUVE will be operated continuously over the entire lunar surface with nadir pointing to address water photolysis in the column down to the surface.

These complementary techniques will enable measuring water from surface sequestration into space, through the space environment, and potentially back to the surface to fully characterize the entire life cycle of water molecules at the Moon.

Orbit requirements: The SOLVENT concept can be adapted to a broad range of opportunities, as there is now significant evidence for water or OH at all lunar latitudes and longitudes, and all orbits provide opportunities to observe the surface near the terminators, where there is evidence for diurnal variability. Polar orbit at relatively high altitude (e.g., 100-200 km) would provide an ideal platform to access the entire surface of the Moon at all local times.

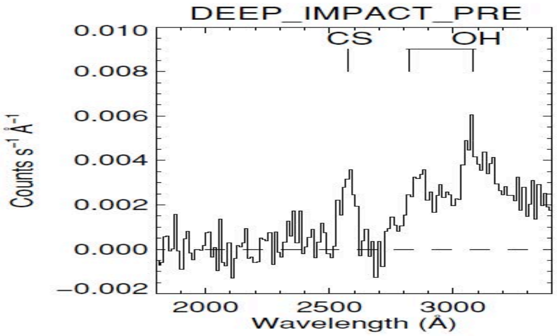

Fig. 4: LOUVE will measure OH above the surface from direct release and from photolysis of water. The figure shows prompt and fluorescent emission from OH and CS in 9P/Tempel 1 after the Deep Impact experiment, observed by the GALEX mission [5]. The distribution and variability in OH at the Moon will measure the rate of UV photolysis and loss from the Moon.

Resource requirements: GSFC has recently conducted a design exercise for a sub-millimeter instrument suitable to accomplish SOLVE goals, including a telescope, calibration mechanisms, and all electronics within a total mass of 8-10 kg, requiring 28W in full operation. Small near-IR spectrometers suitable to fulfill the role of HOHM have been developed at GSFC and deployed on multiple previous missions (e.g., OSIRIS-REx), with mass including telescope of order 5 kg and power of order 5W. Similar mature UV instruments exist for LOUVE (e.g., LADEE UVS) with mass ~5 kg and 5W power. Total instrument mass thus is about 18-20 kg with instrument power requiring 38W for simultaneous operation. Additional mass is required for self-contained pointing and telemetry if these services are not available from the support platform.

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LOW-ENERGY COSMIC RAYS: RADIATION ENVIRONMENT STUDIES AND ASTROPHYSICS ON THE DEEP SPACE GATEWAY.

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Introduction: Low-energy cosmic rays and solar particles are of key interest for human space flight and astrophysics. The proposed location of the Deep Space Gateway (DSG) in orbit around the moon places it in a location that is uniquely suited not only for the investigation of the low-energy radiation that astronauts will be subjected to in deep space, but also to help shed light on one of the most intriguing astrophysical mysteries of today: What is the universe made of?

We propose to place an experiment on the DSG whose observations would facilitate the research of many different scientific communities. By concentrating the efforts of scientists from around the world, the limited resources of the DSG could best be utilized.

Crew Radiation Exposure: Mitigating the effects of radiation exposure poses a serious challenge for plans to send astronauts back to the moon and, ultimately, to Mars and other deep-space destinations. Current measurements [1, 2] suggest astronauts would reach or even exceed their lifetime dosage limits after a single mission to Mars, but such predictions have large uncertainties stemming from the currently limited experimental input. Research into improving shielding technologies and accurately estimating doses and their health impacts—which is crucial to successful long-term spaceflight—requires accurate measurements of the radiation environment and benchmarking against radiation transport simulations.

The space radiation environment is dominated by charged-particle radiation of cosmic origin, the solar wind, and short bursts of energetic particles released by the sun at irregular intervals. Many experiments have been performed to characterize this environment, for example by using particle detectors on the International Space Station (ISS) [3, 4].

Few measurements, however, were performed beyond low Earth orbit (LEO). Spacecraft in LEO are partially shielded from charged-particle radiation by Earth's magnetosphere, which deflects particles with too low energies to penetrate the field. A welcome natural protection for astronauts on the ISS, this effect severely limits our knowledge of the space radiation environment at lower particle energies, because experiments can only detect cosmic rays with energies above the cut-off value at their respective orbital positions. The few measurements available were taken aboard spacecraft enroute to or in orbit around other planets of the solar system—such as aboard the Mars Science Laboratory on its way to Mars and on the Mars surface [1, 2], and the Lunar Reconnaissance Orbiter in orbit around the moon [5]. The primary missions of these spacecraft were, however, not to characterize the space radiation environment. Consequently, the capabilities of their detectors were limited—mostly due to mass constraints—and the measurements therefore only provide a subset of the full picture. Additionally, many measurements were performed over a limited period of time, giving us only a snapshot view at a given point in time and space.

In orbit around the moon or one of the Earth-moon Lagrange points, the DSG will spend about two thirds of its time outside of Earth's magnetosphere. A charged-particle detector would thus be able to access the full spectrum of cosmic rays, allowing the comprehensive and long-term characterization of low-energy cosmic radiation for the very first time. Such a measurement could help to build the future foundation of radiation protection in manned space flight.

Cosmic Ray Studies and Heliophysics: The characterization of the space radiation environment would not only support the manned exploration of space, but also deliver invaluable data for astrophysical studies. Even though a recent measurement seems to confirm the long-standing theory that cosmic rays are, at least partially, created in stellar explosions [6], other measurements indicate that additional sources must exist [7], but their nature has yet to be revealed. An experiment on the DSG could contribute to solving this issue by characterizing the cosmic radiation environment at the low energies that are inaccessible to detectors in LEO. Scientists studying the sun could also greatly benefit from such measurements, as a substantial amount of charged solar-wind particles is deflected by Earth's magnetosphere.

The Search for Dark Matter: One of the most intriguing mysteries in astrophysics today is the question of the composition of the universe. We know that only about 4% of the mass of the universe is made of matter as we know it. About a quarter is made of what scientists call *dark matter*: electromagnetically invisible particles that primarily interact with ordinary matter through gravity. The rest is made of even stranger stuff, which is usually referred to as *dark energy*. We can infer the existence of dark matter from astronomical observations—such as the otherwise unexplainably high rotational velocities of galaxies—cosmological considerations, and directly observable gravitational effects. These observations are very strong hints for the existence of dark matter. They do not, however, let us draw conclusions about the nature of it, nor are they a definite proof of its existence. We only detect the gravitational presence of something that we cannot observe directly by traditional means of astronomy, i.e. using telescopes sensitive in the electromagnetic spectrum.

To understand the nature of dark matter, experiments must be performed that observe the interaction of dark matter and ordinary matter in the context of nuclear and particle physics, that is, at atomic and sub-atomic levels. Several ground-based experiments (e.g. CRESST, DarkSide) attempt the direct detection of such rare interactions, and some supporting data may come from high-energy colliders (LHC, SuperKEKB). Other scientists focus on indirect detection techniques: Theoretical models predict that dark matter particles could decay into detectable ordinary-matter particles, such as gamma rays, neutrinos, and antimatter particles. While experiments focusing on gamma rays (e.g. Fermi LAT) and neutrinos (e.g. IceCube) have so far been unsuccessful in observing a convincing signal, space-based particle detectors measuring cosmic-ray antimatter found a more significant anomaly that may be caused by dark matter. The PAMELA [8], Fermi LAT [9], and AMS [10] collaborations reported consistent measurements of a so far unexplainable excessive flux of positrons at high energies. Even though this could very well be a first piece in the puzzle, the available data is not sufficient to draw a scientifically profound conclusion about the existence and nature of dark matter.

The issue can only be solved through a combination of particle physics and astrophysics experiments. One of the most promising candidates that could complement existing findings is a measurement of the cosmic-ray antiproton and antideuteron fluxes [11]. At very low energies, there are virtually no other known processes that produce these particles. Any unambiguous signal would thus strongly support some existing dark matter theories. Again, experiments in LEO cannot perform such a measurement due to the shielding effects of Earth's magnetosphere. A low-energy particle detector on the DSG, however, would be ideally located to do so.

An Experiment on the DSG: We propose to install a charged-particle detector on the DSG that facilitates the research of scientists from all aforementioned communities—and perhaps even from ones we overlooked so far. We believe there is an overlap significant enough for a single instrument to serve all disciplines, without the need for disruptive compromises. The capabilities of such a detector should complement those of existing and future instruments in LEO or elsewhere, with only a slight overlap in sensitivity to allow the cross-calibration of measurements. We see no apparent reason for duplicating capabilities that can be achieved with less effort at more accessible locations.

The detector should be sensitive at energies below the cut-off values in LEO caused by Earth's magnetosphere. The lower sensitivity limit in energy should be discussed amongst scientists from all interested disciplines, as should the sensitivity in flux. We suspect that much of that discussion may be driven by more 'exotic' disciplines, such as the search for dark matter.

The sensitivity at lower energies means that the detector can be built much lighter and more compact than comparable instruments (e.g. AMS-02 on the ISS), since the magnets required for spectrometry do not need to be as powerful. New technologies may even render the use of a magnetic spectrometer superfluous, reducing the mass and the power consumption of the system further. Recent advances in semiconductor technologies and processing electronics should also ensure an increased efficiency and performance of the detector, as they did in ground-based experiments. Accumulating experiences from previous space-based instruments should help to streamline the detector design.

The instrument would need to be mounted with a free line of sight on the exterior of the DSG, ideally pointing away from the moon surface at all times. There is no need for a particular type of orbit. We estimate that an instrument mass of as low as 100 to 200 kg, a volume of less than 1 m^3, and a power consumption of 200 to 400 W are achievable. After installation, the detector would operate autonomously at all times and would not need any crew interaction.

Conclusion: We believe there is a strong case for cosmic-ray science on the DSG. The gateway will be ideally located to access parts of the cosmic and solar radiation spectrum that are hidden to instruments in LEO. Also, it will provide all the necessary infrastructure to support such an experiment. By concentrating the efforts of different disciplines, one relatively compact instrument could serve a multitude of astrophysical and medical science communities. While we have tried to identify some disciplines that would benefit from such a collaborative effort, we by no means assume our list to be exhaustive. We hope, though, that it will serve as a starting point for discussions.

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Low-Latency Telerobotic Sample Return and Biomolecular Sequencing for Deep Space Gateway

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Introduction: A cislunar Deep Space Gateway (DSG) can provide opportunities to integrate mission concepts leveraging lunar surface operations, sample return, data collection, and scientific research and analysis. The presentation will provide integrated mission concepts that utilize low-latency robotics, crew-assisted sample return, and biomolecular sequencing to obtain and evaluate lunar samples and inform future similar Mars activities. Resources envisioned for the DSG and related infrastructure will also be presented.

The Human Spaceflight Architecture Team (HAT) has explored a number of strategies and mission concepts for how a "Deep Space Gateway" in cislunar space could be utilized for science. Analyses were conducted several years ago by the HAT "Cis-Lunar Destination Team" [1] and then subsequently by a "Translunar Supported Missions Task" [2] that included two separate but related tasks investigating: (1) the use of low-latency teleoperations/tele robotics (LLT) in cislunar space, and (2) crew-assisted sample return in cislunar space (often referred to as Human-Assisted Sample Return as noted in the International Space Exploration Coordination Group Global Exploration Roadmap.

In the summer of 2016, DNA was successfully sequenced in space for the first time by Kate Rubins on the International Space Station using a miniature low-power molecular sequencer [3]. This demonstration showed that a small-scale nanopore sequencer could be reliably used to sequence DNA in a mirco-gravity environment.

This presentation will cover the three areas noted above (LLT from a DSG, crew-assisted sample return, and biomolecular sequencing), integrating them into notional mission concepts that leverage the use of LLT from a DSG to obtain samples from the lunar farside and Apollo landing sites and returning them to the DSG for analysis, including biomolecular sequencing for Apollo site samples, with possible return to earth. We will also touch on broader biomolecular sequencing uses on a DSG for crew health and environmental purposes. Technical and operational implications of these concepts for the DSG will be explored, including potential implications for mass, volume, power, communications and crew-time.

LLT Lunar Sample Return: The HAT LLT analyses included concepts involving crew tele-operating lunar surface rovers to perform surface science, sample acquisition and return to a DSG, and science system maintenance and repair of surface assets. Crew-assisted sample return involves the possibility of using cis-lunar facility such as a DSG to capture, store, analyze and help return a variety of planetary samples back to earth with the crew or a dedicated sample return vehicle.

A "LLT lunar sample return" concept combines LLT with crew-assisted sample return by having DSG crew members use LLT for sample prospecting, acquisition, and return of samples to a cislunar DSG which can then be returned to earth with or without crew – the former of which has the potential to allow more sample mass to be returned to earth (perhaps a factor of 10 or more) [4]. We will touch on details of a notional LLT lunar farside sample return from the South Pole-Aitken Basin, taking advantage of long time periods afforded by a Deep Space Gateway. The South Pole-Aitkin basin is one of the oldest impact basins in the solar system and exploring it is a key science objective from the 2011 Planetary Science Decadal Survey [5].

Although many untouched "pristine" samples could be returned to earth from the DSG to ensure sample integrity, a DSG would allow for some degree of sample analysis on the DSG – which would then allow for an assessment of which samples may be best to return to earth for more in-depth analysis. Such a scenario could also be relevant for Mars samples, for which on-orbit analysis could be more important [6]. A LLT lunar sample return mission could also feed forward to Mars if LLT is needed to analyze a sample containment unit before bringing it inside a DSG or Mars orbiting science facility – which could be tested and practiced with lunar samples using the cislunar DSG. The greater communications distances to Mars, potentially strict planetary protection requirements, and possible requirements to analyze samples in the Mars vicinity, suggest it would be wise to develop and prepare for an effective Mars orbital LLT sampling strategy [7].

LLT from an orbiting DSG is not necessary to obtain samples from the lunar surface, however, surveying, prospecting and sample acquisition could be performed faster via LLT and would help prepare for similar mission scenarios at Mars where exploring large regions in a relatively short time, could be a valuable capability – especially "special regions" of possible biological interest [8].

Apollo Contamination Environment (ACE) Sample Return. The LLT lunar sample return concept can be applied to sampling the Apollo landing sites and returning those samples to a DSG to analyze contamination. Such data could contribute to a better understanding of the overall contamination "foot print" of the Apollo missions, including performing molecular sequencing that could shed light on the effects on biological sources (such as waste) that have been on the lunar surface for almost 50 years. This can then help inform potential future contamination dynamics, including numerous planetary protection knowledge gaps for human extraterrestrial missions noted in a NASA planetary protection workshop report [9], suggesting it would be important to sample the Apollo sites before new contamination is introduced [10]. An Apollo contamination environment sample return mission could also help address strategic knowledge gap (SKG) II-B-4 on radiation shielding effects of lunar material, and such a mission would also need to be compliant with NASA's recommendations on how to protect the historic and scientific value of Apollo landing sites [11].

Some level of robotic in-situ (i.e. on-surface) biomolecular sequencing before returning samples to a DSG might be possible and would have benefits such as (a) increasing the probability of not compromising sample integrity through ascent and human interactions with the sample onboard DSG, (b) reducing any potential biohazard risks to crew, and (c) allowing for effective high-grading before returning samples to a DSG. However, requirements for sample preparation and other factors associated with rigorous biomolecular sequencing may make robotic on-surface LLT/robotic sequencing insufficient or unfeasible, suggesting that sequencing may be more effectively accomplished by astronauts on a nearby orbiting DSG with proper analytical capabilities and biohazard protections.

Biomolecular Sequencing for DSG: This presentation will also address the importance of biomolecular sequencing for DSG environmental monitoring and crew health. For example, in-situ spacecraft microbial analysis will be needed for (a) real-time monitoring of the DSG microbiome, (b) longitudinal studies of new vehicle microbial seeding through long-term population studies, and (c) onboard dependent clinical analysis. Long-term culture equipment for sample growth, collection, and analysis will be beneficial for multi-generational microbial evolution studies and will inform human missions to Mars, including effects of and mitigation strategies for radiation. Our presentation will link to a number of science and HRP (Human Research Program) objectives as well SKGs such as II-D (Maintaining Peak Human Health). Discussion of options for on-station sequencing data analytics will include a review of current and emerging bioinformatics platforms that contain turn-key Graphical User Interface (GUI) workflows for sequence taxonomy classification and functional genomics analysis.

A Deep Space Gateway offers unique opportunities to integrate LLT with crew-assisted sample return and biomolecular sequencing into mission concepts that can address a variety of SKGs and science objectives – possibly with relatively low impact to DSG capabilities, particularly when compared to the potential science and Mars feed-forward value that could result.

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IMPORTANCE OF A LOW RADIO FREQUENCY INTERFERENCE ENVIRONMENT FOR THE DSG.

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Introduction: The Deep Space Gateway (DSG) can serve radio astronomy in a variety of ways: (1) as a base for radio antennas, 2) deployment of lunar radio observatory antennas on the surface could be managed telerobotically by a crew on the DSG, (3) the DSG could serve as a relay to transfer data from a lunar far-side observatory to ground stations, (4) the DSG might provide microwave power beaming to the lunar surface to allow systems to survive lunar night, etc. A key requirement is that it not contaminate the radio-quiet environment of the lunar far-side.

Radio-quiet Environments: A key advantage of a lunar surface radio observatory, if located on the far-side of the Moon, is that it will be in a very radio-quiet environment. The Moon blocks the radio frequency interference (RFI) from transmitters on Earth. As shown in the figure below, a spectral display of 24 hours of data from the Wind spacecraft [1] when it was near the Moon, the terrestrial RFI is very significant, even as far away as the Moon.

It is generally a requirement when establishing radio observatories that a radio quiet environment be located. Examples include the National Radio Astronomy Observatory on the Plains of San Agustin, New Mexico, the Green Bank Observatory in West Virginia, the Atacama Large Millimeter Array in the Chilean Atacama Desert, the Murchison Widefield Array in Murchison, Australia, etc. Likewise, spacecraft with radio astronomy instruments require radio-quiet designs, like those of Ulysses, Wind, STEREO, etc., to permit successful acquisition of weak radio signals from distant sources.

Given that the DSG will likely spend a significant fraction of its orbit in the hemisphere above the far-side of the Moon, it is important that the DSG electronics, the transmitters, and the instruments located on the DSG avoid contributing to significant contamination of the radio-quiet environment of the lunar far-side space and surface. The same requirement should apply to missions operating on the lunar surface on the far side. Also, the DSG may host radio instruments, making the radio-quiet requirement more significant.

Implementation: This requirement means that all assemblies of the DSG and co-located instrumentation should undergo electromagnetic compatability (EMC) testing to determine the noise level in the frequency range from ~100 kHz to 100 MHz. A maximum level may be defined in reference to the MIL-STD-461, which describes how to test EMC. Specific assemblies may require crystal oscillator stabilization, shielding, or other mitigating techniques to meet the requirements established . We will discuss the details in the presentation, based on previous examples of in situ RFI.

References:

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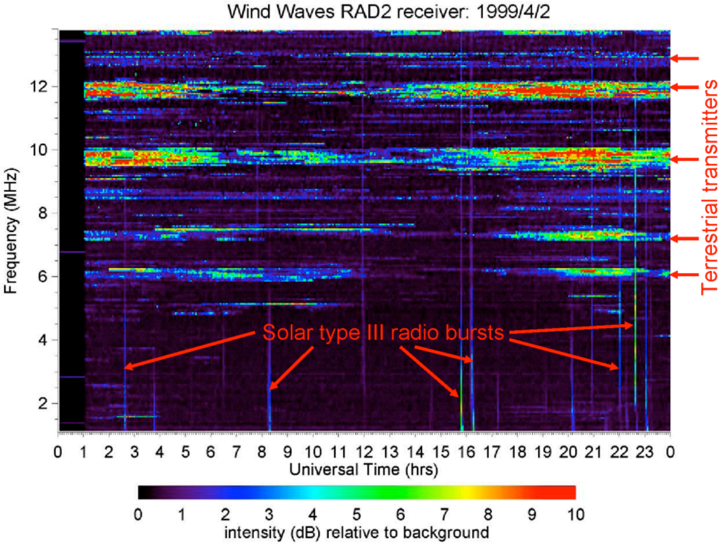

Wind Waves data acquired on 1999/04/02 when the Wind spacecraft was ~10 km from the Moon.

Global Multi-Wavelength Observation of Terrestrial Gamma-ray Flashes

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Terrestrial Gamma-ray Flashes, or TGFs, are very strong bursts of gamma-rays (multi-MeV) that are routinely produced inside thunderstorms. They are mainly observed by spacecraft and satellites, and are so bright that can cause significant dead-times on satellite detectors, hundreds of kilometers away. While TGFs have been linked to lightning initiation, the complete details of the source mechanism that produces TGFs and their relations to lightning are still unknown. TGFs are most suited to be studied using space-borne instruments with broadband sensor capabilities. This is because close to the ground the propagation distance for X-rays and gamma rays is very small.

The current and recent suite of space-borne gamma-ray detectors, such as CGRO, RHESSI, and Fermi, have made great advances in our understanding of TGFs over the past two decades. However, these instruments were built to monitor and study astrophysical sources in deep space and were not optimally designed to study TGFs. Achieving further insights in the physics of the TGF’s source mechanism and relations to lightning and cosmic rays demand new global and multi-wavelength measurements that have not yet been made. In this presentation, we will provide an overview of the latest advances in the physics of TGFs, and analogous processes that are believed to be at work at Venus and Mars. We will discuss the need for broadband and continuous monitoring of the phenomenon and finally will discuss the role of space-based instruments that can serve as monitoring stations for TGFs and its planetary analogs.

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Revolutionizing our Understanding of Heliospheric Dust Dynamics from the Deep Space Gateway

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Science Opportunity: Collisions between asteroids, the outgassing and breakup of comets approaching the Sun, the collisional grinding of smaller bodies, and the motion of the heliosphere through the interstellar medium: all these processes populate the heliosphere with cosmic dust [1].

Dust grains resulting from these processes span six orders of magnitude in radius, from millimeters to nanometers. Gravitational forces dominate the trajectories of the largest grains, while solar radiation pressure and electromagnetic interactions with the solar wind are important for the smallest dust particles. When their paths intersect objects in space, dust grains may have impact speeds of tens to hundreds of km/s in some cases, posing real danger to robotic and human explorers [2,3,4].

Past space-borne in-situ dust detectors have examined interplanetary dust particles with radii of ~0.1 µm to ~100 µm, but their ability to detect nanometer grains (nanodust, <100 nm) were limited [3]. Consequently, there are significant gaps in our our understanding of heliospheric dust physics and our associated dust damage predictive capability.

These smallest grains are messengers, carrying information key to resolving open questions about the balance between heliospheric dust sources and loss processes, as well as questions about interactions between dust grains and the solar wind [3,5,6,7,8]. For example: 1) What fraction of grains near the Sun are destroyed, versus expelled from the solar system by radiation pressure and electromagnetic forces? 2) Does the dust expulsion/destruction rate balance the Sunward migration rate? 3) How does nanodust picked up by the solar wind quantitatively impact the mass and momentum budget of the solar wind? 4) Do transient solar wind structures periodically 'sweep' the inner heliosphere clear of nanodust?

Required Instrumentation: Recent advances have led to a new generation of in-situ detectors able to measure the speed, trajectory, and composition of nanodust grains [9]. Their operational principle is similar to existing in-situ dust detectors. Dust grains enter the instrument sensor head, passing through a set of grid electrodes biased to reject solar wind plasma, then impact a curved voltage-biased target. The hypervelocity impact breaks up the dust and ionizes its molecular and elemental constituents. A grid in front of the target accelerates positive ions toward an ion detector. Electrons and negative ions are recollected by the target surface. Critical advances involve the ability to reject the high heat and solar UV loads imposed by the nanodust-specific requirement to point close to the direction of the Sun.

A single nanodust detector sensor head has an effective collecting area of ~100 cm^2, sufficient to accommodate the 10s to 1000s of nanodust impacts per day inferred from STEREO and Cassini observations [10,11]. Further, nanodust observations require a platform that travels far from Earth's magnetic field (which distorts nanodust trajectories).

Gateway Resources: A nanodust detector requires <10 kg and <10 W. A ~15 kg gimbal mount is also required. Full cycle costs (including design, construction, testing, operations, science support) are comparable to in-situ dust detectors designed for robotic space missions (LDEX on LADEE or SUDA on the Europa Clipper). The instrument is approximately a cylinder of approximately 0.22 m diameter and 0.7 m length (including integrated electronics and gimbal mount). The detector operates autonomously and does not require crew interaction after installation.

NASA's Deep Space Gateway has a cislunar orbit, a long lifetime, and ample resources compared to nanodust sensor requirements, making it a prime platform to enable this new generation of detectors to revolutionize our understanding of heliospheric dust.

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DEEP SPACE GATEWAY AS A TESTBED TO STUDY EFFECTS OF REGOLITH-DERIVED RADIATION SHIELDING ON PLANT GROWTH DURING LONG-DURATION EXPOSURE TO SPACE RADIATION.

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Abstract: In contrast to Earth's environment, planetary destinations like the Moon, Mars and asteroids lack a thick atmosphere and a magnetosphere to naturally protect biological, electrical, and mechanical systems from the damaging effects of incident galactic cosmic radiation (GCR) or solar particle events (SPE). However, these planetary bodies do possess surface resources in the form of hydrated minerals and/or water-ice that can provide a sufficient amount of radiation stopping potential if the shielding thickness and hydrogen content are significant enough to absorb the incident energy of the radiation. High energy protons are present in both GCR and SPE, but their energy level in GCR is much higher (several GeV) than it is in SPE (~10 MeV).

Space radiation will also present one of the highest risk factors to a human crew and their onboard electronics during future interplanetary journeys including to the Deep Space Gateway. These risks could be mitigated effectively and addressed economically by utilizing planetary surface materials to develop regolith-derived radiation shielding rather than launching the radiation shielding from Earth's deep gravity well.

This paper will argue that an external carrier platform at the Deep Space Gateway (DSG) will provide an excellent location and opportunity to study the effects on plant growth due to extended exposure to space radiation, and how hydrated regolith materials can be used as a radiation shielding material to mitigate those effects. Comparable long-duration testing at terrestrial radiation lab facilities under similar radiation and vacuum conditions is not feasible due to costs.

A study of this type at the DSG will also provide data that can be used to better inform the theoretical models of long-duration exposure of space radiation on systems in space. Regolith-derived radiation shielding will be fabricated by consolidating hydrated regolith, and its effectiveness as a radiation shield will be determined as a function of shield thickness and hydrogen content. Software developed by NASA's Human Research Program (HRP) provides an "On-Line Tool for the Assessment of Radiation in Space" (OLTARIS). This software will be used to assess the effects of space radiation on various materials prior to actually testing the materials. The results of the DSG study will inform NASA's STMD and HEOMD on the effectiveness of using planetary and asteroid regolith as in-situ radiation shielding for humans and plants on future missions, and the effect on plant growth of long-duration exposure to space radiation in a vacuum environment.

Resources to be utilized at the DSG include an external carrier platform that is similar to MISSE (Materials International Space Station Experiment), and the ability to retrieve samples (either robotically or by astronauts) after a given amount of time that samples are exposed to space radiation. The total estimated mass is 25 kg and the estimated power requirement is 0.5 kW.

MONITORING THE EARTH'S RADIATION BUDGET.

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Introduction: Since 1997 multiple CERES (Clouds and the Earth's Radiant Energy System) missions provide uninterrupted, accurate data on the Earth's radiative budget. The first, experimental CERES instrument was launched in 1997 aboard NASA's Tropical Rainfall Measurement Mission (TRMM), promptly followed by similar instruments on Terra (1999) and Aqua (2002), then S-NPP (2011) and, lately, NOAA-20 (November 2017). The CERES instruments comprise a set of passive radiometers measuring (2D surface mapping) the Earthshine radiance in three broad bandwidths, the total flux at 0.3-200 µm, the reflected Solar light at 0.3-5 µm and the thermal Earth's emission at ~5-35 µm (the latter varies from instrument to instrument). Detected flux variability is tied to either seasonal or long-term changes in the cloud cover, surface reflectivity and atmospheric transmittance (snow/ice, aerosols, volcanic eruptions, fires) via assimilation of simultaneous data acquired by high-resolution imagers (MODS on Terra and Aqua, VIIRS on S-NPP and NOAA-20).

Here we propose a continuity mission that will exploit the benefits of long exposure times and simultaneous whole-disk Earth coverage provided by a near-rectilinear, cislunar orbit of the Deep Space Gateway. The high orbital ellipticity will improve spatial coverage of the Earth's circumpolar regions, considered among the major sources contributing to long-term changes in the energy budget. The long, uninterrupted exposures in a fixed-gaze mode may help to achieve the required ~0.1% (both short and long-term) radiometric accuracy. The proposed (N. Krotkov et al., these proceedings) imaging suite will provide data on the cloud (cover, optical thickness, altitude), surface (reflectivity and emissivity) and atmospheric (aerosol load, fires, volcanic events) properties. These properties will be ultimately tied to the simultaneously observed changes in the radiative budget, with additional emphasis on the observations acquired on the night side.

Technical requirements: The proposed instrument comprises:

- two identical suites (2×3) of passive radiometers, channels A (primary) and B (secondary)
    - total flux radiometer, 0.3-200 µm,
    - reflective flux radiometer, 0.3-5.0 µm,
    - thermal flux radiometer, 5-35 µm;
- on-board calibration sources: two black-body (BB) sources (the thermal and total channels) and a lamp (the reflective channel);
- 3 observation and calibration ports
    - Earth view;
    - deep-space view;
    - Solar view.

The instrument should be mounted on an external platform providing stable (<0.1^{o}), fixed-gaze Earth pointing. The desired radiometric stability, ~0.1% over mission time (5+ years), requires active temperature control (to ~0.01^{o}C) of the radiometers and the BB calibration sources.

The science goals can be achieved from a near-rectilinear, elliptic orbit that allows the best spatial and temporal coverage, including the Earth's circumpolar regions.

Additional technical parameters:

volume	<0.1 m^3
mass	<50 kg
power	~50 W
data rate	~10Mb/day

minimal crew involvement.

This radiometric suite is to be used in conjunction with the proposed multi-channel imager (N. Krotkov et al., these proceedings).

Deep Space Earth Observations from DSCOVR

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The Deep Space Climate Observatory (DSCOVR) was launched on February 11, 2015 to a Sun-Earth Lagrange-1 (L1) orbit, approximately 1.5 million kilometers from Earth towards the Sun, to provide continuous solar wind measurements for accurate space weather forecasting, and to observe the full, sunlit disk of Earth from a new and unique vantage point. There are two Earth science instruments on board, the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR).

EPIC has 10 narrow band filters from 317.5 nm to 780 nm that were designed to obtain products similar to TOMS (Total Ozone Mapping Spectrometer) and MODIS (Moderate Resolution Imaging Spectroradiometer): total ozone O_3 amount, scene reflectivity, erythemal irradiance, UV aerosol properties, sulfur dioxide SO_2 for volcanic eruptions, surface spectral reflectance, vegetation properties, and cloud product including cloud height. When projected on the 3-dimensional (3D) Earth, the sampling size is about 8 km at nadir (near the center of the image). In order to maximize time cadence by reducing transmission time, the images of all wavelength channels, except 443 nm, have been reduced from 2048 x 2048 to 1024 x 1024 pixels. The 443 nm channel has a resolution of 10 km for itself and the color images, which has been verified by looking at the width of major low latitude rivers in Brazil and Egypt.

For the 4 UV channels (317.5, 325, 340, and 388 nm), and for the 4 visible and NIR channels (443, 552, 680, and 780 nm) in-flight radiometric calibration is accomplished by comparison to the reflectance values measured by current well-calibrated Low Earth Orbit (LEO) satellites observing scenes that match in time and observing angles with those from EPIC [1,2]. Lunar reflectance data are used to help calibrate the two wavelength channels sensitive to the Earth's oxygen absorption (oxygen B- and A-bands: 688 and 764 nm) relative to their adjacent reference channels 680 and 780 nm [2].

The Earth-observing geometry of the EPIC instrument is characterized by nearly constant scattering angle between 168.5° and 175.5°. Figure 1 displays the Sun Earth View (SEV) angle that is equal to 180° minus scattering angle. It is important to note that the distance between DSCOVR and Earth changes approximately by 2000-2500 km per day, or about 0.16% of its nominal distance of $1.5\text{x}10^6$ km during a six month orbital period.

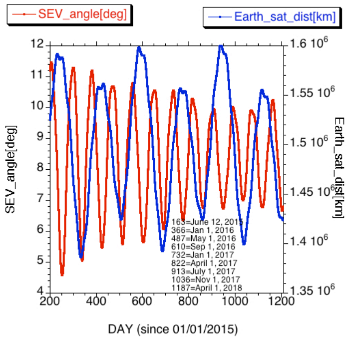

Figure 1. Sun Earth Vehicle (SEV) angle (left axis, red curve) and the distance between DSCOVR and Earth (right axis, blue curve) are plotted versus the day since January 1, 2015. Note that SEV = 180° – scattering angle between solar and viewing directions.

When MODIS on Terra and Aqua cross the equator at 10:30 and 13:30, respectively, DSCOVR/EPIC provides measurements of the sunlit face of Earth from sunrise to sunset. Figure 2 illustrates the key difference between the L1 (EPIC) and LEO (MODIS) observations, where the EPIC's observation of Africa is at 10:56 GMT. Since Terra crosses equator at 10:30, the western part of the left image has a more similar cloud structure with EPIC (middle) than their eastern parts. For Aqua crossing the equator at 13:30, the eastern part of the right (MODIS) and middle (EPIC) images are more alike than their western parts.

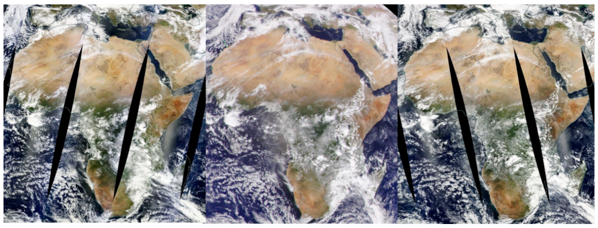

Figure 2. DSCOVR/EPIC image of Africa (middle) taken on March 22, 2016 at 10:56 GMT. Left and right images show MODIS Terra and MODIS Aqua 2330 km wide swaths of the same area taken on the same day. Terra crosses equator at 10:30 am local time so that the western swath of the left image (Terra) resembles cloud structure on the left part of the EPIC image. Since Aqua crosses equator at 13:30 local time, the eastern Aqua swath part of the right (Aqua) and middle (EPIC) images are alike.

Another earth observing instrument on board DISCOVR is NISTAR. It is designed to measure the absolute irradiance reflected and emitted from nearly the entire sunlit face of Earth seen from the unique vantage of the Earth-Sun L1 point. An accurate measurement of the total backscattered irradiance provides insight into Earth radiation balance and helps quantify any changes in the radiation budget over time.

NISTAR consists of four detectors: three active cavity radiometers and a photodiode. The three radiometers measure irradiances within three spectral bands corresponding to the total channel (0.2 to 100 μm), the total solar reflected channel (0.2 to 4 μm), and the near infrared solar reflected channel (0.7 to 4 μm).

The use of active cavity radiometers for Earth radiation budget analysis is not new, but this measurement has always been made from LEO satellites, which mostly misses the large backscatter angles. When combined, NISTAR and the LEO data could provide irradiance measurements from every angle.

In our presentation, we discuss if EPIC and NISTAR-like instruments can be used in Deep Space Gateway (DSG). It is still an open question as to what instrument changes are desirable and required for better Earth observations from the DSG compared to the DSCOVR Earth-Sun L1 location?

Known questions:

1) How does the frequent presence of the Earth-Sun terminator affect retrieval algorithms?
2) How will instrument stabilization for accurate pointing be achieved for high spatial resolution imaging?
3) What downlink bands will be available for high speed transmission of frequent measurements (e.g., 1 full set of wavelengths every 15 minutes from a 2048 x 2048 detector).
4) What is the best infrared instrument to take advantage of the 50% availability night observations.

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FORECASTING SPACE WEATHER HAZARDS FOR ASTRONAUTS IN DEEP SPACE.

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Introduction: Astronauts on interplanetary missions, often far off from the Earth-Sun line, will be subject to high energy solar particle events (SPEs) and high energy radiation (X-rays and γ-rays) from solar flares. In order to protect human life and spacecraft equipment onboard warning systems need to be developed for events for which no accurate warning can be provided from Earth, e.g. flares on the backside of the Sun (as seen from Earth). Protective measures include powering down high-voltage equipment, putting computers in safe mode, and astronauts retreating to a radiation and particle protected safe space in the spacecraft or planetary base. These measures requires alerts of tens of minutes ahead, longer in case of extravehicular or off-base activities. Deep Space Gateway provides a platform to test and validate the required space weather alert systems.

Specifying the Risk: A sudden dose of 300 rem (Roentgen Equivalent Man) is considered lethal for humans. Spread out over days or longer the dose is not lethal. The solar storm of August 1972 occurred in between the Apollo 16 and 17 missions. Had astronauts been walking on the Moon during that storm they would have absorbed 400 rem. A timely warning would have allowed these astronauts to retreat to the LEM, attenuating the dose to about 50 rem, still 50 times the dose of a typical CAT scan. Modern spacecraft, the ISS, and also the Apollo command module attenuate the radiation dose by an order of magnitude or more. Safe spaces inside interplanetary spacecraft and planetary bases can attetuate by at least two orders of magnitude. Hence it is possible to protect human life (and also equipment) on the condition that timely alerts are issued, [1].

Onboard Space Weather Alerts: When not in the Earth-Sun line space travellers are exposed to parts of the Sun that are not visible from Earth. Hence Earth can provide no forecasts for space weather events from those regions. Moreover, slow-rise proton storms are currently predicted from in-situ proton measurements during the initial rise phase (e.g. [2}), so even event visibility from Earth does not suffice for those. Fast-rise events require that the magnetic footprint of the spacecraft to the Sun coincides with the solar flare location. In this case the preflare correlation between soft X-rays and proton flux (observed by the GOES satellites for Earth) provides the SEP alert, [2], and hence again Earth cannot provide the alert

High energy radiation from major solar flares, the second hazard, is emitted in all directions. Warnings for regions not visible from Earth therefore have to be produced on board.

Instrumentation: With the current state of forecasting technology the instruments required are:

1. A vector magnetograph similar to the Helioseismic and Magnetic Imager (HMI) on NASA's Solar Dynamics Observatory, [3]. The technology for this instrument is about a decade old and the software for processing the data is operational. Hence the cost of the instrument will be reasonable. Flare forecasting algorithms, based on machine learning, are rapidly improving, [4,5,6]. DSG provides the opportunity to calibrate the setup in a realistic operational setting.

2. A solar X-ray imager and in-situ proton flux detectors similar to those in NOAA's sGeostationary Operational Environmental Satellite system (GOES). Again the technology and the forecasting algorithms [2,7] exist.

Machine Lerarning Development: The algorithms for flare and SPE prediction through machine learning are undergoing rapid development at this time, in large part through the interdisciplinary efforts of solar physicist and computer scientists, including at GSU's GAIN. Machine learning is required in space because the astronauts cannot duplicate the work of the human forecasters at NOAA's Space Weather Prediction Center (SWPC), while astronaut safety is also a NASA responsibility.

Conclusion: We propose to develop, test, integrate, and calibrate an end-to-end space weather prediction system onboard the DSG, based on current operational instrumentation, with the goal of having an optimal system in place for the planned interplanetary voyages,

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Closing the Loop on Space Waste. A.J. Meier[1] and P.E.Hintze, Ph.D.[2], [1]NASA, Kennedy Space Center, Mail Stop UB-R3-A, Kennedy Space Center, Fl, 32899. Anne.Meier@nasa.gov [2]NASA, Kennedy Space Center, Paul.E.Hintze@nasa.gov.

Introduction: Wherever humanity journeys, whether the mission is conducted by government or commercial entities, and no matter if we are establishing habitation at Deep Space Gateway (DSG), on the Moon, Mars, or even on Earth, we will never escape the need to efficiently manage our waste. A science and technology demonstration of waste conversion for volume reduction and resource recovery at DSG will enable further reliability on waste conversion systems and provide solutions to managing our environmental impact, on- and off-Earth. The demonstration and success of this technology at DSG will be a requirement to move on to longer duration human space flight which must close the loop on space waste.

On current human spaceflight missions aboard the International Space Station, (ISS) logistical and mission waste is stored in cargo transfer bags and stashed in a disposal vehicle, which is then jettisoned to burn up on Earth reentry. Longer missions dictate more waste generation, which indicate future mission challenges. For DSG, a similar variety of logistical items including food, hygiene supplies, and other commodities will have more demanding launch mass requirements and fewer opportunities for resupply. This will commensurately reduce the mass that can be devoted to science and exploration. Using gravity to dispose of waste in low Earth orbit is also no longer an option for DSG missions. Jettisoning logistical waste into space or creating waste heaps on other worlds is inefficient from a mission design perspective, when all of that waste could potentially be re-purposed.

Research Progression: The Trash to Gas (TtG) project run by KSC, as part of the Advanced Exploration Systems Logistics Reduction and Repurposing Project, was tremendously successful from FY12-FY14 at converting various waste products (i.e. astronaut food packaging, spent clothing, hygiene items, fecal, and urine brine), to methane (CH_4) (TRL 4) and demonstrated potential for water (H_2O) production., but the technology was highly gravity dependent. TtG for CH_4 production is a two-step process that would use the waste reactor and a Sabatier reactor for full CH_4 and H_2O production.

Step 1: Trash + O_2 + $H_2O \rightarrow CO_2 + CO + H_2$ + Ash/Tar/Metals
Step 2: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

The six TtG technologies investigated for waste-to-fuel production were mainly thermochemical processes that converted the raw elements of a uniform waste simulant into new products [1–3]. Steam-reforming technology resulted in the highest performance when coupling system mass, power, production rate and carbon conversion.

Waste processing reactors are gravity dependent for the following reasons: 1) The fundamental thermochemical process (ex: combustion) is different in microgravity (µg); 2) waste material falls into the hot reaction zone because of gravity; 3) hot gas rises into the unreacted waste heating it up and causing drying and pyrolysis of the waste before it reaches the hot reaction zone; 4) hot gas is forced to exit the bottom of the hot reaction zone but density differences cause the gas to rise creating mixing that entrains solid particles and mixes gas and tars making sure the reactions go to completion; 5) ash is collected in the bottom of the reactor due to gravity.

Various trash disposal strategies have been investigated for different deep space mission scenarios [3]. On a 1 year mission, it is estimated that a four person crew will produce approximately 2,500 kg of waste materials, consisting of food packaging, used clothing, hygiene items, human waste, life support system supplies and other crew supplies [4]. Jettisoning trash from a vehicle at the DSG or during transit to a deep space location (i.e. Mars) requires energy for pressurization and depressurization and could become an orbital debris issue. Leaving waste on a planetary surface risks the violation of planetary protection rules. The reuse of discarded materials on any long duration, deep space, mission will reduce the overall mission mass, increase usable spacecraft and habitat volume and improve mission reliability and robustness. The repurposed waste can be converted into fuel, air, H_2O, replacement parts and even spacecraft construction and repair materials!

Throughout our development we have combined fundamental combustion science with technology development and plan to continue that relationship. The FY18 and FY19 Space Technology Mission Directorate Early Career Initiative selected the KSC Orbital Syngas/Commodity Augmentation Reactor (OSCAR) project to reduce risk of a space waste conversion system by investigating a µg reactor to duplicate TtG's success in space. This work will unlock science questions and advance the development for DSG and beyond. Over the next two years, the team will utilize iterative development via µg demonstrations with the teamwork of µg and combustion experts at GRC, and a suborbital flight demonstration on a commercial vehicle. These experiments will advance a prototype µg waste conversion system. The behavior of the material in μg will be observed to see if the main reactions and thermochemical processes occur on the surface and/or in-depth of the material or in the gas around the material in the absence of forced air movement. Additional tests with forced air movement can also be done. Corresponding 1-g tests will have natural air movement due to buoyancy. These tests will be used to decide the appropriate method to model the system and help guide the design of how air, or other oxidant, should be introduced into the hearth zone for optimum material conversion.

The next steps after OSCAR are to test and further develop on ISS and then at the DSG. A prototype on ISS will have the benefit of crew interaction and it can be used to mature the μg technology to the point where it can be optimized for long-term, remote, operation.

DSG Infusion: The DSG offers a unique platform for further research and studies that assess the efficiency and effectiveness of reutilizing waste in an operating deep space mission environment. Long duration waste processing on DSG will allow for study of heat transfer into the unreacted waste as it moves into the reaction hot zone, how solids and tars exit the reaction hot zone, as well as studying the fundamental thermochemical processes on mixed waste streams which cannot be done in shorter duration μg studies.

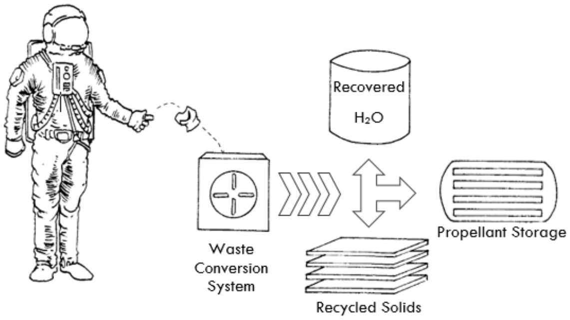
Designing and building a TtG system based solely on tests done in gravity and shorter duration μg testing is not enough. The thermochemical process requires a prototype demonstration on DSG to validate science and processing for use on missions that are greater than 1 year. Most related research on combustion or material thermal processing has been targeted at fire safety or fundamental combustion model development. TtG has provided ground validation, OSCAR will provide insight into the related physics in μg for a sounder design. ISS demonstrations will determine additional optimizations for long duration use, and a DSG prototype demonstration will provide science validation of the waste processing hardware in μg.

During the DSG mission, a waste conversion prototype of ~100kg, using <1KW of power and 200L in volume would be built and demonstrated for waste reduction, gas production/analysis, and H_2O recovery/analysis. The crew logistical waste (food, food packaging, and clothing), would be converted to gas products for fuel use, H_2O for life support, demonstrate volume reduction, remove the trash smell from long term storage, free up working cabin volume, sterilize waste, and provide raw metal recovery (i.e. Aluminum from food packaging).

The amount of crew time required to perform the research with the prototype system is unknown at this stage, but will be reduced after optimization is made from ISS experiments. Access to a vacuum line, gas analysis, and heat rejection would be required. There is no preference on the DSG orbit.

Long Duration Mission Benefits: Fuel production, H_2O recovery, and sterile product gases that can either be sent to a Sabatier reactor or vented are the major opportunities for the waste conversion technology. Waste processing can result in a waste volume reduction of 19 m^3 over the course of a year, equivalent to the pressurized volume of one Orion spacecraft [4]. In a mission benefit analysis for producing propellants from waste, enough delta-V potential for yearly station keeping of a spacecraft at Earth-Moon Lagrange point L2 is produced in either of the cases previously mentioned [5]. With a focus on CH_4 production from waste, enough propellant could be made to send a 200 kg payload from L2 to the lunar surface each year. For a Mars mission, the propellants can help mid-course corrections, depending on the size of the spacecraft.

Along with a commitment to explore and pioneer, comes a commitment to use the resources at our disposal fully, efficiently and responsibly. This is the heart of closing the loop on human spaceflight and logistics reduction and reutilization; but there is significant science and technology development/demonstration needed at the DSG before the benefits of this capability can be fully realized for long term, deep space, exploration by NASA or by commercial space explorers.



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Operational Constraints of Low-Latency Telerobotics from the Deep Space Gateway Due to Limited Bandwidth.

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Introduction: The new era of space exploration will begin in the 2020's by sending humans beyond LEO and beginning the development of the "Deep Space Gateway" (DSG) [1]. The DSG will serve as a base of operations for humans in cis-lunar space and enable operations on the Moon and research about humans ability to perform beyond the protection of LEO. It will also serve as a proving ground for future missions that will go on to Mars. The DSG will have the capability to maneuver between many different cis-lunar orbits via an electric propulsion module. One possible location would be an halo orbit of the L2 Lagrange Point roughly 65,000 km above the lunar farside during some portion of its operation [1]. This position allows for constant low-latency communication down to surface assets on the Moon's surface while maintaining line-of-sight with Earth. Astronauts located on the DSG will serve as a perfect opportunity to perform low-latency surface telerobotics for scientific objectives (e.g. deployment of a low-frequency radio telescope). The benefit of the DSG in regards to teleoperation is establishing low-latency communication and creating a virtual "human presence" on the surface [2]. A virtual human presence is promising but the operational constraints necessary have still not been explored fully. We identify two constraints on space exploration using low-latency telerobotics and attempt to quantify these constraints.

Figure 1. Modified COTS rover operated by human via low-latency teleoperations in search of exploration target.

Low-Latency Operational Constraints: The first operational constraint associated with low-latency surface telerobotics is the bandwidth available between the DSG and a ground asset. Bandwidth will vary depending on line-of-sight conditions between the antenna on the DSG and the antenna on a ground asset. This variation means it is critical to quantify the necessary video conditions for an effective virtual human presence. We designed an experiment to quantify the threshold frame rate required for effective operations; frame rate is just one aspect affected by reduced bandwidth. Our experiment simulated geological exploration using low-latency telerobotics. We had operators identify exploration targets under various video frame rates and used time to discovery as the metric of success. The experiment used a modified COTS rover in a lunar analog environment using painted rocks with symbols as exploration targets (Figure 1). The results indicate that the mean time to discovery (MTD) significantly increases when the frame rate drops below five frames per second (Figure 2). In other words, the threshold frame rate for an effective virtual human presence is five frames per second [3].

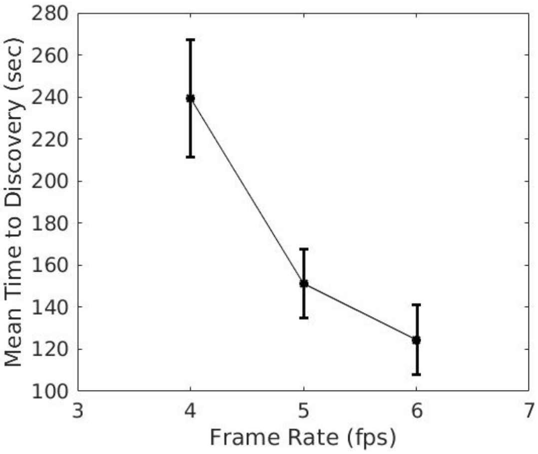

Figure 2. The MTD and associated error bars for the following frame rate: 6, 5, & 4 fps. Note: the lines connecting the data points serve as a reference for the eye.

The next constraint we attempted to quantify was latency threshold. In particular, we compared the latency condition that would be present between the DSG and a lunar ground asset and the best-case latency condition present from Earth to the DSG and down to a lunar ground asset. Specifically, we compared 0.4 seconds and 2.6 seconds of latency (Figure 3). The purpose of this experiment was to determine the significance of a small increase in latency. The results from this experiment show a 150% increase in exploration time when latency changes from 0.4 seconds to 2.6 seconds with all other video conditions remaining the same [3]. This drastic increase in exploration time indicates that 2.6 seconds of latency is too high to produce effective low-latency telerobotic operation using real-time exploration strategies. This means that teleoperation from the DSG is required in order to utilize real-time exploration strategies. Thus, teleoperation from the DSG is necessary to achieve an effective virtual human presence on the surface of the Moon.

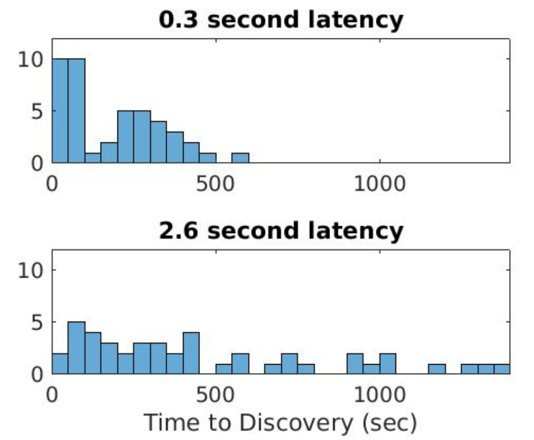

Figure 3. Distribution of the time to discovery for the following latencies: 0.3 & 2.6 seconds. The dispersion clearly increases with the 2.6 second latency.

Low-Latency Assembly Tasks: Low-latency teleoperation from the DSG will allow real-time supervision of the rovers performing autonomous assembly tasks on the lunar surface. While the astronauts will primarily oversee the rovers performing autonomous tasks, the low-latency conditions allow for immediate human intervention when an anomaly occurs in the autonomous task. This is one of the more promising aspects of teleoperation from the DSG because it will allow quicker and more efficient assembly of scientific instruments, such as a low-frequency radio array and infrastructure for future human surface missions. It is critical to conduct experiments on Earth to study the effects of decreased bandwidth on the ability to use low-latency teleoperation for assembly tasks. In particular, it is necessary to identify the threshold video conditions required for humans to efficiently perform telerobotic assembly tasks. We plan to conduct a low-latency assembly experiment aimed at identifying the threshold video conditions for telerobotic assembly tasks. This experiment will involve humans remotely operating a rover equipped with a robotic arm in order to assemble a simple antenna array. The rover is a COTS Parallax rover titled Advanced Rover for Lunar Operations (ARLO). ARLO is capable of zero-point-turning due to two independently powered wheels and two caster wheels. A modular 6-DOF robotic arm will be mounted onto the front section of ARLO. This robotic arm will have a gripper end-effector which will allow human operators to remotely grab components for assembly. The experiment will consist of deploying four antenna units to form an array. The antenna unit is defined as a pre-assembled case with an antenna and a software defined radio USB fastened to the case. The deployment of each antenna unit will consist of two distinct tasks. The first task will be the physical placement of the antenna unit to the designated location on a defined grid. This will require that the human teleoperate the rover and arm to grab the antenna unit from its initial deployment location and transport it to the designated operating location. The second task will be completing the USB electrical connection between the antenna unit and the main computer. The trial will be complete once the operator successfully places and connects the four antenna units to the main computer. Observation of signals from all four antennas will signify a successful antenna array deployment.

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REALIZING A SELF-REPRODUCING SPACE FACTORY WITH ENGINEERED AND PROGRAMMED BIOLOGY.

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NASA studied the technological feasibility of a self-replicating lunar factory nearly four decades ago [1] to mitigate the severe cost of multiple shipments to the moon. The idea was to harness local resources to manufacture desirable products on site. This factory would also grow outwards to slowly increase its capacity from an initial seed (Figure 1) by producing copies of its constituent elements. These elements included autonomous task-specific robots; some would procure raw materials, others would transform these materials into structural and sustenance (e.g., power) outputs, and yet more would store final products for future use.

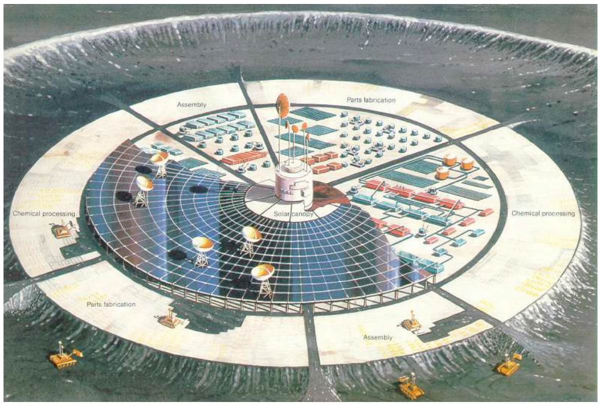

Figure 1 [1]: A 1980 self-replicating lunar factory concept that used autonomous robots in outwardly-growing sectors devoted to chemical processing, parts fabrication, and assembly.

Attempts were made towards realizing this concept in the following years [2], and we examined associated questions such as determining the optimal seed for such factories [3] and ensuring that a self-reproducing collective would be resilient to disturbances like solar flares or meteoroid strikes [4], [5]. But a fundamental trade-off exists with robot self-reproduction [6]: either the self-reproduction process is "simple" because the environment is complex, in that ready-made parts exist to be assembled, or the self-reproduction process is "complex" because the environment is simple (i.e., disordered and unstructured), and thus requisite parts must be synthesized and connected. The latter challenge is applicable to the extraterrestrial environments of self-replicating space factories.

Of course, biology can already self-reproduce, and this complex process has a potential use in "simple" off-Earth environs. In fact, recent studies [7-10] have advocated deploying existing biology for space manufacturing, and we calculated in [9] that such deployment can substantially minimize payloads over abiotic approaches, even before any engineering occurs. These calculations suggested that 26-85% mass reductions are possible depending on the application. Biological technologies can also lower power demand and launch volume, for instance by innately harnessing solar energy and by growing only upon activation using available destination resources, respectively. In [11], we articulated grand challenges facing the resultant nascent field of space synthetic biology. This field was included in NASA's 2015 technology roadmaps [12], where biological technologies were described as having "promising potential" that "deserve some attention."

Our recently-awarded Center for the Utilization of Biological Engineering in Space (CUBES) will leverage partnerships between NASA, other federal agencies, industry, and academia to support biomanufacturing for deep space exploration [13]. CUBES involves five universities: the University of California, Berkeley; the University of California, Davis; the University of Florida; Utah State University; and Stanford University. CUBES will advance the practicality of an integrated, multi-function, multi-organism biomanufacturing system on a Mars mission, and showcase a continuous and semiautonomous biomanufacturing of fuel, materials, pharmaceuticals, and food in Mars-like conditions. Akin to an abiotic, robotic space factory, task-specific organisms will convert raw materials (e.g., Mars atmospheric and regolith resources) for downstream biological use as media and feedstock, and will manufacture structural and sustenance mission products like propellants, building materials (biopolymers that can be 3D-printed), food, and pharmaceuticals. It is envisioned that this biomanufacturing system will be initialized from some seed set.

The biology in this system will not be the only thing that reproduces; CUBES will also study self-reproduction and growth from the factory seed. For instance, for the case of agricultural cultivation receptacles, open questions include how much biopolymer will be required to produce a receptacle of a certain size that will still be manufacturable by a 3D-printer and that will then exponentially increase yield if that bioreactor is used by more biopolymer-producing microbes or is used to grow plants, and how much media will then be required for that biopolymer amount.

Beyond CUBES, there will be a need to program the utilized biology. In general, CUBES harnesses a fundamental trade-off of space synthetic biology: mass savings at a cost of longer process times. Accordingly, any self-reproducing space biofactory deployment will be in advance of astronaut arrival, or on a large scale where some operations are remote from astronaut oversight. Hence, electromechanical or cell-based controllers must ensure satisfactory (quick, and autonomous or telerobotic) space biomanufacturing.

Consequently, the notion of a self-reproducing space factory has come full circle from the original concept, and will be realizable in the near future through engineered and programmed biology. With a deep space gateway, there is an opportunity to test proof-of-concept versions of this biofactory that can self-reproduce from a seed set and that can operate autonomously at this gateway. These tests will be foundational for evaluating a possible vital support technology in future manned space missions.

A first test can start small, such as converting available exhaled carbon dioxide into a fuel or into a biopolymer. Follow-on tests will then scale up both bioprocessing function and autonomy, eventually realizing a near-complete biofactory from a seed. These tests will yield valuable operational and autonomy information. Potential operational insights include corroborating prior studies on minimizing mass, power, volume, and cost over abiotic approaches. Potential autonomy insights include determining the minimum crew interaction required for biofactory operation, and confirming flawless growth from the seed set.

Test needs that will have to be met by the deep space gateway include emulating prospective mission conditions where the biofactory seed would be deployed. CUBES includes a space and complex systems engineering component to analyze, guide, test, improve, and integrate the internal processes of a space biofactory, and will provide the necessary data, metrics, and operating condition information upon center conclusion to inform future space tests and activities.

In sum, there is an opportunity to test a data-driven, technologically-backed space biomanufacturing platform at the deep space gateway that realizes a highly-valued concept, a self-reproducing space factory. This opportunity lies at the intersection of space biology and telerobotics-enabled science.

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The Lunar Occultation Explorer (LOX): Establishing the Moon as a Platform for Next-Generation Nuclear Astrophysics Investigations.

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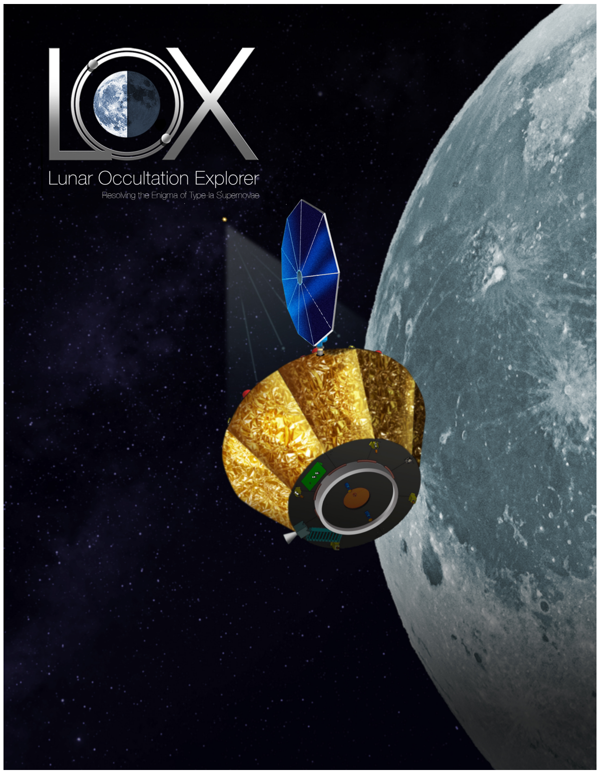
Introduction: The Lunar Occultation Explorer (*LOX*) will leverage the power of a new observational paradigm to transform our understanding of the nuclear cosmos (0.1–10 MeV) and establish the Moon as a platform for astrophysics. Originally developed as a standalone Explorer-class mission, *LOX*'s straightforward implementation strategy and operation profile make the Deep Space Gateway an attractive alternative platform for deployment.

LOX will operate from lunar orbit, using the Moon as a natural occulting disk to temporally modulate cosmic sources of nuclear gamma-rays as they repeatedly rise and set over the lunar limb. The modulation signatures imprinted on acquired gamma-ray time-series data contain *all* the information necessary for source characterization and localization. This innovative use of the Moon, combined with *LOX*'s wide-field-of-view and continuous all-sky monitoring, provides an effective way of addressing multiple Decadal Survey questions in the nuclear gamma-ray regime. The *LOX* approach achieves high sensitivity with a simple instrument design, while also taking advantage of the relatively benign, easily characterized, and slowly changing background environment of the Moon. These capabilities give *LOX* a transformational capacity for discovery.

The tremendous potential of nuclear astrophysics measurements is currently unrealized for the simple reason that instrument sensitivity has been inadequate for nuclear gamma-ray measurements. To date, observational techniques have solidified around a single detection methodology—Compton scatter tele- scopes—that require complex implementation, development, and operational resources to advance their capabilities. The associated technology and cost constraints have limited significant progress in astrophysics at MeV energies for almost a quarter century [1,2]; in fact, from 1980 until today, sensitivity has improved by only a factor of ten. This contrasts markedly with advances in soft X-ray, hard X-ray, GeV gamma-ray, and TeV gamma-ray astrophysics.

LOX directly challenges this paradigm to provide a unique set of time-domain nuclear astrophysics capabilities. *LOX* eliminates the need for complex, position-sensitive detectors, kinematic event reconstruction, masks, or other insensitive detector mass, while also mitigating technology development and implementation complexity as well as their associated costs (e.g., [3]).



Lunar Occultation & the Case for the Moon: Astronomical investigations from the Moon afford new opportunities to advance our understanding of the cosmos. The foundation of *LOX* is the lunar occultation technique (LOT), an observational paradigm uniquely enabled by the Moon and well suited to the all-sky monitoring demands of nuclear astrophysics investigations [4], including uniform and continuous monitoring of the sky at full sensitivity. Temporal modulation is the foundation of the lunar occultation approach.

LOX's location in lunar orbit provides many advantages over traditional, Earth-orbiting gamma-ray observatories. The LOT provides long observing periods, and the correspondingly large number of occultations gives long on-source exposure times. Additionally, the gamma-ray backgrounds from the lunar surface provide an in-situ calibration source that reduces associated systematics to the level of a few percent [5]. The variations in this background, the result of variability in the cosmic-ray flux and lunar composition, are understood and correctible [5]. The irreducible cosmic diffuse gamma-ray flux is also well understood. In contrast, Earth-orbiting observatories must contend with dynamic and complex background environments that change on orbital timescales and are not easily characterized [6].

All aspects of the occultation technique— including source-analysis methodologies [4,7,8], operation of instrument components [9-12], and systematics driven by the lunar background environment—have been validated from lunar orbit.

Implementation: The *LOX* science objectives are achieved using a single-instrument payload consisting of a large array of identical gamma-ray detector modules. *LOX* combines established detector technology with heritage electronics in a straightforward way that minimizes both implementation and operational risk. Our proposed approach meets all science requirements with ample margin.

LOX will place a large-area gamma-ray spectrometer array into lunar orbit and continuously acquire broadband spectra. As *LOX*'s orbit evolves with respect to the celestial sphere, large swaths of the sky are surveyed. Although spectra are acquired continuously, they will be divided into (artificial) observing periods to facilitate the identification of transient gamma-ray signatures and monitor evolving astrophysical light curves.

The instrument will be pointed to the nadir (i.e., toward the center of the Moon), and sources will repeatedly rise and set along the lunar limbs. This low-resource implementation has modest operational demands and currently adopts a large-area (~1.5 m^2) gamma-ray spectrometer as its single instrument. Rather than being monolithic, the *LOX* instrument is an array of individual gamma-ray spectrometer modules that operate as a single instrument (BAGEL, Big Array for Gamma-ray Energy Logging). The instrument's top-level design and functionality are simple and well-established, leveraging design and operational heritage from multiple planetary and astrophysics science missions.

Simplicity is a hallmark of the *LOX* concept. It requires only a non-imaging spectrometer in lunar orbit. Operations are simple because there are no slewing or onboard data-processing requirements; data-analysis protocols are based on flexible and established time-series analyses of acquired spectra [4,5,7]. Flux sensitivity, spectral resolution, field of view (FoV), and source localization are governed by implementation parameters such as spectrometer size, detector type, orbit altitude, and spectrum integration times (i.e., mission-level rather than technology-driven solutions). The *LOX* concept is also highly scalable, limited only by resource constraints such as mass and power.

All elements of *LOX* are high-heritage, and most have operated in-situ from lunar orbit for extended periods of time. Mission operations and operating conditions are proven and well-established, and recent proof-of-principle efforts led to the first high-energy astrophysical source detection from the Moon. These features establish *LOX* as a low-risk, cost-effective, and competitive venture that will address several Decadal Review findings, provide new insights into the lifecycle of matter and energy throughout the cosmos, and resolve the enigma of thermonuclear supernova, the beacons of the cosmos.

Summary: *LOX* is a low-risk, cost-effective, and competitive astrophysics mission concept that challenges established paradigms in nuclear astrophysics investigations, will provide new insights into the lifecycle of matter and energy throughout the cosmos, and establish the Moon as a platform for high-energy astrophysical sciences.

Estimated Mass: 350-500 kg
Estimated Volume: ~20 m^3
Estimated Power Requirement: 100-300 W
Estimated Data Volume: 100-200 Mbyte/day
Location on DSG: External, lunar nadir pointing
Preferred Orbit: Lunar (altitude tbd)
Crew Interaction: None

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SPACE RADIATION AND PLASMA SCIENCE ENABLED BY THE DEEP SPACE GATEWAY.

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Introduction: Lunar orbit is a unique location for studies of space radiation and plasma environments. NASA plans for constructing a Deep Space Gateway (DSG) space station for human operations in cislunar space will provide an important first step for a sustained human presence beyond low Earth orbit and opportunities for routine studies of space radiaton and plasma environments at lunar distances. Travel times from the Earth to lunar orbit are on the order of four days, allowing relatively easy logistics for resupply and operational support. The DSG in orbit about the Moon will therefore provide opportunities for sustained monitoring of the interplanetary space environment outside of the Earth's magnetosphere and the Earth's magnetotheath and magnetotail at lunar distances and experiments focused on specific aspects of those environments of interest to basic and applied science.

This paper considers candidate opportunities for investigating space radiation and space plasma environments from the DSG vehicle in lunar orbit, DSG logistics vehicles used to support Gateway, and subsatellites supported by the DSG.

Space Radiation and Plasma Science Opportunities: The mean radius of the Moon's orbit is ~60 Earth radii (R_E), well outside of the strong dipolar magnetic field configuration of the Earth's central magnetosphere. Galactic cosmic rays (GCR) and solar energetic particles (SEP) at energies of importance to both human health and avionics components have free access to the Moon over its entire orbit [1]. At low energies, lunar orbit is immersed in the free flowing solar wind thermal plasma over ~75% of an orbit with the remaining 25% of the orbit divided between shocked solar wind in the magnetosheath and the low density plasma of the Earth's magnetotail.

DSG Opportunities. Routine operation of the DSG in lunar orbit provides opportunities to investigate a variety of aspects of the space radiation and plasma environments including:

- Moon-plasma interactions in the solar wind, magnetosheath, and magnetotail,
- Magnetotail dynamics at lunar distances,
- Backscattered and sputtered ions from the lunar surface,
- Energetic ions upstream of Earth's bow shock,
- Monitoring quiescent and storm-time GCR and SEP ions of importance to human health and avionics,
- Human central nervous system response to GCR and SPE heavy ions,
- Testing space weather monitoring systems for protecting crew from extreme space radiation environments.

Opportunities from DSG Logistics Vehicles.

DSG will need to be serviced with logistics vehicles providing cargo, supplies, and transfer of crews between Earth and the DSG throughout the operational lifetime of the station. These vehicles provide a secondary opportunity for routine measurements of radiation and plasma environments within the Earth's radiation belts including opportunities to obtain:

- Measurements of trapped energetic particles as a function of flux and energy in the inner and outer radiation belts over a wide range of L-values from low Earth orbit to beyond the outer trapping boundaries. While enabled by the DSG logistics vehicles, these measurements may be useful for routine space weather monitoring of the Earth's radiation belts for terrestrial applications,
- Spacecraft charging investigations using surface potential monitors and charged particle environment measurements in the inner and outer radiation belts.

Use of solar electric propulsion is often discussed as one method for supporting a DSG architecture with routine, low cost logistics flights. One option for these vehicles is a slow spiral out through the radiation belts offering the opportunity to sample multiple local times over a seris of slowing increasing L-values. Another option is to establish a highly elliptical orbit immediately following lauch with apogee well beyond the boundaries of the radiation belt and perigee in low Earth orbit. Perigee is then slowly raised over a period of time until the solar electric support vehicle as climbed out of Earth's gravity well. Spacecraft in these orbits provide an opportunity for sampling the radiation belts over a wide range of L-values in a restricted range of local times over a period of time.

DSG Subsatellite Opportunities. A third set of opportunities my be supported by small satellites operating independently from the DSG but utilizing DSG as a communictions relay or other required support. Examples include studies of:

- Charged particle dynamics in the lunar wake,
- Lunar surface charging from a lunar lander,
- Spacecraft charging in the deep lunar wake,

- Lunar secondary particle (neutron) environments.

Investigations in this category greatly benefit from, or require, orbits relative close to the lunar surface. While the Deep Space Gateway may approach within a few hundred kilometers of the lunar surface during some operations to support lunar landings, it is likely a much higher orbit will be used on a routine basis to avoid the complexitites and fuel needs required to maintain the unstable low altitude orbits in the lunar gravity field. Therefore, options to periodically deploy single, or possibly a constellation, of small spacecraft from the DSG that will operate at low lunar altitudes will provide additional opportunities to study features of the lunar plasma and radiation environments.

DSG Flexibility Opportunities. Hardware response to SPE and GCR is well understood from many decades of satellite operations in GEO. However, new electronics technologies are always being developed that must be tested to characterize their failure modes due to single event effects before they can be used for space applications. Access to terrestrial test facilities is becoming more difficult due to closure of a number of accelerator facilities. An option for electronics single event testing would be to rotate new technologies for extended exposure periods of months to years in the full deep space heavy ion environment at DSG which is the same environment that exploration vehicles will be exposed to on future missions to Mars. Routine changeover of flight crews allows deployment of new and different candidate technologies that can be exposed to the unprotected GCR and SPE flux during periods between human changeover flights.

Summary: NASA's DSG offers a number of new and exciting opportunities for the space physics and applied space science community. Which opportuniites ultimately are successful will depend on the flexibility of DSG operations and the final orbital parameters chosen for the Gateway itself and the logistics vehicles used to support the DSG.

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Introduction: The Deep Space Quantum Link (DSQL) will perform pioneering experiments on gravitational effects on quantum systems, test the basic assumptions of quantum optics theory, and demonstration of quantum key distribution (QKD) at deep space distances.

Background: Quantum optical communications is an emerging space-based technology that could potentially increase the information capacity of communications networks by 100% [1], and provide fundamentally secure communication links between trusted nodes within the network with QKD [2]. Demonstrations of LEO-earth and GEO-earth quantum channels published by European and Chinese agencies have proved the maturity of the underlying technology [3, 4]. The proposed orbits of the Deep Space Gateway (DSG) spacecraft provide a unique avenue to test the effects of both extreme range and gravity on the quantum channel. The tests enabled by DSQL by virtue of the orbit of DSG, are important from the perspective of both fundamental physics and deploying a future quantum communication infrastructure.

Objectives: The scientific objective of DSQL is to test the coupling of General Relativity, the physics most often associated with cosmology, with Quantum Field Theory, the physics of wave-particle duality. The DSQL will perform three experiments. The results of these three tests will represent the first direct probe of how general relativity affects quantum particles. These scientific results, in addition to answering a fundamental question of modern physics, will facilitate the design of future quantum communications missions.

*Experiment A—Quantum Teleportation***.** Entangled photons are a set of photons that are governed by a single wavefunction. Pairs of entangled photons are generated by DSQL, then transmitted to distant receivers designed to recover the quantum state. The transmitter and the receiver will be at different inertial reference frames, at different gravitational potential. The untested theory that describes the proportion of entangled particles between inertial frames predicts that the single particles will undergo changes due to both the mutual acceleration, and the curved spacetime between the transmitter and receiver [5, 6, 7]. Gravity is expected to modulate the fidelity of the particle entanglement. Because of its proximity to the Lagrage point, DSG provides an access to a unique set of inertial reference frames with strongly varying gravitational potential. Because of that, a measurable change in the fidelity of teleported quantum states is expected. The DRO, ELO, NRHO, and HALO orbits available to DSG will result in sensitivity to gravitational effects higher than that of an earth-orbiting spacecraft. The theory predicts that the LLO orbit will have reduced sensitivity.

Experiment B—Bell Test. Experiment B will test for violations of Bell's Inequality by using quantum teleportation. Successful teleportation will prove that quantum wavefunctions are non-local: that a single wavefunction can be used to describe two particles nominally separated by the earth-moon distance. The longest distance Bell's Inequality test to date was conducted over 1600 km between Delingha, China, and the low earth orbiting satellite Micius [4]. The DSG enabled experiment will be the first ever test of Bell's Inequality where the local curvature of the spacetime between transmitter and receiver is predicted to impart a measurable signature upon the teleported state. Conducting the 'Bell Test' experiment along different points of the DSG Distant Retrograde Orbit will allow increased sensitivity to the gravitational effects. Other proposed orbits of DSG will result in an improved Bell Test compared to what is possible with an earth-orbiting satellite (Fig. 1.) By virtue of the distances travelled, this Bell Test will eliminate the freedom-of-choice loophole inherent in ground based tests. A human-operated Bell's Test conducted by astronauts onboard the DSG would test the foundational concept of Local Realism in quantum measurement [8].

Experiment C—Quantum Communication. Experiment C will establish a primitive quantum communication link between DSQL and a ground station. Monitoring the net quantum bit error rate will test the integrity of a free space quantum communication channel that traverses a curved spacetime.

Quantum communication systems surpass classical communication systems performance by adding quantum resources. The ultimate information capacity of an efficient quantum channel is double that of an equivalent classical channel. QKD protocols can provide a fundamentally secure information channel that is immune to eavesdropping. Ground-to-ground fiber-optical quantum links that are longer than a few hundred kilometers apart are ineffective due to fiber losses; a free space link through an orbiting satellite is required for long-range ground interconnects [2]. For these reasons, future quantum communication systems will be space-based. The effects of gravity on the quantum channel must be experimentally measured.

It is predicted that the ultimate quantum bit-error-rate (QBER) of a quantum information channel depends on the spacetime curvature and mutual acceleration between transmitter and receiver. Theory predicts that transmission from any of the proposed DSG orbits will result in twice the sensitivity to QBER modulation compared to earth orbiting satellites (Fig. 2). This prediction will be tested in Experiment C.

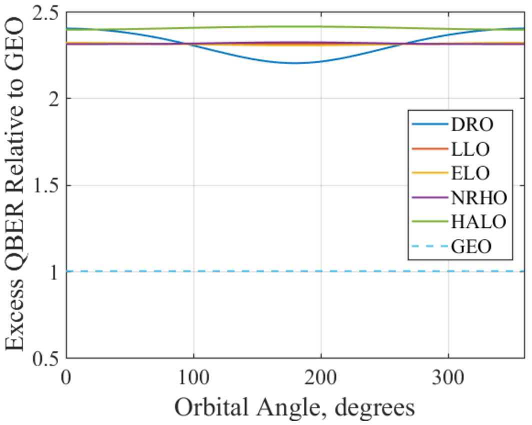

Figure 1

Variations on the experimental setups can be applied to directly probe causal-relationships between quantum detection events. Interestingly, the Copenhagen Interpretation predicts a result for measurably different than the Many Worlds Theory of quantum mechanics. This difference is only reconciled by validating causality in quantum measurement [9] for space-like and time-like separated detectors. This test will be a subset of Experiments A, B, and C.

Instrument Concept: *Size, Weight, and Power:* The DSQL will consist of a source of entangled photons and a source of single photons that also produces squeezed light. It will also have an array of single photon detectors and associated optical conditioning circuits and read-out electronics. Transmission will be accomplished through use of an external gimballed telescope and up to six classical optical links (lasers) used for pointing, tracking, and acquisition. Successful execution of the tests listed above requires an earth-based ground station or an auxiliary satellite to serve as a receiver. The size, weight, and power consumption of the DSQL is estimated based on comparison to similar technology under development at JPL, namely subsystems designed for the Deep Space Atomic Clock and the Cold Atomic Laboratory. The current estimate is 1-cubic meter volume, 190-220kg total mass, with 300W-400W power draw while operating. The DSQL system can be located either inside or outside of the DSG spacecraft—though the gimballed telescope is required to be on the outside.

Photon Source: Successful execution of the experiments requires a narrow bandwidth, high repetition rate source of entangled photons. JPL has pioneered the development of such sources [10]. Broadband sources, which would be required for LEO probes of gravity-quantum coupling [9] have orders of magnitude lower production rate.

Preferred Orbits: All orbits allow execution of the three proposed experiments. The orbits are ranked as follows: (1) DRO, (2) NRHO, (3) HALO, (4) ELO, and (5) LLO. Orbits (1)-(4) are preferred for DSQL. Orbit (5) reduces sensitivity in Experiments A and B. Line of sight time to the receiver will limit all experiments.

Astronaut Involvement: Astronauts onboard the DSG could participate in science experiments of the Bell Test by picking random numbers to define instrument settings during operation per [8] to overcome the pseudo-random number loophole inherent of earlier long range Bell Tests [4] and resolve potential human factors in quantum measurements.

Cost Estimate: The DSQL is based on technology that has been proven to work in space missions. Still, it would represent one of the most complicated optical systems ever flown. The cost for the instrument and ground station is estimated by comparison to similar subsystems developed at JPL: Deep Space Optical Communications, Cold Atomic Laboratory, and Deep Space Atomic Clock. A rough cost estimate is $100M for program planning purpose.

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TELEROBOTIC DEPLOYMENT AND OPERATION OF A LUNAR FARSIDE LOW RADIO FREQUENCY COSMOLOGY TELESCOPE FROM THE DEEP SPACE GATEWAY.

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Introduction: This abstract is part of a series that describes using the Deep Space Gateway (DSG) to enable low-frequency 21-cm cosmology from the Lunar environs. Here, we describe using the DSG to support an instrument that measures the global 21-cm signal from the Lunar surface. The abstract by Burns et al. provides an overview of the scientific and technological opportunities offered by the DSG. In Tauscher et al. we discuss deploying a global 21-cm instrument at the DSG itself, and in Rapetti et al. we describe analysis algorithms for the 21-cm measurements.

The Cosmic Dawn in the Early Universe: Understanding the transformational period of the Universe when the first structures, galaxies, and black holes formed is one of the central objectives in cosmology. In the standard model, this occurred in the first few hundred million years after the Big Bang, corresponding to redshifts $z>15$, when the Universe left the "Dark Ages" and entered into the "Cosmic Dawn". Although the new large ground- and space-borne observatories such as GMT, E-ELT, and JWST will be sensitive enough to probe objects through the reionization epoch ($z<15$), at higher redshifts they will be limited not only by instrumental effects but also by the smaller population of weaker sources. A different type of measurement is necessary to access the key physical processes that drove the Universe through this large-scale phase transition. This measurement corresponds to the 21-cm line from neutral hydrogen gas in the intergalactic medium (IGM), in between the early compact sources. This measurement will contribute in an independent and totally complementary way to explore the early Universe [1]. Specifically, this measurement can access higher redshifts by characterizing perturbations expected in the 21-cm spectrum relative to the cosmic microwave background (CMB). A key component of these perturbations is its monopole term, found through a sky-average, or “global” measurement. Spectral perturbations produced in the redshift range $30>z>6$ are due to UV and X-ray radiation from the first generations of galaxies and black holes impacting the IGM [2]. Perturbations expected earlier, at $z \sim 80$, during the Dark Ages themselves, are due to the evolving density of the hydrogen gas, which coupled in different degrees the 21-cm line with the physical temperature of the gas, which at the time was lower than the CMB temperature. With no astrophysical sources involved, this early perturbation is purely cosmological and its precise detection and characterization would strongly test our understanding of the evolution of the Universe on the largest scales [3]. See Figure 1 for a reference global 21-cm model.

Measuring the Cosmological 21-cm Signal Monopole from the Lunar Farside: Due to cosmological expansion, the 21-cm line (1,420 MHz) from the early Universe has to be observed at ν_{obs} = 1,420 / (1+z) MHz. Therefore, exploring $z > 15$ requires measurements at ν_{obs} < 90 MHz. More specifically, the early, $z \sim 80$ feature has to be measured at ~ 20 MHz. Accurate observations from the Earth become particularly challenging at these frequencies due to the effect of the ionosphere, which significantly attenuates and refracts signals, in addition of representing itself a source of emission. These effects are more severe as frequency decreases, making the detection of the cosmological feature impossible from the Earth [4]. On the other hand, the pristine environment of the Lunar Farside during nighttime is an ideal place for such observation. Moreover, the Moon acts as a shield to artificial radio transmissions from the Earth, which could potentially corrupt the low-frequency spectrum beyond the levels acceptable for extracting the science. Conducting the measurement from the Lunar Farside becomes an imperative for completing the picture of the Universe's evolution between the Big Bang and the present.

Cosmology Enabled by the Deep Space Gateway: In this talk we will discuss how the DSG can support our concepts for a global redshifted 21-cm line experiment deployed on the surface of the Lunar Farside to detect and characterize the signal from the early Universe. The observational strategy considered for this instrument enables precise determination and removal of astrophysical foregrounds from the measurement [5]. However, it benefits significantly from observing from latitudes as close as the Lunar poles as possible [6]. The Farside, especially toward the poles, imposes a variety of technical and logistical challenges that could be addressed and solved with the support of the DSG. They include: 1) The wireless transmission, or "beaming", of power to the instrument during its science observation runs, which have to be conducted in Lunar nighttime as the effect of direct Solar radiation on radio waves has to be avoided. The continuous power requirements are estimated below 200 W, and the DSG could be used as a power supply during complete or partial runs, as it could be supported by a solar panel power station deployed on the surface, in the proximities of the instrument, which stores power when

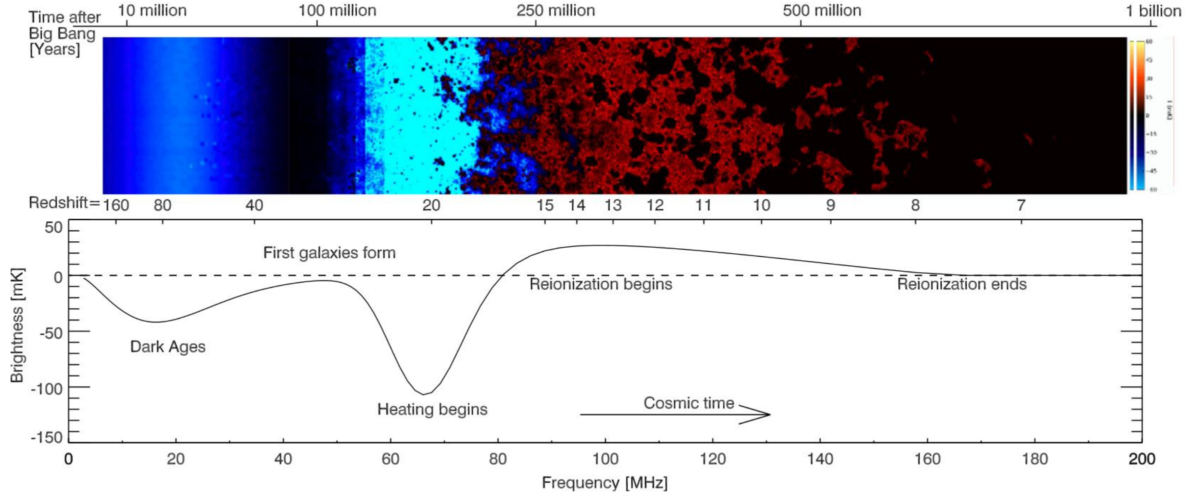

Figure 1. Reference 21-cm model from [3]. The top panel shows the large-scale evolution of the Universe, starting from an isotropic neutral hydrogen gas (in blue, on left hand side) through the formation of structure (red, middle), and the reionized IGM (black, right hand side). The bottom panel shows the equivalent sky-average, or global, 21-cm signal that the DSG will enable to measure from the lunar environs.

the Sun is visible. 2) The transmission of data from the Moon to the Earth. As envisioned, the instrument should conduct the digitization and most of the low-level data reduction on-site. Since it will gather data continuously, a requirement is imposed to send the data to Earth continuously at a similar rate. These data will include all the Stokes polarization parameters of the sky radiation, as well as calibration data and environmental readings, which are expected to amount to < 1 GB of data per day, or ~ 12 kB/s for continuous uninterrupted communication. 3) The deployment of the instrument itself, which involves the landing and precise alignment of the antenna and electronics, as well as the power reception and data transmission units. Power and signal connections between the different parts of the instrument could be done through telerobotics [7], supported by operators on Earth communicating through the DSG, or located in the DSG itself, while a few highly refined antenna alignment maneuvers, also carried out remotely through mechanisms developed by Ball and Lockheed Martin, can be commanded from or through the DSG. As the landing and observation locations become identified more precisely, the possibility for astronauts sent from the DSG, tasked with specific, more intense deployment activities, will be considered. Additional requirements on the DSG include low self-generated EMI for it not to represent an obstacle in the precise determination of the cosmological spectrum. These requirements are consistent with the table in the abstract by Burns et al.

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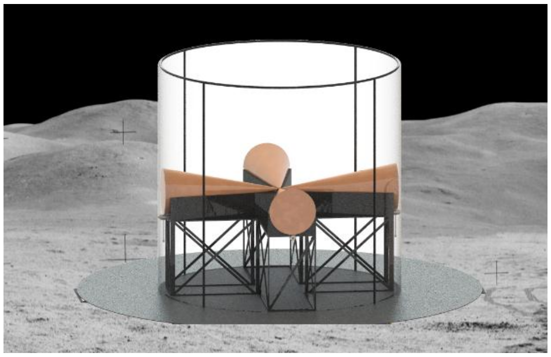

Figure 2. Global 21-cm experiment conception, observing from the surface of the Lunar Farside. For reference, the dipole antenna length is < 10 m.

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HYBRID LIFE SUPPORT SYSTEM TECHNOLOGY DEMONSTRATIONS.

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Hybrid Life Support Systems (HLSS) integrate biological components with physical-chemical components to increase system closure while reducing power and mass in space habitats. SNC is working to develop precursor plant growth components for HLSS, with a plan to evolve the technology developed for smaller International Space Station (ISS) systems into large, standalone systems that can provide significant levels of supplemental food production. This phased approach transitions plant growth technologies from ground-based development, to component and subsystem testing, to mission testing of subscale and full-scale system technologies. This provides a point of departure for transition of these technologies into larger integrated ground and flight testbeds to allow validation of system function and reliability prior to demonstration in a long-duration Low Earth Orbit (LEO) or cis-lunar environment in preparation for Mars transit missions. Plant growth systems first flew in space in the 1960s, and plant payloads since that time have emphasized fundamental gravitational biology research and the capability of plants to play a role in human life support. As part of this process, component technologies for plant growth in reduced gravity have been developed and refined, and testing of subsystems and systems on a small scale have been conducted on the ISS. A renewed emphasis on flight-testing early precursors to plant-based life-support has begun through the development of small-scale crop production systems such as the Veggie units currently growing edible crop plants on ISS. Efforts are now oriented to evolve these precursor crop-production units to larger growing systems that may become components of a HLSS for deep space use. One current effort is the GreenWall modular garden system developed to meet the requirements of NASA’s Exploration Life Support (ELS) salad crop architecture. Demonstration flights with this system would advance the Technology Readiness Level (TRL) of plant support technologies for space applications, validate scaled-up current space-based plant growth system technologies to levels appropriate for life support applications, and generate data to understand bioregenerative systems operating in the space environment. These technology demonstrations would also clarify challenges of hybrid life support by demonstrating configurations that adhere to real-life space vehicle and space operational constraints, and provide data necessary to better evaluate hybrid architectures for different mission scenarios.

SNC proposes to demonstrate a scaled-up microgravity compatible plant growth system and to validate the integration between plant chamber and ECLSS systems, primarily atmospheric composition control and water recovery components. Potential technology demonstration test parameters include:

- Microgravity food production on a scale sufficient to impact crew diet
- Impacts on vehicle atmosphere control systems
- Alternative low ESM nutrient delivery systems
- Biological system reliability
- Plant physiological responses in microgravity
- Radiation shielding potential
- Interface dynamics between biological & physical/chemical life support subsystems
- Plant culture protocols in µg
- Salad crop production protocols
- Microbial food safety
- Role of plant systems in improving human habitability in space
- Operational and crop protocols to accommodate dormant, uncrewed habitat phases

Test durations of 30 days or more would allow testing with crops like leafy greens and radishes. Longer test durations would enable testing with fruiting crops or testing of alternative cropping protocols such as “cut and come again”. Test profiles could include sequential harvests and plantings, or the continued harvests of the same plant over time. The GreenWall unit operation would be initiated and the payload would operate on an automated growing cycle (lighting, water and nutrient delivery) with minimal crew oversight. Experiment data would be obtained through imaging and data communicated to the ground daily for analysis. At crop maturity plants would be harvested by the crew with an option for consumption. Some plant tissue would be frozen for return to ground for detailed analysis. Inedible plant tissue or unused tissue would be packed as trash for disposal. In addition to operational and performance data on HLSS, these tests would enhance the quality of the crews’ habitation during these missions by providing food augmentation, producing fresh food for nutritional and psychological benefits, while providing a potential radiation shelter. One current Greenwall module has 0.74 m^2 of growing area and a volume of 0.9m^3 (1.2m L x 0.6m H x 0.6m W), with a mass of 43kg and a max power draw of 530W. For scaling purposes, plant systems for conducting HLSS research in LEO or cis-lunar space would require approximately a power density of 716W/m^2 and a mass density of 58kg/m^2.

LUNAR GLOBAL HEAT FLOW MAPPING WITH A REUSABLE LANDER DEPLOYED FROM THE DEEP SPACE GATEWAY SPACECRAFT.

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Introduction: Measurements of the heat flow originating from the interior of the Moon help us better understand its thermal evolution and the differentiation history of the lunar crust and mantle [e.g., 1]. During the Apollo program, heat flow measurements were considered high priority and planned on 4 of the landing missions (Apollo 13, 15, 16, and 17). The successful measurements obtained at the Apollo 15 and 17 sites (21 mW/m^2 and 16 mW/m^2, respectively) [2], along with the data from the gamma-ray spectrometer onboard Lunar Prospector [3], lead to the hypothesis that the Procellarum KREEP terrane is hotter than the surrounding areas because of the relative abundance of heat-producing elements, K, Th, and U in its crust [4].

Even though surface distribution of these heat-producing elements has been mapped globally, their vertical distribution is unknown. It is likely that their abundance decreases with depth into deeper crust. In addition, there is considerable geographic variation in lunar crustal thickness (10 to 80 km) as revealed by the GRAIL mission [5]. A thicker portion of the lunar crust may produce more radiogenic heat than a thinner portion.

In order to understand the Moon's internal thermal regime further, we need to more tightly constrain the crust's contribution to the Moon's total heat budget. To achieve that goal, additional heat flow measurements are desired at locations of varying crustal thickness and abundance of heat-producing elements. We believe that the *Deep Space Gateway* (DSG) can be utilized to quickly obtain heat flow data at many locations on the Moon.

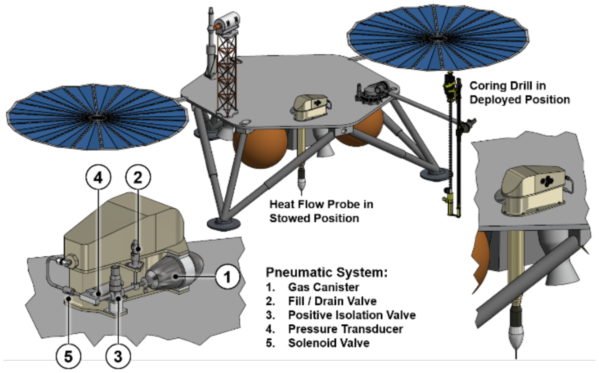

Figure 1. Conceptual drawings of the heat flow instrumentation (with the probe stowed) mounted on a reusable lander, deployed from the *Deep Space Gateway* spacecraft.

Proposed Experiment: We propose to equip the DSG spacecraft with a reusable lander that can shuttle to and from the lunar surface. The heat flow instrument is mounted on the platform of the lander (Fig. 1). Here, we envision a small lander carrying two or three instruments and a geologic sampling tool. It is solar-powered, and also serves as the communication link between the payload and the DSG spacecraft. On each deployment to the lunar surface, the DSG crew navigates the spacecraft and keeps a station above the locality targeted for a heat flow measurement. The lander touches down and stays there for 2 to 3 earth-days and completes all the necessary measurements and sampling. The instruments and tools are operated either by the DSG crew or the Earth-based personnel. When the lander returns to the DSG spacecraft, the crew services the payload instruments and prepares for next deployment. Spare sets of instruments are kept on the DSG spacecraft.

Heat Flow Instrumentation: In recent years, our group has been developing a compact, modular heat flow instrumentation specifically for robotic lunar-landing missions [6]. Our current prototype is at Technical Readiness Level (TRL) 5. The entire system weighs ~2 kg. It is mounted on a lander's platform and designed to penetrate >3 m into regolith, well below the thermal skin depth of the Moon. It uses a pneumatic system for excavating a hole into regolith. The penetrating cone emits gas jets and blows away regolith particles ahead of it, while the deplolyment mechanism on the lander extends the telescoping tube and pushes the cone downward (Fig. 2).

Heat flow is obtained as a product of two separate measurements of thermal gradient and thermal conductivity of the regolith interval penetrated. The instrumentation acquires these measurements by performing a stop-and-go operation on the way down to the 3-m depth. A short, needle-shaped probe (~2-cm long, ~2-mm diameter) is attached to the tip of the penetrating cone. The needle contains a temperature sensor (resistance temperature detector) and a heater wire. During the hole excavation, when the penetrating cone reaches a depth targeted for thermal measurements, it stops blowing gas. Then, the deployment mechanism mounted on the lander pushes the needle probe into the regolith at the bottom of the hole. Temperature of the regolith is recorded as the frictional heat of the needle penetration gradually dissipates. Soon afterwards, the probe utilizes the so-call 'hot-wire' technique and measures the thermal conductivity of the regolith [7]. Compared with the probes used for the Apollo Heat Flow Experiment [2], our needle sensor requires much less time (< 1 hour) for thermal conductivity measurement, because of its thin diameter (2.5 cm vs. 2 mm).

We expect one set of temperature and thermal conductivity measurements to be completed in less than 1 hour. Stopping every 0.3 - 0.5 m into the subsurface, we expect to complete the entire heat flow measurement operation in less than 12 hours. The progress of the operation can be monitored by cameras mounted on the lander and is controlled by the crew on the DSG spacecraft or the Earth.

When measurements at the maximum target depth are finished, the deployment mechanism reverses and retracts the probe. Gas jets are used to loosen and blow-away regolith particles that have partially filled the hole above the penetrating cone. If the probe becomes stuck in the hole, the deployment system can detach the subsurface portion of the instrumentation.

Resource Requirement: The heat flow instrumentation is compact, about the size of a shoe box with the probe stowed, and weights ~2 kg (Fig. 1). Power and energy usage is expected to be less than 10 W and 10 Whr, respectively, even during peak times. A small amount (~100 g) of compressed (~400 kPa) helium gas is needed for the pneumatic system, and it may be shared with the lander's propulsion system. The gas must be recharged by the crew when the lander returns to the spacecraft.

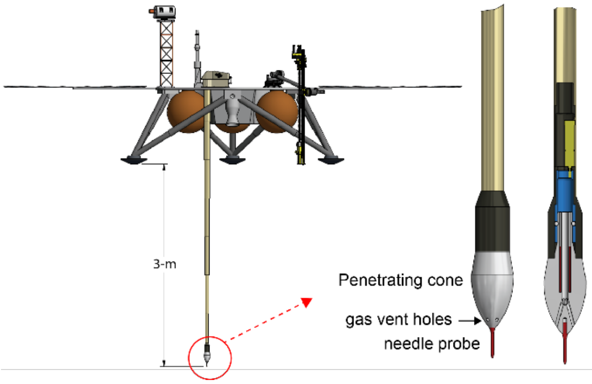

Figure 2. Conceptual drawings of the heat flow instrumentation fully deployed into the subsurface regolith.

Operation and maintenance of the instrumentation are not expect to take up much of the crew's time. Our heat flow instrumentation is a modular system. If one unit is damaged during a deployment, the crew can swap it with another one with little time, when the lander returns to the DSG spacecraft. By keeping multiple units on the spacecraft, the crew simply sends damaged units to the Earth for repair whenever convenient. When heat flow measurement is conducted on the near side of the Moon, the Earth-based personnel can take over the operation entirely, and that frees up the DSG crew's time. For operations on the far side, the DSG crew may need to take control of the instrumentation.

Proposed Landing Sites: Measuring the Moon's global heat flow distribution requires measurements at a variety of locations, but each measurement requires only an earth-day or less on the lunar surface. That makes heat flow measurements an ideal application of a reusable lander based at the DSG. Important measurement locations include regions of both very thin crust (e.g., central Mare Crisium, Mare Orientale, or Mare Moscoviense, far from the basin rim) and regions of feldspathic highland terrane of varying crustal thickness on both the near side and far side. In addition, landing sites in the center of the Procellarum KREEP terrane and on the floor of the South Pole-Aitken basin are also desirable [8].

Reusable Lander as Shared Resource: We consider the reusable lander required for the heat flow experiment as a resource that can be shared by many other ground-based operations. Because the heat flow instrumentation is compact and light, it leaves plenty of room for other payloads. A geologic sampling or coring tool may be one of such other payloads that can share the lander (Fig. 1). Finally, the reusable lander enables us to conduct a variety of ground-based experiments and operations on the Moon without having to land human-crewed spacecrafts.

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AUTONOMOUS MONITORING OF RADIATION ENVIRONMENT AND PERSONAL SYSTEMS FOR CREW ENHANCED SPE PROTECTION (AMORE and PSYCHE).

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Idea Description

Background

Proper mitigation of radiation risks below acceptable thresholds is a must to enable deep space exploration. Solar Particle Events (SPEs) would require, for example, a combination of i) solar physics based forecasting in addition with now-casting provided by real time analysis of the SPE precursors (as measured outside the space vessel), to issue proper "warnings", ii) mitigation procedures to be activated following the warning, including multifunctional and personal radiation shielding systems on board. Understanding the risk level of an SPE from the combination of fore- and now-casting is needed to optimize the SPE mitigation procedure and validate the radiation shielding approach.

For the first time, after Apollo 17, the DSG would allow to experimentally study this issue in the actual deep space radiation environment, providing also grounds for model validations. A combination of external radiation monitoring (for precursors), area & personal monitoring would be needed for the warnings generation and for studying the correlation between warnings and actual risks due to the SPE radiation as measured by the area and personal internal monitors, as well as for validating shielding radiation transport models.

Objectives

Understand the relationship between SPE precursors (as measured outside of a space vessel), the related SPE radiation in the habitat and the associated risk levels, also validating existing models.

Use such understanding to provide best countermeaures suggestions to the crew, with a real time, autonomous intelligent system.

Deepen our understanding of the effectiveness and actual ease of use of innovative personal SPE protection systems for humans in deep space.

Implement this strategy in flight for a demonstration test.

In detail:

1) Study, for the first time in a human habitat in deep space, the detailed relationship between externally measured SPE precursors and the related internally measured radiation field and consequent risk increase. SPE forecasting, from Solar physics results (see for example [1]), and a preliminary study on SPEs databases will permit the selection of the best precursor(s) to be measured suggesting also risk prediction matrices (see, for example, [2]). The project will provide data to validate these strategies and estimate the accuracy of SPE nowcasting. The same data will allow for detailed studies and validations of transport codes through the habitat hull and shielding systems, including personal systems such as PERSEO [3].

2) Intelligent tools will be provided to use at best the information coming from the "nowcasting" in (1) to mitigate SPE impact on the crew, using the detailed knowledge of the shielding capabilities also of all massive items in the vessel, with no intervention of Mission Control, and minimal intervention of the crew.

In order to optimally manage the available shielding of the spacecraft for best SPE protection (attitude variations, internal disposition of the items, shelter preparation etc.) an ad hoc smart system will be developed. This would require the precise knowledge of position and shielding efficiency of all massive items in the vessel, including the movable ones: proper wireless tagging sensors will therefore be developed. The time between the SPE precursors and the arrival of the dangerous part of the SPE may be shorter than the time needed to perform the countermeasure procedures. Starting from the acquired data, the project will estimate the residual risk the crew will face in these conditions through ad hoc designed simulations and models.

During an emergency (such as following an SPE warning), the above procedures will have to be performed in the shortest possible time, and eventually (when in interplanetary missions) with no support from Mission Control due to the large comm – delay. DSG is the best platform to master these procedures in view of these voyages. This project will develop a first set of intelligent systems to collect all the sensors data and the needed knowledge information, including, for example, the health history of each astronaut, providing real time suggestions to the crew.

The system will be mostly automatic, and data will be directly downlinked on Earth whenever possible. Crew activity would be restricted to the mounting and set up of the detectors and eventually the rearrangement of items in the vessel, and would be minimal.

Equipment to be developed / deployed:

i) a set of small light novel and performing radiation detectors - minimum of 2: one external for SPE precursors (probably: X gamma and e-. Nice to have: ions, for an internal-external validation of transport codes), one internal (area detector, nice to have: personal detector)

ii) operating platform – smart system, wirelessly collecting all the outputs of the detectors, could also be implemented on existing systems such as tablets (eg ARAMIS [4]) or smartphones

iii) personal shielding items, such as PERSEO or elements thereof such as flexible water bags, which should be available on board DSG

iv) novel tagging system for the movable items of relevant dimensions associated with the knowledge of the shielding distribution of each item (such as a detailed CAD)

v) models and simulations to estimate the residual risk due to the fastest SPEs, that will not allow for full exploitation of the countermeasures in due time.

Expected impacts

The research described here will provide several key advances aimed at enabling human space exploration:

a) the study and test of the procedures to nowcast incoming SPEs from the precursors that can be measured outside the vessel will i) provide an estimate of the possible minima for warning times, ii) support the minimization of the SPEs radiation risks using the items and shielding available on board, and iii) permit to estimate the residual risk through ad hoc developed models.

b) it will provide a first seed toward a fully automated radiation management system, demonstrating also the ability of migrating the radiation-related decision processes from Mission Control to space. This "smart system" would be open to collect, correlate and analyse inputs from all the radiation and environmental detectors, as well as other relevant information, such as the health history of each astronaut, towards an integrated smart system for the autonomous managing of all operations linked to environmental conditions.

Estimated experiment properties	Description
Mass of hardware	< 1 Kg (including 2 detectors, tagging system and hardware; shielding assumed available on board DSG)
Volume of hardware	< 2 lit
Accommodation (e.g. internal/external)	1 detector external 1 detector, tagging elements, hardware internal
Power required	< 10 W (possibly partly battery powered)
Data generated	< 1 GB / day
Pointing/viewing/line of sight needs	Yes for the external detector.
Communications needed	Nice to have
Duration of experiment	Long (looking for SPEs)
Crew tasks (if needed)	Minimal: mounting, set up, eventually rearrangements of items
Need for retrieval and return to Earth	Nice to have
Specific orbit needs (if any)	No (TBC)
Operations without crew (if any)	Most of the time

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Impact Flash Monitoring Facility on the Deep Space Gateway. D. H. Needham[1], D. E. Moser[1], R. M. Suggs[1], W. J. Cooke[1], D. A. Kring[2,3], C. R. Neal[4], C. I. Fassett[1]…[1]Marshall Space Flight Center, Huntsville, AL; [2]SSERVI Center for Lunar Science and Exploration, Lunar and Planetary Institute, Houston, TX, [3]Johnson Space Center, Houston, TX; [4]University of Notre Dame, Notre Dame, IN.

Science Objective: The Deep Space Gateway (DSG) will provide new opportunities for observing the contemporary impact flux to the inner Solar System by observing impact flashes on the lunar surface. Constraining this flux is critical for 1) understanding the population of meteoroids in our celestial neighborhood, 2) identifying sources for seismic signatures detected in future surface seismometer stations, and 3) assessing the hazards faced by astronauts living and working outside the protection of Earth's atmosphere. One approach is to observe flashes generated during impacts on the lunar surface (Fig. 1), then identify the resulting impact crater by analyzing time-sequenced images collected by LROC or an equivalent orbital camera (Fig. 2). Current Earth-bound observations of lunar impact flashes conducted by NASA Marshall Space Flight Center's Meteoroid Environment Office [2] are limited to the un-illuminated portion of the lunar nearside. Therefore, only about 15% of the lunar surface (~30% of the lunar nearside) is viewed. Installing a similar capability in cislunar space, ideally at Earth-Moon L2, will vastly improve the coverage of the measurements by exploiting continuous cloudless viewing conditions (non-illuminated surfaces are still required), increase the number of detected flash events, enable detection of much dimmer flash events (e.g., smaller, less energetic impacts), and improve our assessments of the impact flux, seismic sources, and hazards to crew in cislunar space. Although a similar facility is scheduled to fly on EM-1 (JAXA's DEtection camera for Lunar impact PHenomena IN 6U Spacecraft, DELPHINUS, a part of EQUilibriUm Lunar-Earth point 6U Spacecraft, EQUULEUS, 6 months operations), a facility on the DSG will be longer-lived, providing a prolonged capability for observing both sporadic impact events and seasonal meteor showers on the Moon.

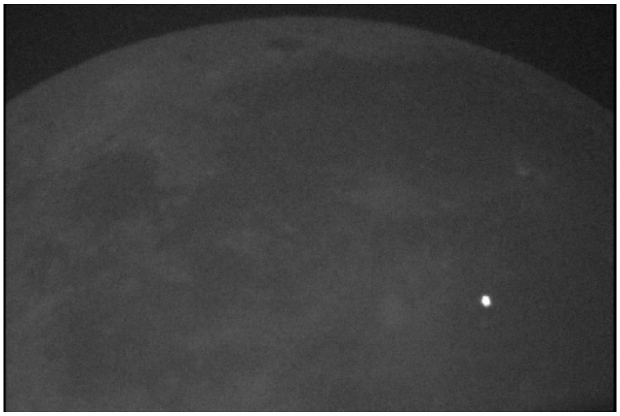

Figure 1: March 17, 2013 impact flash detected by the MSFC Meteoroid Environment Office Lunar Impact Monitoring Program from Earth. This impact event produced a flash >10 times brighter than ever detected before, and resulted in the formation of an 18 m diameter crater, later identified in LRO imagery [1].

Required Instrumentation: An impact flash monitoring facility requires two detectors mounted on the exterior of the DSG; the second detector is necessary to eliminate cosmic ray false detections (if a flash is observed in both detectors, an impact is confirmed). This could be accomplished with two independent optical systems or with one optical system with a beamsplitter feeding two cameras. A dichroic beamsplitter would also allow simultaneous measurements in two colors, yielding impact temperature information [3].

For the following mass, power, and volume estimates, the two-telescope option with commercial off-the-shelf (COTS) hardware was assumed. Actual specifications will vary depending on the materials and design used to construct the space-rated facility.

Optics: The optics for the cameras will depend on the chosen orbit. At a constant distance of 61,500 km (Earth-Moon L2), a camera would require a lens of ~60 mm diameter (focal length ~180 mm) to provide approximately the same sensitivity and field-of-view as the NASA Lunar Impact Monitoring Program on the Earth's surface. At the farthest distance of ~75,000 km (Near Rectilinear Halo Orbit), each camera would require a lens of ~70 mm diameter (focal length ~216 mm).

Mass: Together, the mass of each camera (~100 g) and lens (~1.3 kg) would be approximately 1.4 kg, for a total of 2.8 kg in camera mass. Larger diameter lenses rated for space operations would facilitate detection of fainter flashes at the expense of added weight.

Power: The power required to operate each

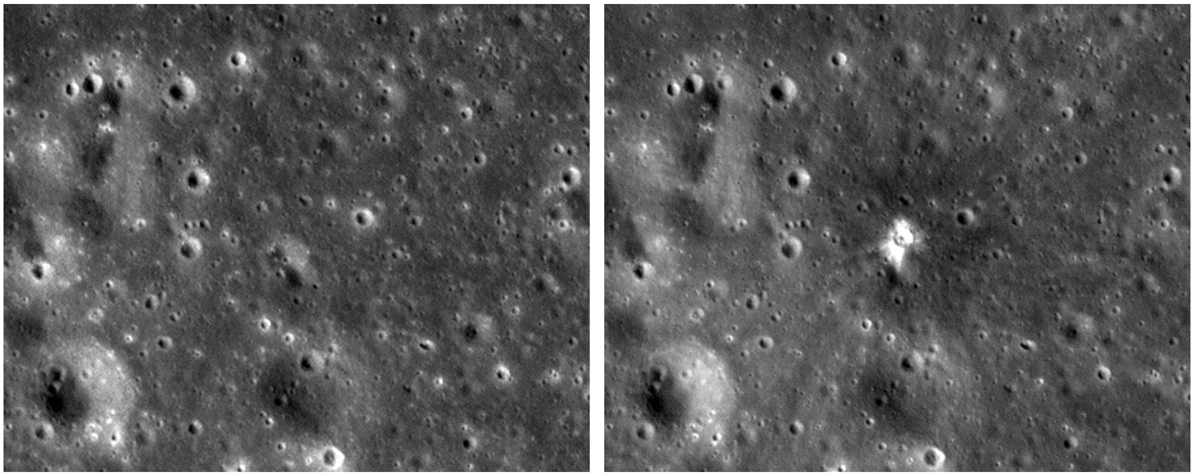

Figure 2: Before (February 12, 2012, M183689789L) and after (July 28, 2013, M1129645568L) images of the new crater formed during the impact flash event of March 17, 2013 [4].

camera is ~1.4 W from a DC+12V power supply, for a total of 2.8 W for camera operation. The on-board processor could consist of a fast general purpose computer, a field programmable gate array (FPGA) or a digital signal processor (DSP), subject to trades for cost and radiation tolerance. The on-board processing to find and correlate the impact flashes and prepare the video frames containing them for downlink is estimated to require ~10 W.

Temperature: Off-the-shelf cameras must be operated at temperatures ranging from -10ºC to +40ºC and stored at -30ºC to +70ºC. Custom space-rated cameras could have wider operating ranges.

Volume: Each camera is ~63mm x 34 mm x 34 mm, with lenses that are 200 mm in length and ~70 mm in diameter. The total volume of the optical system would, therefore, be ~150 mm x 234 mm x 70 mm, excluding the mounting platform.

Mounting Platform: In addition to the cameras and lenses, the impact flash monitoring facility will require a mounting platform capable of pointing the system for calibration and to keep the unilluminated Moon in the field of view. An articulated pointing system will be necessary since flight attitude will not necessarily be fixed relative to the line of sight to the Moon. Alternatively, while the DSG is uncrewed, the Gateway itself could be adjusted to provide line-of-sight from the Impact Flash Monitoring Facility to the Moon, if other instrumentation and system constraints permit.

Crew Interaction: Crew may be required to install and initiate the system. Ideally, this process would use an external robotic arm rather than a crew EVA. Once installed and running, this experiment should be self-sufficient and operate during both crewed and uncrewed DSG statuses.

Data Downlink: Although data is collected from the cameras at video rates, on-board processing would reduce the data to 1 to 10 image frames for each impact flash. MSFC impact detection rates are about 1 every 2 hours and assuming 10 frames of 720x480 pixels at 8 bits per pixel yields approximately 3.8 kbits per second on average assuming no compression. Higher resolution and greater bit depth cameras would require higher rates but lossless data compression would keep the data rate low.

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SOLAR CORONAGRAPHS FROM THE DSG.

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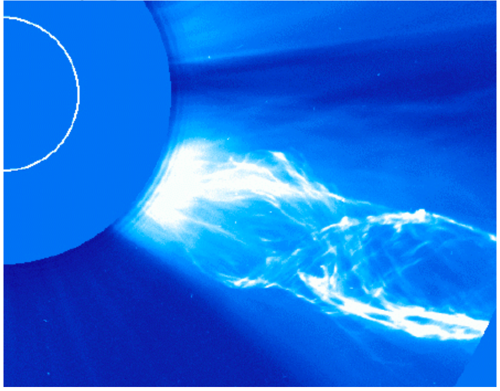
Introduction: Coronal mass ejections (CMEs) are the largest form of dynamics within the corona, yet despite decades of observations we lack key observational constraints on their initiation. CMEs are of paramount importance to the Nation, as they are the drivers of the most destructive forms of space weather, ranging from intense SEP bursts that can severely harm NASA astronauts, to geomagnetically-induced currents that can wreak havoc on our "technological society." Consequently, CMEs are a central focus of every strategic plan for US science, including the NASA Strategic Plan, the OSTP Space Weather Action Plan, the Heliophysics Decadal, and the Heliophysics Division Roadmap. Although solar physics missions have probed the corona at various temperatures and heights, the region within three solar radii where the solar wind and coronal mass ejections are born remains extremely difficult to observe with sufficient spatial resolution and sensitivity to understand these phenomena. CMEs are also the largest and best-observed examples of how the interaction of cosmic plasmas and magnetic field can lead to explosive activity; consequently, determining their initiation mechanism delivers a major advance in understanding basic physical processes throughout the universe.

The CORona from the Gateway (CORG) mission is designed to address questions of fundamental importance: What is(are) the physical mechanism(s) responsible for initiating and driving coronal ejections? How does the corona connect to the heliosphere? There are two major problems that prevent the understanding of CME initiation with the presently available data. First, the coronagraph spatial (> 7 arcsec) and temporal (> 5 mins) resolutions are too low to resolve the magnetic structure and follow the detailed dynamics. Second, there is a large gap between the coronagraph and solar disk extreme ultraviolet coronal images, but to determine how and where CMEs initiate it is essential that the complete corona be observed.

Mission Concept: This requires coronal observations very close to the solar limb. High signal-to-noise measurements require large telescope collecting areas. These two requirements call for large externally-occulted coronagraphs with a long distance occulter-to-telescope baseline, capable of "eclipse-like" observations. CORG will solve both problems above by providing a high-spatial resolution, coronagraph images from 1.05 to >2.5Rsun utilizing the Deep Space Gateway (DSG).

This giant coronagraph system will enrich the solar science with unprecedented study of the close corona. Previous Sun-observing missions such as SOHO incorporate 'internal' coronagraphs to study the corona. But their effectiveness is limited by a phenomenon called diffraction, where stray light overspills the edge of the occulting disk. Progress on this front requires moving the Occulter much further away while still preserving eclipse-like conditions for long periods of time – precisely the performance offered by the CORG external coronagraph.

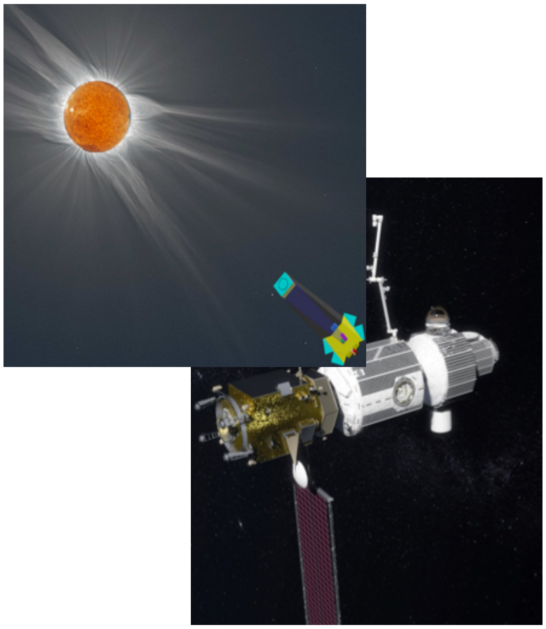


CORG will remove the primary source of arbitrariness in the current solar wind models. CORG will also provide key information necessary for constraining and enabling CME models: initial acceleration and development in the corona. CORG measurements will be invaluable for model validation, especially for the critical early CME development phase. Some of the most important characteristics of CMEs, such as magnetic structure and speed, are locked in once the CME leaves the corona. Improving the present models to the capability of reproducing CORG's observations of CMEs and development in the corona is a major advance toward a robust, predictive capability of CME-driven space weather.

The coronagraph will also provide large-scale images revealing the dynamics of ejected solar material, as erupting prominences or CMEs (see Figure 1). CORG will also address questions related to the origin of CMEs and the solar wind and its acceleration. In addition to CME initiation and development, CORG will observe all aspects of Sun-heliosphere coupling dynamics. These dynamics cover a broad range of spatial and temporal scales, from fast solar wind that can be quasi-steady for days to small coronal jets with lifetimes of only minutes.

One of the most important forms of solar-heliosphere coupling, especially for space weather, is the “slow solar wind,” because Earth is usually embedded in this wind. Therefore, to develop a predictive capability for destructive space weather, such as CMEs, requires understanding and accurately modeling this wind through which space weather propagates to impact Earth. CORG will determine if the slow solar wind originates as closed field plasma continually released into the heliosphere as magnetic plasmoids with enhanced density ejected among the heliospheric current sheet.

Scenario 1: Formation Flying. The optimal solution is satellite formation flying. This is the main driver for the mission implementation consisting of two components; a coronagraph mounted on the DSG and a small satellite launched from the DSG that will separate to provide the external occulter. and a formation flying occulter that simulates a natural eclipse from space All the instrumentation is in the payload spacecraft. The “occulter” spacecraft consists only of a service bus for attitude control and orbital maneuvering.



The formation keeps the spacecraft and DSG along the same Sun-probe vector. The “occulter” spacecraft flies ~100 m closer to the Sun than the DSG carrying the coronagraph-based telescope and provides an occultation for the coronagraph aperture of the second spacecraft in the same way the moon occults a region of the Earth during a total solar eclipse.

Resources: Utilizing the DSG, this mission is extremely resource efficient. Table 1 lists top level, initial requirements. This mission requires mounting on an external, sun facing attach point of the DSG and deployment of the smallsat (CubeSat) sized “occulter” spacecraft. All operations can be done autonomously from the ground without crew interactions.

Table 1: Scenario 1 Resources

Mass	DSG mounted instrument is <100kg, free flyer S/C <20 Kg
Power	<100 Watts
Volume	DSG mounted instrument ~0.8x0.8x1.2m
Telemetry	<200 Gb/day
Orbit	Long as possible direct solar viewing
Cost	<$50M

DSG Rationale: Formation flying of two Earth-orbiting spacecraft is being attempted (e.g., PROBA-3) or can utilize the International Space Station (ISS), however there are multiple advantages to utilizing the DSG. For example, an ISS mounted coronagraph can only observe the sun ~<40% of the time due to day/night cycles, whereas the DSG can have significantly longer uninterrupted solar observing cycles. As the PROBA-3 mission profile is demonstrating, the controls of two Earth-orbiting spacecraft with gravity gradients is also extremely limiting in its ability to observe the sun for long uninterrupted periods. Utilizing the stability of the DSG and the necessity to control only the “occulter” spacecraft relative to the DSG significantly simplifies the mission operations and extends the observations

Scenario 2: Extendable Boom. An alternative approach is to replace the free flying spacecraft with an extended, retractable boom (~20-30m), with an occulter mounted at the end (Figure 2). This boom plus occulter functions the same as the free flying occulter, although with some science compromises (e.g., slightly higher inner field of view cutoff and slightly degraded signal-to-noise) due to the shorter distance. Table 2 lists top level, initial requirements. This mission requires mounting on an external, sun facing attach point of the DSG. All operations including boom extension and retraction can be done autonomously from the ground without crew interactions.

Table 2: Scenario 2 Resources

Mass	DSG mounted instrument is <120kg
Power	<120 Watts
Volume	DSG mounted instrument ~0.8x0.8x1.2m main instrument + ~20-30m boom
Telemetry	<200 Gb/day
Orbit	Long as possible direct solar viewing
Cost	<$50M

DSG Rationale: Similarly, to the free flying option, the DSG offers substantial advantages over Earth orbiting spacecraft. As noted, compared to the ISS, the DSG offers substantial more observing time. If one compares the DSG with a self-contained, Earth-orbiting, sun-synchronous spacecraft with a boom, there are still a number of advantages, most importantly attitude control and stability and boom length.

BASIC AND APPLIED ALGAL LIFE SUPPORT SYSTEM RESEARCH ON BOARD THE DEEP SPACE GATEWAY.

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Introduction: Currently, life support functions are performed with physicochemical systems onboard the International Space Station [1]. These systems require high maintenance [2,3] and are also not capable of producing food. Hence, by definition they are dependent on continuous resupplies and have been identified as insufficient for long term spaceflight missions, as described in NASA's Technology Roadmap area 06 [4,5]. Research is currently being conducted on Bioregenerative Life Support Systems (BLSS) that may address both of these deficiencies. Specifically, the use of algae offers a promising candidate BLSS component due to its potential multifunctional performance in terms of air revitalization, water recycling, food production, and radiation shielding when cultured in a water-based medium [6–8].

One challenge that remains to be solved is the long-term storage of dormant algae. This capability is needed for two reasons: Firstly, to transport inoculum cultures from Earth to the long-term habitat both for initial inoculation but also for backup cultures in case of anomalies. Second, non-continuously crewed habitats require a method to preserve and rapidly restart the algal cultures following dormancy periods. In contrast to the International Space Station (ISS), which is within the protective Van Allen Belts, the Deep Space Gateway (DSG) provides a radiation environment comparable to planetary surfaces and interplanetary travel. Additionally, the DSG is also unique as it is intermittently inhabited and dormant for longer periods of time. These two unique conditions make the DSG well-suited for BLSS research.

The Effect of Long-Term Preservation Methods on DNA Damage of Algal Cultures: The DSG can enable studies to characterize the effect of long-term exposure to radiation on algae-based BLSS. Two strains of photosynthetic algae may be used: *Chlorella vulgaris* Beyerinck (green algae) as a model organism for eukaryotes, as well as the *Nostoc sphaeroides* Kützing (cyanobacteria) as a model organism for prokaryotes. These types of studies can interrogate multiple aspects of future BLSS, including the role of inoculum state (lyophilized vs. in media, e.g. saline solution without carbon source) on cell viability after long-duration stasis in the high-radiation environment of cislunar orbit. A subset of the sample can be shielded to serve as controls of the radiation independent variable. The hardware needed to support these types of investigations would include radiation dosimeters and temperature controlled incubators. Crew time would only be required at the start of the experiment to set it up. Samples can then be automatically fixed at different times during the dormant periods for posterior analyses, including transcriptomics, which would allow us to understand the molecular genetic mechanisms behind any observed phenotypic phenomena. Should there be capabilities on board DSG for full RNA sequencing, gene expression data may be acquired *in situ* by using crew time and only data would need be sent to Earth. Otherwise, fixed samples would return to Earth for processing.

Table 1. Key features required to operate the experiment.

Mass	5 kg
Volume	0.02 m3
Temperature Control	- 20 °C
Crew Time	Start: 2 hours End: 12 hours
Power	100 W
Communication	Data downlink from onboard sequencing
Orbit	No specific requirements

Technology Demonstration of an Algal Photobioreactor as BLSS in Intermittently Occupied Habitats: As the DSG provides uninhabited periods of operation, the results from the basic research are used in a second step, to test the safing of a BLSS demonstrator. A testbed, based on the PBR@LSR experiment on board the ISS, is proposed that is augmenting the primary DSG life support system [9]. A carbon dioxide stream provided by the primary life support system acts as the input to the algal photobioreactor. Through photosynthesis, the algae then produce oxygen that is fed back into the cabin. This system is initially installed during a crewed stay but is from then on automatically controlled. The most promising technique established in the basic research phase of this experiment is implemented into the research reactor so that during the first dormancy stage the algal cells are preserved. Days before the next crew arrives, the culture is reactivated via remote control from the ground and is aiding in preconditioning the habitable atmosphere. As planetary surface bases are intended to employ NASA's proposed exploration atmosphere (8.2 psia, 34 % oxygen) due to the frequent EVA's, the DSG allows a high-fidelity demonstration, as it is also capable of providing that lower pressure but higher oxygen concentration atmosphere [10]. This is a key enabling technology of the DSG as it is in contrast to current ISS sea level atmosphere and therefore allows a demonstration of intermittent BLSS use in an operational environment.

Table 2. Key features required to operate the experiment.

Mass	60 kg
Volume	0.06m3
Temperature Control	30 °C (operating)
Crew Time	Operations: 4 hours Crew respiration: > 1 week
Power	300 W
Communication	Commanding and data downlink
Orbit	No specific requirements
Fluid Provision	Pure CO2

Conclusions: The proposed experiment both enhances our fundamental understanding of radiation effects on dormant algae but also demonstrates the effectiveness of different storage methods for dormant algal cells in terms of radiation robustness. These results are important for future BLSS design for future long-duration human spaceflight missions. If this technology proves to be successful, algae can be used to rapidly initialize a bioregenerative life support system, which is a major advantage over higher plants. Additionally, algae can be used as a temporary backup system in case of major failures of plant-based bioregenerative life support systems due to contamination or other failure mechanisms.

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SYNERGISTIC AND ADDITIVE EFFECTS OF DEEP SPACE RADIATION AND WEIGHTLESSNESS ON CELL AND ORGAN FUNCTION.

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Introduction: One of the biggest concerns for protection of astronaut health and performance during future deep space exploration missions is the combined effects of radiation and weightlessness. Cardiovascular and cerebrovascular diseases, digestive and endocrine disorders and immune system dysfunction are documented following exposure to terrestrial sources of ionizing radiation (e.g., gamma rays and x-rays). In particular, cardio- and cerebrovascular pathologies such as atherosclerosis are of major concern following gamma ray exposure. This evidence suggests a concern for possible degenerative tissue effects following exposures to ionizing radiation in the form of galactic cosmic rays (GCR) or solar particle events expected during long-duration spaceflight. The existence, however, of thresholds at lower doses, the impact of dose-rate and radiation quality effects, as well as mechanisms and pathways, are not well characterized. Degenerative disease risks are difficult to assess because multiple factors, including radiation, are believed to play a role in the etiology of the diseases. Data specific to the space radiation environment must be compiled to quantify the magnitude of these health risks in order to decrease the uncertainty in current Permissible Exposure Limits (PELs), to quantify the impact to disease-free survival years, and to determine if additional protection or mitigation strategies are required.

In addition to the effects of radiation, 0 G also induces changes predisposing to atherosclerotic disease such as structural changes in the upper body cardiovascular system with thickening of the Intima-Media of the arterial vessel walls caused by the redistribution of blood and increased pressures [1, 2]. Other systems are likewise affected by 0 G such as the immune system [3], and biomarkers for oxidative stress and damage are present [4]. Since radiation and 0 G each exhibit these effects, the purpose of this project is to investigate the combined effects on basic cellular mechanisms in order to evaluate whether it will be a health hazard for astronauts to engage in deep space exploration missions. Since these combined effects cannot be simulated accurately on the ground nor in low Earth orbit, Gateway research is critical for this purpose.

Methods: Investigations of mammalian cell cultures as well as organs-on-chips will be done from the Deep Space Gateway by telemetry [5]. Cells will be monitored regularly for metabolic activity, growth and viability, and results compared to data from ground simulations in a GCR simulator at NSRL, as well as to outcomes of ground based simulations of 0 G (bioreactors) effects. The organs-on-chips with pieces of organs will be regularly monitored for changes in selected physiological variables and also compared to ground simulation effects.

Resources Required: Mammalian cell cultures will be imbedded in microfluidic cards and the miniature organs supplied by miniature flows. The monitoring equipment will consist of a 3-color LED detection system, metabolic dye and fluorescence indicators, and microscopy. Provisions for monitoring of specific soluble biomarkers and for stimulation of the mammalian cultures by mitogens as well as activation and deactivation of the organs-on-chips at various time points will also be included. Temperature, pressure, humidity and partial oxygen and carbon dioxide pressures will be monitored in the organs and cell cultures.

Volume: 3 x (0.40 x 0.25 x 0.15) cm^3 = 0.015 m^3.

Mass: 3x 6.8 Kg = 20.4 kg

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GATEWAY STUDIES OF DUST IMPACTS AT THE EARTH AND MOON.

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Introduction: Small dust grains are ubiquitous throughout the solar system, originating from both asteroids and comets. These dust grains impact both the Earth and Moon, generating short-lived flashes of light from the ionization and recombination of atoms from both the impacting grain and its target. While much of the visible emission comes from numerous transitions of ionized iron atoms, the ultraviolet emission lines arise from SiO, Si, Zn, Cr, Al, Co, Fe, Ni, Cr, Mg, Ca and C, as well as minor contributions from H, N and O. More importantly, the intensity of these lines varies with the velocity of the dust grain as it enters the Earth's atmosphere and (to first order) with the energy of the impact into the lunar regolith.

Quantitative analysis of meteor spectra throughout the visible is nearly impossible due to the predominance of iron lines that overwhelm most other emissions. However, Fe emission lines are much less abundant in the ultraviolet and therefore analyses of meteor spectra in the ultraviolet are possible. Ground-based studies of meteors entering the terrestrial atmosphere have been carried out (1) to measure the frequency and velocity of both random meteors and meteor streams, but compositional data from these studies is quite limited. Similarly, ground-based observations of impacts into the lunar regolith are routinely carried out (2), but these observations are limited to the visible region of the spectrum due to atmospheric absorption of UV photons. Analysis of UV meteor spectra is only possible from a platform high above the Earth's surface.

Scientific Rationale: We have entered an age of sample return from a variety of small bodies in the solar system, but we will never visit or return samples from even a tiny fraction of these targets. Meteorites provide a biased sample of the small body population that can both survive atmospheric entry and be recognized as an extraterrestrial sample. Small, fragile grains are destroyed in the atmosphere, while organic- and volatile-rich samples such as the Tagish Lake meteorite are very difficult to identify on the ground except under special circumstances (such as landing on an ice-covered lake). Analysis of ultraviolet meteor spectra over the whole Earth would provide an unbiased survey of incoming meteors, including meteor streams that can be traced directly back to their source asteroids and comets (3) and thus could provide basic chemical data for a much larger sample of the small body population.

Importance to Manned Exploration: Micrometeorite impacts can erode equipment in earth orbit, on the lunar surface and anywhere in between. We have models of the flux and energy distribution of micrometeorites throughout the solar system that are used to establish safety margins for both science spacecraft as well as for manned missions (4). However, these models are relatively simple compared to models that could be derived from near-continuous observations of the ultraviolet emission spectrum of meteors entering the terrestrial atmosphere or impacting the Moon. Detailed predictions of the flux, velocity distribution and composition of the incoming particles as a function of time would provide a much more sophisticated understanding of the relative contributions of random meteors (as a background source) and the individual contributions of meteor streams whose impact velocity can vary from ~3 km/s to over 70 km/s. More complete models of the impacting particle flux on the lunar surface or in cislunar space could provide an enhanced tool for mission planning that would increase safety.

Observational Requirements: Ground-based observations of meteors, meteor showers and lunar impacts already provide information on the flux and velocity distributions of impactors (1,4). Ultraviolet observations of the spectra of these small dust grains between ~100 – 300nm can provide flux and velocity data as well as chemical composition for the large numbers of dust grains impacting the Earth and Moon. This would allow a more accurate analysis of the contribution of asteroids and comets to the small grain background population and would provide a first order composition for each of the small bodies that has been identified as a source for a specific meteor shower (3).

Meteors entering the terrestrial atmosphere are intense streaks of light and do not require a "slit" in order to disperse their spectra across a detector (5). This makes observation of the entire terrestrial atmosphere possible on a continuous basis: a fast UV camera can either observe a reflective grating (see, e.g., Figure 1) to image the target or could image the target through a transparent grating. In either case the spectrum would be dispersed by the grating and collected for analysis by the camera. Lunar flashes ould be recorded as spectrally dispersed point sources by such an instrument.

The terrestrial atmosphere does not efficiently reflect sunlight in the ultraviolet (5) and therefore provides a steady, dark background for these observations.

While the lunar surface does reflect sunlight at the wavelengths of interest, this background should be minimal and constant across the surface compared to the intense flashes expected from most lunar impacts. The major concern in analyses of lunar impacts is in separation of the chemical contribution of the impactor from the target. It might prove impossible to separate refractory element contributions from major elements such as Fe, Mg and Si. However, volatile elements such as C or Zn that should be less abundant on the lunar surface compared to the meteor population could be studied.

Science at the Gateway: Several different orbits have been proposed for the Gateway ranging from those close to the lunar surface, to wide ranging polar orbits. For close lunar orbits a simple nadir-pointed instrument would be sufficient to observe the spectral flashes of dust impacts. Our preference would be for the widest possible spatial coverage, though the spectral bandwidth could be tailored to monitor just a few specific spectral lines to yield, *e.g.,* C/Fe or Zn/Si ratios over the lunar surface. Certain polar orbits could also provide such data. The exact specifications for the grating, camera sensitivity and optics would be determined once the orbit of the gateway is specified. For these observations it would be desireable to have a circular orbit to minimize variations in the flash intensity observed at the Gateway due to variations in the diatance to the lunar surface.

Observations of terrestrial meteor spectra require an earth-pointed instrument and a smaller field of view. As we expect that communications with earth will demand an earth-pointed, high-gain antenna, one option for recording the spectra of terrestrial meteors would be to attach the instrument to ride along with the antenna and record spectra whenever the antenna is pointed towards the Earth. For this option, the instrument should have a field of view roughly twice the diameter of the Earth in order to be sure to capture spectra over the entire disk. For an independently stearable instrument the field of view requirement could be relaxed. The relative variation in earth-moon distance should be minimal in all of the proposed Gateway orbits making the observed intensity variations among meteors more easily convertible into velocity distributions.

Future Studies: Observations of the UV spectra of dust impacts are possible in any of the potential orbital configurations discussed for the Gateway using either the lunar regolith or the terrestrial atmosphere as targets. The exact requirements for such an instrument and the data that can be derived from the observations will depend on the orbit of the Gateway and the ability to point the instrument at the appropriate target. An appropriate trade study should be conducted once more details of the Gateway have been solidified.

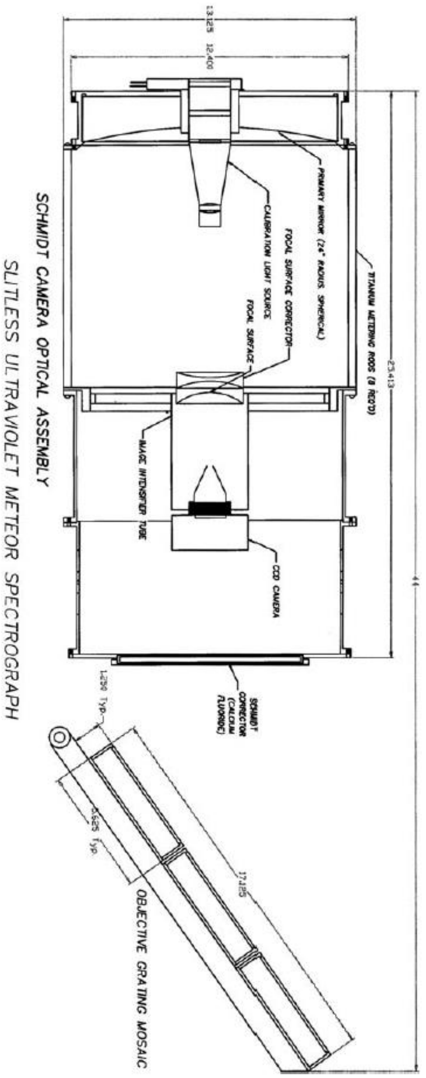

Figure 1. Schematic diagram of the baseline slitless ultraviolet meteor spectrometer (SUMS)

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EVALUATING SPACE WEATHER ARCHITECTURE OPTIONS TO SUPPORT HUMAN DEEP SPACE EXPLORATION OF THE MOON AND MARS,

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Introduction: NASA's Engineering and Space Center (NESC) is conducting an independent technical assessment of space environment monitoring and forecasting architecture options to support human and robotic deep space exploration with William H. Gerstenmaier, Associate Administrator for the Human Exploration and Operations Directorate (HEOMD) serving as the primary stakeholder for the study. The assessment that is being currently conducted considers near-real-time monitoring and forecast needs for space radiation.

The assessment will provide NASA with options for a robust and cost-effective space weather situational awareness architecture that can effectively reduce space radiation risks for crewed and robotic operations in the inner heliosphere in orbits about Earth, cislunar space, and Mars.

Scope: Human and robotic deep space exploration activities at low Earth orbit are relatively well protected from the charged particle radiation caused by galactic cosmic rays and eruptive solar events. However, as the Agency moves forward with its lunar Deep Space Gateway and ultimately journey to Mars goals, many key future human space exploration activities will take place outside the Earth's protective magnetic shielding. Space weather hazards, e.g., charged particle radiation, are some of the key challenges to be addressed when humans enter the deep space environment.

As recognized in the report, "NASA's Efforts to Manage Health and Human Performance Risks for Space Exploration" [1], space radiation remains a top risk for human and robotic deep space exploration. Limited knowledge about degenerative radiation effects is a key concern. While much remains to be understood, it is clear that any reasonable risk mitigation will require advanced situational awareness about space environment conditions that lead to radiation exposure. It is likely that as a part of the risk mitigation, some form of crew storm-shelter procedures will be implemented and executed based on real-time and possibly predictive information about the space environment.

The establishment of robust space weather situational awareness will demand joint usage of observations, models, and analysis. Given the complex nature of the heliosphere, a variety of approaches will be required for an optimal outcome. Further, while leveraging existing interagency and international space weather capabilities, uniquely human and robotic deep space exploration needs and procedures must be considered.

Technical Activities: The assessment will consider near-real timemonitoring assets, space radiation analysis tools, and forecast methods that can support human-vehicle systems for HEOMD and robotic systems for Science Mission Directorate (SMD) missions beyond low Earth orbit in the areas of:

- *In-situ* radiation monitoring hardware planned for deployment on exploration vehicles;
- Existing space environment sensors from NASA, National Oceanic and Atmsopheric Administration (NOAA), the Department of Defense (DoD), and other organizations to the greatest extent possible; and
- A minimal set of new hardware only where necessary.

The technical activities for the assessment include six tasks:

Task 1: Review of Previous Material

Review of prior/current work on space weather architectures to understand any possible gaps in knowledge in fulfilling the requirements. Specifically, the assessment team will consider hardware requirements, habitat designs including storm shelters for manned missions, and space weather monitoring assets for future missions using information from NASA, NOAA, and DoD, such as:

- Availability of space weather monitoring assets for future missionsNational Space Weather Action Plan (SWAP) and Space Weather Operations, Research, and Mitigation (SWORM) activitiesHuman Systems Integration Requirements (HSIR, CxP 70044) and Design Specification for Natural Environments (DSNE, CxP 70023) documents.

Task 2: Assessment of Operational Response Time for Space Weather Monitoring

Develope possible operational response sequences for given sets of observations, models, and tools. This would include assessing the data-stream parameters required for decision making.

Task 3: Review of Relevant Forecasting Tools

Develope a catalogue of physics-based and empirical models and tools for use in conjunction with different observational architectures.

Task 4: Assessment of Solar Energetic Particle (SEP) Threshold Levels for Exploration Missions

- Revisit the current SEP constraints to assess if they are appropriate for Orion, Mars Habitat, and extravehicular activity (EVA).
- Provide recommendations for appropriate SEP constraints.

Task 5: Development of Space Weather Architectures

- Using the latest human deep space exploration scenarios (e.g., cislunar space, Mars, Moon) together with information about possible storm-shelter options, develop two to three observational architectures in support of operational response to major solar events. Architectures include observation locations and instrument types. Importantly, synergies between science and operational monitoring will be considered.
- Assess current and future satellite assets for any gaps in observations (e.g., SOHO, STEREO replacement, possible European Space Agency (ESA) L5 mission, Deep Space Climate Observatory (DSCOVR) follow-on).
- Provide a cost/benefit analysis of additional satellite assets.

Task 6: Space Weather Architecture Cost Estimates

Develope first-order cost estimates for the space weather architectures developed in Task 5. Emphasis will be placed on the most cost-effective solutions that leverage existing national operational space weather infrastructure.

Conclusions:

The NESC assessment team is developing and delivering the assessment report that is due by the end of FY18. The report will cover:

- Two to three space environment/weather monitoring and forecasting architecture options for safeguarding human and robotic deep space exploration. Existing interagency and international space weather capabilities will serve as the baseline for human space exploration-specific considerations.
- High-level specifications for the missions, instruments, systems, and activities associated with the options.
- Estimated costs of the options.

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PLANTS AS PART OF THE DEEP SPACE EXPLORATION SCHEMA.

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Introduction: Successful human deep space missions require a clear understanding of space related conditions impacting biology outside of the protection of the Earth's magnetic field. This is true for virtually every biological aspect of human deep space exploration, from the direct effects on astronaut health through to the effects on the biology needed for extended life support. This requirement is widely accepted and early biology experiments in the Apollo era were designed to collect data on a variety of biology species during trips to the moon and back. But those experiments were few, there are no samples remaining from those experiments and no such deep space biology has been done since then nor after the advent of the genomics era.

There is virtually no information on the impact of the deep space environment on terrestrial biology, and tests evaluated with modern tools of molecular analyses are non-existent. The cis-lunar space envisioned for the Gateway transitions and habitats can provide a research platform to fill this gap in knowledge that is crucial to further exploration, such as an extended mission to Mars.

Plants are ideal candidates for the first stage evaluation of the effects deep space has on terrestrial biology for several reasons. First, plants are model higher organisms, as well as being an integral part of the exploration equation. They have been widely used to test eukaryotic responses to the spaceflight environment, and abundant data exist for LEO responses [e.g. 1, 2, 3]. Second, plants are key components of bioregenerative life support systems [e.g. 4, 5], and so it is crucial that the data for deep space responses become as well understood as those accumulated for LEO microgravity environments. It is also worth noting that in addition to bioregenerative life support, plants are also important to the mitigation of potential psychosocial and neurocognitive decrements associated with long-duration space missions [6]. Third, although plants can be evaluated in many developmental stages, they can also spend extended time in a dormant state as seeds. As seeds, plants can be deployed for a variety of experimental scenarios that require extended transit times before activation, no other higher eukaryote has such a capacity.

An approach utilizing Gateway resources: The importance of the role of plants in human exploration life support and life enhancement is undisputed. There is no question that that's will be a part of the exploration scheme in cis-lunar space and on to Mars. And yet we know almost nothing about how plants will fare in those environments. Integrating a variety of plant support hardware systems in the Gateway facility can fill that crucial gap in knowledge.

It is not yet clear what type of plant support habitats could be integrated into Gateway, but there are a large variety of spaceflight growth systems that have been vetted on the ISS that could be adapted, depending on the focus and objective. Morphological data and biomass data can be produced by a variety of "salad-machine" type facilities such as Veggie and Lada, and an involved crew and sample return option could also provide profiles of the molecular responses to the cis-lunar environment. However, if crew time is limited, and sample return not an option, there is still an approach that could provide robust data on the molecular responses of plants to this environment. Passive imaging hardware akin to the decommissioned Advanced Biological Research System (ABRS) and its successor the Multi-spectrum Imager, could provide passive (limited crew involvement) imaging data of plant growth and development, as well as tissue-specific gene expression by means of fluorescent gene reporters [e.g. 3,7]. Plants could be engineered with a suite of genes of interest that represent both known and suspected dangerous stressors, such as an enhanced exposure to cosmic radiation, and then responses passively observed with telemetric data collection.

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IMAGING GEOSPACE FROM CIS-LUNAR ORBIT.

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Introduction: Photon imaging of Geospace, the global ionosphere and magnetosphere, can be accomplished from the lunar surface, in lunar orbit, or in other orbital locations via trans-lunar assets. The ability to image the entire Earth at FUV wavelengths would transform our understanding of the coupled magnetosphere/ionosphere/thermosphere system.

*Value.*Global observations of ionospheric and magnetospheric phenomena provide measurements that are key to understanding space weather in the regions of space where most scientific, commercial and military space operations occur. These measurements also provide constraints to global ionospheric models and provide keys to solving compelling questions associated with the coupling between the magnetosphere and ionosphere and coupling of the high and mid-equatorial regions of the ionosphere.

Figure 1, an annotated image from the Apollo 16 FUV camera built by George Carruthers of NRL[1], illustrates in coarse resolution the fetures to be observed from the moon.

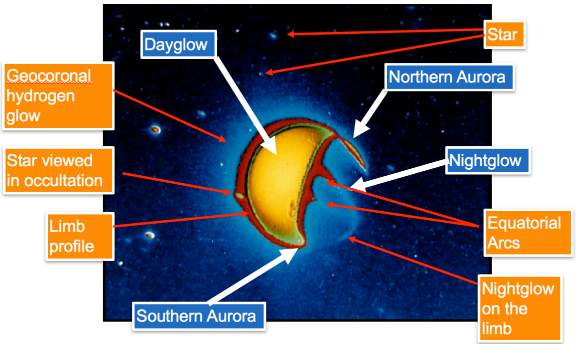

Figure 1. Many of these questions identified above have applications to space weather and therefore have significant value beyond providing an understanding to the dynamics of the coupled Geospace region. Typical products are: O, O2, and N2 limb profiles; O/N2 maps; auroral characteristic energy and flux; auroral boundaries; ionospheric characterization including TEC.

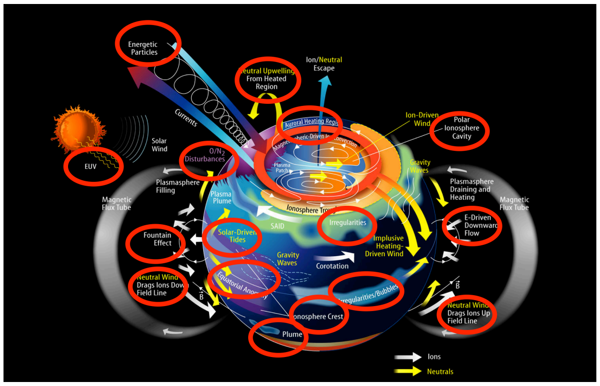

Figure 2. Annotated version of the well-known "Grebowsky" figure. The cirlces indicate the phenomena that have FUV signatures.

The value of FUV remote sensing has recently been reviewed [2]. The signatures, illustrated schematically in Figure 2, cover the inputs and the response of the system. A cis-lunar FUV imaging system would be well suited to providing imagery of the system at either selected FUV wavebands or full spectral information with a low data rate and low power consumption using proven, validated algorithms. The sensor design is not entirely specifiable based on the lack of specificity in the mission concept. However, a sprectographic system using a scan system (ether a mirror or platform) can accommodate a large range of viewing geometries. The cis-lunar platform concept actually provides an incredible opportunity; with the same system wwe can specify the spatial variability of the coupled ionosphere/thermosphere system over three orders of magnitude in spatial resolution. This can be accomplished by not attempting to vary the spatial resolution of the imager – by choosing a spatial resolution suitable for mesoscale imaging and using that to fix the resolution of the system at the effective apogee, we can produce a cost-effective design.

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SERVICING LARGE SPACE TELESCOPES WITH THE DEEP SPACE GATEWAY. B.M. Peterson[1] L.D. Feinberg[2], M.A. Greenhouse[2], J.M. Grunsfeld[2], R.S. Polidan[3], N. Siegler[4], and H.A. Thronson[2]. [1]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218 and Department of Astronomy, The Ohio State University, 140 West 18th Avenue, Columbus, OH 43210, Peterson.12@osu.edu, [2]NASA Goddard Space Flight Center, Greenbelt, MD USA 20771, [3]Polidan Science Systems & Technologies, LLC, 3884 NW Orchard Ct, Suite 100, Terrebonne, OR 97760, [4]NASA Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena CA 91109

Future major missions in astrophysics, including the James Webb Space Telescope (JWST) and the Wide Field Infrared Space Telescope (WFIRST), are designed to operate at Sun-Earth L2, which affords a number of significant advantages relative to low-Earth orbit. Future generations of major missions will probably also operate at SE-L2. However, to fully realize the potential of future major telescopes and amortize their cost, these observatories will require long operational lifetimes, which means that they will need to be serviceable. This was the case with the Hubble Space Telescope (HST), which demonstrated the immense scientific value by using astronauts for regular upgrading of instruments and spacecraft systems.

Servicing at SE-L2 seems unlikely, given the multiple challenges to operate with humans at that distance. However, the energy requirements to move from SE-L2 back to cis-lunar space for servicing are comparatively modest. Observatories at Earth-Moon L1 or L2 would be much easier to service, either robotically, by humans, or likely by some combination of the two. Such a capability would be of significant and easily justified scientific value, just as was the case with HST and its multiple servicing missions.

NASA’s human space flight program has identified the Deep Space Gateway (DSG) as its next major facility beyond the immediate vicinity of the Earth. The early design phase of the DSG affords an opportunity to incorporate features that will enable servicing in cis-lunar space, both with astronauts and their telerobotics partners. Perhaps eventually these capabilities may be extended to enable in-space assembly of telescopes much larger than those currently under study.

DIAGNOSTICS OF THE SOLAR WIND AND GLOBAL HELIOSPHERE WITH LYMAN-α EMISSION MEASUREMENTS

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Introduction: The Sun with the heliosphere around it moves through the local interstellar medium (ISM). The solar wind interacts with the interstellar gas forming a complex interaction region, *heliospheric interface*, at the edge of the heliosphere at the distance approximately 100 AU from the Sun. The schematic picture of this region is shown in Figure 1. The interstellar gas surrounding the heliosphere is weakly ionized plasma mainly consisting of hydrogen atoms (H atoms). Interstellar H atoms penetrate through the interaction region to the heliosphere. As H atoms travel, they interact with plasma protons in the resonant charge-exchange process and a newly created H atom inherits properties from the plasma proton. Since H atoms move through the regions with different plasma properties (regions 1,2,3,4 in Figure 1), different populations of H atoms exists in the heliosphere. Properties of plasma in the heliosphere and its boundary are imprinted on H atoms that can be observed near Earth directly or through remote sensing.

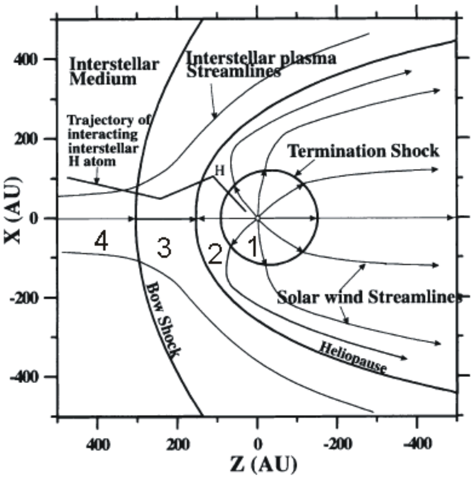

Figure 1. Schematic pucture of the heliospheric interface.

Solar Lyman-α radiation (with the wavelength at line center 1215.67 A and line width about 1 A) is effectively backscattered by H atoms in the heliosphere. Spectral properties of the backscattered Lyman-α emission depend on the distribution of H atoms (density, velocity and temperature). The H distribution in the heliosphere (near Earth) is affected by several factors: 1) solar wind and solar radiation; 2) plasma parameters in the heliospheric interface; 3) parameters in the local ISM. Measurements of interplanetary Lyman-α emission near Earth provide a unique possibility to investigate global properties of the solar wind and interaction of the heliosphere with the interstellar medium. Additionally, observations of Lyman-α are valuable for studies of Earth exosphere and comets. The remote diagnostic of hydrogen through Lyman-α emission remains an important technique due to the difficulty of direct measurements of hydrogen because of their low energies.

Previous mission: The instrument SWAN (Solar Wind Anisotropies) on SOHO (Solar and Heliospheric Observatory) has been mapping the backscattered Lyman-α emission from the interplanetary H atoms for 22 years by now (Figure 2). SWAN observations made possible several important discoveries in heliophysics: 1) to determine the deflection of hydrogen flow in the heliosphere relative to the direction of the local ISM flow which constrained the direction of the magnetic field in the local ISM [1]; 2) to determine the temperature of interstellar H atoms in the heliosphere [2]; 3) to reveal variations of latitudinal structure of the solar wind during two solar cycles and find characteristic maxima of solar wind mass flux during solar maximum reflecting effects of solar active regions [3, 4] SWAN data were routinely and efficiently used for calibration of other instruments, analysis of emission from Earth exosphere and comets.

These scientific results brought a new understanding of properties of the local ISM, nature of the interaction between the solar wind and local ISM and solar wind variability with the solar cycle. Additionally, analysis of SWAN data provided observationally constrained boundary conditions for the global models of the solar wind and heliosphere[4, 5].

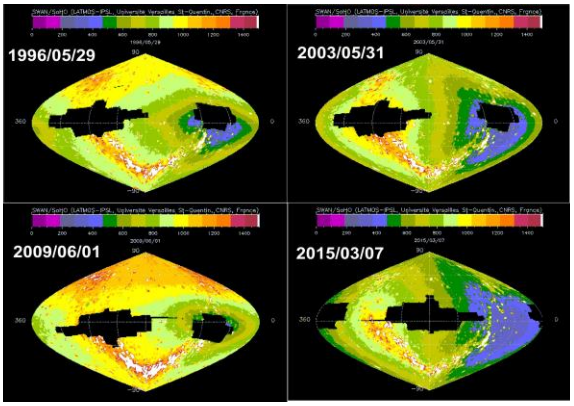

Figure 2. Full sky maps of intensity of scattered Lyman-a emission observed on SWAN/SOHO.

Proposed instrument: To continue global monitoring of the scattered Lyman-α radiation in the future we propose to develop an instrument measuring an intensity and spectra of interplanetary scattered Lyman-α emission. Capability of measuring of Lyman-α line profiles in different line of sights will be a major improvement compared to the SWAN instrument which did not perform systematic measurements of Lyman-α spectra.

The science objectives are the following:

1. **Global monitoring of the latitudinal structure of the solar wind during the solar cycle**

The instrument will deliver full sky maps of scattered Lyman-α emission with increased angular resolution in the range 0.01-0.1° (compared to 1° on exsisting SWAN) every 0.5-2 days (this will depend on the possibility to scan the full sky and the time required to acquire the signal). Lyman-α intensity maps will be used in an improved inversion procedure [6] to infer the latitudinal structure of the solar wind mass flux with a resolution of few degrees. This will allow for the investigation of the variation of solar activity and the distribution of active regions on the Sun during the solar cycle; and will provide an observationally constrained solar wind mass flux that is essential for global models of the heliosphere.

2. **Diagnostics of active regions on the far side of the Sun**

Solar active regions emit higher flux of the solar Lyman-α photons compared to quiet solar regions which results in an increased intensity of scattered Lyman-α emission. If an active region exists on the far side of the Sun (which normally is impossible to observe from Earth) we will see its imprint on the full sky map of Lyman-α emission as a region with stronger intensity [7]. Analysis of Lyman-α intensity maps along with supporting modeling work will facilitate predicting the existence, determining the location and exploring the evolution of active regions on the far side of the Sun.

3. **Determine characteristics of the hydrogen distribution in the heliosphere, perform remote diagnostics of the interaction region between the solar wind and the local ISM**

Analysis of spectral characteristics of scattered Lyman-α emission in different lines of sight together with kinetic models of the hydrogen distribution in the heliosphere [8] will allow to infer parameters of the local ISM (hydrogen density, direction of the interstellar flow, geometry of the magnetic field), their possible temporal variations and study properties of the heliospheric boundary.

4. **Observations and diagnostics of the Earth exosphere**

The geocorona refers to the Lyman-α light scattered from the cloud of hydrogen atoms surrounding Earth known as the exosphere. From the Moon orbit it will be possible to observe full high resolution maps of the geocorona during relatively short periods of time. Intensity maps together with spectral measurements enable to determine the hydrogen distribution (density and temperature) in Earth's exosphere, its variations and the different effects and processes affecting this distribution.

5. **Search for comets and determine their properties**

When a comet approaches to the Sun, a hydrogen cloud forms around it and scatters solar Lyman-α emission. Observations of the sky in Lyman-α allows to locate a comet, determine the hydrogen density and its variation, water production rate, composition and structure of the comet and possibly bring some information on its origin.

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Deep Space Gateway Science Opportunities.

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Introduction: The NASA Life Sciences Research Capabilities Team (LSRCT) has been formulating deep space research questions and needs for the last two years. Members of NASA's LSRCT are submitting a number of other abstracts, in addition this one, to reflect the full range of desirable life science research at the Gateway and are deliberately not eliminating any ideas based on a feasibility assessment.

NASA's programs conducting life sciences studies, the Human Research Program, Space Biology, Astrobiology, and Planetary Protection, see the Deep Space Gateway (DSG) as affording enormous opportunities to investigate biological organisms in a unique environment that cannot be replicated in Earth-based laboratories or on Low Earth Orbit science platforms. These investigations may provide in many cases the definitive answers to risks associated with exploration and living outside Earth's protective magnetic field.

Unlike Low Earth Orbit or terrestrial locations, the Gateway location will be subjected to the true deep space spectrum and influence of both galactic cosmic and solar particle radiation and thus presents an opportunity to investigate their long-term exposure effects. The question of how a community of biological organisms change over time within the harsh environment of space flight outside of the magnetic field protection can be investigated.

The biological response to the absence of Earth's geomagnetic field can be studied for the first time. Will organisms change in new and unique ways under these new conditions? This may be of specific interest in the development of microbial communities over time.

The Gateway provides a platform for microbiology experiments both inside, to improve understanding of interactions between microbes and human habitats, and outside, to improve understanding of microbe-hardware interactions during the exposure to the space environment.

The current plan calls for the Gateway to be human-tended for up to 40 days per year which is ideal to investigate the island biology aspect of long duration space flight. Not having astronauts on the Gateway during most of the research period may even improve the quality of the test results. Their annual presence, however, will assure that the automated systems can be repaired, updated or even replaced and the biological species can be sampled, replaced or restocked as needed to assure continued productivity during the untended periods, in a manner analogous to Space Shuttle servicing missions to the Hubble Space Telescope.

What needs to be done: To enable meaningful biological research that can directly address key knowledge gaps and risk factors for long duration exploration missions, the technical capabilities and resources have to be built into the Gateway facility. The operating conditions, during periods of both crew occupancy and vacant free flight, need to be established during the development phase of the Gateway and needed capability built into the flight system. The types of science to be conducted and the associated operating conditions will be an essential driver in DSG system design. Some of the operating conditions will be critical to the survival of the biological samples and others will have to be held to constant levels so LEO and ground based comparative studies can be conducted. Conducting research investigations on the Gateway enables continuous use of the Gateway during periods of crew occupancy and vacancy, which maximizes the return on investment of the GSD as a research platform.

What should be done: The DSG provides an opportunity to demonstrate and incrementally improve the capability to perform automated and remote life science investigations and production activities. As we move biological systems further away from earth, support system performance will be elevated to critical status. Within the habitat enclosures a stable system containing humans, animals, microbes, food producing systems, and human support systems must work in unison for long periods of time. The DSG, being in the deep space environment, will provide an opportunity to demonstrate and learn about the management of these complex integrated systems. The performance testing of bio-regenerative components in the deep space environment is an essential step in their acceptance for use in both transit systems and surface habitats. The understanding and management of the microbiome within habitats built for the deep space environment both during human occupancy and vacancy is critical to mission success.

How should Life Science be done during the Gateway era: The suite of equipment we currently have on ISS should be a point of departure for the suite recommended for inclusion on the Gateway. The triad of investigations performed at LEO, at the GSD, and within ground test chambers will reveal performance data on how animals, microbes and plants perform in unique environmental conditions. On the ground, we can tightly control the environmental conditions and mimic LEO and the Gateway but without the weightless, radiation, and magnetic field effects. At LEO, we can tightly control the environment and experience weightlessness but not the space radiation and magnetic field effects. At the GSD, we will have a controlled environment, weightlessness, and the radiation and zero magnetic field effects. Together, data coming from these three research locations will reveal the important considerations for further exploration systems.

As a starting point, the Gateway needs to be equipped with a comprehensive internal and external environmental monitoring system. It must have the ability to transmit environment and experiment conditions data to the ground monitoring station. The capability to perform petri dish science with real-time imaging to enable remote operations and data collection is needed. A capability to remotely initiate and control biological experiments will be a key Exploration capability and permit risk reduction studies in the radiation environment. Locations for the storage of prepackaged food is needed so samples can be returned to Earth for analysis after periods of one, two, three, four, and five years for degradation analysis are needed. Each mission to the Gateway will represent a consolidated campaign of life science questions covering the interests of Space Biology, the Human Research Program, Astrobiology, and Planetary Protection.

What is needed to perform Deep Space Gateway Life Science: An EXPRESS rack (or equivalent) location for biological investigations, an external exposure facility, needed sample transfer equipment, and a consistant and stable internal environment is needed.

- Internal to the Gateway Habitat: The equipment being used on ISS has been developed for usage in the EXPRESS racks and a similar capability at the Gateway would enable common equipment usage. The power, fluid, instrumentation, and thermal capabilities would be common to both Gateway and ISS. To best support automated and remote operations, and the computational, data storage, and data communication capabilities needed, the ISS heritage hardware, needs to be upgraded to the current state-of-the-art.
- External to the Gateway Facility: An external exposure location for microbes, spores, and seeds to assess the near and long-term effects of unshielded exposure to the deep space radiation environment is needed.
- Biological samples delivered and returned from the Gateway need to be handled within a set of conditions that supports controlled science investigations at the Gateway and ensures valid post flight analyses.
- The internal environment at the Gateway would need to be maintained at the same conditions during periods of occupancy and vacancy to support biological studies. Those atmospheric conditions should be kept nominally at 14.7 psi, 75° F, 60% humidity, and less then 2000 PPM CO_2.

Conclusion:

The proposed Deep Space Gateway, when used in a coordinated manner with ISS and ground-based facilities, presents an opportunity to acquire the needed understanding of life processes to assure adequate mitigation of the risks to astronauts on deep space exploration missions while providing insights into basic biological processes in a rigorous manner. Appropriate attention to science requirements now can assure the maximum useful operational and scientific return during utilization.

Keys areas of scientific investigation will be on the biological effects of solar and galactic cosmic radiation, the integrated effects of microgravity and radiation on living systems, microbial development in the absence of a magnetic field, and generational development of microbial communities in an isolated and hostal environment.

The Worsening Space Environment: Increased Galactic Cosmic Radiation From Historically Weak Solar Magnetic Fields But With a Sun Still Spawning Historically Intense Solar Particle Events.

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Abstract: The anomalously low solar activity observed for cycle 23 is followed by the mini solar maximum of cycle 24, indicating that we may be entering an era of persistent decline in solar activity. As a result, we have observed the highest fluxes of galactic cosmic rays in the space age, and relatively few solar energetic particle events. A permanent presence in deep space will expose astronauts and equipment to a different radiation dose environment than experienced on the International Space Station. Here we report on observations from CRaTER (the Cosmic Radiation Telescope for the Effects of Radiation) on Lunar Reconnaissance Orbiter (LRO). [1] used the evolution of the interplanetary magnetic field from [2] to project dose rates from galactic cosmic rays on the lunar surface predicting a ~ 20% increase in the dose rates from one solar minimum to the next. Comparing actual dose rates observed by CRaTER in the last 4 years with the predictions of [1] shows a 10% further increase, indicating that the radiation environment is worsening even more rapidly than previously estimated [3]. Here, we apply a more recent reconstruction of the interplanetary magnetic field from [4] for past solar grand minima conditions, including the Maunder minimum (1645-1715) and the Dalton minimum (1790-1830), to predict the dose rates of galactic cosmic rays throughout the next solar cycle [5]. We use these results to predict the most conservative allowable mission durations based on 3% risk of exposure-induced death (REID) at 95% confidence level in interplanetary space.

Despite the persistent paucity of solar activity, the solar energetic particle event of September 2017 was extremely hard with the largest dose rates in D3/D4 (the most shielded detectors of CRaTER). It occurred as the result of successive fast coronal mass ejections. The occurrence of the September 2017 event after more than a year of very few solar particle events shows that besides the high galactic cosmic radiation, discrete solar energetic particle events remain a significant hazard [3]. We suggest that an instrument such as CRaTER on the Deep Space Gateway (DSG) could provide realtime knowledge of ionizing radiation.

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Thermal Infrared Earth Imaging from the DSG.

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Introduction: The general goal of NASA Earth Science research is to understand surface and atmospheric processes that lead to a better understanding of the Earth System. To advance this knowledge, data are used to model and monitor both short and longer-term change. In so doing, we enable more accurate prediction of those changes and improve our understanding of their consequences for life on Earth. Much of the data needed for this research are collected by an array of low Earth orbiting (LEO) and geostationary (GEO) satellite-based instruments coupled with ground and airborne measurements. However, these platforms do not provide data of the whole-Earth view at rapid timescales, which could be possible from the Deep Space Gateway in near-Lunar orbit.

An “Earth Observatory” at this location would offer a unique, stable, and serviceable platform for global, continuous, full-spectrum, unique views of the Earth needed to address a range of Earth Science issues over time. It would also provide instrument synergy among multiple LEO and GEO satellites for cooperative operations, enhanced calibration, and science. Depending on the final DSG location, full or somewhat limited views of the Earth will be possible. Earth-focused instruments on the Deep Space Gateway would be immediately useful for Earth science and instrument testing. Over a longer-term phased approach, however, time-dependent data of atmospheric composition, ecosystem health, and hazard monitoring could be possible.

The rotation of Earth as seen from the future DSG would provide unprecedented temporal views of transient phenomena. Furthermore, the Earth’s orbital precession would allow observations of the polar regions (something not possible with GEO satellites). However, the DSG will be many times further from Earth than GEO satellites, which makes acquiring data with useful spatial scales for smaller-scale processes more difficult.

Measurements: A dedicated Earth Observatory based on the DSG allows for global, continuous full-spectrum views of the Earth to address a range of Earth Science issues. The high temporal data frequency coupled with the ability to observe a given location for up to 12 hours enables detection and analysis of time-dependent atmospheric composition (i.e., global mapping of emissions, long-range transport of pollution plumes, greenhouse gases sources and sinks). This observational geometry makes new solid-earth, ecosystem and climate monitoring possible (i.e., volcanic eruptions, wildland fires, health and structure of vegetation, drought and land degradation). With climate change comes the critical need to observe changes in the cryosphere (i.e., ice shelf disintegration, sea ice change, snow cover cycles). Such a platform also allows the Sun-Earth system to be observed simultaneously, providing data on the Earth’s radiation balance and solar variability influence on climate. Finally, the numerous limb occultation opportunities over wavelengths from the visible (using stars) to the microwave (using GPS signals) to VHF (using communication signals) provide additional opportunities for observing the vertical structure of the Earth’s atmosphere.

Instrument Concept: Thermally-elevated features (volcanic, fire, and anthropogenic activity) are currently monitored at high spatial resolution with LEO-based instruments such as ASTER, TIRS and MODIS. These features are monitored at high temporal resolution by GEO-based observations. These sensors are not able to capture data at time scales really required for scientific and hazard analysis in near-real time; nor can they track a specific event over time.

A DSG-based instrument capturing high temporal frequency data could achieve the needed temporal frequency. Perhaps even more critically, it could serve in conjunction with LEO and GEO satellites in an enhanced sensor-web approach. Such an instrument could be phased, upgrading over time from a more simplified multispectral imager to a full spectral resolution imaging spectrometer. Full Earth views are critical for such a concept to be fully realized, but the telescope could be as small as 30-50 cm and achieve acceptable spatial resolution.

Thermal infrared (TIR) image-based and spectral-based data would be one important data set to consider for a DSG application. These data allow for the detection of thermally-elevated features as well as detailed compositional analysis of atmospheric and surface processes. Instruments in Earth and Mars orbits have shown the scientific importance of these data and a recent observation of Earth from a great distance (Fig. 1) by the OTES instrument on the OSIRIS-REx Mission confirm these measurements are possible and quite useful [1].

At the 2007 Lunar Workshop in Tempe, AZ, we summarized a concept of a modest TIR imager having a 30 cm aperture with a 0.2° IFOV and a 2,048 pixel array (similar to the HiRISE Camera Mars Reconnaissance Orbiter) that would provide 10 km/pixel (TIR) data [2]. Such an imager would only cover a 1,000 km x 1,000 km field of view during a given scan. A complete Earth view could be built up over time. However, if the sensor was made pointable, it could be integrated into a sensor web concept with LEO and GEO satellites to target quickly any given location on Earth. Alternatively, the instrument could target a particular location and track it throughout the 12-hour period that it would be in view. Examples targets necessitating this tracking option would be wildfires, large volcanic plumes or pollution events.

Such an instrument could be part of an initial suite on the DSG designed be upgradeable over time. This would involve astronaut involvement to upgrade focal plane arrays, incorporate new technologies, operate in research mode, and provide real-time link between GEO and LEO observations.

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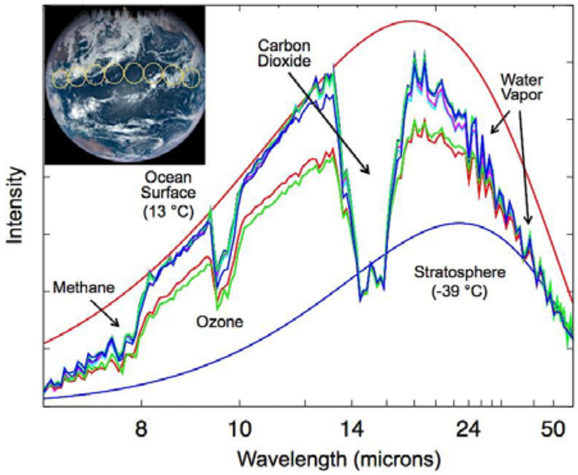

Figure 1. Showing almost entirely ocean and clouds, planet Earth (upper left) appears misnamed in this view taken by OSIRIS-REx on Sept. 22, two hours after its closest approach to Earth. The circles, each about 500 miles in diameter, indicate where the OTES spectrometer made its observations.

HYDROGEN COSMOLOGY FROM THE DEEP SPACE GATEWAY: DATA ANALYSIS PIPELINE FOR LOW-FREQUENCY RADIO TELESCOPES.

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Introduction: This is a companion abstract to two others presenting proposals for low-frequency radio telescopes. One is to be bolted on the NASA's planned Deep Space Gateway (DSG), and therefore on lunar orbit (Tauscher et al.), and the other to be deployed from the DSG to the surface of the Moon (Monsalve et al.). The goal of these instruments is to take advantage of the radio quiet environs above the lunar farside at night, with no ionospheric effects and hidden from Earth's radio frequency interference (RFI) and Solar radio emissions. All this is critical to not only detect, for the first time, the hyperfine line of neutral hydrogen (HI) produced, during Cosmic Dawn and Reionization, by the first stars, galaxies and black holes, but also to precisely measure this signal, rich in astrophysical and cosmological information on these early epochs of the Universe.

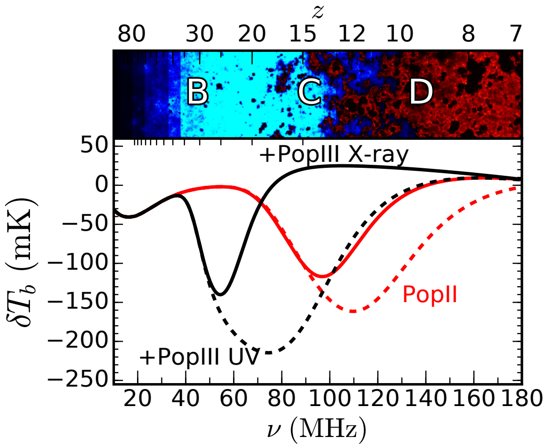

Figure1: The upper panel shows the evolution of a slice of the Universe from early (left) to late times (right), and the lower panel, different models of the global 21-cm spectrum relative to the CMB temperature. The red lines are conservative models with metal-rich stars (Pop II), while the black curves assume that metal-free stars (Pop III) also occur, but only in low-mass galaxies where atomic cooling is inefficient. The dashed and solid curves differ in specific emission and stellar properties (see Burns et al. 2017 [3] for details). The epochs B, C and D correspond to the ignition of the first stars, the initial accretion of black holes, and the onset of reionization, respectively. Figure from Burns et al. (2017) [3], adapted in turn from Pritchard & Loeb (2010) [4] using the new models from Mirocha et al. (2017) [2].

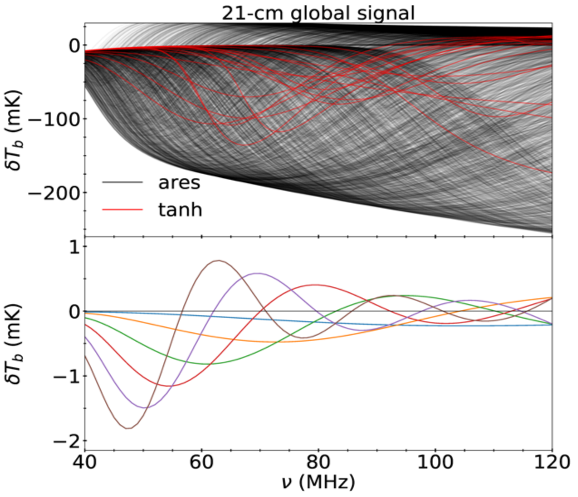

Figure 2: Upper panel: thinned sample (black curves) of the signal training set used in the analysis of Tauscher et al. (2017; hereafter T17) [5] and generated with the *ares* code (https://bitbucket.org/mirochaj/ares) for reasonable bounds of the physical parameters. The red signals are taken instead from the tanh signal modelling of Harker et al. (2016) [6]. Lower panel: the first 6 SVD basis functions (from most to least important: blue, orange, green, red, purple, brown) obtained from the *ares* training set. Figure from T17. See there further details on the calculation and utilization of SVD modes within our pipeline.

The multi-wavelength radiation emitted by these first luminous objects shifted the spin-flip temperature of the intergalactic medium (IGM) gas, and therefore the strength of the 21-cm line of HI [1, 2], with respect to that of the Cosmic Microwave Background (CMB). Fig. 1 shows characteristic shapes for this sky-averaged signal, depending on factors such as the metallicity of the first stars and the emission efficiency of the sources.

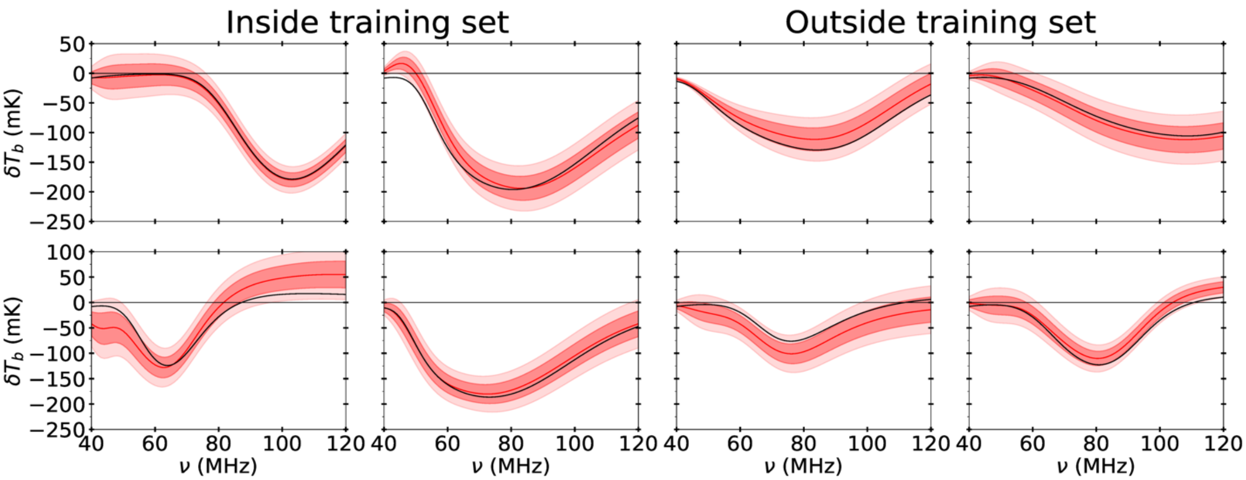

Figure 3: Representative signal extractions using the first step of our data analysis pipeline via the *pylinex* code (https://bitbucket.org/ktausch/pylinex). The latter is able to obtain such results by using a linear model defined by SVD eigenmodes calculated from signal (see, in this case, Fig. 2) and systematics (see Fig. 1 in T17) training sets. The black curves show the input signals, the red curves the signal estimates, and the dark (light) red bands represent the posterior 68% (95%) confidence regions (see further details in T17). For all plots, the input beam-weighted foregrounds (systematics) came from the training sets in Fig. 1 of T17. The input signals for the four plots on the left came from the signal training set in Fig. 2, whereas the input signals for those on the right were generated by the tanh model [6]. Even though the difference between these two sets is very small by eye, as shown in Fig. 5 of T17, on average these are different. Figure from T17.

Signal extraction: Given the large variety of theoretical models available (see e.g. Fig. 1) and their corresponding, mostly unconstrained physical parameter spaces, we employ a well-known pattern recognition technique, in combination with information criteria, to extract the signal from systematics (large beam-weighted foregrounds and residual instrument calibration) in frequency channel space.

The use of this machine learning algorithm, Singular Value Decomposition (SVD), allows us to separately characterize the signal and systematics with distinct training sets. Fig. 2 shows for example the signal training set utilized in T17 to demonstrate the ability of our pipeline to quickly constrain very different input signals, as shown in Fig. 3.

Overall data pipeline: After extracting the signal in the first step of the pipeline, in the second step we perform a multidimensional interpolation in order to translate that signal from frequency channel space into a physical parameter space. Once this is achieved, this provides us with a starting point from which we can efficiently explore the full probability distribution in this space, within a Bayesian framework, through a Markov Chain Monte Carlo (MCMC) analysis (Rapetti et al., in preparation).

Summary: The DSG will therefore provide a unique opportunity to operate low-frequency radio telescopes shielded by the Moon, either on orbit or the surface, and utilize our state-of-the-art pipeline for precision hydrogen cosmology.

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TECHNOLOGY ASSESSMENT FOR EXTERNAL IMPLEMENTATION OF ARTIFICIAL GRAVITY UTILIZING THE DEEP SPACE GATEWAY PLATFORM.

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Introduction: There is substantial rational to continue research on artificial gravity to prevent spaceflight induced alterations in all physiological systems. Artificial gravity (AG) and AG analogue studies with animals demonstrated some measure of protection against microgravity-induced alteration in model organisms [1]. However, this phenomenon was not tested in real spaceflight studies due to their paucity as well as their short-duration. As beyond LEO-class manned missions are planned and developed, new technology to test AG as a countermeasure in spaceflight is needed. Several approaches exist for research of artificial gravity as a spaceflight countermeasure. Implementation of traditional centrifuge strategy for creation of artificial gravity is associated with challenging issues such as; vibration, significant mass, and power to support a centrifuge. Furthermore, all ground-based studies are extremely expensive given that studies needed for AG should be of very long duration to observed gravity-associated alterations. Although there are several possibilities of introducing a centrifuge to International Space Station (ISS) [2], the ISS-based space studies utilizing centrifusion has a disadvantage of a small radius in addition to the challenges raised above, and therefore unlikely to be feasible for future human accommodation. Therefore, a space centrifuge will have to be designed with little mass and variable radius of rotation which can be possibly accomplished by using a cable connected inflatable habitat. Jet or electrical propulsion engines will provide controlled acceleration as well as tangential velocity in open space relative to the orbital station. The adjustable radius of rotation and tangential velocity will provide an artificial gravity environment (including a head-to-foot gravity gradient) with specific gravity levels including a “comfort zone” suitable for animals and humans with a minimum period of adaptation. The hypothetical AG protocols that may counteract microgravity-associated physiological alterations in all physiological systems have been developed in previous studies [3]. The most suitable for the AG application is electric propulsion and has been used on spacecraft for decades [4]. The electric propulsion with an external power source (transmissible through the solar panels) can provide small thrust of 47.5 m/s for a long time and is enough to provide the artificial gravity centripetal acceleration with around 1 g and angular velocity of 1.97 rpm at the radius of rotation of 230 m which is in the “comfort zone” for humans. The results of the proposed project will justify experimental proof-of-concept, design, implementation, and operation to control artificial gravity parameters. The design could be the starting point in the continued search for comprehensive architectural upgrades and operational protocols suitable for Mars missions which are of long duration.

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THE DEEP SPACE GATEWAY AS A TESTBED FOR ADVANCED CURATION CONCEPTS.

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Introduction: The role of NASA curation is to store and distribute NASA's extraterrestrial sample collections including lunar samples from the Apollo and Luna missions, meteorites, asteroid and cometary material, and implanted atoms of solar wind. In the next 5 to 10 years it is likely that NASA curation will receive samples that necessitate novel curation methods to preserve sample integrity and protect human researchers. For example, samples returned from a comet or the lunar surface may require cold storage and may be adversely impacted by thermal and physical stresses that accumulate during or after entry into Earth's atmosphere. Furthermore, planetary protection requirements for Mars sample return will necessitate a sample transfer somewhere in orbit in order to, "Break the chain of contact with Mars," and ensure biological containment [1]. The DSG (Deep Space Gateway) is an ideal place to test advanced curation concepts like cold curation and biocontainment/sample transfer in micro-gravity since it will be a likely transfer point for samples collected on the lunar surface and/or returned from the upcoming Mars 2020 mission. Additionally, it may be possible to conduct some preliminary analyses on returned samples at the DSG that would not be possible after those samples have been altered by the heat and gravitational stresses associated with entry into Earth's atmosphere.

Cold Curation: NASA curation is developing methods for curating volatile-rich samples on Earth, but these methods should be extended to a micro-gravity environment. Samples collected from permanently shadowed regions at the lunar poles are likely to contain volatile compounds including water-ice that are temperature sensitive [2]. Furthermore, the DSG could be used as an orbital platform from which to collect meteoroid and/or cosmic dust samples before they are impacted by Earth's atmosphere. The DSG could provide opportunities to collect micrometeoroids and cosmic dust via passive collectors such as low-density aerogel or foil targets; these collectors can be deployed during periods in which the Earth is known to intersect cometary dust streams. Unlike collectors in low Earth orbit, these would be comparatively free from orbital debris contamination. The Deep Space Gateway may also provide a test platform for experimental active dust collection methods, such as electromagnetic deceleration. In order to limit the loss of volatile compounds from these samples they will need to be maintained at temperatures as close as possible to those under which they would be collected (-196 to -80°C). If the DSG is to be used as an orbital laboratory or even a sample transfer point it will be important to have these cold-curation techniques tested and validated. Lunar and cometary volatile simulants, currently under development by NASA curation, could be created on Earth and curated on the DSG. Periodic analysis of the DSG samples in orbit could be compared to the corresponding samples stored on Earth. This parallel set of analyses would allow the effectiveness of cold curation techniques in both environments to be evaluated and improved. A rudimentary analytical suite will be required on the DSG to characterize the physiochemical properties of the volatile-rich samples prior to subjecting them to the stresses of reentry. This analytical suite could include facilities for visible microscopy and chemical analysis similar to those tested during the Desert Rats program [4]. Other non-destructive techniques for sample analysis such as visible, near-infrared, and mid-infrared spectroscopy should also be considered. An instrument capable of high sensitivity chemical analysis, like a mass spectrometer, should also be included

Mars Sample Return: A crewed platform such as DSG would provide an opportunity to replicate the Mars-Earth transit portion of a Mars sample return (MSR) mission. The purpose of this experiment would be to replicate the stage of Mars sample return where samples are launched from Mars, travel to Earth, and undergo Earth atmospheric entry and landing. This process will expose MSR samples to vibration, various forces associated with launch and landing, and exposure to an interplanetary radiation environment which will impart some measure of alteration to any organic and mineral species in the samples. Constraining and quantifying these effects would reduce risk for meeting MSR science goals and would provide valuable Contamination Knowledge (CK) data to the scientific community. This endeavor would be performed by launching an MSR sample suite simulant to the DSG, exposing it to the temperature range and approximate radiation exposure time concordant with a Mars-Earth transit. The samples will experience a launch from Earth and Earth atmospheric entry as an analogue to the Mars-Earth launch and landing events. The samples would be examined afterwards by 3D tomography to ascertain movement and physical alteration of the samples, and organic chemistry analyses designed to characterize and quantify chemical alteration.

Biocontainment: The Mars 2020 rover will be collecting samples and caching them with the intent that they be returned to Earth by a separate undetermined mission. Planetary Protection directives state that any sample returned from Mars must, “be contained and treated as potentially hazardous until demonstrated otherwise.”[1]. This includes a prohibition against allowing unsterilized hardware that has directly contacted the Martian surface or atmosphere to return to Earth without sterilization [1]. The DSG provides a venue to address these requirements. Sample containers returned from Mars could be quarantined at the DSG for preliminary study and transferred to clean and sterile containers. Initially, return samples from Mars will need to be strictly isolated from their environment, and BSL 4 requirements will be required. Current containment facilities onboard the International Space Station (ISS) are only certified for BSL 2 type containment [3]. It will be necessary to test our ability to maintain quarantine in a microgravity environment prior to initiating Mars sample return. Furthermore, in the case of a Mars sample return or other Category 5 Restricted Earth Return missions, it is important that the containment and initial evaluations take place outside low earth orbit to minimize the risk to Earth.

Toxicology: The biocontainment facilities could also be used to conduct toxicological assessments of extraterrestrial dust on human health. The DSG allows for two complementary types of toxicological approaches: defensive and proactive. The defensive studies will occur concomitantly with the biocontainment of Category 5 Restricted Earth Return campaigns. Given the risk of unknown pathogens or unforeseen hazards, it is important to perform at least a preliminary evaluation of the toxicity of the extraterrestrial dust before it is brought back to Earth. Proactive studies will utilize the proximity to the Moon to evaluate the importance of capturing the innate surface reactivity when performing dust toxicity testing. Access to pristine dust samples will allow for the most representative materials to be evaluated. Not only will this allow for more accurate toxicological evaluations of lunar dust but it will also elucidate the role of innate reactive surfaces in causing inflammation and disease, relative to passivated dust. The results can then be used to extrapolate the toxicity of other extraterrestrial dusts for which we only have passivated or “re-activated” samples. This knowledge will be vital when performing risk assessments based on returned samples and could be vital to mitigating astronaut risk during surface operations.

Conclusion: The DSG represents a new opportunity to collect samples of pristine astromaterials that have never been subjected to the thermal and physical stresses associated with entry into the Earth’s atmosphere. These samples would enable new scientific research and provide a deeper understanding of the effects of the microgravity environment on physical and chemical properties. Furthermore, the inclusion of facilities to test cold curation, biocontainment, and toxicological concepts on the DSG would allow the DSG to serve as a hub for return sample science.

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HIGH-RATE LASER COMMUNICATIONS FOR HUMAN EXPLORATION AND SCIENCE*[1].

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Introduction: A capable Deep Space Gateway (DSG) supporting human exploration and science initiatives in lunar vicinity will require sophisticated communications capabilities. For comparison, the International Space Station (ISS) today provides return data links (ISS to Earth) at rates up to ~600 Mbps and forward data links (Earth to ISS) at rates up to ~20 Mbps for telemetry, command and control, astronaut health monitoring, video-streaming, software updates, science data transfers and many other applications. A DSG will require similar capabilities with the additional challenge of operating those links at ranges that are 10-1000 times longer than the ISS links.

At lunar ranges, the use of laser communications rather than radio-frequency (RF) communications may offer substantial benefits for high-rate links. Because of the use of a high-frequency laser carrier (~192 THz in the optical C band used for terrestrial fiber telecommunications) the beam directivity associated with a laser communications terminal can be >10,000 higher than a similarly sized RF terminal. This can result in substantial reductions transmitted power requirements and terminal sizes both at the transmitter and the receiver. Links from lunar ranges to Earth operating at >1 Gbps can be established with a ~10-cm aperture on a DSG and a ~1-m aperture on the ground. That same 10-cm DSG aperture could also be used to provide proximity links at >100 Mbps from lunar CubeSat-sized spacecraft in nearby lunar orbits with or lunar surface users with ~1-cm apertures. Laser communications has the added benefit that spectrum in the optical domain is plentiful, with >4 THz in the optical C band alone, and unregulated. Because of the narrow beam widths associated with typical laser communication systems, interference with neighboring systems is unlikely and coordination of spectrum is unnecessary. High-reliability fiber-telecommunications-grade electro-optic components enable utilization of the available optical bandwidth in ~50-GHz channels.

Previous Laser Communications Efforts: While the potential benefits of high-rate laser communications links have been recognized for many years, it is only recently that the engineering challenges associated with implementing such links have been overcome with successful demonstrations by the National Aeronautics and Space Agency (NASA) and others.

Lunar Laser Communication Demonstration. NASA's first laser communication success was the Lunar Laser Communication Demonstration (LLCD) which operated on the Lunar Atmosphere and Dust Environment Explorer (LADEE) in 2013-2014 [1]. LLCD demonstrated a 622 Mbps return from a 10-cm gimbaled optical telescope with a 0.5-W laser transmitter to a transportable 80-cm optical receive telescope with a sensitive photon-counting receiver located in White Sands, New Mexico [2]. While the LADEE spacecraft with its relatively low-data-rate science instruments relied on a ~100-kbps S-band radio link operating at ~100 kbps for its primary science data (citation), LLCD demonstrated an ability to downlink the entire 2-GB LADEE data buffer in a few minutes (limited by the 40-Mbps data interface to the buffer). LLCD also demonstrated a 20-Mbps ground-to-space link based on a 40-W, 15-cm telescope transmitter and the 10-cm gimbaled telescope on the LADEE spacecraft as well as a ~1-cm spacecraft-to-ground range measurement capability utilizing the duplex wideband optical communication links.

Relay Demonstrations. Today, relay communication operations are common near-Earth, where low-Earth orbiting (LEO) satellites utilize a space relay, often in geosynchronous orbit (GEO), like NASA's Tracking Data Relay Satellite System (TDRSS), to provide high-availability near-continuous communications to ground terminals which are always in view of the GEO spacecraft but rarely in view of the LEO spacecraft. Relay communications may also be used for lunar or planetary link scenarios to reduce the communications burden on a small spacecraft or surface users by enabling a shorter link to the relay satellite which then provides a more capable link back to Earth.

While LLCD demonstrated the capability of direct-to-Earth laser communications at lunar ranges, laser communications may also offer many advantages in relay scenarios. The European Space Agency (ESA) first demonstrated optical communications between a spacecraft in LEO and a GEO relay in 2015 and today

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provides an operational 1.8-Gbps optical link capability with its European Data Relay Service (EDRS) [3]. NASA is also working to demonstrate an optical relay known as the Laser Communication Relay Demonstration (LCRD) [4]. While the LLCD mission was limited by the relatively short lifetime of the LADEE spacecraft and other operational constraints, LCRD is expected to operate for several years, providing deeper understanding of the operational details associated with laser communication links and providing a technology basis for the development of NASA's next generation relay capability. LCRD comprises a space segment with two optical space terminals based on the LLCD telescope coupled to a 2.8-Gbps differential-phase-shift-keyed modem, on a spacecraft in GEO and a ground segment with two optical ground terminals located in California and Hawaii. The LCRD space segment is expected to launch in 2019 on Space Test Program Satellite 6.

Current Development Efforts: Today, NASA is developing two laser communications terminals for use near Earth and at the Moon that will extend the capability of systems like LCRD and start to transition laser communications to operational use for human exploration mission. The Integrated LEO LCRD User Modem and Amplifier Terminal (ILLUMA-T) will develop an LCRD-compatible user terminal that will be installed on the International Space Station in 2021 to demonstrate LEO-to-ground optical communications at rates of 1.244 Gbps (return from ISS) and 51 Mbps (forward to ISS) via the LCRD GEO relay. The Orion EM-2 Optical Communications Terminal (O2O) will be installed on the first human-crewed Orion mission, planned to launch operate at lunar ranges in 2022. The O2O terminal will provide duplex communications between the Orion vehicle and a ground station at forward rates up to 80 Mbps and return rates up to 20 Mbps. The system is readily scalable to several Gbps return rates or longer ranges, such as from the Earth-Sun Lagrange points, with only minor changes to the space and ground hardware.

The laser communications terminals for both O2O and ILLUMA-T are based on a new design developed for use in a wide variety of laser link scenarios—the Modular, Agile, Scalable Optical Terminal (MAScOT), see Fig. 1 [6]. MAScOT was first developed to provide a terminal for spacecraft in LEO where wide field of regard and fast slew rates are required. The MAScOT architecture is designed to be modular and scalable. The ILLUMA-T and O2O programs will demonstrate the viability of the MAScOT design for space missions, making it suitable for operational use on future space missions, like DSG. While current efforts are developing ~10-cm user terminals, larger apertures based on the same terminal design are also envisioned for future applications.

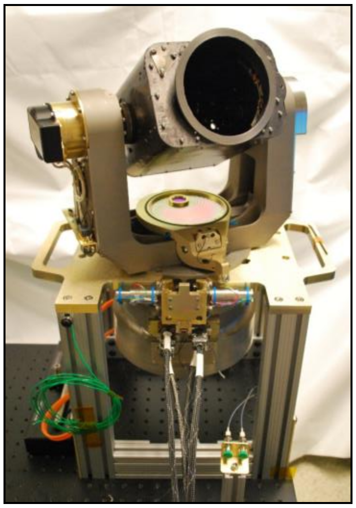

Figure 1. Engineering unit of 10-cm MAScOT beam director developed for use on Orion and the International Space Station.

It is expected that a terminal similar to the ILLUMA-T or O2O terminals could be easily accommodated on a future DSG to support human operations and science. The MAScOT beam director (pictured in Fig. 1) has a mass of ~13 kg. In addition to the beam director, an optical terminal for DSG would also include electronics to control the beam director and a modem to generate and receive the optical signals. The mass of these avionics modules is typically ~20 kg and they typically dissipate ~100 W, as demonstrated on previous efforts, like LLCD. A user terminal for proximity operations on a spacecraft or surface user could be significantly less power (~1-3 kg, <10W).

Summary: The use of laser communications technology can provide many benefits to a future DSG operating at lunar ranges. In addition to supporting human activities on the DSG, high-rate laser communications links can enable large-volume direct-to-Earth downlink of science data from DSG to ground as well as high-rate proximity links to nearby spacecraft and ground users with very small terminals. The technology for both direct-to-Earth has been successfully demonstrated on previous missions and is transitioning to operational capabilities today.

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PLATFORM FOR CONDUCTING EXPERIMENTS TO STUDY THE LONG-TERM EXPOSURE EFFECTS OF SPACECRAFT COATING, MATERIALS AND COMPONENTS IN A DEEP-SPACE ENVIRONMENT.

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Scientific Domain: Physical Sciences, Materials, Coating, Technical Readiness Level (TRL), Aging.

Introduction: The rapid growth in research and development of spacecraft capable of deep-space travel results in an increasing demand for technology capable of enduring the conditions that come with this kind of longterm exposure. Space travel to potential destinations like Moon, Mars and others involve demanding technological challenges to overcome long term exposure to bombarding space radiation, huge temperature fluxes, possible attack of micro-meteorites etc. that degrades the health of spacecraft in several ways. This calls for technology and materials capable of sustaining outer space for long periods at a time. Materials exposure testing has been conducted previously, with the MISSE experiments on the ISS [1], but the limitations of those experiments are their large testing platforms, and lack of exposure to a deep space environment. Other exposure experiments, such as the biological EXPOSE-R [2], has also been performed on the ISS previously, but suffers the same limitations as mentioned above. Therefore, improved designs on existing concepts will be required for materials that can endure the above mentioned environment, which requires a simple, reliable, versatile and adaptable method for testing new technologies being brought forward to meet the challenges mentioned above. The Deep Space Gateway will be of a small size, an expected pressurized volume of 2,684 cu ft, compared to the ISS which is has a pressurized volume of 32,898 cu ft, which will result in less options in terms of exterior space and number of attachment points. Therefore a more compact and centralized testing platform, capable of holding any type of exposure experiment adjusted to fit, on the outer hull of the space station would allow for solving this issue.

Idea description: The idea of this experiment is to provide a platform for testing various kinds of coating, paint, materials, components etc. to determine that the experiment being tested is suitable/viable to be applied on future spacecraft/space stations used for deep-space travel. The platform can also be used to test anything designed to be placed on the outside of a spacecraft, for example solar panels, protective alloys and many other currently existing, and upcoming concepts.

The platform (Fig. 1) would be designed as a 11 sq ft plate (plate size is subject of change), which has a grid-shape designed placement to fit in 8 smaller plates, which would hold the experiment that is of interest in testing in a deep-space environment. The centre of the central plate would leave room for attachment of sensors, which can be interchanged based on what is of interest to measure. This plate would be attached to the outside of the space station. The smaller plates would be attached via a detachable method to the main plate. The smaller plates would have different kinds of coating applied, to be tested over a long-term period. Most of the coatings that would be tested might already have a TRL of 9, but what hasn't been possible before is long term monitoring of these coatings, as well as possible sample return for closer examination. Other components can be tested on the same central plate, having been modified to fit to the central plates' attachment mechanism. Several sensors will be mounted to the central plate to check important variables such as radiation, temperature gradients, light-levels etc, but there will also be room to add other sensors that are relevant for a specific experiment, and these, too, can be interchanged. A monitoring camera would be attached next to the central plate, and connected to a live network which can be accessed and checked by onboard crew as well as researchers on ground. The camera would be able to monitor micro-meteorite impacts on the experiments, and provide a visual result of this event.

A few examples of experiments (fig. 2) that could be performed on this platform would be to test a new type of Multi-Layer Insulation (MLI) material designed to be used in spacesuits with a current TRL of 6 and associated sensors of relevance, experiments that could lead to further development in spacecraft coating for deep-space travel, testing protective alloys to protect from different elements, such as micro-impacts. Many components/materials of existing and upcoming concepts would allow for possible increase in TRL and development of better versions more suited to the long-term exposure, as well as improving the sustainability and protection of human passengers on board a spacecraft located in deep space. The long term-exposure effects could be quantified and new improvements for existing spacecraft can be formulated from this, resulting in less degradation over time.

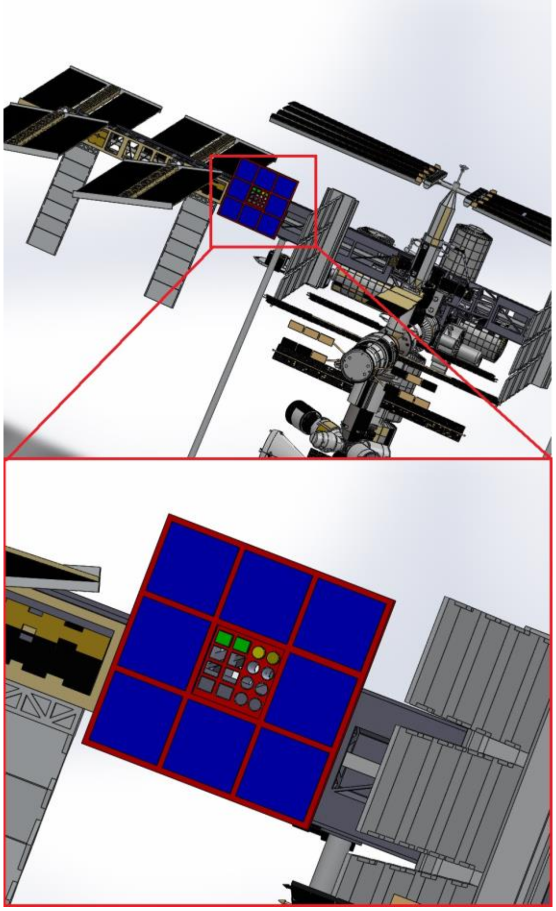

Fig.1: The images above illustrates a simple model of the platform attached to a space station, NOT to scale.

This testing platform offers the possibility of raising the TRL of many upcoming concepts with a simple, inexpensive testing method, opening access for more companies, research groups etc. to improve the TRL for their concept ideas, that involves deep-space exposure. There will likely be interest from research groups, companies, agencies etc. to bring back the experiments to Earth for closer examination of the long-term exposure test. This will be easily achieved, as the experiments would be of a fairly small size to fit on the main plate, which allows for easy and lightweight transport on a spacecraft heading back to earth.

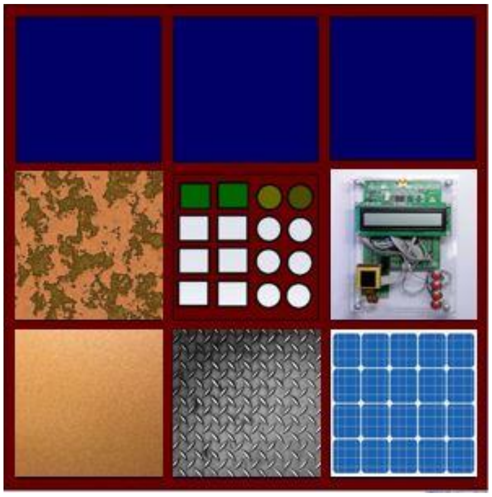

Fig.2: The above image illustrates the platform with attached examples of experiments such as coatings, materials and components.

On-board crew would have to be available to attach the main plate to the exterior hull of the space station. They would also have to be available to detach experiments and attach new ones on to the main plate. A simple attachment mechanism would allow for experiments and sensors to be easily interchanged by the crew. Should robotic manipulation, such as a Canadarm [3] be available, the central plate and the attachment mechanism could be modified to attaching experiments via this method. Ability to survey the experiments from the station would be recommended, possibly through a window, or a live-feed from the monitoring camera connected to a monitor inside the station. At some of the proposed lunar orbits, continuous live-feed would not be a possibility, so an option of recording during the blackout-periods would have to be available.

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USING AUTONOMOUS BIO NANOSATELLITES FOR DEEP SPACE EXPLORATION.

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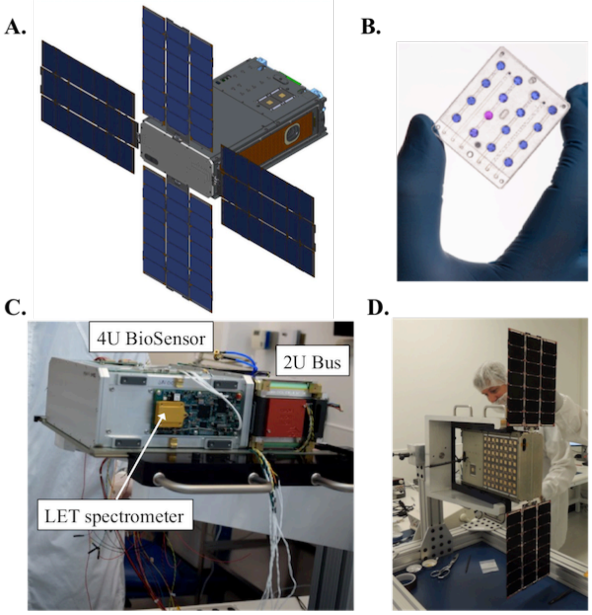
Introduction: NASA Ames Research Center has been the leader in developing autonomous bio nanosatellites to address strategic knowledge gaps about the effects of space travel on biological organisms, including GeneSat, PharmaSat, EcAMSat, and BioSentinel. BioSentinel will conduct the first study of biological response to space radiation outside Low Earth Orbit (LEO) in over 45 years. BioSentinel is an autonomous platform able to support biology and to investigate the effects of space radiation on a model organism in interplanetary deep space. It will fly onboard NASA's first Exploration Mission (EM-1), from which it will be deployed on a lunar fly-by trajectory and into a heliocentric orbit.



(A) Rendering of BioSentinel's 6U spacecraft. (B) Microfluidic card. (C) BioSensor & LET spectrometer fit check. (D) Solar panel deployment test.

BioSentinel will measure the DNA damage and response to ambient space radiation in a model biological organism, which will be compared to information provided by onboard physical radiation sensors and to data obtained in LEO (on the International Space Station, ISS) and on Earth. Even though the primary objective of the mission is to develop an autonomous spacecraft capable of conducting biological experiments in deep space, the BioSensor payload itself will be an adaptable instrument platform that can perform biological measurements with different microorganisms and in multiple space environments, including the ISS, free flyers, and other exploration platforms. Thus, nanosatellites like BioSentinel can be used to study the effects of both microgravity and space radiation, and can house different biological organisms to answer specific science questions. In addition to their flexibility, nanosatellites also provide a low-cost alternative to more complex and larger missions, and require minimal crew support, if any.

Instrumentation: BioSentinel is a 6U (11.6 x 23.9 x 36.6 cm; 13.6 kg) biosensor-based nanosatellite. The BioSensor payload currently under final development consists of a hermetic containment vessel of ~ 4U volume (10 x 20 x 20 cm) and 6 – 8 kg of mass. Our BioSensor advances multiple nanosatellite systems in order to perform autonomous biological measurements: (A) biology support in 18 independent microfluidic cards with 16 microwells each; (B) fluid delivery system consisting of pumps, valves, tubing, and media external to cards; (C) dedicated thermal control for each fluidic card capable of maintaining biological payload during stasis and growth phases; (D) dedicated 3-color optical detection system at each microwell for optical density and metabolic dye absorbance measurements; (E) biofluidics managing long-term (12 – 18 months) biological stasis and modular integrated samples instrumentation; (F) close integration of living biosensors with miniature physical radiation spectrometers (LET spectrometer), pressure and humidity sensors; (G) shielding-, hardening-, design-, and software-derived radiation tolerance for electronics; (H) communications from distances of ≥ 500,000 km.

BioSentinel is being developed at NASA Ames Research Center and funded by NASA's Advanced Exploration Systems (AES).

SPACE BIOLOGY MODEL ORGANISM RESEARCH ON THE DEEP SPACE GATEWAY TO PIONEER DISCOVERY AND ADVANCE HUMAN SPACE EXPLORATION.

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Introduction: Human space exploration has focused on low Earth orbit (LEO), inside the protection of the Van Allen Belts for over forty-five years, since the return of Apollo 17. Investigations using a wide range of biological specimens have provided a tremendous amount of data for identifying physiological changes and developing an understanding of how biology responds to the space environment within LEO. This scientific information provides the foundation for advancing fundamental space biosciences to investigating how life responds, acclimates, and adapts to the true deep space environment in which the next generation of space explorers will travel for long duration missions to the moon and Mars. The Deep Space Gateway will enable scientists to conduct long duration space biology research to characterize the basic biology of life in this new environment, which cannot be truly replicated on LEO platforms or in Earth laboratories. The objectives of this research using biological organisms are to advance fundamental scientific knowledge of space biology that can be translated to addressing knowledge gaps and identifying countermeasures required for reducing the risk to human health and habitation during deep space exploration missions.

Model Organisms and Space Biology: A model organism is a non-human species that has been extensively studied to understand its physiology and biological mechanisms and phenomena. Due to a highly characterized biology, the discoveries and data derived from its study are expected to provide insight into the biology of other organisms and diseases. Also, the common genetics and biochemical and molecular mechanisms shared between species allows these organisms to be used as surrogate systems for experiments that are not possible to conduct in the original target subject. Space biology research uses model organisms to study physiological systems, such as organs and tissues, down to cellular and molecular levels to conduct deeper analyses for identifying the root biochemical and molecular mechanisms that respond to the space environment. This integrated systems biology approach provides comprehensive physiological data that may be translated to understanding the biological changes observed in astronauts. Also, these organisms enable the development of technologies that advance scientific research capabilities on spaceflight platforms and habits, such systems for environmental bioregeneration and growing food crops.

Space Biology classifies model organisms and specimens into five categories: 1) vertebrate animals, such as mice and rats, 2) invertebrate animals, such as fruit fly (*Drosophila melanogaster*) and nematodes (*Caenorhabditis elegans*), 3) microbiology, such as bacteria, yeast, and fungus, 4) plants, such as *Arabidopsis thaliana* and plant food sources, and 5) cell and tissue cultures. Vertebrate, non-vertebrate, and *in vitro* cell and tissue culture systems are widely used to investigate a variety of questions and hypotheses concerning biological responses to the space environment, including conducting comparative analyses of the data derived from these organisms to identify commonalities and differences in their responses. In addition, they are use as surrogates to study human physiology in space, including, but not limited to, intracranial pressure, oxidative stress, visual impairment, cardiovascular changes, immune dysfunction, vestibular impairment, neurovascular system, response to radiation exposure, stem cell and tissue regeneration, and the microbiome interrelationship to whole body physiology. Microbes are extensively used for spaceflight research to characterize the microbiome of the built environment, changes in microbial behavior, host-microbe interactions, endogenous viral reactivation, and radiation-induced DNA damage. Yeast are particularly important organisms for studying radiation-induced DNA damage and repair due to space radiation. The yeast genome has been completely sequenced, and many of the genes associated with DNA damage responses have been identified and well characterized. An example of its use to study space radiation is the beyond LEO Biosentinal mission using wild-type and mutant yeast strains to characterize deep space radiation impacts on DNA damage and repair. Plants have been instrumental in developing an understanding of how gravity regulates development and mature plant structure and function. LEO plant investigations that studied responses to gravity changes and lighting on seedling germination to plant development and propagation provided foundational knowledge for developing next generation systems for growing food crops, such as the NASAVEGGIE and PONDS developed at KSC, as well as plant-based bioregenerative systems.

Biological Studies on the Deep Space Gateway: Although the primary known differences between the LEO and deep space environments are radiation and the electromagnetic field, scientist know little about deep space and its impacts on biology. Therefore, other unknown environmental factors that impact life may exist. The Deep Space Gateway provides a platform on which a diversity of scientific investigations using model organisms may be conducted within the living space and on the external surface of the platform to address these differences. The investigations can be run during crew presence on the Gateway to run experiment protocols and return of the experiments and during the absence of crew using automation, such as telerobotics and data/commanding telemetry, or passive housings. Examples of studies that can be conducted within the Gateway include, but are not limited to, monitoring of the environmental microbiome, radiation and microgravity interaction, multigenerational adaptation, long duration space environmental exposure within a controlled environment, on-orbit centrifuge study to isolate the non-gravity effects of the deep space environment, and variable gravitational biology investigations combined with radiation studies. External vehicle studies using active and stasis cultures directly exposed to deep space for variable durations would be scientifically beneficial. Also, studies to test or develop technologies can be conducted. One of the important types of technology development study using space biology science involves growing plants for long duration environmental bioregeneration or food. These studies will be used to develop and prove out the concept for a Gateway garden. A very important aspect of deep space biology investigations is omics-based research, whose derived data may be uploaded to the NASA GeneLab Data System (GLDS) for open science use. The GLDS is building a collection of omics data from different species that allows for deep molecular and biochemical analyses, which enables cross comparisons within and between species to identifying pathways, mechanism, and biological networks that are affected by the space environment. By conducting post-flight omics analyses from experiments conducted on the Deep Space Gateway, the derived data from these investigations can be used to compare against other data in the GLDS from ISS and ground studies to identify biological affects that are unique to the deep space environment.

In order to conduct science investigation using these organisms and specimens, some level of environmental control is required. The environment may come from a fully self-contained incubator system that allows for investigator-defined conditions. For these incubators, continuous power will be required. Alternatively, some organisms may be able to use the ambient environment of the Deep Space Gateway. However, for these experiments, specific environmental set points may be required, especially when the crew are not on the Gateway. For example, rodent investigations will require control of Gateway cabin temperature, CO_2 levels, oxygen levels, and humidity.

It is envisioned that investigators will request opportunities to use the ISS along with the Deep Space Gateway to conduct biological comparative analyses between the different space environments. These investigations will include ground controls. Such studies may help to identify unique factors of deep space that can impact biology. The differentiation of the biological effects between these different environments is important to identifying physiological systems that may respond in common or uniquely to each environment. These findings will ultimately provide greater insight into which biological changes, biomarkers, and mechanisms are specific to deep space in order to develop effective health monitoring and diagnosis technologies and countermeasure to maintain nominal explorer health.

Additional Information: The members of NASA's Life Sciences Research Capability Team (LSRCT) are submitting a number of other abstracts in addition to this one to reflect the full range of desirable life science research at the Gateway and are deliberately not eliminating any ideas based on a feasibility assessment.

CISLUNAR INTERCHANGEABLE OBSERVATORY FOR HELIOPHYSICS (CLIOH): A DEEP SPACE GATEWAY SOLAR VIEWING PLATFORM FOR TECHNOLOGY DEVELOPMENT AND RESEARCH PAYLOADS.

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Abstract: The Deep Space Gateway (DSG) has the potential to serve as an invaluable location for a solar viewing platform that can accommodate multiple payloads on a rotating basis. Through the use of standardized payload canisters that dock interchangeably, several payloads can be tested and operated through the shared resources of the platform and exchanged on a schedule compliant with launch availability. The CisLunar Interchangeable Observatory for Heliophysics (CLIOH), comprised of a pointing platform and the payloads, allows for the testing and utilization of cutting edge technology prior to, or in lieu of, investment in accommodations on a free flyer explorer-sized spacecraft, thereby substantially reducing technological and financial risk.

Comparable to the International Space Station (ISS), the DSG provides the capacity for high telemetry rates and power supply. Being within range of a launch vehicle also potentially permits the ability to repair or swap expendable equipment or to refill consumables – options that are not available to free flyer missions. Advantages over the ISS include notable reduction in the contamination and vibration environment due to less human and vehicular activity. In addition, there is the potential for increased solar viewing and a more stable thermal environment, depending upon the orbit. MSFC has performed a preliminary design study on a version intended for installation on the ISS; however, the ISS was deemed to not have suitable capability for accommodating the operational volume of the observatory.

The cislunar orbit also allows for the testing of technologies in an operational deep space radiation environment, critical for equipment such as advanced detectors and associated electronics. The low lunar orbit is the least conducive option, insofar as viewing and thermal stability are concerned, for the successful implementation of this observatory concept.

Instruments suitable for this platform are those that require observations taken above the earth's atmosphere for an extended period of time (e.g., to capture flares and coronal mass ejection events). Such opportunities that would benefit from the DSG instead of Low Cost Access to Space options include situations wherein sounding rocket flights provide insufficient elapsed viewing periods, balloons fail to achieve appropriate altitudes, cubesat volumes and pointing capabilities are too limited, and the ISS is unable to accommodate the payload (either due to ISS capacity or payload requirements). Also, instruments that are deemed operational, but require regular input of consumables which inhibit their lifetimes on free flyer spacecraft, could be considered for such an accessible platform.

Despite sounding rocket flights being too limited in duration for many types of instrumentation, the rocket program has proven to be a remarkably successful avenue for demonstrating technology using shared resources, interfaces, and integration procedures. The foundation of the CLIOH concept is modeled after the sounding rocket interchangeability of payloads using a common infrastructure for mechanical design as well as documentation, testing, and verification. Another key advantage of the CLIOH platform is that it is designed to accommodate multiple instruments operating simultaneously. This versatility lowers risks, reduces cost, and elevates the platform's (and, in turn, the DSG's) return on investment.

An example payload that could be well accommodated in this paradigm and that offers considerable benefit to the DSG is the Coronal Spectrographic Imager in the EUV (COSIE), an instrument under consideration for installation on an external ISS mount. This particular instrument provides wide field images of the high temperature plasma in the corona, including the disk of the sun, which provides a considerable advantage over traditional coronagraphs. This type of instrumentation is relevant to the purpose of the DSG as it would greatly benefit deep space travel by providing timely, detailed information concerning coronal mass ejection trajectories and energetics.

The DSG platform would allow for instrumentation, such as COSIE, to be tested and to potentially provide operational information to astronauts and high altitude orbiting satellites. These instruments could then be uninstalled from the platform and replaced by subsequent solar viewing instrumentation that have been integrated into the standard packaging.

While the concept proposed here is intended for Heliophysics use, the design could also be repurposed. For example, a parallel platform design could accommodate earth viewing instrumentation to observe large scale magnetosphere features by simply changing the pointing target (noting, however, that all of the instruments on one platform would necessarily be focused on the same general target). In addition, some payloads would not rely on pointing at all, such as those installed for radiation environment testing.

A bonus feature of the interchangeable design is that instruments can be provided by domestic and international entities via standardized interfaces and integration practices through a range of funding mechanisms.

Based on the preliminary design work performed by MSFC, an observatory such as this would have the following requirements (all values are approximate). The initial design considered a maximum of 4 instrument slots based on two 18-inch [primary] and two 10-inch [secondary] diameter canisters, akin to sounding rocket skins; however, this would need to be revisited based on the accommodations available from a DSG module.

- Mass: ~200 kg for the platform; ~50 – 100 kg per instrument
- Power: 120 Vdc & 28 Vdc for the platform; 224 W @ 28 Vdc for the primary instruments; 112 W @ 28 Vdc for the secondary instruments
- Cost: ~$30M for the platform (ISS design only); ~$20-50M per instrument (highly variable due to radiation environment)
- Volume (static, based on an ISS Flight Releasable Attachment Mechanism): 47” x 41” x 78”
- Telemetry: ~ 15 Mbits/second, continuous (adjustable, depends on established Concept of Operations plan)
- Crew interaction, via a robotic arm, would be necessary for the installation of the platform as well as installation and removal of the instruments. Astronauts may also be needed special circumstances, such as the replacement of consumables. The crew is not expected to be needed for any observatory operations nor are spacewalks anticipated.
- Desired deep space gateway orbits: NHRO, EMDRO, or EML2 (LLO is not suitable; ELO is moderately suitable).
- A static holding platform and robotic arm would be needed during installation and exchange. Temperature control options may need to be considered. Module ephemeris information would be needed by the platform in order to control pointing stability.

Dose Spectra from Energetic Particles and Neutrons (DoSEN).

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Changing Space Environment: Over the last decade, the solar wind has exhibited low densities and magnetic field strengths, representing anomalous states that have never been observed during the space age. The abnormal solar activity between cycles 23 and 24 has caused the longest solar minimum in over 80 years [1] and continued into the "mini" solar maximum of cycle 24 [2]. As a result of the weak solar activity, we have observed the highest fluxes of galactic cosmic rays in the space age [3], and small solar energetic particle events [1]. Recent observations [4] from the Cosmic Ray Telescope for the Effects of Radiation [CRaTER, 5] on the Lunar Reconnaissance Orbiter (LRO) compared the predictions of [1] with the actual dose rates observed by CRaTER in the last 4 years. The observations show dose rates that *exceed* the predictions by ~10%, showing that the radiation environment is worsening more rapidly than previously estimated. Much of the increase in Dose observed by [4] attributable to relatively low-energy ions, which can be effectively shielded.

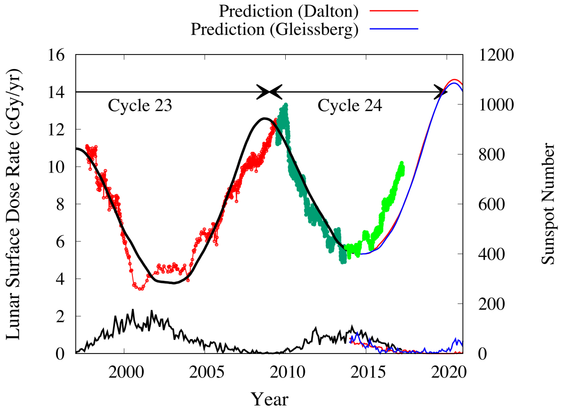

Figure 1. *Recent CRaTER data (bright green) are updated after the [1] study to further test the predictions. The sunspot number predictions (the lower black and blue dashed lines) show two cases based on a Gleissberg-like and a Dalton-like minimum, the results of which are similar. Updates to the sunspot number (lower black) are adapted from the international sunspot number released by Sunspot Index and Long-term Solar Observations (SILSO, http://sidc.oma.be/silso/home). The dose predictions (solid blue line and the upper black and blue dashed lines) are from a sunspot-based model of the heliospheric magnetic field and the correlated variation in modulation of GCRs [Appendix A, of 1]. The ACE data, CRaTER data, and model results are projected geometrically to the lunar surface.*

Despite the continued paucity of solar activity, one of the hardest solar events in almost a decade occurred in Sept 2017 after more than a year of all-clear periods. These conditions present important issues for planning long duration missions (e.g, to the Moon, an asteroid, or Mars). Particle radiation remains a significant factor that must be carefully studied and accounted for in mission designs.

Understanding Surface Interactions and the Hydrogenated Surface Layer at the Moon

The distribution of hydrogen, hydroxyl (OH), and water (H_2O) on the Moon is important. All three have the potential to be useful resources for long-term missions to the Moon, and their distribution helps us understand how volatiles can be delivered to the Moon and how subsequent processes affect them [for a recent review, see 6]. Many questions remain. It is clear that the polar regions of the Moon have a significant deposit of H [e.g., 7], and the sunlit lunar surface seems to be covered by OH and/or H_2O [8, 9, 10]. The source of this hydrogen, though, is still a mystery.

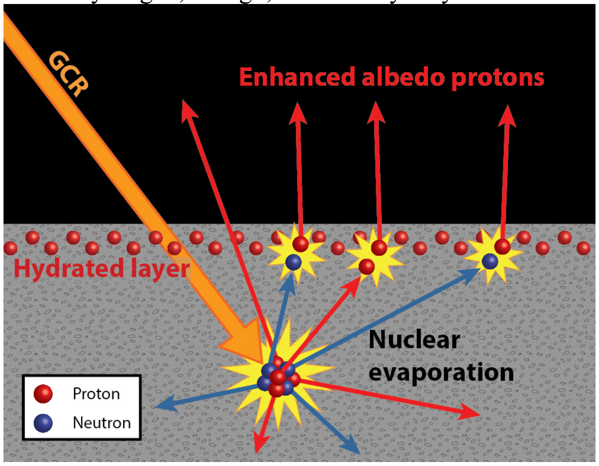

Figure 2. *Illustration of the effects of a hydrogenated layer of lunar regolith. The nuclear evaporation process from deep in the regolith produces abundant secondary particles in all directions. The highest flux of secondary particles near the surface will be neutrons of up to ~100 MeV. If a neutron collides with a hydrogen nucleus near the surface, the collision would yield an additional tertiary proton. The interaction of secondaries from the regolith with the hydrogenated layer create an excess of albedo protons.*

We showed recently that CRaTER measures energetic (~64−120 MeV) protons emanating from the regolith [11]. They are ejected by GCRs exciting atomic nuclei in the regolith. In other words, CRaTER is capable of directly detecting hydrogen exiting the lunar surface. CRaTER measured more albedo protons emanating from the polar regions than from near the equator [12]. The best explanation for this is a layer of regolith rich in H (Figure 2). As protons and neutrons are released during nuclear evaporation, some of them collide with and eject the H nuclei, i.e., protons. This decreases the flux of secondary neutrons and increase the flux of "secondary" protons (in this case, the protons are both secondary and tertiary). Recent work has shown that this hydrogenated surface layer likely varies diurnally [13].

The DoSEN Instrument: The neutron flux is essential in the creation of albedo protons: secondary neutrons collide with the excess hydrogen atoms in the hydrogenation layer resulting in an enhanced flux of albedo protons. The suppression of the high energy neutron flux due to the presence of excess hydrogenation provides a complimentary measurement allowing unique discrimination of the effects of the hydrogenation layer.

Application of a newly developed detector Dose Spectra from Energetic Particles and Neutrons [DoSEN, Figure 3, 14] provide the measurements of neutrons needed to discern effects of hydrogenation at high energies. DoSEN is a promising early-stage space technology project that offers unique advantages for active measurement of the complete spectrum of radiation. DoSEN combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. For LET measurements, DoSEN contains stacks of thin-thick Si detectors similar in design to those used for the CRaTE. With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically-based quality factors provide not only doses and dose-rates, but also dose-equivalents, associated rates and even organ doses. DoSEN measures neutrons from ~1-500 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce.

DoSEN develops the new concept of combining these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. We will show proof-of-concept examples of laboratory measurements from DoSEN with radiation sources. DoSEN is a next-generation radiation detector, a natural extension of the successful CRaTER instrument, that is ready to be utilized in new missions to the Moon, Mars and beyond.

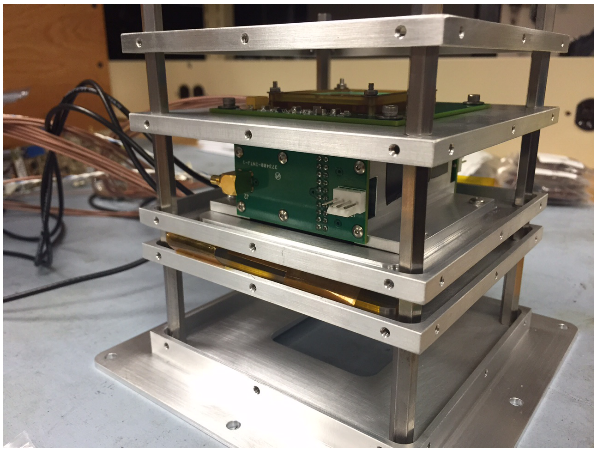

Figure 3. *The complete DoSEN detector stack including p-terphenynl surrounded by anti-coincidence material, and thin and thick silicon detectors above and below the p-terphenynl.*

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The Linear Sled "Hybrid" Approach for Artificial Gravity as a Countermeasure for Crewed Deep Space Gateway Missions.

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Introduction: Future crewed space missions with a long duration, and into deep space will require enhanced countermeasure technologies to ensure astronaut health. One such hazard is extended exposure to reduced gravity levels (i.e., microgravity, lunar gravity, or Martian gravity). Reduced gravity impacts a variety of physiological systems, leading to hydrostatic intolerance, musculoskeletal atrophy, sensorimotor impairment, bone demineralization, cardiovascular deconditioning, and visual alterations [1]. Various countermeasures have been employed for mitigating these effects, such as exercise, pharmaceuticals, diet, and fluid loading. However, these approaches treat individual symptoms, such that each physiological system is addressed with primarily one countermeasure. An alternative to this approach is artificial gravity (AG), which promises to be a holistic, comprehensive countermeasure [2]. The technologies that create AG (acceleration) are promising potential countermeasures and it has been an ongoing research area of NASA, though traditional centrifuge designs typically include the drawbacks of Coriolis forces, gravity gradients, and vestibular cross-coupled illusions.

As an alternative AG approach to a centrifuge, we have proposed a Linear Sled-Hybrid (LSH) AG system to mitigate astronauts physiological deconditioning. This system functions by applying linear acceleration and deceleration to produce footward loading; there is a half rotation (180°) to reorient the rider between acceleration and deceleration such that the loading remains footward, as when standing on Earth. The rotation also provides footward acceleration to the lower body through centripetal acceleration; hence the "hybrid" aspect of the design (Figure 1). The efficacy of this "duty cycle" of gravity (i.e., alternating between pure gravity loading during linear acceleration/deceleration and variable loading during the half rotation) has not yet been studied. However, the existing data from intermittent (i.e., ~1 hour per day) AG on a centrifuge during bed rest suggest benefits in mitigating physiological deconditioning [2].

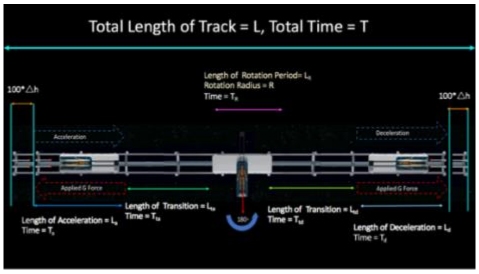

Figure 1:Linear Sled Hybrid AG system - from left to right the rider accelerates to produce footward loading, does a half rotation, then decelerates also producing footward loading and then the sequence repeats.

This proposed system will be added to the outside of the gateway vehicle as a subsystem to the vehicle and part of the crew accommodation to keep the crew healthy. We propose a pressurized pod to enclose the rider, which performs the sequence of motions in Figure 1. An airlock will be used to connect the habitable module of the vehicle to the LSH pod as shown in Figure 2.

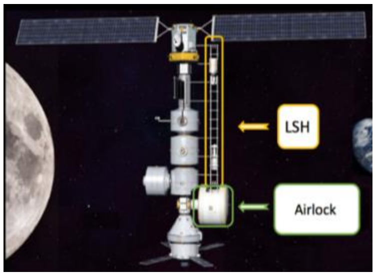

Figure 2: The LSH airlock interface to the spacecraft, with two pods shown in operation.

Feasibility of the LSH: There are three categories to be considered with the feasibility of this system; human health benefits, human tolerability during LSH operation and engineering design expectation. As mentioned previously the effect of AG systems on human physiology is an ongoing research area supported by the NASA Human Research Program and others. Previously, the tolerability of the LSH was evaluated via simulation of the well-validated "observer" computational model of orientation perception. The motion profile was found to be well-perceived with no cross-coupled illusion occurring, even if the simulated person tilts his/her head [3]. Further pilot studies at the University of Colorado have been performed, assessing the potential concern of motion sickness during the 180° rotation phase, which have been successful. A tolerable LSH AG system may allow for a comprehensive countermeasure for spaceflight-induced physiological deconditioning. The main part of this abstract will be focusing on engineering design and interactions between the deep space gateway vehicle and the LSH subsystem.

Engineering Analysis: The need for the LSH system is driven from a requirement of keeping an astronaut alive and healthy in a gateway craft for deep space exploration regardless of the orbit altitude to other planetary bodies such as the moon or Mars. This requires the LSH pod to provide life support for a period of time. The current Low Earth Orbit exercise protocol requires ~2.5hr every day per crew member [4]. Data from analog studies on centrifuge AG systems suggest benefits of ~1hr in mitigating physiological deconditioning, during which the astronauts will be riding in the pod, and requiring a life support system extension from the gateway craft [5].

Engineering Design: Mass, power, and volume of the LSH subsystems were main design drivers for defining this concept. Total added mass was the sum of masses of the pod, actuators, and structure of rail on which the pod travels. Leveraging mean ECLLS requirements, we estimated the required mass of the pod.. This included pressurized volume, environmental control, and life support systems. The pod mass was estimated to be 158 kg. The power inside of the pod was dependent on the electronics used inside such as a fan for ventilation, cabin lights, and heat removal from inside the pod. We estimated the power required to be 4.33 Kw-hr. The mass of the structure was a function of the length and material used for the railing. The duration of each phase of linear acceleration/deceleration and half rotation dictated the length required. This motion profile was design for a one time pass thru of the track yielding a duty cycle motion that would be repeated based on operation protocol for health of the crew. We included a margin of safety at both ends of the track to allow for a tolerable emergency stop. The motion profile for maximum and minimum case study are shown in Table 1, where $T_{a/d}$ is time spent during acceleration or deceleration, T_R is defined as the time during rotation phase, T_T is a transient time between rotation and acceleration or deceleration phase.

Table 1: Structure Mass and Motion Profile

Case	Acceleration (m/s^2)	$T_{a/d}$ (s)	T_T (s)	T_R (s)	Length (m)
Max	9.81	1	1	1.67	49.47
Min	9.81	0.25	0	1.12	6.95

The mechanism of actuation of the LSH is dependent upon the profile of the motion. After determining the motion profile for the LSH, the power requirements for both linear acceleration and rotation phase were computed for the structure of the LSH, the values are presented in Table 2 for the max and minimum track lengths defined in Table 1.

Table 2: Mass and Power Estimation (Pod and Track)

Case	Mass (Kg)	Power (Kw-hr)
Max	26,226	33,602
Min	3,684	28,964

The LSH as shown in Figure 2 is attached outside of the gateway craft. Therefore, is not going to affect the existing internal habitable volume of the vehicle. The pod design adds a small habitable volume to the overall spacecraft of ~1.5 m^3. This volume was designed to keep the astronaut alive for the duration of intended use (<2.5 hr). The thermal system, the oxygen provision system and the CO_2 removal strategy in the pod were designed to be integrated with the gateway craft. The cost analysis for the LSH system needs to be further developed.

Conclusion: Based upon our preliminary analysis, the LSH system appears to be a feasible approach to creating AG, which may be beneficial to protecting against astronaut physiological deconditioning on a gateway spacecraft in cislunar space or even further away from Earth. Specifically, we found the motion sequence is likely to not be disorienting for the rider and provided preliminary engineering analysis of the track length, and pod in terms of mass, power and volume. Future work should further define these parameters and assess the viability of a LSH system with cost and benefits regarding the health of crew.

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SEARCH FOR NEAR-EARTH OBJECTS FROM THE DEEP SPACE GATEWAY

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Introduction: Synthetic tracking is a relatively new technique for analyzing CCD/CMOS images for moving objects such as near Earth asteroids/comets, collectively called near-Earth objects (NEOs). Moving objects like NEOs will produce a streaked image in a long exposure CCD image, reducing the sensitivity needed to detect them. Synthetic tracking uses a "shift/add" algorithm to stack multiple short exposures that "freeze" the motion of the object but allow faint objects to be detected in the properly stacked synthetic image. Synthetic tracking can improve sensitivity to moving objects by over an order of magnitude. A synthetic tracking camera with a ~30cm telescope and 16Mpix sCMOS sensor at the Deep Space Gateway would be able to detect ~1,500 new NEOs per year, roughly equal to the perfoemnce all present-day ground-based telescopes combined. However, for some of the most interesting fast moving objects such as the recently discovered interstellar asteroid 2017U1 "Oumuamua", this facility would improve our discovery rate by a factor of ~30 compared to all current ground-based facilities combined. The technology is planned to be deployed by the USAF on its global network of ground based space survelance telescopes.

Synthetic Tracking Concept: The synthetic tracking (ST)[1],[2] concept starts with multiple short exposures. Typically ~100 of 5-sec exposure images. With modern sCMOS the read noise would be low enough that the dominant noise would be the zodiacal dust background. These images are thes co-added with each subsequent image shifted to represent an object moving linearly across the field of view. Because we do not know the velocity of the object until it is detected, the ST computationally tries all reasonable velocities (typically ~10,000 velocities.) This computationally demanding approach is made relatively inexpensive with the introduction of modern GPUs and FPGAs which offer teraflop computing perfeomnce at low cost in a space environment.

Instrument description: The instrument would consists of a ~30-cm wide-field telescop with a 16Mpix sCMOS sensor with a ~2 sqdeg field of view (FOV). The sensor would be attached to a PC type computer with a GPU or specially programmed FPGA perform the multi-vector shift/add algorithm. Since the camera takes ~5 second exposure, it is desirable for the telescope pointing to be stable to ~ 1 arcsec on time scales of 5 seconds or shorter. Because the camera takes multiple short exposures, it would not require the ultra-high pointing stability of large astronomical telescopes. It would require that the telescope be on a vibration isolation steerable gimbal mount attached to the exterior of DSG.

Mass: 30 kg;

Power: ~100 W (for computer);

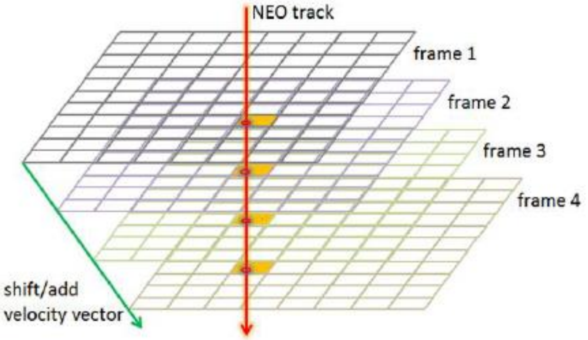
Volume ~0.1m^3;

Cost: most of the componets for this instuemtn would be commercial-off-the shelf, thus reducing the cost. Our estimates suggest a cost of less than $10M;

Crew Interaction Totally automated operation after initial crew setup.

Orbit: Any orbit where the Moon does not obscure a large fraction of the sky.

Other considerations. External mounted, vibration isolated steerable gimbal.



Our experience suggest that a ground based-version of this instrument consisting of a telescope, sensor, and computer may be assembled by an advanced amateur astronomer for less than $30K.

Performance estimate: We can estimate the sensitivity of this telescope, when used to search for NEOs with a nominal set of operational parameters. A typical observation would consists of a 500-sec integration consisting of 100 of 5-sec exposure images. We would set a detection threshold at 7.5 sec, and would be able to detect NEOs with a limiting magnitude of 22.2 mag. A typical 30 m diameter NEO moving 10 km/s with respect to the observatory would be detected at a distance of 0.19 AU and would move ~35 arcsec during the 500-sec observation. The data would be analyzed on board and if a moving object is detected a "follow up" observation would be scheduled a few hours later. The FOV of 2 sqdeg would be moved systematically across the sky to cover ~60° radius cone in the anti-Sun direction.

We did a quick simulation of how such an instrument would perform, using the Granvik NEO model, similar to a simulation we performed for a constellation of small satellites in solar orbit [3]. The Granvik model is a synthetic population of NEOs in orbit around the

Sun. We placed the telescope in space and systematically scanned the sky within ~75 deg of the anti-Sun direction. When a NEO was in the field of view, its apparent magnitude is calculated to determine if it can be detected. The simulation runs in time steps of one observation 500 sec and just steps through for several years of search. We vary parameters in the simulation to optimize the discovery rate, such as the maximum angle from the anti-sun direction, the length of the integration time etc.

A newly detected asteroid triggers a follow up observation 1-2 hours later. This is possible if the data analysis is done in space at the DSG. Current NEO search programs take images of the same part of the sky ~4 times over a period of ~15-45 minutes. A moving object has to appear in all 4 images, and move linearly in time over that period or it's discarded as a false positive. The use of the time dimension is an important factor in removing false positives. Synthetic tracking automatically makes use of the time dimension and is robust against false positives, similar to the 4 image tracklet.

Measuring Orbits of NEOs: Finding new asteroids is not very useful if they are subsequently lost. Currently many, perhaps most, small NEOs discovered are subsequently lost because there are insufficient follow up observations. A significant percentage of NEOs come close enough to be detected but only for a short period of time, one or two weeks. Currently with ground based NEO detection, ~4 observations over a period of ~20-25 days or more are needed to get a "crude" orbit that lets us "link" that set of observations with observations taken years or decades later. A significant fraction of discovered NEOs are not detectable for ~3-4 or more weeks. Here the orbit of the DSG may help in a significant way.

Over a short span of time (hour) the motion looks like a straight line. The telescope only measure 2 of the 3 coordinates of the asteroid's position. The asteroid has to be followed over a ~3-4 week time frame for the curvature of its motion to be sufficiently pronounced to derive an orbit. With a telescope on the DSG, it may be possible to shorten this ~3-4 week period to a few days, by making use of orbital parallax. If the DSG were in orbit around the moon (not L2 or L1) that orbital motion can be used to measure the distance to the asteroid by using the parallax effect. Cataloging asteroid orbits should be a required part of detecting 90% of potentially hazardous asteroids [4].

Interstellar Asteroids: In October 2017, the 1st interstellar asteroid was discovered by the Panstarrs telescope as part of its NEO search program. The closest the object later named "Oumuamua " came to the Earth was ~0.3 AU, moving at ~57 km/s. Interstellar asteroids move much faster across the sky than local asteroids and as a result leave a long streak reducing the sensitivity of normal cameras. Normal NEO search programs use a 30 sec CCD exposure and 2017U1 at its closest approach would move ~13 arcsec. This reduces the detection sensitivity by a factor of 13. Very crudely speaking Syn tracking would detect objects ~13 time dimer and using the current power law of # object vs size/brightness this would lead to increasing the discovery rate by about a factor of 30.

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Advantages of Science Cubesat and Microsat Deployment using DSG Deep Space Exploration Robotics.

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Introduction: Important scientific missions can be accomplished with cubesats and microsats. Providing support capabilities for these satellites allows for relatively independent missions that can make tremendous contributions in many areas of solar system study including everything from investigating the lunar surface to observing near-earth asteroids [1]. Deep Space Exploration Robotics (DSXR) is a concept for a self-relocatable robotic manipulator [2, Figure 1] that would be able to move around the exterior of the Deep Space Gateway (DSG). A capability for the release of cubesats and microsats could be integrated into DSXR.

Cubesat and Microsat Science:

Science missions would benefit from the following advantages that are offered from having an independent cubesat/microsat deployment capability as part of DSXR:

- Significant number of cameras in proximity to capture images of the mission deployment that can be used for public outreach and proof of successful launch.
- Increased control over timing of satellite release
- Increased protection during launch
- Increased control over the initial orbital trajectory

Timing is an important consideration. For cubesats, such as the planned Near Earth Asteroid Scout [3], that are heading toward targets at greater distances, being able to time the release of the cubesat can allow for fuel savings and therefore allow more science targets to be accessible.

Different science missions require different orbits and would benefit from an ability to control initial trajectory. Orbit influences the spacecraft pointing relative to solar illumination (taken together, this forms the phase angle), therefore reflectance measurements and analyses of landform shape or morphology are heavily influenced. The ability to detect and characterize asteroids is also affected by the available orbital trajectories.

Deep Space Exploration Robotics for Cubesat Deployment:

A satellite release capability integrated into DSXR would afford a deployment capability for those cubesats or microsats that get a gentler ride to the Moon via the cargo vehicle (rather than the Orion-to-Stage Adapter). These satellites would then be taken by an astronaut and put out on a platform that the DSXR could access. DSXR could then pick up the payload for deployment.

There are two potential scenarios for cubesat deployment via DSXR:

1. Point a a deployment mechanism such as the Payload Orbital Delivery System (PODS) Hosted Payload Assembly (HPA) mechanism [4, Figure 2] built for the DARPA Phoenix program. The option of using a deployment tool or mechanism can offer a safe and reliable jettison capability for DSXR to support science through deployment of cubesats/microsats.
2. Place deployment mechanisms already loaded with satellites at specific external locations on the Deep Space Gateway from which they could deploy their cubesat/microsat at a later time.

In both of the above situations, the deployment could be positioned such that it is viewable by cameras on the arm. The current concept for the arm has 360-degree cameras, situational awareness cameras, and cameras on the end of a smaller, dexterous arm. These cameras would be useful for capturing images of the satellite deployment. These images could then be shared on social media if desired.

Conclusions: Cubesats and microsats have significant potential to achieve a variety of planetary science goals. The ability to release cubesats using the envisioned Deep Space Gateway DSXR robotic system has clear advantages.

Acknowledgements:

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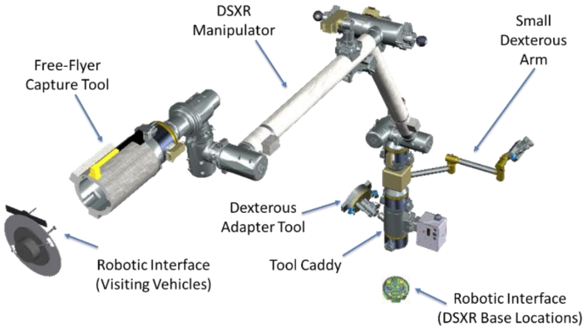

Figure 1: DSXR Flight System Concept Elements

Figure 2. MDA's HPA Payload Ejection Mechanism

TOOLS FOR SYSTEMATIC IDENTIFICATION OF CROSS-DISCIPLINARY RESEARCH RELEVANT TO EXPLORATION MISSIONS.

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Introduction: Long-duration flights in deep space are made difficult by a unique set of hazards [1]: altered gravity level, distance from Earth, radiation, hostile and closed spacecraft environment, isolation and confinement. These hazards lead to specific risks to human health and performance. The NASA Human Research Program (HRP) is investigating these risks in a rigorous manner, and many other organizations within NASA are equally absorbed with associated engineering and operational issues. Human research in a Deep Space Gateway (DSG) will offer an unprecedented opportunity to investigate many of these areas in the more challenging environment of deep space. Even more so, it presents a fresh opportunity to investigate interactions between key variables across traditional disciplines.

The Problem of Interactions: HRP has a good handle on the main risks to health and performance and a broad research program to address them. What is needed, however, is a way to systematically identify and track interactions [2]. This should include not only the life sciences but also involve engineering and operational aspects. There are many compelling reasons to identify and track these interactions:

- A very practical reason of immediate relevance is that this provides a systematic and objective way to prioritize experiments and select experiment complements for DSG missions: those factors that have many interactions with other factors might have a higher priority, and the interacting set of factors could suggest related investigations that form a natural complement to be performed together.
- When examining risks one at a time, it is possible that each would be sufficiently mitigated on its own, but that their interactions would lead to an unanticipated problem. Thus it is possible to fool oneself into thinking that the robustness of the overall mission is acceptable based solely on the performance of each subsystem independently.
- Aerospace mishaps are almost invariably the result of a cascade of interacting effects, none of which by itself would cause an overall mission failure.
- Explicitly examining interactions is true to physiology, psychology, performance, and behavior.

A Solution: A tool is needed to identify key interactions to help guide the selection of investigations that might form a coherent complement for implementation on a DSG mission. We propose one such tool. It is based on a Contributing Factor Map (CFM): a systematic categorization of the many factors that contribute to the success of a long-distance long-duration human space flight [3]. These factors span the range from task and mission design to training to spacecraft design to psychology and physiology and finally mission outcomes. While simply a taxonomy at this point, the CFM provides a foundation for examining interactions by identifying connections between factors. This might be done with a form of text analytics, in which technical and scientific documents from the different disciplines (factors) are searched for common features such as keywords, authors, or concepts and related using the common language of the CFM factors. Commonalities in this literature analysis can be inferred to represent connections between factors, which can be indicated on the CFM by interconnecting lines, the width of each depending on the strength of the connections thus identified.

This map, in the form of a network, could then guide the process of selecting a complement of investigations for a DSG mission that purposely incorporates an interrelated set of factors. This provides a deliberate approach to examining important interactions, rather than an *ad hoc* approach or one that tries to examine interactions *post hoc* among investigations that were not designed with interactions in mind (lacking simultaneous synchronized data acquisition across disciplines, with corresponding metadata, as an example). These investigations would then provide valuable data to inform human health, performance, and mission-risk models for future missions.

Final Thoughts: Even if this approach is successful, implementation challenges will remain. Availability of organizational resources is one issue: when there is insufficient time and money to solve known problems within each discipline, there is little remaining to investigate interactions. Nevertheless the approach described here provides a common language and a unifying principle to guide DSG experiment planning and cross-disciplinary risk mitigation.

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Investigation of the Magnetic Fields and Energetic Particles in Earth's Magnetotail

Deep Space Gateway Science Mission Abstract

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Category: Heliophysics

An opportunity to deploy a spacecraft from the Earth-Moon L2 libration point (EML2) would enable important scientific research to be performed in a region of Earth's magnetic environment that deserves much further study, the region known as the magnetotail. Plasma of solar wind origin enters the Earth's magnetosphere and stretches the Earth's magnetic field into an elongated magnetotail that extends many hundreds of Earth radii in the antisunward direction. The location and dimensions of the Earth's magnetotail fluctuate, but Earth-Moon L2 is well within the frequent position of the magnetotail. The magnetotail plays a crucial role in the interaction of the solar wind-magnetosphere interaction. The magnetotail stores mass, energy, and momentum captured from the solar wind and periodically releases it to power geomagnetic substorms and auroral displays. These events are frequently accompanied by the release of vast plasma bubbles, or plasmoids, that move antisunward down the magnetotail. The conditions governing these disruptive events, crucial to understanding space weather within the Earth's environment remain unknown. Furthermore, the magnetotail is an ideal laboratory to study a wide variety of fundamental plasma physics processes, including the microphysics of reconnection, the Kelvin-Helmholtz instability, and diffusion.

Measurements of vector magnetic fields and the energy spectra and velocity vectors of charged particles in the plasma can be made by spacecraft deployed near EML2 since many opportunities to make in situ measurements of magnetotail conditions would occur. The spacecraft can be of modest size, such as cubesats, and it would be especially useful to deploy a constellation of several spacecraft that would maneuver to take positions on similar orbits but separated by several to many Earth radii. This would enable researchers to determine the extent and occurrence patterns of the various phenomena, hence their significance to the overall interaction and space weather. No new technologies are needed for these instruments. Their resource requirements are modest. As mentioned in the decadal survey report *Solar and Space Physics: A Science for a Technological Society: An Overview* (National Academy Press, ISBN 978-0-309-31392-6, 2014, page 8), "A key question for future research is, What are the interactions and feedbacks that connect the magnetosphere, solar wind, and ionosphere?" Answering this question includes understanding the physics of the magnetotail through more investigation of it.

This mission can be performed with a small spacecraft such as a cubesat, with low-thrust propulsion such as solar electric ion drive. No requirement of astronaut intervention would be necessary post-deployment.

Observing the Magnetosphere in Soft X-rays: The Lunar X-ray Observatory (LX).

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Abstract: Lunar orbit and the lunar surface provide unique vantage points to image the dynamics of the global solar wind-magnetosphere interaction [1]. Wide field-of-view soft X-ray imagers have now been developed to the point where they can be used to track the emissions generated when high charge state solar wind ions exchange electrons with neutral hydrogen in the Earth's outer exosphere [3]. Simulation results demonstrate that integrated line-of-sight emissions of these soft X-rays with energies ~0.25 keV map the locations of the Earth's bow shock, magnetosheath, magnetopause, and cusps [6]. Global images of the dayside magnetosphere with cadences on the order of 2-5 min and spatial resolution of ~0.125 Earth radii (R_E) will suffice to track the dynamic motion of these plasma structures in response to both varying solar wind dynamic pressure and interplanetary magnetic field orientation [8]. In particular, the images can be used determine the rate at which the magnetopause and cusps erode in response to magnetopause magnetic reconnection driven by southward interplanetary magnetic field turnings and to determine the nature of subsequent recoveries in the locations of the magnetopause and cusps driven by magnetic reconnection within the Earth's magnetotail. Given accurate magnetohydrodynamic model predictions, the very same soft X-ray observations can be used to deduce the properties of the Earth's exosphere as a function of solar cycle, e.g. determine its radial density profiles and identify any deviations from spherical symmetry.

Imagers in the same locations can also provide important information concerning the composition of the lunar exosphere and its variability [7], particularly if information is obtained concerning individual line emissions. A reexamination of past ROSAT observations confirms that the emissions are present and shows that they can be used to infer lunar limb column densities [2]. Soft X-ray observations of emissions resulting from charge exchange in the lunar exosphere could be used to map exospheric composition as a function of latitude and longitude and as a function of varying solar wind conditions. They could be used identify the effects of entries into and exits out of the Earth's magnetotail on solar wind sputtering. They might be used to detect the effects of meteoroid bombardment on the exosphere. Since soft X-ray emissions depend not only on exospheric but also solar wind plasma density structures, they can be used to map the low density lunar wake and mini-magnetospheres above magnetic anomalies generated by the solar wind's interaction with the Moon. These and other tasks are described by [8].

Finally, a wide field of view soft X-ray imager pointed in the antisunward direction during northern hemisphere winter will be able to quantify the dimensions and intensity of emissions from the helium focusing cone formed when and where the Sun's gravitational forces focus neutral Helium ions entering the heliosphere [4, 5]. Emissions might be expected to vary as a function of solar wind conditions.

We propose to place a prototype imager on the Deep Space Gateway, followed by a larger and more powerful instrument on the lunar surface. The prototype LXO imager features slumped microchannel plate optics, a large area CCD, and passive cooling. It comprises a "lobster-eye" optic using a 12x12 element array of 4 cm x 4 cm Nickel-coated square pore microchannel plates slumped a 50 cm radius with a very large field-of-view. A flat plane of to four 6 cm x 6 cm CCDs is placed half way to the focal point to provide imaging with moderate spectral resolution.

The effective area is about 12 cm^2 at 500 eV with a point spread function of less than four arc minutes, and an anticipated energy resolution of about 50 at 500 eV. Total power consumption is estimated at 11 W during operations, which includes 6.7W for primary input for the CCD plane and associated electronics with a passively cooled CCD and 4.3W primary power for a coldfire processor. The entire package weighs about 17 kg. Dimensions are 66x50x50 cm^3. The instrument should not point at the Sun or be covered when it does. It can operate through temperatures from -10 to 40 C.

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MULTIFUNCTIONAL INTERFACE FACILITY FOR RECEIVING AND PROCESSING PLANETARY SURFACE MATERIALS FOR SCIENCE INVESTIGATION AND RESOURCE EVALUATION AT THE DEEP SPACE GATEWAY.

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Introduction: The concepts presented here describe prototype hardware and instrumentation related to the study of planetary surface materials at the Deep Space Gateway (DSG) following a sample return mission. The concepts outlined in this paper represent a progressive evolution of capabilities for DSG and will also address specific capability needs that were included in recent architecture studies for the Evolvable Mars Campaign [1].

The scientists and engineers in the Granular Mechanics and Regolith Operations (GMRO) Lab located in the Swamp Works R&D facility at NASA Kennedy Space Center (KSC) have the expertise to design, fabricate, and to test the proposed hardware in collaboration with other NASA centers. The Swamp Works approach to advancing research and technology is to drive design improvements through lean development and early stage testing. The GMRO Lab develops fully functional prototype systems to handle, analyze and process granular regolith simulants that will be found on the Moon, Mars and asteroids. These prototype systems have been ground tested, used on reduced-gravity flight experiments, and field tested in support of NASA STMD programs and NASA Analog Missions, such as Desert RATS. For some GMRO Lab personnel, their payload development experience includes Spacelab and Space Shuttle missions as well as current support of ISS projects.

Space Materials Airlock Laboratory: Lunar, Martian and asteroid regolith materials are of great interest to planetary scientists for advancing our knowledge of the evolutionary history of the Solar System and of the current state of planetary surfaces. They also provide a source of useful raw materials that will enable a sustainable future human exploration of deep space [2]. In their natural unaltered state, these planetary regolith materials might also contain potentially hazardous components that need to be isolated from the human crew. If EVAs are planned to conduct proximity activities of returned samples, as part of a DSG mission in high lunar orbit for example, then there should be concern about the large uncertainties related to the unknown composition and toxicity levels of the materials that the crew may have to handle and analyze.

We propose an addition to the Deep Space Gateway in the form of an airlock space in which samples of space materials would be brought in from docked robotic sample carrier spacecraft under controlled atmosphere without being admitted into the lab itself. The airlock “receiving room” would be designed as an inside wall facility instrumented for mineralogical, chemical, and physical analysis to serve as a laboratory accessible from inside the crew habitat (Hab). A crew member could work in the lab pressurized environment and access the received samples by manipulators only without the need to conduct an EVA. The Space Materials Airlock Laboratory would serve as the place where all handling and analysis takes place in a pressurized, controlled environment in which this type of work can be done with state-of-the-art analytical instrumentation and would enable trained geologists and other scientists to examine each sample in close contact with adequate protection.

An alternative to a “sample receiving room” is a hermetically sealed **External Sample Analysis Interface** panel as an enclosure inside the hull wall of the Hab laboratory that interfaces between the interior of the Hab laboratory area and the outside. Samples of planetary materials brought to the in-orbit DSG by robotic carriers or by crew during EVA would be delivered to the outside panel where they remain evacuated. Preliminary analysis tools would be part of this panel to obtain mineralogy information and surface chemical signatures to assess their level of hazard or their sensitivity to contamination and alteration inside the Hab prior to entering the sample preparation area inside the Hab hull. The investigation of materials such as volatile-rich regolith may require that the analytical facility be situated in-vaccuo and offer low-temperature handling of the samples to preserve their natural state in order to understand the physical and chemical interactions of minerals and volatile species [3]. The corresponding interior panel inside the Hab would include controls and displays for the crew to operate and manipulators to handle and prepare the samples without ever admitting the samples into the Hab. The facility would include in-vaccuo storage capability for future transport of these samples to Earth or disposal. The through-hull interface facility may reach an estimate of 300-500 kg in mass and require on the order of 500 W of power.

External Facility for Sample Analysis and Material Processing: The Deep Space Gateway will be involved in crewed missions in stable lunar orbits (e.g. LDRO) and is the ideal crewed space vehicle to interface with and support the systems that will handle and characterize planetary materials from sample-return missions. The other manned spacecraft at the DSG will be Orion, which is not likely to be equipped to support these systems.

Similar in concept to the External Sample Analysis Interface panel described above, the proposed prototype facility would be part of the external shell of the Hab in the form of a panel structurally linked to the Hab frame. In addition to the analytical suite described for the External Sample Analysis Interface, the Sample Analysis and Material Processing panel would be designed with a variety of locking fixtures on which materials processing subsystems would be mounted, such as feeders for granular materials, crushers, chemical reactors, water extractors, etc. When planetary surface materials such as drill core segments, regolith, and surface rocks are introduced into these systems and processed, the effluents of such reactions would be carried into the Hab laboratory area and supplied to analytical instruments for crew investigations. The primary purpose of such an added capability to the Hab is to enable full assessment of potential resources revealed by scientific samples by processing such planetary surface materials without having to bring them into the Hab, thus eliminating the need for special handling and Planetary Protection (PP) protocols inside the Hab. The Sample Analysis and Materials Processing would have an estimated 500 – 700 kg mass and require on the order of 1 kW of power.

External Carrier Platform: The DSG may play the role of a launching and docking station for small robotic spacecraft that conduct missions to low lunar altitudes for high resolution geological, mineralogical, and resource mapping and to the lunar surface for sample retrieval. Sample return missions from asteroids may also be designed to deliver samples to the DSG, especially if it is stationed at orbits such as LDRO for easier access. This essential role of DSG for planetary materials science investigations will involve the use of multiple robotic assets that will require a platform from which to launch toward their destination and to which they will return with samples and data. We propose to study a prototype of such an External Carrier Platform that would be an attachment to the Deep Space Gateway so that the crew can manage the operations with full vision of the platform in a similar way that the open Spacelab carrier was used aboard Space Shuttle missions. The platform also would enable the remote operations of the transfer of samples into the external Sample Analysis and Materials Processing facility and where the crew would take control of the handling of the samples and their assessment of the need to admit them inside the laboratory.

This flexible set of concepts range evolve in complexity as the missions require to ultimately transform the DSG in a base of operations for lunar sample return missions using small reusable landers ferrying between the DSG-Orion stack and the lunar surface and enable advanced material processing systems to be tested with lunar samples without having to land complex hardware on the lunar surface. It uses the capabilities desired by EMC for the DSG crew to teleoperate surface assets from orbit and allows the program to gain operational experience in this area in anticipation of Mars orbital missions. The External Carrier Platform would have an estimate mass of 1 t and require 0.5 – 1 kW of power.

This concept is also aligned with the vision of commercial exploration of space resources for mining purposes because it offers these private companies a testbed for such tests in a win-win public-private partnership.

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Lunar heat flux measurements enabled by a microwave radiometer aboard the Deep Space Gateway. M. Siegler[1,2], Christopher Ruf[3],Nathaniel Putzig[1], Gareth Morgan[1], Paul Hayne[4], David Paige[5], Seiichi Nagihara[6], R. C. Weber[7]; [1]Planetary Science Institute, [2]Southern Methodist University, [3]University of Michigan, [4]University of Colorado, [5]University of California Los Angeles, [6]Texas Tech, [7]NASA Marshall Space Flight Center.

We would like to present a concept to use the Deep Space Gateway as a platform for constraining the geothermal heat production, surface and near-surface rocks, and dielectric properties of the Moon from orbit with passive microwave radiometery. This will compliment desired landed heat flux measurements from a reusable lunar lander as well as orbital thermal and radar data. We target and instrument with wavelengths between 300MHz and 3 Ghz (100cm-10cm). This should allow detailed mapping of the upper ~15m of the Moon to constrain **1) dielectric properties, 2) presence of bedrock, buried rocks and ground ice, and 3) subsurface temperatures that would constrain geothermal heat flux.** Despite this potential capability, no purposefully designed, passive microwave instrument has explored another body for geophysics measurements. With renewed interest in human and robotic site assessments enabled by the Deep Space Gateway, we believe the time for a microwave radiometer has come.

Any warm body will emit microwaves from a depth determined by the wavelength of the emitted microwave radiation and the properties of the material overlying it. Passive microwave instruments are traditionally used for atmospheric (e.g., JUNO MWR) and sea surface observations (e.g., Jason, Topex); however, microwave observations of a solid surface will reveal a wealth of information about subsurface temperatures and material properties. While instruments like the JUNO MWR can measure temperature profiles 100s of km into the Jovian atmosphere, similar wavelengths will see subsurface temperatures ~1-10m into lunar regolith. The depth which is measured depends on the dielectric properties of the surface.

Therefore, if we know the near-subsurface temperature profile (which is now well constrained by LRO Diviner), we can constrain near surface variations in dielectric properties. This is especially applicable to short wavelengths (~3Ghz, 10cm) which predominately sample the near surface layers constrained by infrared measurements. These measurements will be critical for interpreting microwave wavelength radar measurements of the subsurface from orbit. For the Moon, we know surface transparency in microwave wavelengths varies mainly due to changes in minerology (dominated by the dielectric properties of TiO_2 and ilmenite) and density (i.e., subsurface rocks). This allows a microwave radiometer to be used to map Ti-rich minerology as well as buried density anomalies.

Once shorter wavelengths have been used to constrain near dielectic properties, longer wavelengths can be used to find variations from expectations of standard a lunar regolith column. Decreases in microwave brightness temperature are indicative of buried rocks of bedrock, which prevent microwave radiation at depth from being seen. Increases in microwave brightness temperatures from expectation are indicative of high geothermal heat flux.

Passive microwave maps of the Moon have been produced by Earth-based radio observations and recently by a twice-flown Chinese Chang’E 1 and 2 lunar orbiting microwave radiometer (MRM). The Chinese lunar instrument was a copy of a terrestrial meteorology instrument, rather than specifically designed for the Moon, and it has known calibration issues. Despite these shortcomings, published work and even can extend our knowledge of the thermal and physical state of the subsurface beyond the infrared and yield information about electrical properties unobtainable from radar.

The longest Chang'E wavelength was 3GHz (10cm), which has should show a small variation due to geothermal heat flux, on the order of 1K per 10mW/m^2. When expected temperature differences due to latitude, slope, and albedo, this appears to be exactly what we see (Figure 1). Interestingly the areas where the largest increase in brightness temperature are seen are also rich in Th and other heat producing elements (Figure 2), suggesting that we are indeed seeing increased geothermal heat flux. As temperature differences due to variations in heat flux become larger with depth, we desire measurements to ~100cm, where temperature differences on the order of ~5-10K per 10mW/m^2 should be expected. Given a large platform like the Deep Space Gateway, we believe that such an instrument can revolutionize our understanding on the near surface and interior composition of the Moon.

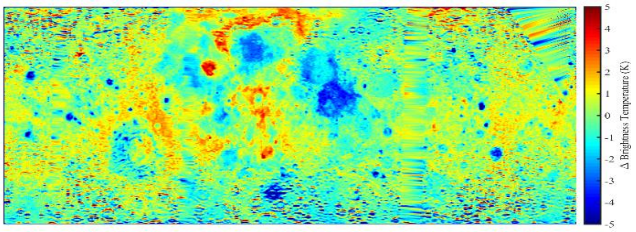

Figure 1: Chang'E-2 MRM 3GHz midnight data corrected for latitude, slope, and albedo variations. Note the prominent cooling from high-Ti mare and rocks (e.g. Orientale), but residual warming of low-Ti areas in the Procellarum region.

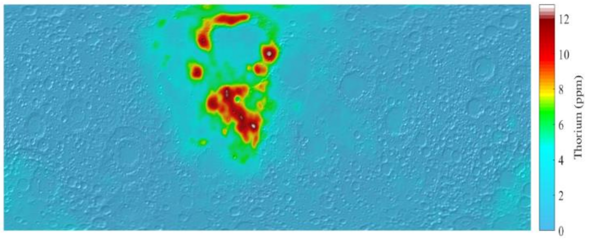

Figure 2: Thorium in the upper 1m of the lunar regolith as measured by Lunar Prospector. Note that areas with high crustal Th, and therefore expected higher crustal heat production, are also hotter than expected in the Chang'E data in Fig. 1.

We have designed a preliminary system with 300MHz to 3Ghz frequency range that should exceed the capability of the Chang'E MRM. The longer wavelengths will allow for heat flow constraint in even Titanium-rich regions and global mapping of regolith thickness. The basic instrument is simply electronic instrumentation that can be added to existing radar or communications antenna systems. In the case of communications or SAR instruments, nadir pointing would be required.

Table 1. Microwave Radiometer Specifications		
	Min	Max
Frequency Range (MHz)	300	3000
Gain (dB)	37	97
Dynamic Range (Hardware)	0	25
Noise Figure (dB)	2.5	3
Lo Synthesizer Lock Time (μs)		500
Switch Transition Time (μs)		90

- Mass: >2kg electronics added to existing communication or radar antenna system
- Power: ~4.6 and 8.6W depending on digital switching mode.
- Cost: ~$1-5M
- Volume: Minimal electronics, antenna pointed to nadir desired.
- Amount of crew interaction: None, if using communication antenna, nadir lunar pointing required.
- Desired deep space gateway orbit: Any, but favored greatest time of day/latitude/longitude coverage, minimum orbit height (LRO-like orbit)
- Other resource needs: None

In-Space Assembly of Large Telescopes for Exoplanet Imaging and Characterization.

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Introduction: Envisioning the need for future large segmented telescopes to one day exceed the fairing size of existing or even planned launch vehicles, NASA will need to begin considering the in-space assembly and servicing of these future assets. Large aperture telescopes benefit all astrophysics as well as planetary and Earth science but are a necessity for advancing the search for life outside of our solar system. They provide unprecedented spatial resolution, spectral resolution, and signal to noise. Large telescopes equipped with coronagraphs will be able to explore the habitable zones of more distant Sun-like stars and, perhaps just as important, will more effectively probe their atmospheres in the near infrared where there are important spectral lines, potentially revealing information about life. This is because the resolution element, λ/D, is adversely affected at longer wavelengths but compensated with larger apertures. Improved spectral resolution is achieved because of the greater photon collecting power of these larger telescopes enable more detailed spectral features, potentially revealing new information about these exoplanets' atmospheres. Perhaps even life as we don't know it. Improvements in signal to noise enable greater sensitivities to faint objects, like exoplanets, and the ability to obtain more time-resolved data looking for changes in the surface features and seasons of exoplanets.

Gateway Assembly: NASA's proposed Deep Space Gateway (DSG) architecture provides an opportunity to assemble large space telescopes, test them, and release them onto the low delta-v highway arriving at the stable Sun-Earth L2 orbit. From the Sun-Earth L2 orbit, cis-lunar is an economic location to return for servicing. The same low delta-v highway may potentially bring telescopes back resulting in less fuel having to be carried. Servicing in cis-lunar in the vicinity of the DSG could include repairing (robotic servicers with and without astronaut support), replacing and upgrading spacecraft subsystems and payload instruments, refueling to extend lifetime, and re-positioning to new orbits when necessary. As has been shown with the Hubble Space Telescope, this capability may potentially enable longer telescope lifetimes and more frequently allow for instrument upgrades providing the science community with more advanced and timely technologies. The approach of assembling large telescopes in space could very well help break the cost model for large telescopes by creating a new paradigm. A paradigm where telescopes across multiple wavelengths can escape the constraints of launch vehicle fairing sizes and mass limitations and complicated deployments by being assembled in space. These telescope apertures could even be designed to be increased over time and serviced to ensure longer lifetimes with continuously updated instrumentation.

We will present a few different concepts in which the DSG can be used to robotically assemble large space telescopes – both filled apertures like the JWST but working at UV/O/IR wavelengths as well as interferometers working in the near and mid-IR. We will examine potential interfaces and needed augmentations to the expected DSG assets and examine the use of telerobotics, servicers, and astronauts.

GATEWAY BIOBOX: A COMPACT, MULTI-PURPOSE BIOLOGICAL HARDWARE SUITE FOR IN SITU EXPERIMENTS AND ANALYSES IN DEEP SPACE.

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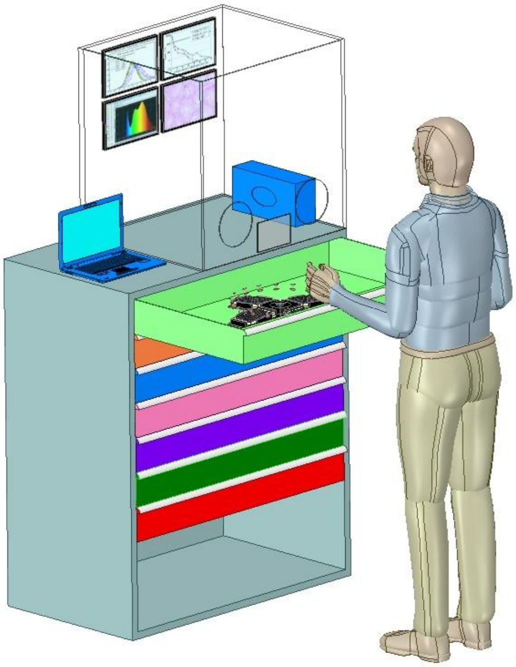
Introduction: A look across the history of NASA life science payloads (including International Space Station experiments and all predecessor studies on the Space Shuttle and Mir) reveals that most biology experiments were simple: packaged into containers, transported to orbit, then activated to grow in the microgravity environment and eventually returned to the ground after cryopreservation or fixation. Although some basic reporter genes or growth patterns could be elucidated or imaged on orbit (depending on the specimen), more sensitive biological analyses and assays typically occurred days, weeks, or even months later in ground laboratories once samples were transported back to Earth – i.e., not in the space environment. *This paradigm for biology experiments must change with the Deep Space Gateway*.

Encouragingly, four spaceflight missions launched to the ISS in 2016-17 demonstrated a new suite of instruments designed to generate molecular datasets on orbit. With proven functionality of Wetlab-2 [1], miniPCR [2], RAZOR [3], and the Biomolecule Sequencer (BSeq) [4], research teams demonstrated that end-to-end biological experiments can be conducted in space. A new era of biological research in spaceflight can now be planned and empowered by on-orbit, flexible analyses using miniaturized, efficient molecular machinery for lysing cells or tissues, extracting and purifying biomolecules of interest, amplifying and identifying genes, and even preparing libraries for nucleic acid sequencing. Leveraging universal features of these successful in-flight instruments as well as ISS legacy systems for performing biological experiments in space, we propose the "*Gateway BioBox"*, a multi-purpose, adaptable hardware suite that will prepare NASA for beyond low Earth orbit expeditions where fundamental biology questions must be examined without reliance upon sample return.

Gateway BioBox: With volume, mass, and power limitations in the Deep Space Gateway habitat inevitable, a compact, multi-purpose biological research hardware suite will be needed. The Gateway BioBox is a compilation of NASA's smallest & nimblest biological tools and hardware systems that will allow for a wide range of specimen cultivation and analysis, from the most sensitive molecular measurements to cell and tissue biology assays performed routinely in Earth laboratories. It adapts elements of ISS hardware already flown (e.g., MSG, Wetlab-2, BSeq, Bioculture, etc.) and adds 1-g gravity controls plus ancillary equipment and environmental sensors that will be useful for a variety of conceivable life science investigations.



The BioBox will accommodate specific model organism categories in each individually-controlled, stacked drawer that can slide out for experimental manipulations. For instance, a single drawer could be dedicated to either bacteria, fungi, human cell cultures, fruit flies, or plant seedlings. Inside each drawer of the BioBox would be a standard set of environmental control devices (e.g., LEDs) and sensors (e.g., dosimeters, thermocouples, relative humidity monitors, etc.). Specimens would be able to grow in microgravity conditions and/or attach to a centrifuge positioned inside the drawer capable of spinning liquid media containers (e.g., 96-well plates) or solid media containers (e.g., agarose petri dishes) used for experimental growth. BioBox drawers will be programmable or manually adjustable through a user-friendly master control panel, allowing each model organism to grow at experimentally optimal conditions. Microfluidic cards from small spacecraft (i.e., cube-sats [5]) could also be installed inside drawers for miniaturized and automated life science experiments requiring a stable, powered and controlled environment. Above the BioBox drawers computer tablets can provide a simple crew interface, as well as a workbench for preparing and processing samples inside a sterilizable glovebox. State-of-the-art tools would be inside the glovebox. Today, that might include Wetlab-2's Sample Preparation Module, fluid transfer and de-bubbling devices, and real-time quantitative PCR thermocycler [1]. An automated library preparation tool and miniaturized sequencer [4] would also provide multi-purpose analytical functions for most life science investigations. Specific BioBox instruments should be down-selected later in order to acquire industry-leading, miniaturized capabilities that cannot be readily predicted at this time. At the bottom of the BioBox will be a dedicated refrigerator for storing reagents used for biological assays at 4 °C.

BioBox Resources. Mass (50-100 kg); Power (0.2-0.5 kW); Cost ($10M); Volume (0.5-2 m^3); Crew Time (could involve either autonomous or crew-tended operations); Location (inside Deep Space Gateway crew habitat); Other Resource Needs (periodic re-supply of reagents, supplies, and model organisms).

Need for the Facility: Despite decades of ISS research, our understanding of combined and potentially synergistic effects of deep space radiation and microgravity is nearly non-existent. The Gateway BioBox would enable model organism studies investigating biological responses and mitigations for long-duration, low-dose deep space radiation which cannot be reproduced on ISS or on Earth. Serving as a core facility for the Deep Space Gateway, the BioBox could support research projects examining a wide array of exploration knowledge gaps, including multigenerational growth patterns; symbioses; pathogenesis; microbiome relationships with human and plant health; bone, skeletal, and vascular changes; T-cell and immune system responses; and medical countermeasures (drug benefits, radiation mitigation, adaptation, and effects of artificial gravity).

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RESEARCH POSSIBILITIES BEYOND DEEP SPACE GATEWAY.

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Introduction: The early missions for the Space Launch System (SLS) are planning to carry four crew members in the Orion spacecraft along with co-manifested habitat modules to assemble the Deep Space Gateway (DSG) in cis-lunar space. [1] The initial DSG modules will be limited in mass and volume but could be considered a stepping stone to even larger research facilities. Beyond the initial DSG manifest, SLS will have payload launch capabilities that could put in place large research facilities in a single launch as planned for the Deep Space Transport (DST). [2] This abstract explores those possibilities for larger research facilities at the DSG, using the same module design and basic layout planned for the Transport, to be implemented either before, after, or simultaneously with the Transport module production.

The research facilities module envisioned for beyond the DSG timeframe is of the scale that can be flown in a payload configuration on SLS, up to 8.4m in diameter, and about 45mt. Numerous iterations of large Mars transport habitats have been designed in previous studies since the SLS derived habitat, or "Skylab II" study in 2013. [3,4,5] An initial concept for using this module as a research facility was devised in 2015. [6] Figure 1 shows one vehicle concept of the DSG with an attached large volume research module and an asteroid retrieval vehicle.

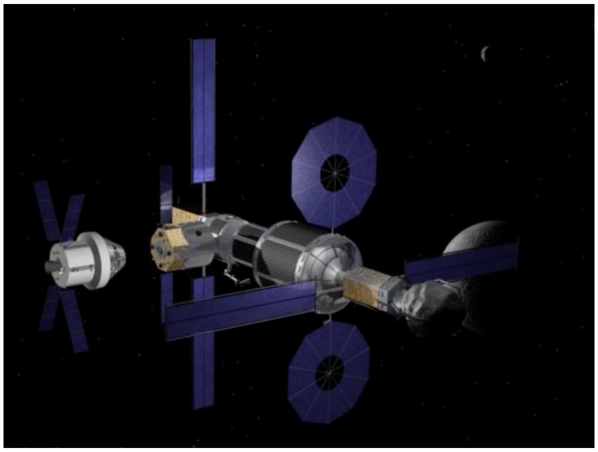

Figure 1. Deep Space Gateway with Large Volume Research Facility.

The interior layout for the Main Deck (Figure 2) proposes a wide variety of research facilities to support deep space science, engineering, and technology development that has the potential for opening the door to permanent habitation beyond Earth.

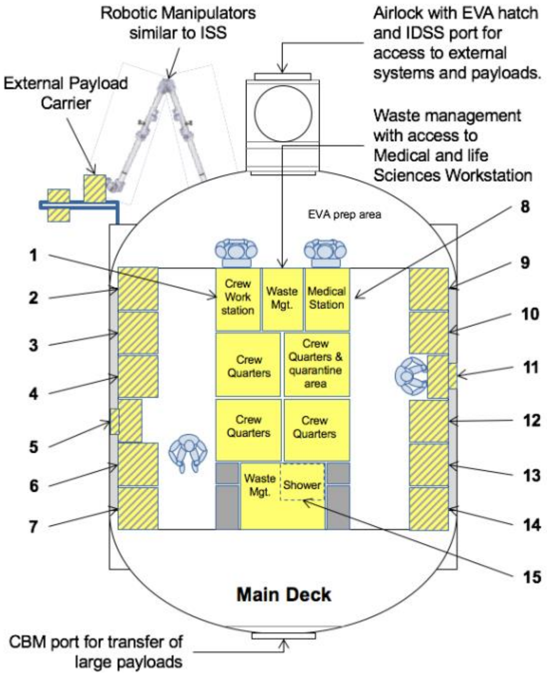

Figure 2. Research Laboratory Layout: The Main Deck of a 3-deck level layout is shown, supporting the primary laboratory functions for materials and life sciences research.

The research facilities proposed at this early concept stage include the following from Figure 2 above:

Materials and Geological Science: (assumes availability of lunar and asteroid materials for in-situ resource utilization development)

1. Workstation 1. Physical Sciences

2. Multi-purpose Glovebox

3. Research Lab 1. Scanning Electron Microscope

4. Research Lab 2. Gas Chromatography Mass Spectrometer

5. Window and Sample Stowage 1. Freezer/Incubator for Geo samples

6. Research Lab 3. Raman/FTIR Spectrometer

7. Thermal/Vacuum Control System

Medical Research: (includes waste management facility with access to medical & life science stations)

8. Workstation 2. Medical and Life Sciences

9. Sample Stowage 2. Freezer/Incubator for Bio samples

Zoology Research: (space environments research on animal life forms)

10. Research Lab 4. Live Animal Quarters, including Glovebox & Cold Sample Storage

Astronomy:

11. Window Observational Research Facility (WORF). Includes tele-workstation and portable equipment for additional viewing locations

Physics:

12. Research Lab 5. Microgravity Lab

Engineering Research: (includes waste water recycling development)

13. Clothing Maintenance Workstation. Includes washer & dryer facilities

14. Stowage and Waste Water Management. Supports washer and shower facility

15. Shower. Integrated with waste & hygiene area

Additional features not shown include research facilities on the Upper and Lower Decks:

Lower Deck: Includes Workstations 3 & 4 for maintenance, 3D printer equipment, and printer materials processing.

Upper Deck: Includes Research Lab 6 for a Plant Growth Chamber and a Life Sciences Glovebox (Botany).

Work has been in progress for several years on a mockup of the SLS-derived habitat at the Marshall Space Flight Center (Figure 3). The layout shown in Figure 2 can be the same as a habitat for Mars transit missions by utilizing stowage along the exterior walls in place of the extensive laboratory equipment shown.

Research possibilities for the facilities described include development and test of materials processing systems from lunar and asteroid materials, medical research on the effects of the microgravity and radiation environment of deep space, food production systems development, and habitation systems research and development. In addition, this facility could provide a platform for demonstration of long duration missions in preparation for future Mars transits, which includes habitat demonstrations for four to six crew for missions of 1000 or more days.

Figure 3. SLS-Derived Habitat Mockup: Layout is suitable for both a deep space laboratory and a Mars transit habitat configuration, (NASA, MSFC, Bldg. 4649).

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Deep-Space test of a neutrino detector. N. Solomey[1] , N. Barghouty[2], M. Christl[2], L. Johnson[2], R. McTaggart[3] and H. Meyer[1], [1]Wichita State University, Wichita, KS 67260 email: nick.solomey@wichita.edu, [2]Marshall Space Flight Center, NASA, Huntsville AL 35812, [3]South Dakota State University, Brookings, SD 57007.

Introduction: The Sun provides all of the energy that our planet needs for life and has been doing so for five billion years. Understanding our Sun and its interior is one of the major goals of the NASA Science program. Still this is a very difficult task because very little makes it directly out of the Sun's interior. The energy we see today that warms the Earth was made 50,000 to 80,000 years ago and is only now coming to the surface to make light. However, neutrinos penetrate matter almost without interaction and make it to Earth in only eight minutes. Since neutrinos interact only weakly they are hard to detect; never-the-less within the last ten years neutrino detectors on Earth have started to reliably detect neutrinos from the fusion reactions in the interior of the Sun and scientists have started to use this information to investigate the Sun's nuclear furnace. Changes in solar neutrino flux make it advantageous to take a neutrino detector into space since the solar neutrino intensity changes dramatically as the inverse square of the distance from the Sun, by five orders of magnitude when going from the Earth to the Sun or from the Earth to the current position of the Voyager 1 space craft. Eventually launching a space-craft with a neutrino detector into close solar orbit would perform unprecedented science study opportunities. Before committing to such an ambitious mission we will need a space borne platform that can test a small prototype detector away from the Earth and in the deep space environment – the Deep Space Gateway is a promising candidate.

Considerations for the Study of biological effects in the deep space environment. M. B. Sowa[1], T. C. Lusby[1], T. Staume[1], [1]NASA Ames Research Center, Space BioSciences Division, Moffett Field, CA 94035.

Introduction: Exploration of deep space will result in long term protracted exposures to microgravity and space radiation. Our current understanding of the fundamental mechanisms of response to these stressors on biological systems and human health remain limited. Current radiation risk estimates for crewed space flight are based predominantly on human epidemiology data following low linear energy (LET) radiation exposures. These data are scaled to the radiation types and fluences commonly encountered in space through the application of radiation quality factors and dose, dose rate modification factors. NASA and the scientific community acknowledge the limitations of this approach, however appropriate data on the radiation quality dependence for high energy, high atomic number ions (HZE) such as those found in space are currently unavailable making for large uncertainties in risk estimates. The majority of data available do not mimic the complex exposure scenarios found in deep space where the effects of both microgravity and radiation contribute to the response, therefore studies beyond low earth orbit (LEO) utilizing the deep space gateway platform will provide a wealth of new scientific information.

Space Radiation Environment: The general climate of galactic cosmic radiation (GCR) varies fairly predictably on an 11-year cycle, however solar particle events (SPEs) are unpredictable, both in character and timing. Episodic SPEs can be managed by providing sufficient shielding, but GCRs are always present and their energy spectra extend to very high energies with sufficient intensity such that shielding cannot eliminate all potential hazards. Both SPEs and GCR contain protons and heavier nuclei (HZE particles). Despite being present in relatively low abundance, HZE particles have a high ionization potential and will be the main contributors to risk [1],[2]. Animal studies indicate that HZE nuclei are more biologically effective than low LET radiation. For example the relative biological effectiveness (RBE) factors comparing γ-rays with HZE ions in mice or rats for skin tumors indicate values as high as 25-40 [3]. Furthermore, tumors appear to develop earlier after high-LET radiation than after low LET [4]. This short latency and increased effectiveness observed for HZE ions compared with sparsely ionizing radiations suggests that the scaling currently used in risk assessment approaches may be insufficient to define critical radiation quality effects.

Uncertainties in predicting risk from space radiation exposures: NASA currently models risk using the double detriment life-table for an average population [4],[5],[6]. This latter model is based primarily on epidemiological studies of the Japanese A-bomb survivors and is “scaled” using a radiation-quality factor (Q) and a dose, dose rate effectiveness factor (DDREF) [7]. The A-bomb survivor data predicts risk largely based on colon dose [8]. These risk models do not explicitly account for the actual biological effects of radiation that lead to the increased health risk, and they do not account for potentially synergistic effects occurring due to the combined exposure to microgravity. The frontier of risk sciences is in developing integrated experimental and computational models of health consequences that embrace the underlying biology with as much mechanistic detail as experimentally and computationally tractable with realistic exposure condition inputs. Additionally, the choice of the biological model employed, whether it be cells grown in monolayers, 3D tissue cultures, or animals, must be robust and capable of addressing the most pressing questions identified for furthering deep space exploration.

The value of high throughput data collection and computational approaches: The biological responses observed following exposure to a relatively low level but protracted stress such as produced by the space environment can be both difficult to measure and evaluate. Mathematical models are useful for understanding the operating principles of complex biological networks under these conditions. They can be used to organize information, to uncover the relationships between measured biological variables, and to generate testable hypotheses [9],[10]. Mechanistic models have been developed for a few well-studied signaling and metabolic pathways. While these models are useful for understanding the operating principles of a particular pathway and to generate predictions about intervention targets, they are parameter intensive, and demand a level of knowledge that is currently unavailable for all but a few of the pathways within the cell. It is critical that data collected in deep space exploration can be utilized for model development and for relative risk evaluations. Data capable of being deposited into a structured database such as that provided via the GeneLab platform, will provide more power and greater efficiencies for science conducted in deep space.

The Importance of Radiation Monitoring: The biological responses induced by protracted low dose exposures to the deep space environment will be inhomogeneous in both their temporal and spatial distributions. Likewise the radiation field will have a variable energy and spatial spectra. In order to correlate the induced biological responses the external environmental variables, we must have accurate characterization of the environment. Many radiation detection technologies currently available for exploration missions have substantial limitations, including the need for complex modeling to convert directional response to omni-directional dose and dose equivalent and estimation of the neutron contribution. Ames has developed an innovative compact dosimeter (Fig. 1) based on the tried-and-true tissue equivalent proportional counter (TEPC) technology. TEPCs have served as environmental monitors against which other dosimeters are compared and have been used extensively on the ISS, the Space Shuttle, high altitude balloons, and in aviation. However, current TEPCs, including those on the ISS as well as their ground-based counterparts, are not suitable for missions beyond LEO - they are too large, power intensive, and would saturate during a substantial solar event, at a moment when real-time dose information would be most urgently needed for the interpretation of biological responses.

The choice of dosimeter must account for limitations in mass, volume, and power expected on exploration missions. Time-PIX, TID, Liulin, and RaySure are very compact Si-based sensors employing various detection approaches. The advantages of the Si sensors are their small size and low power requirement. The disadvantages are their directionality and insensitivity to neutrons. Neutrons may contribute 30% of the dose equivalent depending on shielding and surface location.

The mini-TEPC was developed as part of a collaboration between NASA Ames and investigators at Texas A&M University and Colorado State University [11]. The challenge was to develop a TEPC that could satisfy the small size and low power requirements while also providing reliable dosimetry for the complex radiation environment in space, which includes steady-state GCR, highly variable and potentially very intense SPE radiation, and secondary neutrons. The mini-TEPC is compact, with low power requirements and a broad response spectrum (0.5 kg, 0.5 W, 300 cm^3, neutron sensitive, 0.2-1200 keV/µm LET response, and omni-directional). This characterizations make it a promising candidate dosimeter for human exploration missions. In addition, the mini-TEPC responds reliably to the wide range of dose rates possible during exploration missions. This is not the case for the TEPCs presently available, which would saturate at the high dose rates expected during a large SEP event. Biological data collected as part of deep space missions will be significantly more impactful when coupled with appropriate and complete dosimetric data.

Conclusion: Currently insufficient data exists to accurately predict fundamental biological responses induced in complex radiation and microgravity environment encountered in deep space, and to be able to translate such data to the determination of individual risk to crew. In this abstract we touch on several important areas of consideration in designing experiments for deployment in deep space, including the value of high-throughput and computational approaches and the importance of appropriate dosimetry to facilitate interpretation of induced biological responses.

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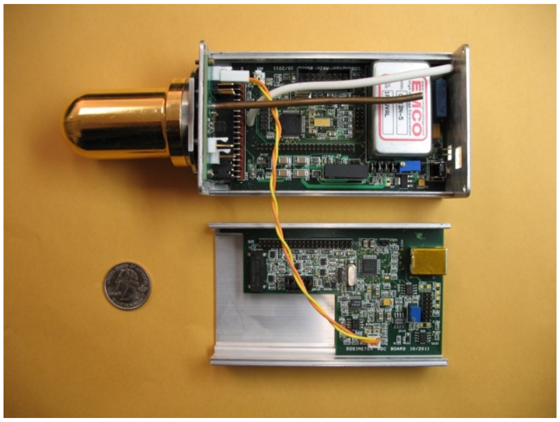

Figure 1. Compact TEPC for stand-alone applications. Serial data can interface through USB port.

FROM TEMPE TO DENVER: REALIZING THE WARGO AXIOM WITH THE COSMIC RAY TELESCOPE FOR THE EFFECTS OF RADIATION (CRATER).

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Introduction - Tempe: In February 2007, NASA's Lunar Reconnaissance Orbiter (LRO) mission was still in development. LRO's initial mission goals were responsive to the NASA Authorization Act of 2005 and to NASA's 21st Century Vision for Space Exploration (VSE), namely, to enable a safe return of humans to the Moon. LRO's science payload consisted of seven instruments designed to quantify various aspects of the lunar terrain and environment needed for human exploration of the Moon. One of those instruments, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) [1], was still in Phase C/D in late February 2007 when the NASA Advisory Council Science Committee held the "Workshop on Science Associated with the Lunar Exploration Architecture" in Tempe, AZ.

The "Wargo Axiom": At that meeting, the CRaTER science team laid out the various science goals that could be accomplished with their instrument which had initially been designed (and selected) for human exploration but which nevertheless could also accomplish new science. Mike Wargo, then Chief Scientist for NASA's Human Exploration and Operations Mission Directorate (HEOMD), passionately promoted the notion that "Exploration enables science, and science enables exploration", a mantra that became known as the "Wargo Axiom". Even before LRO's launch, the science payload teams were already imagining the science opportunities that LRO could enable as the first of the HEOMD VSE missions.

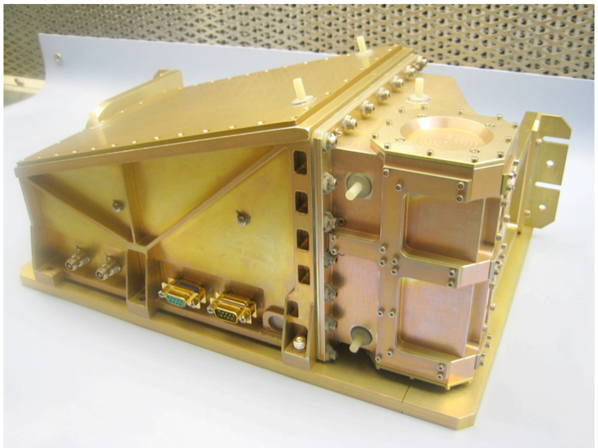
Beyond Tempe: The NASA community now returns to this topic at the "Deep Space Gateway Science Workshop" to be held in Denver, CO in late February 2018. In the 11 ensuing years since the Tempe meeting, the CRaTER science team is representative of a broad part of the science community that has realized the Wargo Axiom. We completed the build, calibration, delivery, and integration of the CRaTER flight unit between 2007 and 2009. In September 2009, the LRO mission was launched to the Moon. LRO completed its primary HEOMD-inspired mapping mission by September 2010. During that prime phase, the LRO mission and CRaTER met or exceeded our HEOMD exploration goals.

Starting in September 2010, the LRO mission transitioned from HEOMD to the Science Mission Directorate (SMD). LRO spent the next two years as a science mission, accomplishing lunar and heliophysics science through September 2012. LRO's prime science mission made clear that instruments designed for exploration could accomplish great science. As with other LRO instrument teams, the CRaTER science team turned its attention to how the remarkable data from an exploration platform could be used to explore new science topics. Many of the exciting discoveries from this first science phase would not have happened otherwise. LRO science continues to date, going through first and second extended science mission phases with a long string of science accomplishments and discoveries.

On to Denver: In this paper, we present a retrospective of this 11 year period from the perspective of the CRaTER science team. We review the synergies between exploration enabling science and science enabling exploration from the point-of-view of space radiation. The physics and chemistry (and sometimes biology) of ionizing radiation caused when energetic particles pass through matter remains one of the most significant risks to human exploration. The processes which accelerate and transport these charged particles remains a vibrant topic of study in space plasma physics. The role that these particles play in modifying the surfaces of solar system bodies has emerged as an important new area in planetary science. Through related studies since LRO's launch, we demonstrate how these intertwined topics are driven by exploration needs, which in turn have fueled scientific discovery in multiple parts of SMD.

To the Gateway: The CRaTER instrument remains fully functional and is in excellent health even after eight years of flawless operation, both as an exploration radiation monitor and as a multi-faceted science instrument. We point out that both exploration and science capabilities would be greatly increased if we possessed multi-point measurements of the radiation environment, ideally with an identical instrument to CRaTER. We note that such as an instrument exists and at dimes on the dollar.

During the prime LRO development, the CRaTER instrument team developed a fully-functional, fully-qualified flight spare. The instrument is designed to operate on a robotic spacecraft and so requires no support from a flight crew; the instrument operates completely autonomously. The flight spare has a mass of ~5.5 kg, consumes about ~6.5W of power in normal operations; the characteristic length in each of the three principle axes is ~30 cm. For optimal operation, the telescope should have unobstructed views above and below the principal axis. A photograph of the CRaTER instrument is shown below.



The CRaTER flight spare has remained in bonded storage and is available for flight to the Deep Space Gateway at a small fraction of its original development cost. It would provide a second or continued measurement of a well-proven and well-understood data product valuable for human exploration, complementing those measurements available from the CRaTER instrument still orbiting the Moon on LRO. Finally, we discuss the science enabled by dual measurements of this sort, as well as the advantages for exploration and science if deployed to various exploration destinations.

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ADVANCES IN PLANETARY PROTECTION AT THE DEEP SPACE GATEWAY.

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Introduction: Deep Space Gateway (DSG) environments provide an opportunity to address planetary protection knowledge gaps that will feed forward into architecture concepts for surface operations at Mars and for deep space travel, particularly concerning the return of astronauts to Earth after visiting the martian surface.

Spacefaring nations have, since the earliest years of the space programs and as reinforced by the Outer Space Treaty (OST) in 1967 [1], committed to protecting solar system objects from harmful contamination carried by interplanetary spacecraft. One result has been that the scientific investigation of extraterrestrial targets can be performed without the threat of being compromised by terrestrial biological contaminants. As we consider the potential of future sample return missions, especially those involving human crew, the other significant role of planetary protection comes to the fore (also reinforced by the OST); that of protecting the Earth (the biosphere on which we all depend) from the potential release of an extraterrestrial biohazard present in a returned martian sample.

Planetary protection policies to achieve these protection goals are relatively mature for missions performing robotic exploration of Mars. Over time they have been informed and refined, reflecting our increasing knowledge about the martian environment from successive orbiter and lander missions, as well as our growing understanding of the limits and capabilities of terrestrial life on Earth. However, when considering the future human exploration of Mars, it is clear that the fixed "at launch" bioburden requirements historically applied to robotic missions are not readily transferable to a crewed mission, where the combined microbiomes of the astronauts and their habitat exceed the currently permitted spore levels for a robotic explorer by many orders of magnitude. Nonetheless, for a human mission to Mars to be undertaken successfully, prevention of harmful contamination and the loss of integrity of martian science become all the more important, while the safeguarding of Earth from potential backward contamination continues to be the highest priority.

The continuing and as yet unresolved challenge for the international space exploration community is to determine how such harmful contamination is to be prevented in future space exploration missions. The recent (2016) COSPAR workshop on Refining Planetary Protection Requirements for Human Missions is part of that narrative, evaluating recent efforts, activities and the state of the art in the context of current COSPAR Planetary Protection Policy [2], collecting inputs and identifying and prioritizing knowledge gaps on the path to establishing numerical requirements against which a crewed mission concept can be designed and validated.

In this context, the DSG vehicle provides a platform for planetary protection investigations that could be performed to inform the planetary protection requirements development process. This includes experiments performed on the inside of the vehicle, to improve understanding of interactions between microbes and human habitats operating outside LEO; and on payloads located outside, to improve understanding of microbe-hardware interactions when organisms and organic materials are exposed to the space environment.

Scope of Studies for Planetary Protection: Proposed studies could include:

- *Studies for evaluating microbial responses to the deep space environment:* For example, microgravity; long duration vacuum exposure; radiation exposure; UV exposure; and combinations of these exposures not possible in the LEO environment, to develop and confirm post-launch microbial reduction approaches and refine planetary protection constraints at Mars.
- *Assessing performance of advanced life support and EVA systems:* These, together with relevant robotic operations, need to be assessed with respect to microbial cleanliness for 'feed-forward' regarding contaminants in habitats, transfer vehicles, and planetary surface systems development.
- *Monitoring changes in microbial characteristics:* Such changes need to be assessed from 'As launched' through 'As returned back to Earth' conditions, to inform assessments of human support systems and astronaut health during long-duration spaceflight before (and eventually after) exposure to other planetary materials, and to assess population dynamics and planetary protection implementation approaches and processes.

Closure of Knowledge Gaps: The knowledge gaps identified by recent COSPAR and NASA workshops concerning planetary protection for crewed missions fell into three categories; microbial and human health monitoring, technology and operations for contamination control, and natural transport of contamination.

Of these, a significant fraction could be addressed by these studies on the DSG, including in the area of in space human health monitoring, where development of sampling collection and analysis technologies and procedures need to be developed together with diagnosis and treatment options. Also required is to understand and manage the astronaut and vehicle environmental microbial populations during long term flight in deep space, needing for example ECLSS-compatible low toxicity disinfectants and prevention of biofilm induced corrosion/fouling.

In the area of technology and operations, the DSG is a suitable venue for proving technologies needed for safe cleaning, sterilization and decontamination, as well as for acceptable containment and venting capabilities, procedures and protocols for living spaces and EVA systems (although some of these aspects could also be performed in LEO).

Finally, to the extent that elements the DSG system architectures are similar to those of potential surface systems, they have the potential to inform researchers on what will leak and/or vent out of pressurized containers or human facilities, including information on the leak rate, size, biological diversity, organic molecules, cells, etc. of material vented during operations, and will potentially assist in establishment of acceptable contamination generation rates/thresholds for human landing/habitation sites and mobile-crewed systems (pressurized vehicle or suited crew).

Accommodation of Planetary Protection Studies: It is anticipated that these studies could be accommodated within planned capabilities for the DSG, with limited resources in terms of volume, mass and power, particularly if there is the capability to deploy investigations (robotically or by crew) to an external DSG location. These studies would provide significant benefit in terms of utilizing the DSG in both crewed and uncrewed mode to retire planetary protection risk for future surface operation at the martian surface. This abstract is presented as one of a series originating in discussions within the NASA Life Science Research Capabilities Team.

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Space Weather Diamond: A 10x Improvement in Real-time Forecasting.

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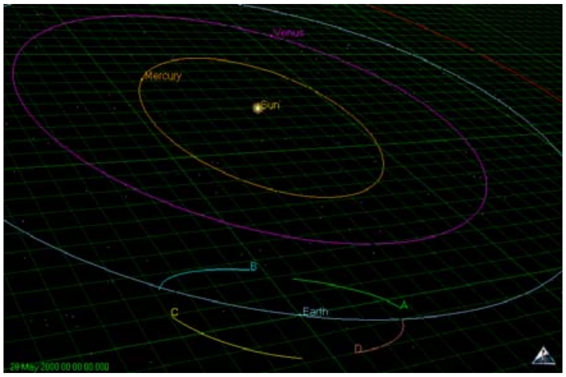
Introduction: This paper promotes an applied heliophysics mission concept named “Space Weather Diamond” (SWx◊). Such a mission facilitates the connection between science and societal needs, as well as supports NASA’s human and robotic explorers. It provides an *order of magnitude* improvement over present-day L1 libration point monitors that measure the solar wind input to Earth’s magnetosphere. It would also provide advance warning of solar energetic particle (SEP) events and energetic storm particle (ESP) events associated with shocks in the solar wind. Numerous techniques have demonstrated that sub-L1 measurements could provide significantly improved warnings of these radiation hazards in support of NASA’s human exploration mission. Additionally, the mission concept provides for significant science return, which is briefly outlined in this paper.

The next logical step in acquiring measurements to improve space weather forecasting is a sub-L1 platform. The SWx◊ concept offers an opportunity to make that significant advancement without the use of solar sails or other exotic methods of in-space propulsion.

Mission Concept: Space Weather Diamond is based on a constellation of four platforms that are phased into eccentric heliocentric orbits but, from the perspective of a fixed Sun-Earth line, the spacecraft appear to orbit Earth [1]. The approach is based on a concept called “distant retrograde orbits" [2] which are heliocentric orbits that remain in the vicinity of Earth. It is similar to a mission concept called “elliptical string of pearls" [3]. The mission orbit is readily achievable using present day launch capabilities and lunar gravity assists.



Four platforms of SWx◊ mission appear to circle Earth at ~0.1 A.U.

The space weather monitoring platforms in our conceptual SWx◊ would be equipped with primarily *in situ* instrumentation to monitor solar wind plasma, energetic particles, low-frequency radio/plasma waves, and interplanetary magnetic field characteristics. An enhanced payload including remote sensing instruments would significantly increase the scientific return of the mission, and these potential science goals are considered in the next section.

Potential Science with SWx◊

Beyond the obvious utility as a monitor of upstream solar wind conditions, there are numerous scientific possibilities for the SWx◊ concept. Here we describe several that we have considered, but a formal airing in the scientific community would certainly uncover additional ideas. The first science goal involves resolving the internal structure of interplanetary coronal mass ejections (ICMEs). We know that at 1 A.U. ICMEs have typically a 0.1-0.3 A.U. diameter, but details of their cross-sectional geometry are unknown at this time. Coronal white light observations would suggest near circular cross-sections (this is also the minimum energy configuration of the internal magnetic field); however, current state-of-the-art MHD heliospheric models predict significantly distorted cross-sections due to the interaction of the fast moving ICMEs and the ambient solar wind. Current 1 A.U. *in situ* observations can provide only a single track through the body of the ICME. These limited observations have been unable to distinguish between highly elliptical and circular cross sections. However, multiple measurements separated by ~0.1 A.U. would provide the necessary measurements to resolve this puzzle.

A second science goal would be to resolve the beam width of solar energetic particles (SEPs). The precise physical mechanism of solar energetic particle acceleration is still debated, and different proposed mechanisms have different predicted initial beam widths. Spacecraft separated by ~0.1 A.U. would provide the ideal platform to compare the SEP flux and energy profiles from the same event, thus providing valuable clues to the energization process.

A third science goal would employ triangulation studies with low frequency radio instruments. Single spacecraft observations heavily depend on the theoretical density profile of the solar wind in the inner heliosphere. A separation of ~0.1 A.U. is sufficient to allow precise tracking of shocks in the inner heliosphere, and multi-spacecraft triangulation relaxes this critical assumption.

If an enhanced payload included remote sensing instrumentation, then significant additional science would be possible. The first additional scientific aspect that SWx◊ would address is the critical need to perform 3D stereo imaging of the Sun--particularly active regions to obtain coronal magnetic structure using triangulation techniques. Magnetic field directions (but not magnitude) can be obtained for a large number of loops in the active region corona from stereo pairs of EUV images. These data can be compared with results from magnetic field extrapolation models. Initial comparisons using STEREO data and HINODE vector magnetic field measurements have shown that significant errors are found in the extrapolations of ALL models. The extrapolated field directions typically differ from the observed direction of the magnetic field by an average of 30 degrees. The STEREO spacecraft traversed these small elongations rapidly (in a few months) and very few active regions were available when these measurements were possible. Additional observations would provide unique checks on the validity of coronal magnetic field extrapolations which are used as the basis for most modeling and scientific research on the corona and heliosphere. Several researchers have concluded that there is a need for either more suitable (coronal rather than photospheric) magnetic field measurements or more realistic field extrapolation models. STEREO did not include magnetographs as part of the payload, so one approach to solving this problem would be to obtain vector magnetograph measurements from multiple vantage points such as would be offered by SWx◊.

A second scientific problem addressed by SWx◊ involves stereoscopic helioseismology, which has been widely discussed as a promising direction to extend that technique in the future. With stereoscopic helioseismology, new acoustic ray paths can be taken into account to probe deeper layers in the solar interior. The value of smaller separation angles for stereoscopic helioseismology is under study. Such measurements could help solve the puzzle of the solar cycle and advance our understanding of the operation of the solar dynamo.

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RETINAL EVALUATION USING OPTICAL COHERENCE TOMOGRAPHY (OCT) DURING DEEP SPACE GATEWAY MISSIONS.

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Introduction: Spaceflight-associated neuro-ocular syndrome (SANS) is reported to affect ~ 40% of astronauts on long-duration spaceflights (as of May 2017) and is determined by one or more findings: optic disc edema, hyperopic shifts, globe flattening, cotton-wool spots, or choroidal folds [1]. The etiology underlying SANS is still under investigation and at present is believed to be secondary to the cephalad fluid shifts that cause increased fluid volumes in the head and neck area in the weightless environment of spaceflight. It is unknown whether exposure to deep-space radiation, which is significantly higher in both exposure levels and heavy ion composition than radiation exposure in low Earth orbit, will further increase fluid accumulation or extravasation in the retina and optic nerve head, potentially increasing the severity of SANS signs and symptoms [1]. Although astronauts on the International Space Station (ISS) are currently evaluated during flight using a variety of eye testing devices, these same diagnostic capabilities will probably not be feasible during Deep Space Gateway (DSG) missions because of mass and volume limitations. Quantitative optical coherence tomography (OCT) is the most sensitive and informative eye imaging technology, and OCT-based metrics of optic nerve head morphology will be important for tracking changes in the retina and optic nerve and detecting optic disc edema as early as possible during DSG missions. Recently, 12 ISS crewmembers were evaluated with fundoscopy and OCT imaging before, during, and after an ISS mission. OCT measures of average minimum rim width (a measure of optic disc edema) and peripapillary choroidal thickness significantly increased from average preflight values as early as the first inflight data collection time point on flight day (FD) 10, and was maximal on flight day 150 (minimum rim width: 47 ± 42 µm, $P < 0.001$; choroidal thickness: 40 ± 23 µm, $P < 0.001$) [2]. Both of these variables recovered to preflight values about 45 days after landing. In contrast, fundoscopy identified in-flight optic disc edema in only 3 of these crewmembers, and the edema was not observed until after FD30, highlighting the greater sensitivity and utility of OCT.

Methods: Crewmembers assigned to Deep Space Gateway missions will be consented for participation in a study that will evaluate changes to the retina and in particular the optic nerve head and its surrounding structures, using an OCT device. OCT imaging will be performed before, during, and up to 1 year after spaceflight. Extensive eye testing will be conducted before flight (12 to 3 months before launch) and after flight (10, 30, 90, 180, and 365 days after landing) using a suite of devices including imaging and functional tests. In-flight OCT evaluations will be conducted at 2 timepoints, early and late in the 45-day mission, to assess multiple measures including maximum rim width and peripapillary choroidal thickness, and results will be compared to preflight measures. Postflight recovery will be evaluated up to 1 year post landing.

Resources Required: The current total mass of the OCT unit on ISS is approximately 12.6 kg with a volume of 0.023 m^3. We anticipate future technology advancements will reduce the mass and volume of OCT hardware, therefore enabling OCT technology to be integrated into the deep space gateway vehicle architecture.

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MOON WATCH: CONTINUOUS MONITORING OF THE LUNAR SURFACE TO CONSTRAIN IMPACT FLUX.

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Introduction: The surface of the Moon is heavily cratered, recording a history of bombardment through the solar system. Though very large impacts are rare on the lunar surface today, there is evidence that small impacts occur regularly across the lunar surface. The LRO Camera (LROC) has measured a flux of impactors (>10 m in diameter) in monitored areas that is ~33% higher than anticipated and has observed secondary cratering processes that churn the top two centimeters of regolith on a timescale that is more than 100 times faster than previous models [1]. These measurements have altered our understanding of the current impactor flux with potentially significant ramifications for model ages of surfaces across the Earth-moon system as well as safety hazards faced by future robotic and human explorers.

One technique for measuring the current lunar flux is to monitor lunar impact flashes from Earth [e.g., 2-6]. These observations are complicated by atmospheric interference, the available resolution (both spatial and temporal) of instrumentation at great distances, and limitations in observable area to the near- side and during certain lunar phases. Placing an impact flash monitoring station on the Deep Space Gateway could mitigate many of these limitations and address three main questions in planetary and lunar science: 1) What is the current lunar impact flux? 2) What is the distribution of impactors across the lunar surface? 3) What is the range of meteoritic infall size?

Background Science: *Impact Flux.* Impacts large enough to damage future lunar infrastructure occur on the surface of the Moon frequently. Approximately 8 years of LROC Narrow Angle Camera (NAC) temporal pairs have revealed ~222 new craters with sizes from 1-75 m and ~47,000 new changes in surface reflectance (termed “splotches”) that are likely caused by secondary impacts or small primary impacts [1]. So far, only ~9% of the Moon has been covered by this LROC temporal imaging, and thus these numbers may significantly underestimate the number of impactors that have struck the Moon over the course of the LRO mission.

Examination of impact craters on the lunar surface also reveals a putative leading-trailing hemisphere dichotomy in the impact flux [7]. This dichotomy is seen on other planetary bodies in the solar system as well. (e.g., the Galilean satellites [8]). Because they are limited to near-side observations, current observations of lunar impact flux (*e.g.*, the impact flash monitoring campaign led by Marshall Space Flight Center [*e.g.*, 9]) are not able to measure whether the number of impactors hitting the Moon is different on the leading versus trailing hemispheres. A monitoring campaign able to see more of the lunar surface could help to address this outstanding question.

Impact Flash. Following a hypervelocity impact, the energy from the projectile is converted into heat, light, and kinetic energy and deformation within the target material (e.g., damage accumulation and ejecta). When a hypervelocity projectile impacts a target, a light flash is produced at the moment of first contact. Time-resolved light intensity curves can be used to monitor the flash and determine the starting conditions of the observed impacts [10,11]. Time-resolved intensity curves are characterized by a rapid rise in luminous intensity to a peak value, followed by a more gradual decay in light (Fig 1). Laboratory experiments examine flash characteristics for impacts into a variety of target materials, including metals and geologic targets. For impacts into metal targets, the peak intensity of the flash occurs during the initial projectile penetration, with the signal quickly decaying [12,13]. Impacts into particulate targets produce a source of blackbody radiators in addition to the initial flash. This source extends the resulting light intensity profile well beyond the time of initial contact [e.g., 11,14]. Measurements of the flash in different wavelengths exhibit similar general shape characteristics, however the peak intensities and rise and fall time differ across as a function of wavelength.

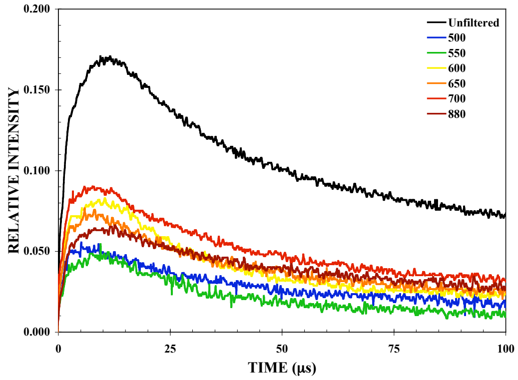

Fig 1. Light curves measured at different wavelengths for a typical laboratory experiment of a hypervelocity impact of pyrex into pumice performed at the NASA Ames Vertical Gun Range [14]. Note that this is for a laboratory experiment; lunar flashes are due to larger impacts and so would last longer than this example, probably on the order of 10s to 100s of ms.

Motivation for Flux Measurement Studies: A better understanding of impact flux is a goal of scientific investigations in the current Planetary Science Decadal Survey [15].

The lunar surface is often used as a baseline for age dating throughout the solar system, with methods largely based on the istopic model ages from returned samples, crater counts from imagery and the understanding of the lunar impact flux. However, the modern flux is highly uncertain, which can lead to large uncertainties in model ages from crater counting techniques.

Further, the safety of future crewed and robotic missions at the Moon (and across the inner solar system) may depend upon understanding the impact flux at small scales. For example, a better understanding of typical impactor size distributions during a given meteoroid stream may provide information to evaluate which are more or less dangerous to human activities. This, in turn, may provide important information about when astronauts should be taking extra precautions or seeking shelter.

A Mission Architecture to Monitor Current Lunar Impact Flux: The measurement strategy to monitor current impact flux on the Moon includes two main techniques: flash detection and measurement using a high-speed multi-band radiometer and flash locality determination using a combination of wide-field and high-resolution cameras.

The general conops includes continuous monitoring using the high-rate radiometer staring at the surface of the Moon. The signal will be continually buffered and data only saved when an event occurs. When an impact flash occurs, the rapid rise in intensity seen by the radiometer will trigger the cameras. Two separate camera types are envisioned. A wide-view camera would cover the full disk of the Moon and can be used to track where on the lunar surface the impact occurs generally. To provide operationally useful locations to orbiting cameras, a narrow angle, high-resolution, high-speed camera (or, perhaps an array of narrow-angle cameras) can image smaller portions of the disk detail. This will allow for a more resolved image of the impact plume as well as provide better targeting for follow-up observations by orbital assets (e.g., LROC).

The main data returned from this monitoring campaign would be the number of flashes and their time-resolved intensity, and the location of impacts on the lunar surface. This catalog would be useful in determining the recent and current impact flux and where the impacts are occurring on the surface (providing targets for cameras to view new impact craters). Measurements of flash intensity could be translated to energy and provide estimates of impactor size and speed. If resolved images of the impact plume are captured by the high-resolution camera, these data may also provide a method for determining impact trajectory and angle as well [*e.g.*, 9,17].

This setup requires a small footprint on the outside of the Gateway and no maintenance once installed. The mass and power needs are small. The system is designed to collect data without the need for humans in the loop. However, the data volume could be large depending on the resolution and frequency of data collected.

Conclusion: Understanding the impact flux is important to provide an understanding of the geologic record and assessing current inner Solar System exploration hazards. Providing information and catalogs of this current flux directly addresses questions in the decadal survey and has the potential to aid in future exploration of the Moon and aid in developing a better constraint for model ages of surfaces on the Moon and throughout the solar system. A relatively simple system of high-speed radiometers and cameras, requiring low resources and external footprint, can be designed to track this flux and return images and time-resolved light curves following lunar impacts.

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MEASURING EARTH'S RADIATION BUDGET FROM THE VICINITY OF THE MOON. W. H. Swartz[1], S. R. Lorentz[2], R. E. Erlandson[1], R. F. Cahalan,[3] and P. M. Huang[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723 <bill.swartz@jhuapl.edu>, [2]L-1 Standards and Technology, 10364 Battleview Pkwy, Manassas, VA 20109, [3]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771.

Summary: We propose to measure Earth's radiation budget (ERB) from the Deep Space Gateway or a small satellite in lunar orbit using broadband radiometers and other technology that are being demonstrated in space. The radiometer instrument payload for measuring the integrated total and solar shortwave (SW) ERB, based on the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat, is compact, autonomous, and has modest resource requirements. The instrument could either be (1) externally mounted on the Gateway and pointed using an agile two-axis gimbal that provides a full hemispherical field of regard or (2) flown on a small satellite in nearby lunar orbit, relying on the Gateway as a communications relay.

Introduction: Climate change is driven by the small imbalance between incoming solar irradiance and the outgoing, combined reflected solar and terrestrial thermal emission [1, 2, 3]. Current space-based assets measuring Earth outgoing radiation (EOR) are in fixed local solar times, either in low Earth orbit (e.g., CERES) or at the L-1 Lagrange point (NISTAR).

The lunar vicinity provides a unique vantage point in that the full diurnal cycle of the Earth can be sampled, in combination with a good sampling of all Earth latitudes over the course of each month. The proposed observations will provide an independent measurement of EOR and will also complement the CERES and NISTAR datasets.

The lunar-based ERB total and SW measurements will improve our understanding of ERB, including the impacts of human activities and natural phenomena. The new information can also be used for climate science.

Operations Concept: The primary measurement will be Earth's outgoing total integrated and solar-reflected SW ($\lambda < 5.5$ μm) radiation using an array of broadband bolometers with fields of view marginally larger than the angular size of the Earth from the vantage point of the vicinity of the Moon (about 2°). In addition to absolute calibration in the laboratory prior to launch, on-board calibration will be provided by periodic observations of the Sun for absolute scale, deep space for dark offset, and an on-board gallium fixed-point black body calibration target to track long-term degradation of the total channel.

Independent instrument pointing is required, both for Earth observation and for solar/dark space calibration maneuvers. This will be provided either by an agile two-axis gimbal (if the radiometer instrument is externally mounted on the Gateway) or spacecraft attitude control (if the instrument is mounted on a free-flying small satellite). The decision whether to locate the instrument on the Gateway or a small satellite will be the subject of a trade study.

All the hardware described in the proposal is flying or has flown in space, significantly reducing risk.

Instrument Description: The proposed instrument is very similar to that flying on the RAVAN CubeSat (see Figure 1) [4, 5, 6]. RAVAN is a technology demonstration funded by the NASA Earth Science Technology Office. RAVAN comprises a pair of radiometers (total and SW channels) using carbon nanotube absorbers and an analogous pair using tradition cavity absorbers. In addition, two gallium black bodies are housed in the instrument's radiometer covers. Launched in November 2016, RAVAN has been operating in orbit for more than a year, and excellent instrument stability has been demonstrated.

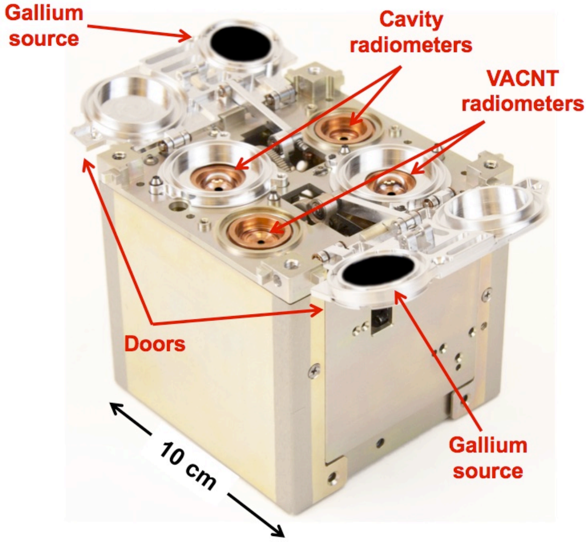

Figure 1: RAVAN payload.

The RAVAN-like instrument proposed here also comprises four radiometers, although they would all be based on the same technology, either carbon nanotubes or cavities. One (identical) pair would be used less frequently, thus reducing cumulative exposure and providing a means to assess degradation on orbit. RAVAN's wide field of view of 130° would be reduced to comfortably accommodate the 2° angular extent of the Earth as viewed from the Moon.

Resource requirements for the radiometer payload are listed in Table 1.

Table 1: Instrument Requirements (excluding pointing technology).

Parameter	Requirement (notional)
Mass	1 kg
Power	2 W (average)
Cost	~$2M
Volume	10×10×10 cm^3
Crew interaction	None
Desired orbit	TBD
Pointing	0.1° (see Pointing Technology section, below)
Other resources	Instrument interface temperature control

Pointing Technology: Relatively fine pointing control is required by the instrument, of the order of 0.1°. Two options to achieve this level of pointing are described here.

Two-axis gimbal. If the radiometer instrument is mounted on the Gateway itself, a gimbal will be needed to provide the required pointing. Our concept makes use of an agile two-axis gimbal that provides a full hemispherical field of regard, with a pointing accuracy of 0.04° and a maximum slew rate of 15° per second. The proposed gimbal is a low-cost system that has been space-qualified and is currently in orbit.

Small satellite host. It may be more advantageous to fly the instrument payload on a small satellite that in turn uses the Gateway as a communications relay. There are several commercial small satellite bus providers at this time. Blue Canyon Technologies, for example, provided the RAVAN CubeSat bus, exceeding our pointing requirement, and is developing hardware that will fly at the Moon and beyond. We therefore view the small satellite bus as a commodity that can be selected later.

Conclusions: We propose a low-cost means to measure the Earth radiation budget from the unique perspective of the vicinity of the Moon, contributing to a better understanding of Earth's energy budget and climate science. The proposed instrument and associated technologies are based on similar hardware that are currently flying in low Earth orbit.

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The Gateway to Cosmic Dawn: A Low Frequency Radio Telescope for the Deep Space Gateway

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Introduction: If the Deep Space Gateway (DSG) is placed in low lunar orbit, it will experience a uniquely radio-quiet environment when Earth-based Radio Frequency Interference (RFI) is blocked by the Moon above the lunar farside [1]. To take advantage of this opportunity, we suggest fastening a dual-polarization low-frequency (20 MHz $\leq \nu \leq$ 100 MHz) radio antenna and receiver to the DSG. The primary scientific goal of this instrument would be to measure the never-before-observed sky-averaged (global) highly redshifted ($13 \leq z \leq 70$) spectrum arising from the 21-cm hyperfine line of neutral hydrogen. NASA's 2013 Astrophysics Roadmap [3] advocated for a small antenna in lunar orbit to measure the 21-cm signal and the 2010 Astrophysics Decadal Survey [4] pinpointed understanding Cosmic Dawn—the time of the birth of the first compact objects and a key knowledge gap addressed by the 21-cm signal—as one of its top 3 recommended priorities.

Accessible Science: Since the global 21-cm signal is a measure of the effect of the hyperfine transition of neutral hydrogen on the surrounding radiation field, it contains a history of all effects which change the relative number of neutral hydrogen atoms in the upper and lower energy states—or, equivalently, effects which change the excitation (or "spin") temperature of the transition. Because the frequency behavior of the 21-cm signal is determined entirely by how much the 21-cm photons have been redshifted since being emitted or absorbed, the spectrum can be transformed directly into redshift space, and thus can be interpreted as a history of radiation backgrounds which will fill in the gaps of our knowledge of the Universe's history (see Figure 1).

Spin Temperature Coupling Mechanisms: The three mechanisms known to couple to the spin temperature are (see [2] for a review): 1) the strength of the Cosmic Microwave Background (CMB), 2) collisions of hydrogen atoms with other atoms, which are determined by the kinetic temperature of the gas, and 3) the Wouthuysen Field (WF) effect—an effect where hydrogen gas is excited by stellar Lyman-α radiation and de-excites into either state of the hyperfine transition.

First Compact Sources Abundance and Properties: While the effect of CMB photons is essentially known, the other two effects are modulated by the strengths of local radiation backgrounds created by compact sources, specifically the X-ray background which heats the gas and the Lyman-α background which triggers the WF effect. The sensitivity of the spin temperature to these local sources leads to a 21-cm signal which, when averaged across the entire sky, contains information about the distributions of properties of the first stars and black holes. Since the amount of these sources depends on the amount of matter available after recombination, the 21-cm signal also probes parameters of the standard ΛCDM model, especially at low frequencies.

Exotic Physics: Since anything which heats the Universe's hydrogen gas would affect the spin temperature and, hence, the global 21-cm signal, some exotic physics mechanisms could be probed with the signal. One example of such a mechanism is the existence of dark

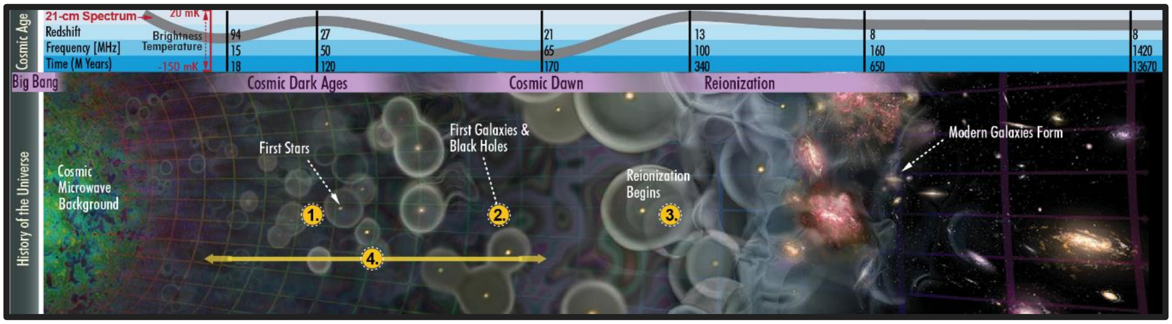

Figure 1: Schematic of the history of the Universe along with a fiducial 21-cm global signal. The first local maximum (1) comes at the end of the Dark Ages, when the first stars ignited, driving the signal into absorption via the WF effect. The local minimum during Cosmic Dawn (2) occurs when X-rays from black holes begin to heat up the gas. A local maximum occurs at the beginning of reionization (3) because the neutral hydrogen sourcing the signal begins to disappear. Note that this diagram does not include exotic physics such as self-annihilating dark matter, which would affect the signal most in the region marked (4). Given current uncertainties, the signal trough could be located anywhere between 50 and 150 MHz and can be anywhere between 50 and 300 mK deep.

matter which is its own anti-particle. Collisions between these particles would release heat into the Universe even before the first compact objects, changing the kinetic temperature of the gas.

Reionization: Because the 21-cm transition only occurs in neutral hydrogen, the strength of the 21-cm signal is proportional to the neutral fraction of hydrogen in the Universe. Current knowledge leads us to believe that the Universe was reionized sometime before z~6. The first measurements of the 21-cm signal should be able to better constrain this period.

Polarization Capability and Signal Extraction: The science objectives described above can only be completed if the global 21-cm signal can be differentiated from the Galactic foregrounds. This requires considerable effort as the foregrounds are 10^4-10^5 times larger than the signal. To mitigate this, the suggested antenna and receiver have the capability to measure all 4 Stokes parameters describing the incoming polarization (see Figure 2). This helps separate the signal from the foregrounds because the former appears only in the total power channels as it is unpolarized and isotropic while angular anisotropies of the latter interact with the large beam of the antenna to generate a projection-induced polarization signal. The data from this experiment would be analyzed using a data pipeline similar to that described in [5], which uses simulated training sets to help pick out this differential structure.

Requirements on the Deep Space Gateway: Once deployed, spacecraft maneuvers may be necessary to point the antenna in a particular direction (to within ~0.5°) but no further interaction with the crew is necessary. The ideal DSG orbit for the experiment is a low-inclination orbit about 100 km from the lunar surface which leads to an orbit period of about 2 hours. Due to the orders of magnitude difference between the Galactic foregrounds ($\sim 10^3 - 10^4$ K) and the global 21-cm signal ($\sim 10 - 100$ mK), in order for the thermal noise of the observations to be low enough to meet the science goals, the instrument must observe for a total of 800 hours when above the lunar farside and with the Sun out of view. A key requirement this experiment would impose on the DSG is a restriction on the EMI environment. In the 20-100 MHz range being measured, the instrument must be shielded from EMI at a level 50 dB better than the MIL-STD461F standard. Further requirements are listed in the Table 1.

Unique Utility of the Deep Space Gateway: The Deep Space Gateway offers opportunities to perform science which may be impossible to do from an Earth-based environment. For low frequency radio astronomy, the opportunity is especially fruitful because the lunar farside is the only place in the inner solar system free from human-generated RFI. We suggest that the Deep Space Gateway could also be the gateway to new knowledge of the first billion years of the history of our Universe.

Figure 2: The antenna for the low frequency radio telescope is a pair of wideband orthogonal bicones surrounded by a cylindrical sunshade (shown transparent here for clarity). The antenna rests on a deployable ground plane and is connected to a temperature-stabilized backend consisting of a pilot-tone calibrated receiver and a high-resolution digital spectrometer.

Table 1: Basic requirements placed on the Deep Space Gateway by the low frequency radio telescope described and shown in Figure 2.

DSG Requirement	Estimate
Mass	50 kg
Volume	64 m^3
Power	95 W
Data rate	1.6 Gb/orbit
Pointing accuracy	0.5°

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DEEP SPACE SPACEFLIGHT: THE CHALLENGE OF CREW PERFORMANCE IN AUTONOMOUS OPERATIONS.

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Introduction:

Distance from Earth and limited communicatons associated with Long Duration Exploration Missions (LDEMs) will increase the demands for crew autonomy and dependence on automation (i.e., completing tasks using onboard systems, without close supervision or coordination with Mission Control Center (MCC)) [18, 19, 3], and Deep Space Gateway presents a unique opportunity to study the impacts of these increased demands on human performance. The importance of understanding how Deep Space Gateway and Transport (DSG/T) missions may alter both operations and safety is revealed by previous missions (e.g., Mir, Skylab) which manifested on an Apollo mission as tension between the crew and the MCC [11]. Results from a recent ISS study [16] demonstrated that instituting just a 50-second communication delay with MCC were associated with reduced ratings of crew well-being and communication quality on communication-delayed tasks, when compared to real-time communication tasks. Communication delays were also associated with increased stress and frustration, and qualitative data suggested communication delays negatively affected task efficiency and teamwork processes. In two NASA analog studies (HERA and NEEMO) with comm delays of 5 to 10-minutes, crews committed more errors and required time-consuming assistance, with both crew and analog control centers reporting decreased effectiveness each way as compared to non-comm delay days [8]. With more autonomous operations, there is a need to better understand human–machine interactions and the human-interface related to LDEM requirements (cf., the collision of Progress 234 with the Mir space station) [3, 7]. We must anticipate that LDEM missions will consist of dynamically changing functions, at times being executed concurrently and sequentially—demanding different allocation schemes between human, computer, or MCC resources[14]. Increased exposures to known spaceflight hazards increase the importance of better characterizing the cognitive, motivational, and affective components of both crew/team performance and the human–machine system framework [13]. Human processes are defined as actions that convert inputs to outcomes through cognitive or behavioral activities [9]. LDEM spaceflight will involve multiple task variables that will involve dynamic allocations of control between crew, onboard systems, and mission control to increase overall system performance [10]. Human processes and states not only influence the outcomes of safety and performance but also can be affected by other preexisting factors. Thus, measurement of these variables is highly informative and necessary to achieve successful human–machine interaction. The DSG missions offer an important opportunity to better undersand the interplay of training, skills, completing tasks with and without automation support in preparation for future DST missions that necessitate a more autonomous environment. We also must understand the impact of different adaptive/responsive systems that allow an interdependent autonomy (i.e., between crew and onboard systems) in order to assess the effect on crew mental health, performance and team processes as these missions become more autonomous [7, 1].

Methods:

We propose assessing the variables that affect the human-machine systems: the multitasking environment, task type, task load, and task complexity requirements for crew that can impact on performance [6]. We propose to leverage the visual attention components of a cognition battery [2] along with assessments of key factors that influence human performance, e.g., visual attention, mental workload, situational awareness [9] trade-off between performance, workload, and situation awareness with the inclusion of degrees of automation [15]. We also propose to assess crew interpersonal traits and individual differences given how these attributes influence and affect both coping with workload demands (and therefore allocation of tasks) and performance [20]. We propose to assess the dynamic allocation of adaptive and responsive systems in response to crew vs mission control vs onboard systems in order to assess the overall system performance in human vs automation adaptability in support of autonomous systems [5]. We propose to assess the multitasking environmental demands to assess LDEM mission requirements during which crew is required to switch between tasks to assess effectiveness of multitasking, while assessing perceived reliability of automation and how that varies based on crew's workload [6]. We propose to assess task load (i.e., number of resources or demands crewmember is responsible for) and how that relates to both workload and situational awareness [4,17]. We will also assess crew ratings of task complexity using the following characteristics: (a) the number of elements included in the task, (b) relationship between task elements, and (c) how this relationship evolves with both skill and adaptive allocations to determine how the intrinsic characteristics that influence task performance [12, p. 559]. These assessments will assist NASA in predicting and quantifying the complex interplay of allocation of tasks and performance demand allocations between automotion and robotic systems and their interface and influence with human performance and spaceflight system safety to inform and evaluate system design features in the context of longer-duration missions.

Collection of longitudinal physiological and behavioral metrics (such as cognition, fine motor skills, task monitoring and others) and monitoring in-mission clinical events will enable an assessment of whether inflight changes in the proposed biomarkers can be used as early predictive measures of human performance changes over the duration of the mission.

Resources Required: Pre-, in-, and post-mission assessments task performance skill capability, situational awareness, cognition battery testing, and measures of trust in automotion, along with assessments of attitudes toward autonomous missions are needed. Pre-mission assessments of interpersonal traits is also needed. We propose to leverage Cognition Battery testing and biomarkers that are part of HRP Standard Measures.

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Tunable Light-guide Image Processing Snapshot Spectrometer (TuLIPSS) for Earth and Moon Observations.

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Introduction: A tunable light-guide hyperspectral image processing snapshot spectrometer (TuLIPSS) for hyperspectral Earth Science Research and Observation is being developed through a NASA Instrument Incubator program NNH16ZDA001N-IIP at Rice University (Tkaczyk, PI; Alexander Science-PI) and Marshall Space Flight Center (Luvall, Science Lead). TuLIPSS will be capable of acquiring instantaneous images across the visible and near-IR, within a flexible spatial/spectral resolution tradespace. This is accomplished using custom adaptable fiber optic image processing bundles whose input is in the form of a densely-packed coherent waveguide. The optical output from each waveguide, or line of waveguides, can be flexibly designated as spatial or spectral, enabling a wide variety of observational configurations. Thus, the system's innovative aspect is the controlled repositioning of pixels between the input and output of waveguide coherent structures, allowing efficient multi-dimensional (x, y,λ) snapshot imaging and operational flexibility. The tunable waveguide works in connection with adaptive band and spectral sampling components. In addition, an active spatial filter is being considered to allow accommodation of different dynamic ranges for different spatial-spectral cube region of interest - ROI. This flexibility enables a range of spatial/spectral configurations (e.g. specific sub-bands around target lines, prioritization of spatial or spectral resolution, improving signal to noise ratio, ROI defined dynamic range adjustment etc.) to satisfy specific observational goals.

Use in Cislunar Space: TuLIPSS is low resource but highly capable. While the overall cube size is smaller than that of push broom modalities, the smart selection of appropriate data content compensates for the size while eliminating scanning – stitching artifacts, improving single quality and enabling applications like tomographic and topographic reconstructions. The ability to collect data across an entire scene in a single exposure makes TuLIPSS uniquely suited to a range of Earth and Lunar science applications, including the ability to record earth transient surface and atmospheric phenomena, full disk earth/moon images for satellite calibration, spectroscopic imaging of Lunar impact sites, and to provide multiple views through an atmospheric column for tomographic studies.

TuLIPSS will allow:
a) snapshot hyperspectral image acquisition and high light collection efficiency
b) tunable adjustment of spatial and spectral resolution, and flexible selection of target wavelengths - enables a number of unique observational applications to be accessed
c) spectral coverage across relevant wavelengths from 400nm – 1700nm,
d) the system allows lower data volume for transmission to the ground by optimizing system parameters for specific applications.

TuLIPSS Resource Requirements:

TuLIPSS is designed for use on platforms requiring low-mass, low-volume data and minimal power requirements using highly integrated micro-scale fiber components. TuLIPSS could be mounted externally with target point ability or in a more limited configuration inside the manned station similar to the ISS SERVIR Environmental Research and Visualization System (ISERV) Pathfinder camera. Crew interaction requirements for interaction and managing the instrument are minimal with exterior mounting and significantly increased if used internally. No specific orbital requirements have been determined at this time.

TESTING FUNDAMENATL GRAVITY WITH INTERPLANETARY LASER RANGING.

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Introduction: Lasers—with their spatial coherence, narrow spectral emission, high power, and well-defined spatial modes—are highly useful for many space applications. While in free-space, optical laser links would have an advantage as opposed to the conventional radio-communication methods. Laser optical links would provide not only significantly higher data rates, it would also allow a more precise navigation and attitude control. In fact, precision navigation, attitude control, landing, resource location, 3-dimensional imaging, surface scanning, formation flying and many other areas are thought of in terms of laser-enabled technologies [1-2]. Deployment of laser instruments on the Deep Space Gateway (DSG), may lead to advances in many science areas. In particular, high-precision laser ranging may offer very significant improvements deep-space navigation & in many areas of relevant science investigations.

We propose the development of the Interplanetary Laser Ranging Terminal (ILRT) on the DSG. The ILRT will enable advances in gravitational and fundamental physics experiments performed in the solar system. By conducting very accurate range measurements, the ILRT will push high-precision tests of astrophysics and fundamental gravity into a new regime. It will explore the physics of the universe by measuring the curvature of space around the Sun, as represented by the parameterized-post- Newtonian (PPN) Eddington parameter γ, reaching the measurement accuracy of better than 2.0×10^{-7} (today's best accuracy is 2.3×10^{-5}, achieved by the Cassini mission to Saturn). Such a test would provide a crucial information to separate the modern scalar-tensor theories of gravity from general relativity, to probe possible ways for gravity quantization, and to test modern theories of cosmological evolution [3-7].

Other science objectives of the ILRT include measurements of (i) the time-rate-of-change of the gravitational constant, G; (ii) the non-linearity of gravity (as given by another PPN parameter β); and would test (iii) the gravitational inverse square law at interplanetary scales; and also (iv) the Equivalence Principle by using either spacecraft or celestial bodies of the solar system. The ILRT will improve the current results in many of these tests by a factor 10-50; in some cases, improvements by a factor of 100 are expected. In addition, the ILRT could be used for precision laser-enabled navigation of any laser-bearing spacecraft (either laser ranging or astrometry) at heliocentric distances of up to 3 AU.

Measurement concept: The ILRT will conduct high-precision measurements of the distance between the DSG and several types of laser instruments that could be either the set of passive laser corner-cube retroreflector arrays currently on the lunar surface (deployed by the Apollo missions) and/or yet to be deployed in the near future. It can also work with several other types of instruments, such as active laser transceivers on a spacecraft in the solar system (for instance, on a smallsat in orbit around (or landed on) Phobos/Mars or asteroid).

The LIRT could be developed to operate in two different regimes – incoherent (i.e., measuring the time of flight) and coherent (i.e., measuring the phase of the received signal) ones. In an incoherent mode ILRT will rely on a moderate-power CW laser modulated at GHz frequencies to allow for <1 mm range accuracy for distances of up to 3 AU. In a coherent mode, ranging to an asset within 50 Earth-Moon distances could be done with a precision better than 1 μm (precision of 1 nm is possible for quasi-drag-free operations using an onboard accelerometer or differential operations).

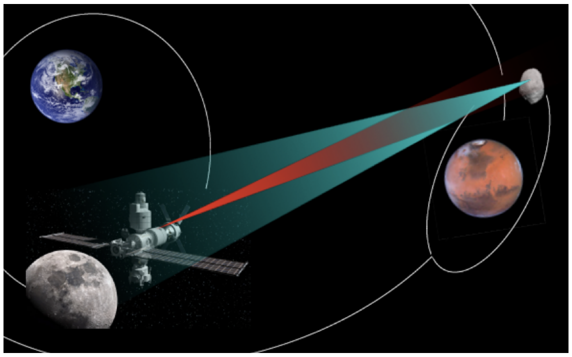

Fig. 1. The concept of interplanetary laser ranging to Phobos with a laser transceiver delivered to Phobos by a separate small-sat-class misison (currently being developed at JPL).

Instrument description: After launch from Earth and arriving to DSG, the ILRT will be deployed on its exterior surface, including a 30 cm diameter telescope, a medium-power (~10-50W) CW laser, an array of fast photo-detectors, imaging system, and a precision timing. The instrument will be on a gimbal to allow poining towards a laser target. For 1 hr/day or more the ILRT will transmit laser signal to, and receive laser signals from, a laser ranging instrument involved in the experiment (i.e., deep-space, Phobos or the moon).

The instrument data, consisting of time intervals between photon transmissions/ detections will be analyzed onboard or directly sent to the Earth via an RF link or a dedicated lasercomm facility. The timing measurements will be processed to give the DSG-s/c range accuracy of <1 mm. ILRT will take tracking passes of 0.5 hr/day for nominal 3 years of operations.

The ILRT relies on a medium power (~50-100W) CW laser and uses a telescope with 30 cm aperture to conduct precision laser ranging. The instuemnt could weigh 40-45 kg, including a gimbal for pointing. It may also need a ~30 kg thermal radiator to keep the ILRT at a room temperature. The instrument would occupy an estimated volume of ~0.7 m^3 and must be located one the exterior surface of the DSG. If a ~100W laser is used to operate the ILRT (in incoherent mode), < 300W electrical power is needed to operate the instrument. For the coherent mode of operation, a less-powerful laser could be used, reducing power requirements.

The primary data generated by the instrument will be the time-stamps of the transmitted and received signals (for incoherent mode) and/or phase measurements (for coherent mode), together with the environmental data, and relevant auxiliary information. This would result in the estimated lifetime data volume of ~10 GB.

The ILRT will be mounted on a gimbal on the exterior surface of the DSG. The instrument will be thermally insulated from extremal mounting; it needs to radiate heat to cool down the laser. In general, stable thermal environment is desired. An ideal orbit for the instrument will allow for the links between DSG and Phobos, and between DSG and the Earth. If the Earth-facing side of the moon is also available (even part of the orbit) it opens up the possibility of clock transfer, precision navigation, and optical communication.

The unit may have an three-axis accelerometer to decouple it from the non-gravitational noise contribution anticipated from the DSG. In this regard, the most accurate measurements will be achieved when the DSG is not occupied by a crew. Thus, the ILRT needs to be capable of remote operations. The instrument design is based on existing laboratory lasers and an array of photo-detectors which will be ruggedized to operate in space. JPL's Table Mountain Observatory, CA (TMO) is already equipped with a high-power (1.1 kW, average) laser for the lunar laser ranging (LLR, discussed below), that will be used in conjunction with the ILRT.

The ILRT development cost of $53M (FY 2017 $) was estimated, including ruggedization of the laser and the detector system for 16-month Phase A/B, 40-month Phase C/D, and 3 years of science operations. ILRT could be started in 2018 for launch in 2022.

Relevant facilities at JPL: ILRT will benefit from the existing high-power laser ranging facility recently constructed at the TMO. This facility uses a CW fiber amplifier laser with a 1.1 kW average power ouptut to conduct very precise measurements between the Earth and the retro-reflectors currently on the Moon. We amplitude-modulate the laser to conduct differenced LLR measurements accurate to 30 μm (atmosphere limited).

The logic for the optical schematic of our DLLR facility is as follows: For transmission, a seed laser is first phase-modulated to broaden the linewidth to ~10-20 GHz to avoid the spontaneous Brillion scattering (SBS) in the fiber amplifier, then amplitude/frequency-modulated with a chirping waveform (50-500MHz), which provides the absolute ranging information. This seed source is then fed into the fiber amplifier. The high power laser beam (~1.1kW) is then collimated in free space and propagate into the telescope. On return, a CCD is used to roughly point the telescope. A narrow bandpass and a Fabry-Perot filters are used to limit the IR detectors to the laser bandwidth. A high quantum efficiency IR camera provides the fine pointing information. We use a commercial IR photo-multilier tube detector with ~1-nsec time resolution. The return flux from the Moon is estimated to be ~1e4 photons/sec.

With high photon flux, the fundamental limitation of the accuracy of the LLR is then no longer sqrt(N), but the atmospheric delay. The delay from Earth's atmosphere (~2.3 m at zenith) produces a ranging uncertainty of ~8 mm after correction using the temperature, pressure, and humidity. However, the differenced delay error from OCTL to two or three sets of lunar corner-cube retro-reflectors can be as little as ~30 μm.

We expect a similar class performance from the ILRT which would open many areas for laser-enabled science investigations and precision navigation.

Conclusion: The deployment of laser transceivers in space will provide new opportunities for highly improved tests of the Equivalence Principle and measurements of various parameters of fundamental gravity. While in free space, the laser links allow for a very precise trajectory estimation and control to an accuracy of the order of 1 mm at distances up to ~5 AU. With their anticipated capabilities, interplanetary transponders will also lead to significant advances in the tests of fundamental physics and could discover a violation and/or extension of general relativity, and/or reveal the presence of an additional long-range interaction in physical laws. As such, these devices should be used for the next steps in lunar and planetary exploration and also to the future interplanetary missions to explore the solar system.

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SPECULAR REFLECTION OF SUNLIGHT FROM EARTH

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Benefits of the vantage point: The unique vantage point of the Deep Space Gateway offers some excellent opportunities for Earth observations, including observations of sun glint. For simplicity, the word "glint" is used here for any specular reflection, regardless of whether it occurs at the surface (especially water) or in ice clouds. The Deep Space Gateway can provide two main advantages for glint observations when images of Earth are taken repeatedly through full lunar cycles:

(1) A single fixed narrow field-of-view camera can detect and characterize glints for all solar elevations;

(2) Glint observations can be obtained throughout the (daytime) diurnal cycle at all longitudes.

Since neither low Earth orbits nor geostationary orbits can offer the combination of these two advantages, the Deep Space Gateway could provide glint observations at unprecedented detail and coverage. The key limitation would be that instruments near the Moon can observe glints only at low latitudes.

Science questions: Space-based glint observations can help in addressing science questions such as:

(1) What are the rates of occurrence, characteristics, and radiative impacts of ice crystals that, instead of tumbling in the air in random orientation, float in a systematic horizontal orientation? Specular reflection from such ice crystals has been the focus of several satellite studies (e.g., [1], [2], [3]); future observations can characterize these crystals and their radiative impacts more comprehensively (for example by observing the daytime diurnal cycle of glint occurrence and properties).

(2) How much sunlight do atmospheric aerosols absorb? Recent studies explored the use of satellite images of ocean glints in estimating aerosol absorptivity (e.g., [4], [5]). Such observations can help estimate the impact of aerosols on atmospheric and surface energy budgets, and can also help distinguish aerosol types that have different absorptivity and air quality implications (for example soot and sulfates).

Since glint observations may be obtained as part of imaging the entire Earth disc facing the Moon, they may also be used for testing algorithms that rely on glint signals in seeking to detect oceans on exoplanets (e.g., [6]). They could also give information on the role glints play in shaping the angular distribution of the sunlight reflected from our planet, and may help testing the models of this angular distribution that are used in estimating Earth's energy budget (e.g., [7]).

Instrument considerations: Glint observations could be collected by an imaging radiometer that may also serve other purposes and image even the entire Earth disc. The key features for glint oservations are a wide dynamic range (to avoid saturation at the bright glints and to also image the darker areas where glint does not appear), and an ability to take frequent images of a small area around the location of possible glints (this is needed to obseve glints at a high angular resolution as the Earth rotates). A spatial resolution in the order of a km would also be desirable to resolve cloud structures. As for spectral coverage, an Oxygene absorption band and a nearby near-infrared band would be most helpful for detecting glints and determining their altitude (which also allows distinguishing surface glints from cloud glints). Visible and ultraviolet wavelengths would help estimate aerosol absorption, while polarization and shortwave infrared observations could provide additional information on particle size and shape. The data volume could be controlled by adjusting the frequency and spatial extent of the data archived and transmitted back to Earth. Most likely, the instrument could be mounted externally and would not need astronaut intervention once installed. Most lunar orbits could be suitable; orbits allowing longer unobstructed views of Earth would work better.

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CHARACTERIZATION OF OUTER SPACE RADIATION INDUCED CHANGES IN EXTREMOPHILES UTILIZING DEEP SPACE GATEWAY OPPORTUNITIES.

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Introduction: Early integration of science and exploration concerns into the design of the Deep Space Gateway (DSG) is essential to maximizing its science and exploration potential. The proposed concept, *characterization of outer space radiation induced changes in microbial extremophiles*, requires the DSG as infrastructure supplying power, communications, *etc.* to otherwise autonomous systems. Survival and proliferation of life beyond low earth orbit (LBLEO) can be accomplished by exposing extremophilic microorganisms in outer space radiation (OSR) conditions using DSG system. Extremophilic microbial survival, adaptation, biological functions, and molecular mechanisms associated with outer space radiation can be tested by exposing them onto DSG hardware (inside/outside) utilizing the traditional microbiology methods and state-of-the-art molecular biology techniques.

Exposure of Microbial Extremophiles Concept: The proposed OSR extremophiles concept is a flight experiment and hypothesis-driven research investigation, resulting from several "omics" approaches that would translate spaceflight derived data into new knowledge about microorganisms. With this approach NASA's Space Biology Program science element (microbiology) and its guiding questions can be addressed: (a) How the genetic, molecular, and biochemical processes of the OSR-tolerant extremophiles are influenced by the space environment and (b) What systems biology mechanisms and functional pathways are responsible for the enhanced virulence in spaceflight when compared to the ground controls. This concept directly responds to *understand the underlying mechanisms that control responses, adaptation and performance of microbes in space (e.g.: LBLEO) environments at the cellular, molecular and genomic level.* Microorganisms are known to drastically affect human health in a closed system therefore understanding their behavior in space environment (e.g.: biofilm formation, virulence) or reaction to sterilization technologies is critical to protecting crew. Generating empirical data set that can be used to set guidelines for assessing acute radiation risks is essential.

The data generated from DSG will be important for assessing both, the probability and mechanisms of survival, of microbial contaminants during future human exploration to the Mars and beyond. We can use the results to calculate the rates of inactivation of microbial species caused by the low pressure and high desiccation in simulation experiments as well as DSG conditions. Such empirical data sets will give broad insight on the ability of terrestrial microorganisms to survive in the DSG environment. The molecular analyses that can be employed in this project will detect "omics" changes in OSR extremophiles that may correlate with "omics" changes that occur in response to the need to adapt to the conditions in space. In addition, innovative capabilities of the analytical system in detecting subtle changes between microorganisms in different environments can be demonstrated. Such techniques can be applied to numerous future biologically oriented missions (e.g. life detection, instrument development, and astronaut health). At the end of the implementation of the concept, resulting data will enable to assess the probability and mechanisms of survival of microorganisms. These results can be used to calculate the rates of inactivation of microbial species caused by various aspects of space conditions. Overall the results will give further insight into the behavior of resistant microbes in space environments beyond LEO.

Microbial Extremophiles: The spacecraft associated extremophiles have been reported to withstand several space related parameters including radiation recorded at high altitude (*1*) and outside International Space Station (ISS) conditions (*2-9*). It is hypothesized that spacecraft associated extremophiles would be the ideal candidates for surviving under DSG conditions since these extremophiles exhibited molecular tenacity and plasticity in surviving extreme space conditions for 18 months exposure time (*5, 10, 11*). Hence, exposing OSR extremophiles under LEO environment using DSG mission is important to understand their biological functions and characterizing likely survival mechanisms. Furthermore, virulence properties exhibited by fungal population need to be tested after exposing them beyond LEO orbit (*12, 13*). Once these OSR extremophiles exhibit survival (*14, 15*), their proliferation inside the DSG spacecraft would enable developing biofilms and such phenomenon should be tested under beyond LEO environment. Subsequently, there is a need to develop countermeasures to eradicate or contain these OSR extremophiles without human intervention for long duration missions. An understanding of the mechanisms of resistance in OSR extremophiles will help design Life Support and Habitation (LSH) mission systems that provide a harsher environment to microbes protecting astronaut health. Since the genomes, transcriptomes, and base modification systems (epigenomes) of all the OSR extremophiles included are already available (*16, 17*) or will be in early 2018, their comparison with matched, DSG-exposed species will facilitate recognition on a molecular level of the resistance mechanisms in microbes.

Microbiome of Closed Systems: As recommended by the National Research Council Decadal Survey, generating microbial census of surfaces of the closed system is needed using traditional culture-based methods, molecular microbial community analysis techniques, and bioinformatic computational modeling. The proposed DSG-microbiome analyses will provide significant insight into spaceflight-induced changes in the populations of beneficial and potentially harmful microbes. This approach would also provide both mechanistic understanding of these changes, for example cataloging population changes and mapping/linking these to environmental niche and genomic changes, as well as insight into practical countermeasures for mitigating risks to humans and environmental systems. Leveraging results of the NASA-funded Microbial Tracking experiments and also accounting expertise gained from the Mars Program funded projects would allow to analyze samples collected from DSG modules. The DSG microbiome database will augment NASA GeneLab program with which NASA will acquire ability to accurately and confidently assess the status of microbes associated with closed habitation and crew health maintenance. In addition to overall microbial profiles, this approach will determine which microbial taxa pose particular threats to crew health. Furthermore, the DSG-microbiome concept will enable NASA to resolve applicable NASA-Human Research Program integrated research plan risks.

Significance: The aims of the OSR concept are to perform biological research intended at preparing for future human exploration missions. As stated in the NASA Space Biology objectives, the OSR concept is related to fundamental research–gaining knowledge of spaceflight alterations in the microorganisms isolated from ISS to improve life on Earth. Understanding the molecular mechanisms in the spaceflight microorganisms might reveal the presence of potential stress-induced biomolecules and adaptations that are essential to adapt to beyond LEO conditions. Such stress-induced biological system modifications could be identified and applied (early diagnostics and superior countermeasure development) to improve crew health as well as recognize secondary metabolites that are useful compounds for the biotech industry (antibacterial, novel pharmaceuticals, biosynthetic gene clusters, etc.). Similarly, identification of stress-induced biomolecules that are antimicrobials will facilitate maintaining crew health and their closed habitat system for the future human exploration.

The OSR concept will serve several purposes by investigating the common underlying molecular networks, pathways, and mechanisms of life in space-exposed microorganisms (and compare with Earth counterparts) which are important to understanding human health and environment in space, and will translate space-derived knowledge to address specific human health conditions and environments here on Earth. Therefore, “omics” data of the targeted spaceflight microorganisms and ground-based investigations with direct translational research connections proposed in the OSR concept will directly address the important key priorities for the DSG and for the NASA Space Biology mission(s).

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Using The Deep Space Gateway To Build The Next Generation Heliophysics Research Grid.

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Introduction: The Heliophysics Research Grid (HRG) is envisioned as a system of sensors, both in situ and remote sensing, distributed in key locations in the inner Heliosphere, providing measurements for both basic research and Space Weather (SpW) operations. The HRG is a natural evolution of the NASA HSD's highly successful Heliophysics System Observatory (HSO) but employs novel instrument and mission concepts, such as miniaturized telescopes, small sats, and orbit designs, to build the necessary space infrastructure with a schedule-flexible, cost-effective approach. Also, HRG adopts a research-to-operations strategy to support terrestrial SpW needs as well as the space exploration needs on the Moon, and, for future Mars voyages.

The DSG can play a key role in enabling and supporting the HRG, both as an observing platform and as a storage and staging hub for asset launches into heliospheric orbits using lunar gravity assists. The latter can build the HRG via so-called '*string-of-pearls*' missions as we discuss in the following representative scenarios.

'*String-of-Pearl*' Missions: A series of spacecraft (s/c) in Earth orbit (trailing and/or leading Earth) spaced at semi-regular intervals from each other.

Why? To enable multi-point, but *small separation,* coverage of transients and solar wind structures for in-situ science and stereoscopic imaging (5°-15° separations) or stereo reconstructions (> 15° separations) for remote sensing.

How? The s/c are launched from the DSG or SLS into drifting orbits ahead or behind Earth (depending on the science case, see example scenarios below). Other orbits, such as quasi-satellite or L1, may be possible. The s/c are small sats with single instrument payloads launched individually or in groups, as hosted payloads. This mission design offers flexibility in launch schedule and budget profile.

Scenario#1: Binocular Imaging of Active Regions The scenario is based on the ILWS-COSPAR 2015-2025 roadmap concept [1].

Science Objective: Estimate the magnetic configuration and strength of an erupting magnetic flux rope (MFR) from an active region.

Approach: This concept entails stereoscopic imaging of the active region corona to derive their 3D loop structure and thus constrain coronal magnetic field extrapolations.

Implementation: Launch a small s/c with a 2-channel EUV imaging telescope in a slowly drifting orbit (ahead or behind Earth) of ~ 2°/yr. It assumes that a similar asset is available along sun-earth line (e.g. GOES/SUVI). If not, the concept requires two s/c with identical instrumentation.

Requirements (s/c): s/c separation between 5°-12° for direct stereoscopy and up to ~ 20° for forward modeling methods. A strawman mission comprises a ~2-yr duration cruise phase to get to 5° and a prime phase of ~ 3-4 years. Given the single payload, the s/c can be quite small (meter-class, similar to ESA/Proba-2) and could be launched as hosted payload on SLS en route to DSG or released from DSG.

Requirements (payload/CONOPS): Full disk imaging at 3-arcsec resolution and AR imaging at 1.5-arcsec resolution. Cadence of 0.5 – 1 min. DSG acts as relay to enable high telemetry. Field of View >1.8 Rs (i.e. similar to SECCHI/EUVI) and 2.5 Rs (goal). The two EUV wavelengths should be sensitive to (1) temperatures of 1-2 MK to capture quiescent corona at high contract (e.g. 171Å or 195Å) and, (2) hotter temperature (~10 MK) to capture the formation, and evolution of the MFR (e.g. 131Å).

String-of-pearls implementation: Identical s/c could be launched at regular intervals (every 2-3 years) to maintain baselines of < 10°-12° between telescopes. A relay capability could be included at alternate s/c to maintain high telemetry rates from the more distant s/c. A coronagraph and/or heliospheric imager could be added (or could replace the EUV telescope) at certain s/c to provide off Sun-Earth imaging of Earth-directed CMEs. The latter requires larger angular separations (at least 30°) to provide useful 3D information.

Scenario #2: Evolution of SEPs and CIRs

Science Objective: To measure the plasma and magnetic structure of Earth-directed transients (CMEs and CIRs) and associated SEPs.

Approach: Deploy s/c with small angular separations to measure the plasma, magnetic and energetic particle fine scale structure of near-Earth transients. Quasi-satellite orbit (to be studied) with apogee of 0.3AU is another option.

Implementation: Launch of a series of small s/c with magnetometer, solar wind and SEP packages in a slowly drifting orbit (ahead or behind Earth) of ~ 2°/yr. Similar asset are almost always available at the Sun-Earth line (e.g., DSCVR).

Requirements (s/c): the s/c separation is flexible but we know from Helios and STEREO that the solar wind structure can vary significantly with even 2° separation. The in-situ packages are small and naturally lend themselves to a CubeSat format. The magnetometer may require a deployable boom. The s/c are spinning to increase the spatial/angular coverage of the payload without need for additional sensor heads.

Requirements (payload/CONOPS): density, proton velocity/temperature, and magnetic field vector. An SEP sensor could be launched/included on alternate s/c to provide a coarser coverage (~10° separation) of SEP longitudinal spread. A dedicated heliospheric imager s/c could be part of the chain launched upstream (towards L4) to provide imaging of incoming CIRs (best viewed from upstream locations) and context for the in-situ measurements.

String-of-pearls implementation: Launch schedule is similar to previous scenario. DSG serves as storage and launch platform for the s/c. Constellation can be replenished during Orion trips. A launch every 1-2 years ensures an angular separation of ~2° between the sensors. The s/c are launched either downstream of Earth (to provide early measurements of incoming CIRs) or upstream (to provide measurements of upstream magnetic connectivity). The modest telemetry requirement (probably 1-4 kbps), and the relaxed pointing (spinners) make this a good case of interplanetary CubeSats.

Scenario#3: Comprehensive Coverage of Near-Earth Heliosphere Combining the previous string-of-pearl concepts forms the basis of HRG and leads to comprehensive coverage of the activity in the near-Earth heliosphere.

Science Objective: To measure the plasma, magnetic structure, and SEP production of Earth-directed transients (CMEs and CIRs) from the Sun to Earth.

Approach: Deploy s/c both leading and trailing Earth, with imaging or in-situ payloads, in orbits with varying angular separations, to observe the eruption sources and measure the plasma and magnetic properties of near-Earth transients.

Implementation: Launch of a series of small s/c with either imaging (EUV imager, coronagraph, heliospheric imager) or in-situ (magnetometer, solar wind, SEP) package in varying drift orbits (Figure 1).

Requirements (s/c): single payload per s/c. Imaging s/c are 3-axis stabilized with few-arcsec jitter requirement and carry larger antennas. In-situ s/c are spinners on 6U CubeSats with omni antennas. The imaging s/c can be used as relays to send the in-situ data to earth.

Requirements (payload): Full disk EUV imager to 2 Rs (1-3 arcsec resolution, <1 min cadence, 2-3 wavelengths). Coronagraph (2-15 Rs, 30-arcs resolution, 10 min cadence). Heliospheric Imager (40° FOV, 50°-90° elongation, 1-arcmin resolution, 15-30-min cadence). Magnetometer with sub-nT accuracy. Plasma measurements: density, proton velocity/temperature. SEP sensor similar to ACE or Solar Orbiter/SIS.

String-of-pearls implementation: Orbit drift drives launch order. COR launched on a fast drift (5°-10° per yr) towards L5. HI launched with similar drift towards L4. It will provide imaging coverage from 0.03AU to Earth starting from 2° separation. Coverage increases to 0.1 AU upstream when HI reaches 10° separation. The COR and HI s/c could be launched. The EUV telescope is launched (towards L5 or L4) on a 2°/yr drift orbit and starts mission when it is at 5° from Earth.

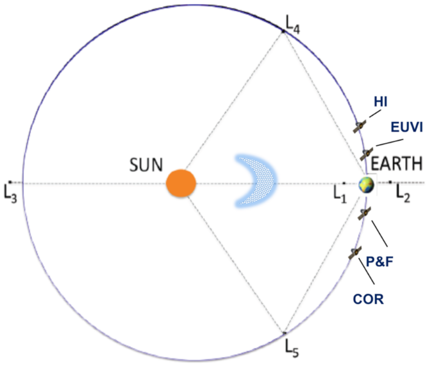

Figure 1 A comprehensive string-of-pearls concept that could form the basis of a Heliophysics Research Grid.A HI imager observes transients impinging on Earth with higher resolution than SECCHI/HI2. An EUV imager and a plasma & fields (P&F) package provide 3D info on erupting ARs and arriving transients in combination with similar assets at Earth/L1 orbit. A coronagraph (COR) at >30° separation derives reliable CME kinematics. The concept can be maintained and expanded with hosted-payload and DSG launches as programmatic conditions allow.

The in-situ s/c are launched either towards L4 and L5. The L5 direction is slightly preferred because it provides some advance notice/measurements for CIRs. An SEP s/c every 2 'plasma-fields' s/c. SEP payload may be better places towards L4 to provide SEP measurements from upstream Parker spirals. Plasma-fields s/c would benefit from a few degree separations. SEP science can accept larger angular separations of 10° or so. A minimum set of 2 EUV, 1 COR, 1 HI, 2 Plasma-Fields and 2 SEP s/c should provide a comprehensive set of measurement of solar wind structure at 1 AU.

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IXION: A WET-LAB HABITAT PLATFORM FOR LEO AND THE DEEP SPACE GATEWAY.

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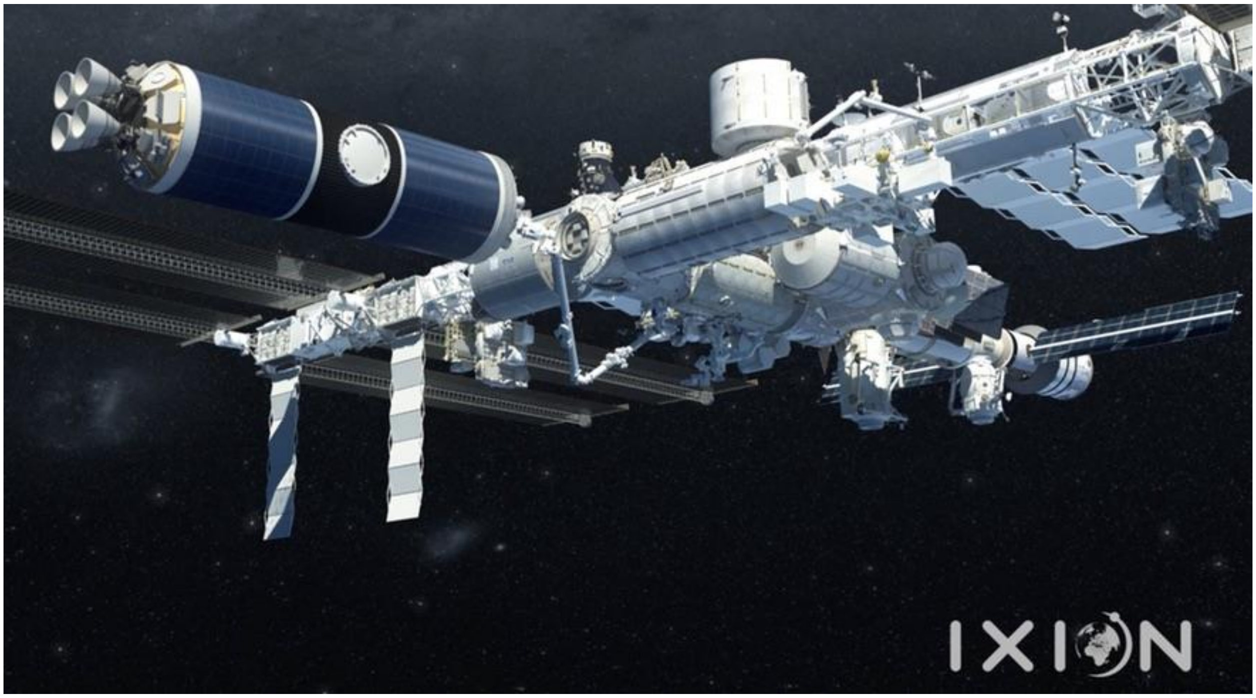

Abstract:

In the 1960s, NASA MSFC engineer and architect Wernher von Braun quickly recognized the value of repurposing rocket upper stages as habitats. Since rocket upper stages are placed in LEO as part of the overall launch activity and they are large, space-worthy structures, von Braun saw great potential for lowering habitat costs while developing robust capabilities. During the Shuttle era, engineers considered converting the large External Tank into a 'web-lab', however, despite many inherent benefits, the concept remained technically challenging and was never implemented. Today, with new advances in launch hardware and robotics, the strategy of repurposing rocket upper stages to serve as habitats is more appealing than ever, and could revolutionize the capacity and costs of in-space habitation.

In 2017, an industry team known as Ixion and comprised of NanoRacks, MDA / Space Systems Loral (MDA/SSL) and Space Adventurers, in close coordination with NASA, methodically demonstrated that the concept of repurposing the upper stages of ULA's Atlas 5 into habitats is practical, safe, and far more affordable than traditional habitat development options. Ixion development will continue over the coming years so that NASA, the science community, and commercial and international partners may enjoy the substantive and financial benefits of this innovative concept, including eliminating much of the launch costs associated with hardware built on the ground for in-space use.. The Ixion platform provides a basis for exploration and scientific utilization in cislunar space in the form of the DSG as well as LEO as a commercial ISS habitation augmentation module and DSG test-bed.

While each of these use cases will provide their own unique applications for utilization, they share the benefits of the wet-lab architecture. The habitats, based on the ACES upper stage, provides significant interior pressurized volume at minimal cost. Integrated power, thermal, ECLSS and MMOD systems allow for up to four Ixion crewmembers and the support of numerous internal and external payloads for long durations. The airlock enables ingress and egress of crew and cargo.. Robotic systems used for interior outfitting of the propellant tanks are used for in-space assembly of payloads and operations during uncrewed peeriods. Docking and berthing ports allow for both visiting vehicles as well as further expansion of the station.

Th Ixion team presents detailed specifications of both LEO and cislunar habitats and discuss possible use cases for each. We look forward to discussing the needs of the scientific community as we move forward with development of the habitats.

Geocoronal Imaging from the Deep Space Gateway

L. Waldrop, T. Immel, J. Clarke, M. Fillingim, K. Rider, J. Qin, D. Bhattacharyya, R. Doe

It has been four decades since Apollo 16 returned the first wide-field UV imagery of the earth and revealed the vast extent of exospheric hydrogen (H) atoms around the planet [1]. Since that time, appreciation has grown regarding the significance of this outermost atmospheric layer, whose charge exchange interaction with ambient ions dissipates magnetospheric energy, generates the energetic neutral atoms (ENAs) widely used for remote sensing of the ring current during geomagnetic storms, and accelerates gravitational escape and thus permanent atmospheric evolution [2-5]. Despite the importance of Earth's H exosphere to the solar-terrestrial system, however, current understanding of its global structure and dynamical evolution is poor, such that the origin of persistent discrepancies between measurements and models remains unresolved.

Remote sensing of UV emission from geocoronal H atoms, generated through resonant scattering of solar radiation at 121.6 nm (Lyman-alpha, "Ly_α"), is the only empirical means available to investigate the terrestrial exosphere, which extends in a nearly spherical cloud out to 30 earth radii (Re). Orbiting space-based platforms, such as NASA's IMAGE, TWINS, and TIMED missions, have observed geocoronal Ly_α emission routinely for nearly two decades and yielded fundamental insights regarding the seasonal and solar cycle dependence of the exospheric density distribution and its kinetic partitioning [e.g., 6-9]. These investigations have also revealed that contemporary models of exospheric structure, both analytical and numerical, must be missing important physics since they are consistently unable to accurately reproduce the emission data.

Unfortunately, the limited spatial and temporal sampling associated with these missions amplifies the notorious challenges of radiative-transport based data analysis and has prevented reliable assessment of the physical mechanisms responsible for the reported data-model discrepancies. For example, while limb scanning of H Ly_α emission from low earth orbit by TIMED yields a local altitude profile of H density out to a few earth radii (Re), global structure can only be detected over the 4-month duration of orbital precession, and temporal variability is obscured by the low instrument sensitivity and consequent need for multi-day averaging of individual scans [6-7,10]. Stereoscopic sensing by TWINS from its higher altitude (~7 Re apogee) vantage is more suited for large-scale density estimation, but in this case, reported reconstructions are confined to the optically thin region from 3-8 Re (mainly on the dayside northern hemisphere) and also require long time averaging in order to accumulate sufficient observational coverage [8-9,11-12].

The inability of current sensing platforms to measure global exospheric dynamics at high temporal cadence particularly limits quantification of its critical role in mediating the terrestrial response to space weather. During geomagnetic storms, redistribution of exospheric H atoms has been shown to drive *storm-averaged* enhancements in H density of up to 40% in the outer exosphere (>3 Re altitude) along with depletions of ~25% near the exobase [10-12]. Conventional analyses of storm-time ENA images do not account for transient exospheric variations and instead adopt a static H distribution in their inversions. The lack of detailed knowledge regarding the global, time-dependent H distribution is thus a source of significant uncertainty in space weather monitoring and modeling [3]. Meanwhile, the lack of observations beyond 8 Re prevents reliable determination of the non-thermal H escape flux, leading to large uncertainties in models of secular atmospheric evolution.

NASA's Deep Space Gateway offers an unprecedented means of overcoming the current limitations of exospheric remote sensing, since its distant vantage enables wide-field imaging of the H Ly_{α} geocorona at the high spatial and temporal resolution needed to advance understanding of space weather dynamics as well as upper atmospheric physics. As an example of potential payloads capable of acquiring the needed measurements, we will describe our design of two high-heritage Ly_{α} cameras: (1) a refracting UV imager which can measure the entire geocorona in one image; and (2) a reflecting UV imager with a smaller field-of-view and higher sensitivity able to target the inner geocorona at higher temporal and spatial resolution. Interplanetary background emission could be measured around Earth using a steerable mirror system or by small satellite platforms at complementary vantages, which would also enable stereoscopic geocoronal sensing.

State-of-the-art radiative transfer modeling of each (nested or tiled) emission image would yield the global distribution of exospheric H density from the exobase out to 30 Re as well as the incident solar Ly_{α} flux, a critical space weather parameter which drives solar EUV heating and ionization [13]. Each global H density reconstruction would allow for quantification of potential spatial asymmetries and localized depletions as well as the kinetic partitioning of the H population and its escape flux. In general, we envision returning images every 2-4 hours, though the high instrument sensitivities enable image acquisition every 15-30 minutes, an observing mode which could be activated during storms. Sequential image analysis would reveal both climatological and sporadic variability in the global H density distribution in support of more reliable space weather monitoring and physics-based model development.

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VR SIMULATION TESTBED: IMPROVING SURFACE TELEROBOTICS FOR THE DEEP SPACE GATEWAY.

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Introduction: Developing new capabilities for surface telerobotics represents a complex, multifaceted problem that typically requires significant time and resource investment. In this work, we describe the design of a virtual reality (VR) simulation testbed for prototyping surface telerobotics that may reduce such barriers and enable more rapid and iterative development processes. Our goal is to create a framework with robust physics and kinematics that provides a platform for advancing algorithms that govern low-level robot autonomy and support interactive trade-offs between teleoperation and supervised control. Further, this testbed may enable explorations into the design of new interfaces that support ground control, and/or crew operation of surface robots from the Deep Space Gateway (DSG) to significantly improve critical NASA lunar exploration missions.

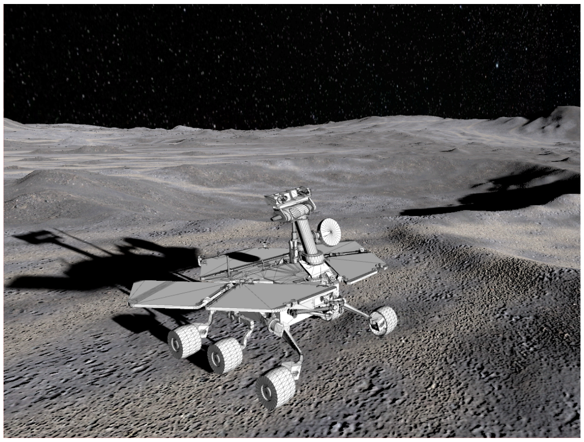

Figure 1. Virtual rover and lunar surface as seen from a virtual reality head-mounted display. This experimental framework allows for 3rd and 1st person rover teleoperation for user studies, user training, and rapid prototyping of user interfaces and rover designs — all without the need of physical hardware.

Virtual Reality Immersive Simulation: We have constructed a Virtual Reality (VR) simulator with a multiphysics engine core to provide real-time, and robust physics-based environmental model. A VR head-mounted display (HMD), HTC Vive model, allows users to fully immerse themselves within the simulation (see Figure 2). A MER-A rover 3-D model has been integrated within the virtual environment with full teleoperation control with the native VR HMD controllers (see Figure 1). Users can switch between third and first person control of the robot to simulate the teleoperation of the robot on the lunar surface from the DSG.

This work will be extended to create a high-fidelity testbed for rover teleoperation simulations with realistic terrain, authentic rover design and kinematic model, and a state-of-art planning and control interface.

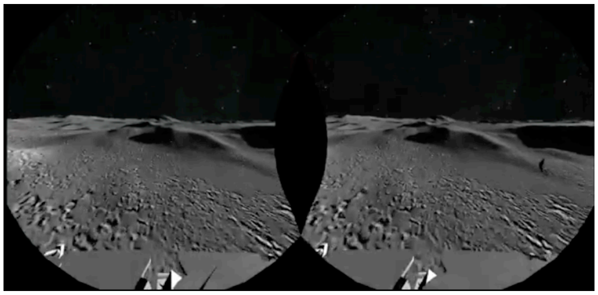

Figure 2. View of the simulation from within a VR HMD with stereoscopic imagery. A different image is displayed for each eye to establish a sense of depth in the virtual environment.

Environment and Terrain: Lunar topography will be simulated with high-resolution synthetic terrain modeled after the actual surface of the moon. Surface data will be analyzed to provide us with authentic terrain features (i.e. crater density and distribution, elevation deltas, etc.). Surface optical properties like specularity, reflectivity, albedo, sky-map, etc., will be simulated to give a feel of limitation for autonomous Simultaneous Localization, and Mapping (SLAM) algorithms. As a starting point, HAPKE model [1] parameter maps for moon [2] will be considered. Rover-terrain Interaction, tractive force models and consequent dynamics will be modeled to give a feel of slip, and skid of the vehicle in real-time. Thermal lumped models of the Lunar terrain will be modeled incorporated with Lunar local time as variable input [3].

Rover Virtual Prototype: A virtual prototype of a terrain mobility system will be designed, and developed for Lunar terrain. The models to be incorporated into the virtual prototype are as follows: (1) SLAM algorithms will be designed to specifically handle Lunar environment, specifically answering issues like Lunar terrain specularity, high reflectivity if terrain, and albedo of the terrain [4]. This data along with auxiliary environment perception sensors and multiple strategies (visual odometry, wheel odometry, dead reckoning, etc.) will be used for reactive path planning and semi-autonomous avoidance of obstacles [5]. This research will also generate data which will feed into requirements, layout, and placement of on-board sensor systems for perception of environment. (2) Proactive planning of the path by using existing Lunar terrain high resolution images from multiple missions like LROC, and Clementine will be generated. Using the same in conjunction with absolute landmark based localization algorithms, absolute position of rover on the terrain will be derived on a larger scale [6]. (3) Line of Sight (LoS) from known terrain data will be simulated to suggest better directions of traverse for path planning and potentially provide input to antennae design on lander/rover.

Planning and Control Interface: The interface will be focused on providing real-time situational awareness (latency≈0.4s [7]) via multiple modes of sensory feedback (visual, auditory, and haptic), to aid the human-in-loop system (i.e. operators in the DSG) to react and respond quickly. (1) Interface for efficient human-in-loop supervision and intuitively control of the rover will be designed with telepresence capability. We would like to leverage existing research in this area to accelerate development [8]. (2) Absolute navigation on lunar terrain by Landmark matching will be used to localize rover location on terrain, and this will be overlaid on the Digital Elevation Model to give real-time location on lunar terrain [9]. (3) Efforts will be taken to overlay scientific and instrument specific data like spectral, and photogelogical mapping [10] on the DTM/ dervied local map so as to aid in easier scientific exploration.

We propose to use this system for mission training/rehearsal for astronauts on ground. One novel application we are proposing is to utilize this tool for real-time contingency state evaluation. The idea is that in case a contingency comes up like the rover getting stuck in a crater/slipping, the crew and/or ground control may immediately recreate a VR terrain of the local environment from latest derived local map from SLAM, and DTM data to visualize, evaluate, and quickly converge on measures to resolve this contigency by leveraging on the graphic, and physical realism capabilities of the system. Another proposed use of this system is rapidly prototyping user interfaces to ease the primary task of teleoperation as well secondary tasks such as environment navigation, supervisory control and command, and hazard marking and avoidance.

Acknowledgements: This work was directly supported by the NASA Solar System Exploration Virtual Institute cooperative agreement 80ARC017M0006 to J. Burns (PI).

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Partial Gravity Biological Tether Experiment on the Deep Space Gateway.

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Introduction: A cislunar platform at the L2 near-rectilinear halo orbit (NRHO) around the Moon provides an excellent opportunity for an advanced partial gravity risk mitigation experiment addressing the Human Research Program (HRP) risk of "Risk of Adverse Health Effects Due to Host-Microorganism Interactions" and HRP gap MICRO-04 "*We need to determine how physical stimuli specific to the spaceflight environment, such as microgravity, induce unique changes in the dose-response profiles of expected medically significant microorganisms.*"[1][2][3]

.

Background: Specifically, this would be a first-of-its-kind study to sequentially document and define the dose-response profile between altered levels of gravity and cellular adaption. *Staphylococcus aureus (S. aureas)*, named for its golden yellow color, would be used as the experimental "subject".

Since S. aureas stops producing its pigmentation in response to the reduced gravity levels of spaceflight, a gradual decrease in gravity levels would provide important data points as to when normal terrestrial cellular processes have stopped. The primary mechanism of determining that the processes have stopped is by a color change. The importance of this pigment molecule is multifaceted and includes:

- serving as a biological indicator to evaluate the impact of varied levels of gravity
- the fact that its synthesis is universal among animals, plants, and microorganisms (e.g. cholesterol production in humans) and thereby applicable across a range of life
- providing insight towards the therapeutic disarming of pathogens on Earth, as pigmentation is a hallmark of, and is involved in, the virulence of numerous pathogenic microbes.

In addition to pigmentation, growth and metabolic data will also be collected and will increase scientific insight by providing mechanistic understanding to the observed phenotype. This data could also then be used in discussion of changes in the internal cell processes.

Mission Concept: The planned concept of operations of the "partial-g satellite" would be to provide multiple data points to identify the line equation in Figure 1. Specifically, the investigation would involve a S. aureas control population on Earth (1g), another on ISS (μg) and a population of S. aureas experiencing several gravity levels on the partial-g satellite (0.2g, 0.4g, 0.6g and 0.8g).

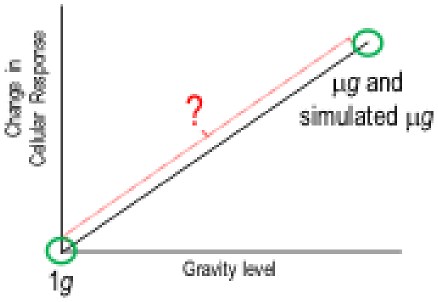


Figure 1 Bacteria-Gravity Plot

These varying g levels would be obtained by spinning a tether with different masses at each end, thus resulting in an "off center" composite center of mass. Once started in rotation by a propulsive, controlling end mass, different rotation rates and therefore different apparent gravity levels will be seen by the end mass containing the bioexperiment. For example, as shown in Figure 2, if the tether were 1 km long and the controlling (and propulsive) mass at one end was approximately 90kg and the other mass (containing the bioexperiment) had a mass of 10kg, the composite CM would be approximately 900 meters away from the bioexperiment. If the mass of the tether is neglected, and the tether were rotating at 0.015 rad/s, the apparent gravitational field at the bioexperiment end mass would be 0.20 g since $a = \omega^2 r$ where a is the centrifugal acceleration (in m s^{-2}), ω is the tether system rotation speed (in radians/s) and r is the distance from the endpoint to the CM (in meters). Table 1 shows the resulting rates to obtain the desired g levels.

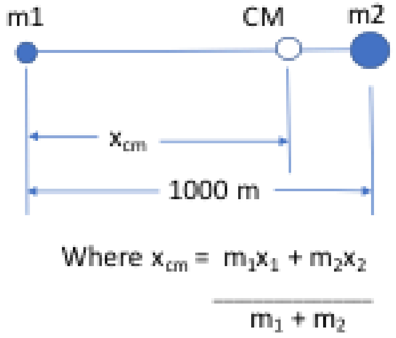
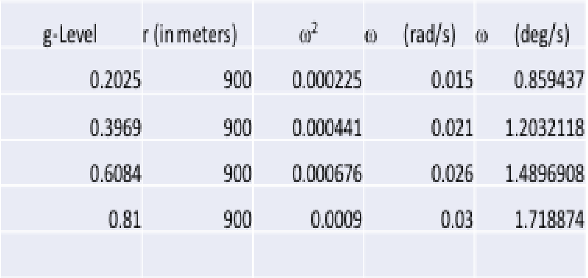


Figure 2 Center of Mass (CM) Equation



g-Level	r (in meters)	ω²	ω (rad/s)	ω (deg/s)
0.2025	900	0.000225	0.015	0.859437
0.3969	900	0.000441	0.021	1.2032118
0.6084	900	0.000676	0.026	1.4896908
0.81	900	0.0009	0.03	1.718874

Table 1 Low-G Satellite Rotation Rates vs G-levels

Vehicle Configuration: The spacecraft is not complex and consists of three components. The first component is the biological experiment module. The second component is the "controlling" module (shown as m2 in Figure 2 above) and the third component is the non-conducting tether itself.

The biological module consists of a small software defined radio, several color cameras, lighting, a solar cell power subsystem, and a biological support system. For planning purposes, this biological experiment is very similar to the NASA Ames Research Center (ARC) and German Aerospace Center (DLR) *Euglena* & Combined Regenerative Organic-food Production In Space (Eu:CROPIS) [4] payload.

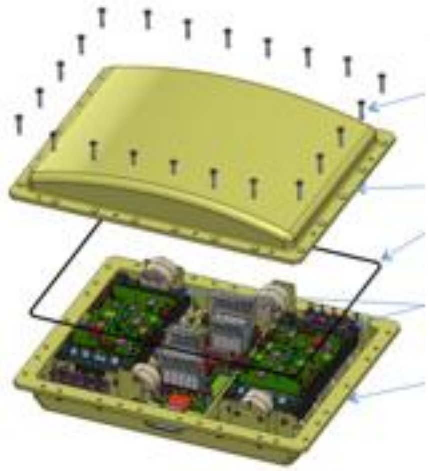


Figure 3: ARC and DLR EuCROPIS Experiment as representative S. aureas bioexperiment

The other, larger spacecraft contains all the other spacecraft functions to conduct the experiment and control the combined satellites and tether. It would also contain the tether deploy/retract reel (with tensiometer), attitude determination and control components, as well as power, communication and propulsion systems to control the spin rate of the combined satellites and tether. During test operations on-orbit, tether tension and rotation rate would be continually monitored to ensure a consistent g-environment.

In additional consideration, tether activities around the Moon are highly desirable in order to avoid triggering alarms from the United States Government (USG) *Space Fence* second-generation multistatic radar space surveillance system currently under construction. What would appear to be separate spacecraft in near vicinity to each other (i.e. 1km) would probably trigger multiple, if not continuous conjunction alarms.

Figure 4: ARC and DLR EuCROPIS Experiment as representative S. aureas bioexperment [4]

Summary: A tether-based partial gravity biological experiment deployed from the Deep Space Gateway represents a viable biological experiment to investigate the fundamental internal cellular processes. Use of the *Staphylococcus aureus* bacteria provides an advanced partial gravity risk mitigation experiment addressing the sequential documention and definition of the dose-response profile between altered levels of gravity and cellular adaption.

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IN-SITU MEASUREMENTS OF ELECTROSTATIC DUST TRANSPORT ON THE LUNAR SURFACE.

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Introduction: Electrostatic dust charging and transport on airless planetary bodies, due to the exposure of their regolith to the solar wind plasma and solar radiation, has been a long standing problem. This process has been hypothesized to explain a number of unusual space observations [1]. The first set of evidence was from several Apollo observations, including the so-called lunar horizon glow, the high-altitude ray-pattern streamers reported by the astronauts, and the low-speed dust impact events registered in the Lunar Ejecta and Meteoroid Experiment (LEAM) instrument. Since then, observations of other airless bodies, such as the radial spokes in Saturn's rings and the "dust ponds" on asteroid Eros and comet 67P, have also been suggested to be casued by the electrostatic dust transport processes. It has remained an open question to understand its role in shaping the surface properties of the the Moon and other airless bodies.

However, one fundamental problem about the exact charging and transport mechanisms remained unsolved for decades. Recent laboratory studies have greatly advanced our understanding [1,2]. In the laboratory experiments micron-sized dust particles were lofted to several centimeter high by exposure to ultraviolet (UV) radiation and/or plasmas (Fig. 1).

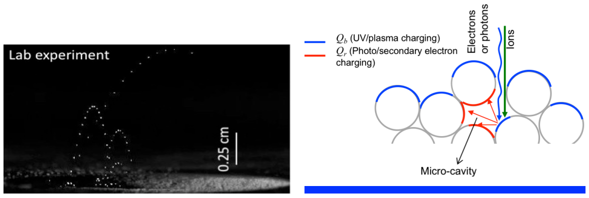

Fig. 1 Left: Trajectories of lofted dust particles under UV radiation; Right: Patched charge model.

A new "patched charge model" (Fig. 1) has been developed and validated with the experiments. It explains that emitted photo and/or secondary electrons can be re-absorbed inside microcavities formed between neighboring dust particles, causing the accumulation of surprisingly large negative charges on these particles. The resulting repulsive force between them ejects the dust particles off the surface. These experiments also showed that electrostatic dust transport can be an efficient process in shaping the surfaces of airless bodies, such as the surface morphology and porosity, surface materials redistribution, and alteration of space weathering effects, providing a new paradigm for the surface formation and evolution.

Based on these laboratory results, electrostatic dust transport is a surprisingly fast and efficient process. However, its true contribution to reshaping regolith surfaces can only be tested by in-situ measurements in space. These measurements will provide an insight into their effects on the regolith physical properties and near-surface dust environments around airless bodies, such as the Moon. In addition, these measurements will estimate and evaluate the potential dust hazards and enable the development of mitigation strategies for future robotic and/or human exploration.

Instrument and Mission: A new dust instrument, called the Cubesat Electrostatic Dust Analyzer (CEDA), is under development at the University of Colorado. CEDA is a 6U cubesat with an integration of a 2U dust sensor deployed on the surface of the Moon or other airless body. This instrument measures the charge, velocity, mass of lofted dust particles, and provides their lofting rate that estimates the efficiency of the dust transport process.

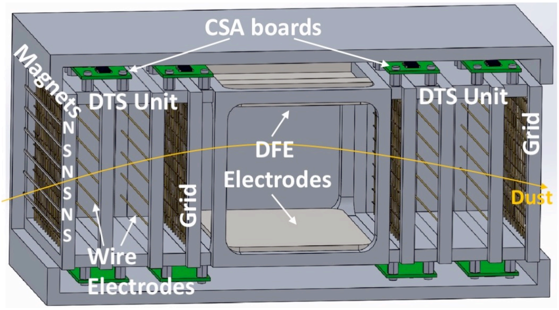

Fig. 2 Cut-view of the 2U dust sensor.

The design of the dust sensor is based on a prototype of the Electrostatic Lunar Dust Analyzer (ELDA) [3]. The sensor consists of two identical Dust Trajectory Sensors (DTS) each on one end of the sensor and a Deflection Field Electrodes (DFE) unit lying in between the two DTS, as shown in Fig. 2. A charged dust particle can enter the sensor from either end. The charge and velocity are measured with two arrays of the wire electrodes in the DTS on which the image charge of the dust particle is induced. The charged particle will be then deflected by the DFE and exit through the second DTS on the other end. The mass is derived from the deflected trajectory. The charge signals are measured using the Charge Sensitive Amplifiers (CSA).

The 2U dust sensor will be integrated in the 6U cubesat (Fig. 3). CEDA has a symmetric design so that the dust sensor measurement is independent of the random landing positions. The cubesat will be tilted for larger field-of-view (FOV) using miniature linear motion actuators (mLMA). Solar wind plasma and UV radiation are blocked by door covers. The tilted side and open door are away from the Sun which position is determined by the sun sensors.

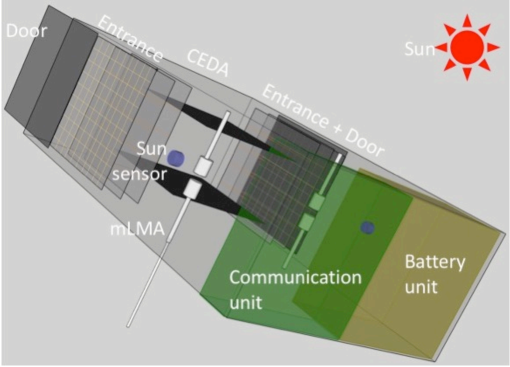

Fig. 3 Schematic drawing of CEDA. It includes the 6U cubesat system with an integration of the 2U dust sensor.

With the landing support, CEDA can be deployed from a robotic lander or rover, or by astronauts on the lunar surface. The Deep Space Gateway will be used as a communication relay between the CEDA and Earth to command the spacecraft and downlink the data.

Summary: Electrostatic dust charging and transport has been suggested to explain a number of planetary phenomena including several lunar observations. Recent laboratory studies have shown the supportive results for its occurance on the Moon and other airless bodies. The Deep Space Gateway provides a great opportunity for conducting in-situ measurements on the lunar surface. These measurements will verify and better characterize this phenomenon and its effect on the lunar surface processes and near-surface dust environment as well as potential dust hazards to future robotic and human exploration.

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LUNAR SEISMOLOGY ENABLED BY A DEEP SPACE GATEWAY.

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Introduction: The lunar seismic data gathered during the Apollo missions revolutionized our understanding of the Moon's interior and its formation and subsequent evolution. Nevertheless, many questions remain regarding the amount and distribution of seismicity, as well as the detailed structure of the crust, mantle, and core. The lunar community recognizes geophysics as a high-priority science objective for future lunar landed missions [1,2]. We outline several concepts for lunar seismology as enabled by the Deep Space Gateway.

Preferred architecture: Soft-landed: Seismometers are stationary instruments that monitor the ground for seismic shaking induced by artificial sources, natural tectonism and meteorite impacts. Ideal measurements are enabled by a globally-distributed network of instruments, however only a single station is needed to achieve basic seismic science. Seismometers require good ground coupling, continuous data collection/transmission, and longevity – the ability to survive for many diurnal cycles, ideally over a period of several years up to a decade. Therefore, lunar seismology is maximally enabled by a DSG architecture that incorporates a reusable lunar lander/ascent vehicle that can deploy identical instrumentation at globally distributed locations [e.g. 3]. DSG could also act as an orbital relay asset for far side nodes of such a network of instruments.

Geophysical package. To enable high-priority geophysical measurements, NASA formulated the International Lunar Network mission concept, which enlisted global partners to establish a geophysical network on the Moon. The nominal payload of each node included a seismometer, heat flow probe, magnetometer, and laser retroreflector [4]; the LUNETTE mission was proposed to provide the first two nodes [5] (Fig. 1). A network of the minimum 4 seismometers needed to triangulate event location and depth was preferred, but did not fit under the Discovery cost cap. Therefore a Lunar Geophysical Network (LGN) mission was prioritized for the New Frontiers class in the 2013 Decadal Survey [1]. Seismometers for solar system exploration are currently being developed [6,7]. The DSG lander/ascent vehicle would augment the LGN with additional nodes.

Supporting observations: The DSG also enables a variety of complementary observations in support of surface-deployed instrumentation.

Penetrators. As a follow-on to the former LUNAR-A project, the Japanese are continuing to pursue penetrators to deploy seismometers that can withstand the free-fall impact from orbit [8]. Penetrators are battery limited, requiring new equipment to be emplaced as power sources are consumed (after ~1 year). The DSG would reduce the power required to transmit the data from a surface instrument back to Earth.

Active source seismology. Once seismometers are deployed on the surface, the DSG can release and track impactors as artificial sources of seismicity.

Laser interferometry from orbit. Laser interferometry is one of the most sensitive methods for the measurement of small displacements [9], but it is recognized to be challenging without a relatively stable orbital platform and/or in the presence of a rough surface target. Resulting noise would swamp signals from ground motion. A high sampling-rate laser that is pulsed to exceed the relative motion of the Moon and DSG would be capable of capturing ground motion signals via interferometry. This laser must also be sufficiently high powered to ensure enough photons are retrieved from the surface; a series of well-located corner reflectors on the surface would further enable this concept.

Other supporting orbital measurements. If a seismic network is deployed, a variety of other instruments can provide supporting observations, in addition to enabling separate scientific goals. A very high resolution imager could observe thrust faults and wrinkle ridges over time to get images before and after shallow moonquakes, to examine whether tectonism is responsible for these events and the extent to which they trigger mass wasting [10]. Monitoring of the darkened limbs of the Moon for impact flashes would provide event epicenters and temporal constraints on the recorded seismic signals [e.g. 11]. A laser altimeter or synthetic aperture radar could investigate post-seismic deformation.

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Estimates for lander and instrument/payload mass, volume, power, and cost will be established once these concepts are brought to a higher level of maturity

Mission Concept	Description	Advantages	Challenges
Soft-landed geophysical network	4-6 landers carrying very broadband (<0.01-1Hz) ultra-sensitive (>10^{-10} m/s^2/√Hz) triaxial seismometers, operating for 6 years, including a far-side node.	Meeting the science objectives of Lunar Geophysics defined in the Decadal Survey for Planetary Exploration.	Mission duration, Robotic emplacement, Instrument sensitivity – requires more sensitive seismometers than ever developed, Bandwidth, Complex mission operations, Orbiter required.
Penetrator array	Deployment of a large (dozens) of nodes evenly distributed around the Moon.	Simple deployment concept (no landers) and possible replenishment program. High tolerance to failure thanks to the large number of nodes.	Achieving required sensitivity in a small shock tolerant package; vertical penetration in an atmosphere-less body; Bandwidth: will require smart processing at the network edges – technology yet to be developed. Orbiter required.
Laser interferometry	A network of several (TBD) laser reflectors including far side, evenly distributed around the Moon for several years.	Passive instruments. No surface operations required.	Continuous global coverage is impossible with a single orbiter; Orbit stability at expected seismic amplitudes and periods may not be achievable; Mission duration.
Surface monitoring including laser altimetry, SAR, imager	Orbital instruments monitoring for seismicity-induced surface changes	No surface operations required.	Continuous global coverage is impossible with a single orbiter; Orbit stability and instrument sensitivity at expected seismic amplitudes and periods may not be achievable; Mission duration.

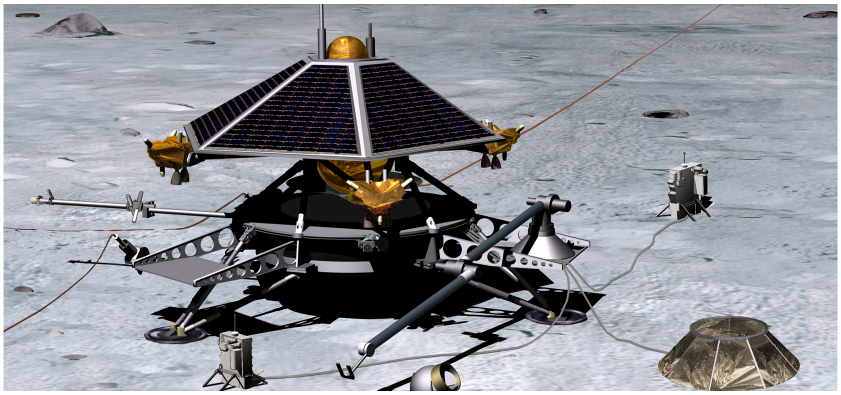

Fig. 1 LUNETTE lander concept. Image credit: JPL

DISC: DEEP-SPACE INTERSTELLAR DUST COLLECTOR. A. J. Westphal[1], A. L. Butterworth[1], C. E. Jilly-Rehak[1], Z. Gainsforth[1], S. R. Messenger[2], R. Ogliore[3], R. M. Stroud[4], [1]Space Sciences Laboratory, U. C. Berkeley, Berkeley CA 94720-7450 (westphal@ssl.berkeley.edu), [2]ARES, NASA/JSC, Houston, TX 72110, [3]Materials Science Physics Department, Washington University, 1 Brookings Dr, St. Louis, MO 63130, [4]Materials Science and Technology Division, Naval Research Laboratory, Code 6366, 4555 Overlook Avenue SW, Washington, DC 20375

Introduction: Interstellar dust and gas are the fundamental building blocks of the Solar System. **Deep Space Gateway presents an unprecedented opportunity to carry out an interstellar dust sample return mission with a collecting power sufficient to collect and return hundreds of particles to terrestrial laboratories**. The Deep-space Interstellar Dust Collector (DISC) would have a collecting power more than an order of magnitude greater than that of the pioneering Interstellar Dust Collector onboard the Stardust spacecraft. DISC would require no power or telemetry. It would be modular and lightweight, but, somewhat reminiscent of photographic film, would require recovery to carry out the scientific objectives.

Samples of the galaxy: The Solar System is moving at ~26 km/sec with respect to the local interstellar medium. This motion results in a continuous stream of interstellar gas and dust that, from our perspective, appears to originate approximately from the constellation Ophiuchus [1]. Dust from this stream can be captured by appropriate passive collectors, and returned to terrestrial laboratories for analysis.

Stardust heritage: Stardust, the fourth in NASA's Discovery line of planetary science missions, was launched in 1999. Before its encounter with comet 81P/Wild 2 in 2004, it exposed a dedicated ~0.1m^2 aerogel and Al foil collector to the interstellar dust stream for ~200 days. In 2014, the analysis team announced the discovery of seven particles of probable interstellar origin identified in the Stardust collector [2]. These particles exhibited surprising diversity. The measured interstellar dust flux was smaller than anticipated, and no more than ~12 particles greater than 1 pg (10^{-12} g) in mass were captured by the collector. Laboratory confirmation of interstellar origin of these candidates through measurement of oxygen isotopic composition is underway, but it is clear that the compositional and mineralogical diversity observed in the Stardust collection requires a statistical sample at least an order of magnitude larger than that collected by Stardust to make measurements that can be used to understand the bulk properties of interstellar dust, and to compare with bulk astronomical observations.

DISC Science Objectives: Collection of >100 large interstellar dust particles will require a collecting power (the product of area and exposure time) more than an order of magnitude larger than that of the Stardust Interstellar Dust Collector. This objective would be fulfilled using a ≥1 m^2 collector exposed to the interstellar dust stream for at least six months.

Sample return enables analyses using state-of-the-art instruments in terrestrial laboratories. Some instruments are far too large ever to fly in space. Stardust interstellar dust candidates, for example, were analyzed using x-ray and infrared microprobes at synchrotrons – these are facilities the size of shopping malls. Samples returned by Apollo, Genesis, Stardust, and other sample return missions are now being studied using instruments that did not exist at launch of these missions. These analyses include x-ray (Fig. 1) and infrared absorption spectroscopy, x-ray fluorescence mapping, x-ray diffraction, isotopic analysis using ion microprobes, and others.

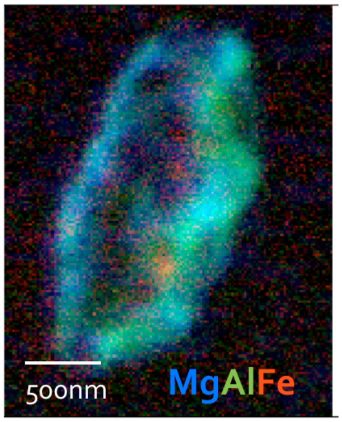

Fig. 1. Scanning transmission x-ray composition map of the interstellar dust candidate Orion, extracted from the Stardust interstellar dust collector[2,7]. (Beamline 11.0.2, Advanced Light Source, Lawrence Berkeley National Laboratory).

Lessons from Stardust: The community learned two important lessons from the Preliminary Examination of the Stardust interstellar dust collector [1].

The first lesson was that a variety of collecting media broadens the science that can be done. The Stardust collector was composed of aerogel [3,4] and Al foils [5] (85% and 15% by area, respectively). The foils were used as an engineering feature, but turned out to be important as a serendipitious capture medium [5]. Here we envision three capture media: aerogel tiles, polished high-purity Al plates, and high-purity, semiconductor-grade Ge wafers, similar to those used on the Genesis mission [6], overlaid with ~10 nm-thick silicon nitride membranes for trajectory reconstruction. This would enable high-precision elemental and isotopic composition measurements of interstellar dust particles. Other capture media (e.g., carbon-based aerogel, isotopically-doped silica aerogel, graphite planchets) could be accommodated as they are developed.

The second lesson was that any part of the spacecraft in the field of view of the collector is a potential source of secondary ejecta due to impacts of micrometeoroids on the spacecraft. Impacts of secondary ejecta in the collectors can lead to a substantial background. While these particles can usually be identified through various means [5,7], this is labor intensive and each analytical step adds risk to the samples. It is highly preferable to accommodate the collector in such a way that no part of the spacecraft is in the field of view of the collector.

DISC Payload: An interstellar dust collection mission with large collecting power would be enabled by the Deep Space Gateway. Several key characteristics of DISC facilitate accommodation in the DSG architecture:

- No power is required
- No telemetry is required
- No thermal control is required
- Modular design
- Lightweight (< 30 kg)
- Compact stowed envelope for launch and recovery
- Deployable and recoverable with robotic arm
- Deployment and recovery timing are not critical, because of the near constancy of the interstellar dust stream flux

Requirements:

- The collector shall be recovered to complete science objectives
- The collector shall be mounted externally on the DSG with an unrestricted view to space
- The integrated interstellar dust stream exposure time shall be >180 days for a 1m^2 collector
- The collector shall be deployed to maximize the exposure to the interstellar dust stream
- The orientation of the collector during exposure shall be recorded

Interstellar dust radiant tracking:

The Stardust interstellar dust collector was mounted on an articulated arm, which enabled alignment of the normal vector of the collector with the interstellar dust stream. Because of effects of light pressure during interstellar dust transport in the heliosphere, the interstellar dust radiant direction is not unique, but depends on β, the ratio of the light pressure force to gravitational force [8]. For Stardust, the collector was aligned during the exposures to the β=1 interstellar dust radiant. DISC would track on the β=0 radiant, corresponding to larger and more compact particles. This alignment maximizes the collecting power of the collector for capture of large interstellar dust particles, and, for capture media such as aerogel that record trajectories, allows for rejection of interplanetary dust particles, which also constitute a background. In principle, DISC would also be aligned as much as possible to the ISD radiant during exposure. A passively articulated mount might be periodically re-oriented using the DSG arm. Multiple external mount points to which the collector could be moved during the course of a one-year exposure could also optimize the collecting power and minimize backgrounds. A detailed model of the expected orientation history of the DSG would be required to determine the relative distributions of trajectories of interstellar dust and interplanetary dust impacts. Interstellar dust capture speed for DISC would be comparable to or lower than that of Stardust during times when Earth's motion is generally aligned with the interstellar dust stream.

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SOLAR WIND SAMPLE COLLECTION AT THE DEEP SPACE GATEWAY.

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Introduction: Returned samples of the solar wind have greatly increased our understanding of the solar system and its formation, as well as understanding of the acceleration of the solar wind. A number of important science objectives can be attained if new, longer-duration collections are performed. Solar-wind collection must be done outside of the Earth's magnetosphere, and hence requires deep space missions that return to Earth. We propose to use the Deep Space Gateway to perform long-term collections of solar wind for return to Earth and subsequent analysis.

History: Not much was known about the composition of the solar wind prior to the Apollo missions. On several of the lunar missions, foils were deployed to collect solar wind for periods of about an hour to nearly two days [1]. These experiments revealed, among other things, that solar neon is isotopically much lighter than terrestrial neon, providing strong evidence for the loss of the Earth's primary atmosphere due to hydrodynamic escape (e.g., [2]).

The success of these short-exposure experiments prompted the development of the Genesis mission, which collected solar wind for 2.4 years at the Earth's L1 point [3] from 2001-2004. Successful analyses of these samples yielded the isotopic composition of solar oxygen [4] and nitrogen [5], resolving a long-held mystery surrounding the origin of oxygen isotopic heterogeneities in solar-system materials (e.g., [6]) by pointing to carbon monoxide self-shielding [7] and similar likely effects with nitrogen (e.g. [8]), providing a unique window into the environment of the solar nebula. Elemental abundances determined from the Genesis samples has led to ongoing work in understanding the acceleration of the solar wind from the solar surface (e.g., [9]).

While the Genesis mission was a success, a number of important objectives of solar-wind sample analyses have not yet been realized. Analyses requiring relatively large surface areas (e.g., 20 cm^2 or larger), such as to use radiochemistry with neutron activation analysis to determine solar abundances of rare-earth elements, could not be carried out with the relatively small samples from Genesis. Other tests, such as determining the solar carbon isotopic composition, or the ratio of volatile to dust-forming elements in the sun (e.g., [10]) have not been possible. Observation of the lithium and beryllium isotope ratios [11], indicative of the history of the mass of the solar convection zone, would also be desirable.

Deep Space Gateway Solar Wind Collection Concept: A follow-on solar-wind collection experiment on the Deep Space Gateway would be required to be sun-pointed. Collector materials would be exposed for significantly longer than on the Genesis mission, to enable maximum science return. We envision two identical experiments, one which would be exposed for five years, and another to be exposed for ten years. The redundancy and the earlier return of the first samples reduces risk, and if the ten-year experiment is successful, it would provide more than four times the solar wind fluence compared to Genesis. Each experiment would cover approximately one square meter of sun-facing surface with ultra-high purity collector materials such as silicon wafers (e.g., Fig. 2). The materials should be shielded by line of sight from contaminants that may be emitted by the spacecraft. The collector materials could be folded up for return to Earth. Each passive experiment would require no power and would have a mass of approximately 5 kg.

In addition to the passive collectors, each of the two (5- and 10-year) experiments might optionally include a solar-wind concentrator. The Genesis instrument provided a 40x boost in solar-wind fluence for key isotopes. The Deep Space Gateway solar-wind concentrator could be tuned for isotopes of Li, Be, and B, or for other important isotopes. The design used for the Genesis mission [12] measured 46 cm diameter by 21 cm (Fig. 1), had a mass of 7.6 kg, and used very little power (~ 2 W). Its sun-pointing requirements are more stringent, within a couple of degrees of the average solar-wind direction, and a monitor, providing solar-wind speed in real time would be required. A careful study might help determine the value of adding the concentrator to the passive experiments.

Summary: Collection of solar wind at the Deep Space Gateway represents a simple experiment with the potential to return important fundamental science to enhance our understanding of Sun, the solar wind, and the evolution of the solar system. This collection requires deep space.

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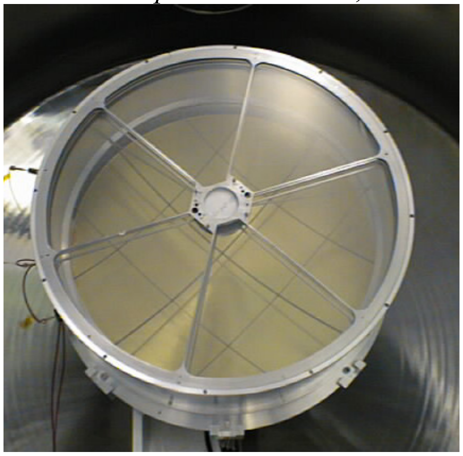

Figure 1. Genesis Concentrator, a reflecting ion telescope. Solar wind is collected in the underside of the center circle (target).

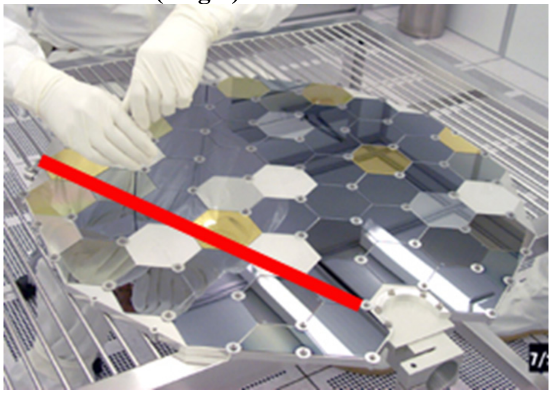

Figure 2. Example of a Genesis-mission solar-wind collector array. Red line is approximately 60 cm.

CLOCK COMPARISON AND DISTRIBUTION BEACON AT CISLUNAR ORBITS.

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Introduction: We propose to deploy an advanced space optical clock system (ASOCS) on a Deep Space Gateway Station (DSG) and establish a high-precision time and frequency beacon to Earth and into deep space. ASOCS will operate a space-based clock at unprecedented fractional frequency stability of 1×10^{-18} [1], which can be disseminated via microwave and/or optical links. Clock comparison measurements to existing clocks on Earth will provide opportunities for direct detection of ultra-light dark matter (DM) fields [2,3,4]; tests of gravity-induced frequency shifts and time delays for fundamental physics measurements [5,6]; and precision one-way spacecraft Doppler tracking and ranging in deep space. The high-performance clock and link asset at DSG will also enable future clock-based gravitational wave detections when properly linked to another high-performance clock in deep space [7,8].

Background: There has been tremendous and rapid advancement in the development of high-performance atomic clocks in the form of *optical clocks* (OC). Optical atomic clocks utilize ensembles of laser-cooled atoms, with technologies similar to those at the heart of the ISS-based Cold Atom Laboratory (CAL), but confined in optical lattice potentials for unprecedented insensitivity to interactions, thermal effects, and environmental perturbations. The clock signal is derived from a stable laser frequency-locked to a metastable optical transition at 100s of THz, which has recently achieved record fractional frequency stabilities at 10^{-18} (2.2×10^{-16} at 1 second) [1]. Operating an OC aboard the DSG would provide unique opportunities for a range of applied and fundamental physics applications via unprecedented long-baseline clock comparison experiments between Earth and DSG. The demonstrated optical clocks now reach sufficient precisions for gravitational wave detections using clocks directly.

Objectives: The primary science objectives include:

1) Searching for direct evidence of dark matter, thereby providing insight into the widely unknown nature of DM and/or testing the validity of contemporary DM theories with stringent bounds.
2) Improving the test of clock time dilation described by Einstein's general relativity of space-time, often known as the gravitational redshift, by several orders of magnitude over the current limit.
3) Seeking a violation of Lorentz invariance (LI) with unprecedented precision in the framework of Einstein's special relativity [6].
4) Demonstrating the utilities of the clock asset at cislunar orbits for deep space time and frequency dissemination and for possible gravitational wave detection similar to those by the Cassini Doppler-tracking gravitation detection experiments.

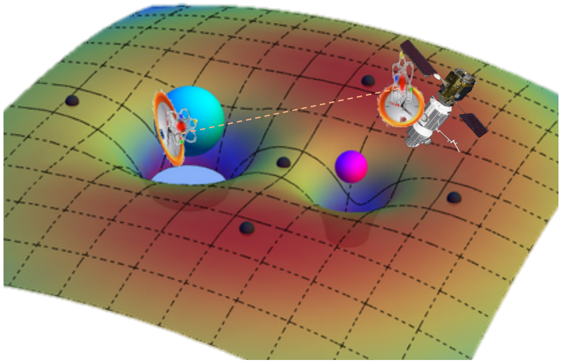

Figure 1: High-precision time and frequency comparisons between DSG-based and terrestrial optical clocks enable novel searches of ultralight DM and high-precision tests of Einsten's general relativity.

Searching for signatures of DM: Determining the composition and properties of dark matter is one of the grand challenges in astrophysics and cosmology today. The challenge lies in the range of uncertainty of the mass of dark matter fields. While the range of massive particles is mostly investigated in high energy accelerator physics, ultra-light dark matter can be probed through precision measurements using clocks [2,3,4].

It is known that the DM coupling to the standard model fields results in changes of fundamental constants such as the fine structure constant. A change in these fundamental constants affects atomic transition frequencies and, therefore, atomic clock ticking rate. By comparing atomic clocks of different species or separated by a distance, we would be able to detect the presence and dynamics of DM fields, which can be in the forms of sinusoidal waves [4], clumps of topologic defects [2,3], or stochastic backgrounds.

Figure 2 gives existing constraints on the DM energy-coupling-scale ($\Lambda\alpha$) for topological DM defects from clock-cavity comparisons [3], and astrophysical measurements [9], as well as projected sensitivities that may be achieved using trans-continental networks of GPS and OC. Comparisons with OC onboard DSG and terrestrial clocks promise to increase bounds on the $\Lambda\alpha$, increase the measurable defect size, as well as extend the bounds to lower masses for DM waves. A network of three clocks can also detect stochastic backgrounds through cross-correlation measurements [10].

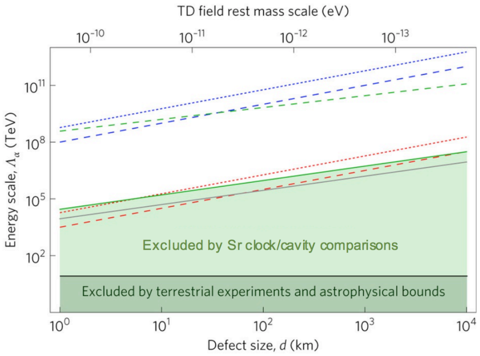

Figure 2. Constraints on the DM energy-coupling scale (Λ_α) for topological defect dark matter. The region below the solid green line corresponds to constraints from Sr clock/optical cavity comparison measurements [4]. The region below the solid black line corresponds to constraints from fifth-force searches and astrophysical measurements [5]. The dashed red and blue lines correspond to the sensitivities that may be achieved using a trans-continental network of GPS clocks and Sr clocks, respectively [3].

Test of gravitational redshift of clocks: Einstein's general theory of relativity offers the most elegant description of gravity and so far, the most successful theory in fundamental physics. However, there are compelling reasons to believe that the gravity theory is not complete. A violation could exist at some scales. General relativity predicts the slowing down of a clock in a gravitational field, the gravitation redshift. This effect was validated by the Gravity Probe A experiment in 1979 by Vessot [9]. ASOCS at cislunar orbits of nearly zero gravity can be compared with clocks on the ground at the full Earth gravity, offering the opportunity to perform the most precise test of general relativity, and improve the violation limit by 10,000, and potential for new discovery [5].

Test of Lorentz Invariance: Special Relativity relies on the assumption that Lorentz Invariance is a fundamental symmetry of nature. However, several theoretical frameworks predict that LI may not hold at all energy scales [2]. The highest-precision constraint of the LI violating terms is given by a comparison campaign of strontium OC in different locations throughout Europe [6]. Here, the clocks travels at different velocities (varying by up-to 22m/s in the inertial geocentric frame) due to their different positions on the Earth. By utilizing a DSG-based OC and undergoing similar clock-comparison campaigns with terrestrial OC worldwide, it will be possible to perform similar experiments with more than two orders of magnitude increased precision. The DSG orbits provide access to diverse speed and orientation changes for these measurements.

Instrument Concept:
The advanced space optical clock system will consist of an optical clock and a hybrid optical-microwave link for time transfer. The optical link provides high-performance frequency and time links with other clocks on Earth, for high precision clock comparison experiments, while the microwave link is intended for demonstrating time signal reference covering an appropriate omnidirectional antenna and receiver while also providing frequency references for lunar and interplanetary missions.

The experiment concepts take advantage of the nearly zero gravity potential at DSG relative to that on Earth, large simultaneous ground coverage, and greater range of orientation and velocity changes. The very long baseline of cislunar orbits from Earth also increase the dark matter signal strength for ultra-light particle fields with long wavelengths. The main payload can be either inside or outside, the antenna needs to be outside. Multiple ground stations are assumed. Quiet EMI and vibration environments are preferred. Similar to ISS environment is acceptable.

Size, Weight, and Power: The clock payload will be < 200 kg, including antennas, dependent on the functionality and capability requirements, < 1 m^3, < 500 W. Stable temperature and vibration environment is desired

Preferred Orbits: Constant earth viewing, with varying gravity that passes through zero potential point of L1 is preferred.

Astronaut Involvement: No.

Cost Estimate: $100M WAG is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

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DEEP SPACE SPACEFLIGHT HAZARDS EFFECTS ON COGNITION, BEHAVIORAL HEALTH, AND BEHAVIORAL BIOMARKERS IN HUMANS.

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Introduction:
Spaceflight hazards have been demonstrated to both directly (i.e., space radiation, altered gravity) and indirectly (i.e., isolation and confinement, distance from Earth, hostile environment) impact on humans' neurophysiology and cognitive performance [1]. Among the specific risks are exposures to galactic cosmic radiation, toxic gases, hypercapnia, fluid shifts, sleep deprivation, chronic stress and others [2, 3]. Reports of "space fog" relate to the perception of cognitive slowing [3]. Crowding, lack of privacy, and limited sensory stimulation can all have negative impacts to human neurological and behavioral health. An additional and more unique challenge is the radiation environment in deep space, which is much stronger than that on Earth or in low-Earth-orbit. Compared to other organ systems in the body, the central nervous system (CNS) has a greatly decreased ability to repair and regenerate itsself, making it particularly at risk from radiation damage. NASA's Apollo lunar crews are the only humans with exposure in this radiation environment—but those few days of exposure do not allow us to characterize the risk associated with multi-month and multi-year missions planned for the Deep Space Gateway (DSG) and beyond. These potential hazards pose risks to the astronauts' intact neurocognitive functioning and highlight the need to systematically monitor crew performance using a comprehensive, sensitive and valid neurocognitive assessment tool. There is a need to identify the risk of both behavioral performance and cognitive perturbations caused by these stressors, in particular since space radiation guidelines pertain only to missions in Low Earth Orbit (LEO) [4]. There is a need to scientifically parse both the sources and effects of neuroinflammatory processes related to risk factors in spaceflight, identifying the biomarkers and performance measures relevant to crew performance. Missions beyond LEO offer the opportunity to identify biomarkers related to neuroinflammatory processes resulting from increased exposure to space radiation, as well as the potential compounding of oxidative and behavioral stress reactions with the other spaceflight environmental factors (e.g., microgravity, isolation). The Gateway research provides the mission-critical Deep Space proving ground for the synergistic effects of these identified spaceflight hazards.

Methods: The methods will leverage the biomarker detections in fluids that include stress hormones and cytokines related to neuroinflammation and brain performanace pathways. A computerized neuropsychological test battery, Cognition [1], with sensitivity in the assessment of 10 cognitive domains—including reaction time, emotion processing, spatial orientation, and risk decision making—will be used. Cognition was specifically designed for the high-performing astronaut population and is based on tests known to engage specific brain regions as evidenced by functional neuroimaging.

Resources Required: The Cognition Battery software must be loaded on a computer system within the vehicle, which may be a system computer or payload laptop. Crewmembers would watch a standardized familiarization video that explains software handling and each of the 10 Cognition tests before performing Cognition for the first time. During this familiarization phase, crew would be required to perform a practice version of each test before taking the actual test (available for 8 out of the 10 Cognition tests). Crewmembers will perform all 10 tests of the battery: 2 times pre-DSG Mission: L-6 months, L-3 months; weekly during DSG mission, and 2 times post-DSG mission R+14 and R+30. During the DSG mission, Cognition will be scheduled immediately prior to scheduled bed time (with some exceptions during mission-relevant demands). During pre- and post- DSG Mission testing subjects would not be allowed to perform Cognition within 1 hour after waking up (to avoid sleep intertia) or after being awake for 16 hours or more (to avoid sleep deprivation). A brief, Visual Analog Scale (identical to the survey administered on the ISS and in the ground studies in astronauts, astronaut candidates, and mission controllers) will also be administered prior to each Cognition Battery. The HRP Standard Measures will also be used to identify sleep periods and awakenings based on 60 second movement activity counts during scheduled sleep times. Datasharing of inflight biomarkers is planned to monitor and correlate neuroinflammation markers with cognition testing.

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TRI-Worthy Projects for the Deep Space Gateway.

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Introduction: There is no satisfactory analog for the deep space environment that provides the isolation, confinement, danger, radiation exposure and weightlessness that humans will experience in deep space. The International Space Station and various spaceflight analogs have been used for decades to provide a test bed for the technology development required to support ever-longer duration space missions. However, we know that each of these analogs successfully models only a portion of the actual deep space environment. Even experiments and testing on the ISS aren't exposed to deep space radiation, confinement, and communication delays. Certain experiments and testing will require these features of deep space that seem only to be available in deep space.

At the new Translational Research Institute (TRI) for Space Health, we have examined potential risks to human health on spaceflight missions with deep space exploration missions in mind. We also considered the charge of our Institute – to translate emerging scientific and biomedical advances, radically disruptive technologies, and new engineering capabilities and facilities that bridge earth and space health medicine. We have identified a small group of projects that require some aspect of deep space in order to reach useful scientific outcomes or technological deliverables, and at the same time, are particularly well-suited to how we work.

TRI-Worthy Deep Space Project Ideas:

How will deep space radiation affect human physiology?

New beakthroughs in engineering and tissue culture have resulted in the development of organs -on-a-chip (OOCs). OOCs incorporate each organ's various cell types into a three dimensional structure that preserves their indivudal functions as well as the function of the organ as a whole. The chips include automated mecahsnisms for feeding and waste removal mimicking the organ's natural blood flow. OOCs are still relatively early in development with no standardized organ prototypes agreed upon yet, but development and validation are advancing quickly. OOCs with lieftimes of 21-30 days are now in testing. OOCs are being used on the ISS, and we think they are an excellent candidate for use on deep space missions because they would enable exposure of real human cells to deep space radiation. OOCs on a deep space mission would be the first human tissues to experience deep space radiation since the Apollo astronauts. Now we have the capabilities to perform far more detailed biochemical analyses to determine impacts on DNA itself, on gene expression, and on function of the proteins that are each cell's machinery. Use of OOCs permits more invasive testing than would be feasible with astronaut subjects, and with fully automated feeding and waste removal, would even be feasible for unmanned deep space missions. All care and maintenance would have to be completely automated, as would all analyses of organ health; these are technical challeneges but they are acheiavble in the coming year. More advanced experiments could include testing of potential countermeasures to prevent or reduce effects of deep space radiation or combination of multiple OOCs into a "body-on-a-chip".

Will stored medications be affected by deep space radiation?

It is known that medications degrade over times, and that degradation can be accelerated by environmental exposures that include light, temperature, oxygen and humidity. However, it is not known if deep space radiation accelerates any the typical degradation reactions exhibited by medication dosage forms. A NASA-funded project has recently developed a Raman spectroscopy-based device that enable the nondestructive analysis of medication dosage forms by relatively untrained personnel [1]. We propose that this device, or something similar, be modified such that it can operate autonomously and then employed to perform analyses of mission-relevant medications on a regular schedule, and deliver the data to ground for examination by pharmacists, pharmaceutical scientists and physicians. This automated drug stability device would enable the first analysis of deep space radiation on medications. Ideally, these experiments could be implemented on deep space missions with durations similar to those anticipated for crew, but information from shorter missions would permit the development of degradation modelling similar to that used by pharmaceutical manufacturers.

How could we use robotic companions in deep space?

Crewed and robotic spaceflight missions are often considered mutually exclusive. However, humans want to expand their horizons and will continue to venture into space, whereas robots can provide highly complementary capabilities. For example, robots can provide superior strength and durability, are unaffected by continuous or monotonous demands, and are not susceptible to illness or the same types of degradation as biological systems. As an initial step from current technology, a robotic companion could conduct basic long-duration situational monitoring without tiring, serve as an assistant during medical or other emergencies, or perform basic tasks in dangerous conditions (e.g., outside habitats, in toxic environments). Given ample strength, a robotic companion could also serve as a sherpa to carry significant loads on behalf of crewmembers, or become a personal trainer, including being part of the exercise hardware itself. Robotic companions could have numerous other benefits as well. For example, while live pets on long-duration flights generate significant logistical challenges, caring for even a robotic pet can provide significant mental health benefits. Face-to-face interaction with intelligent robots can also be more "personal" than text or even video interactions, supporting the concept of robotic therapists. Similarly, a robot could serve as a highly impartial mediator to help resolve disagreements among crewmembers. Thus, by combining recent advances in robotics, sensors, emotion recognition, computerized therapies, and artificial intelligence, a robot could provide numerous unique capabilities to support crewed space missions.

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Earth's Microwave Pulses from a Lunar Orbit

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The solar radio flux at 10.7 cm wavelength is a widely used index to monitor Sun's activity since the World War II, but there is still nothing equivalent today for Earth. The terrestrial microwave emissions contain rich information on its climate as well as man-made changes.

Despite a large number of microwave sensors employed by research and operational weather satellites, the observation of microwave pulses from Earth as a whole has not been established. It requires an Earth view from a vintage point away from the planet, far enough to minimize sampling biases toward a particular terrestrial region or local time. The Moon orbit can be used to stare at Earth for a period of time from seconds to days under the similar Sun-Earth geometry. It will not bias the sampling to a particular local time nor to a specific region on Earth. Because Moon has a permanent face towards Earth, it is feasible in the future exploration to establish a ground station on the lunar surface to monitor long-term variations of Earth's microwave pulses as did for Sun.

Microwave receivers nowadays can make both broadband and hyperspectral measurements at high accuracy and precision in a wide range of frequencies (1-2000 GHz), with good stability over more than 10 years. The envisioned instrument is a single-beam spectro-radiometer with multiple spectral bands in 1-2000 GHz and its field-of-view covering the full disk of Earth. Thanks to advances in modern detector technologies, this type of receivers now can measure a microwave spectrum over 100 GHz bandwidth, allowing simultaneous detection of multiple emission features and their intensity. In addition, improved detector sensitivity will be able to sense a small (e.g., 0.1%) change in brightness temperature, should Earth fluctuates in seconds, in days, or in decade. Among the terrestrial processes that affect the outgoing microwave radiation, the most important variables include surface temperature/emissivity, atmospheric gases (e.g., O_2, H_2O, O_3), and clouds. At low frequencies (<30 GHz), human has begun to generate significant power worldwide. All of the above can be observed from the vintage point of lunar orbit, and the observation is a manifestation what Earth is like collectively at microwave frequencies.

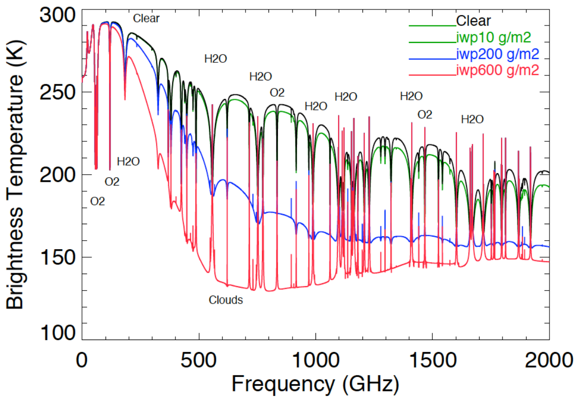

Fig.1. A snapshot of Earth microwave spectra at 1-2000 GHz from clear and cloudy skies. Major spectral line features are mostly from O_2 and H_2O gases. The spectra with cloud scattering from different amounts of ice contents are depicted by colors. Earth's microwave pulses are the collective efforts from millions of these spectra as Earth spins and clouds move around.

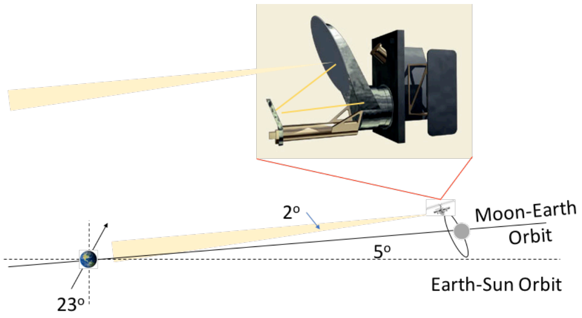

Fig.2. A simple radiometer system like the Microwave Instrument for Rosetta Orbiter (MIRO) can readily achieve the field of view needed to cover the full disk of Earth. (Credit of MIRO instrument photo: Jet Propulsion Lab)

REAL-TIME PENESTRATING PARTICLE ANALYZER (PAN).

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Introduction: Using a magnetic spectrometer with particle identification capability, it is possible to measure and monitor the flux, composition, direction and time variation of highly penetrating particles (> ~100 MeV/nucleon) in deep space, to a precision that has never been achieved before. Deploying such a device on the Deep Space Gateway (DSG) will allow real-time monitoring and long term measurements over a full solar cycle (~11 years). These precise measurements will improve our understanding of the connection between the high energy particle environment in deep space and the solar activities, and bring new insight to the origin and the propagation of these particles. The real-time monitoring of the penetrating particles is crucial for future deep space human travel since these particles are difficult to shield, therefore needed to be constantly monitored. In the baseline version, the proposed instrument, called the Real-Time Penetrating Particle Analyzer (PAN), weighs about 20 kg and consume about 20 W. But the instrument is highly scalable.

Radiation environment in deep space: In space, particle radiation comes mainly from 3 sources: particles trapped in the geomagnetic filed, particles from solar flares (Solar Cosmic Rays or SCRs), and Galactic Comics Rays (GCRs). In deep space, the trapped particle contribution can be neglected, leaving only the SCR and the GCR as main contributors. SCRs are burst of energetic particles produced by solar flares, consisting of mainly electrons below 1 MeV, but also protons and Helium nuclei, mostly with energy below 30 MeV. GCR is the dominant particle source above few hundred MeV, consisting of mainly protons and Helium nuclei, but also heavier nuclei produced in nucleosynthesis and through the interactions of GCRs with the interstellar medium. In deep space the GCR flux below a rigidity of ~20 GV is strongly affected by solar activities, through solar winds and through the modulation of the interplanetary magnetic field.

Science objectives: The energetic particle environment at the LEO has been studied in great details, in particular since the launch of the PAMELA [1] satellite in 2006 and the installation of the AMS-02 [2] spectrometer at the ISS in 2011. In deep space, however, only the non-penetrating particle (< ~100 MeV/n) environment has been precisely measured, and indeed continuously monitored over more than 17 years by the CRIS instrument [3] on NASA's ACE mission. While the particle flux above 20 GV, predominantly from GCR, is largely unaffected by the geomagnetic field and the solar modulation, thus allowing the AMS measurement to be extrapolated into deep space, the same is not true for particles below this threshold. A precise measurement of particle flux between ~100 MeV/n to ~20 GeV/n in deep space is therefore missing (for a review of the current and planned particle observation missions, see e.g. [4]). The science objective of PAN is to fill this gap of observation, allowing to measure the particle flux in deep space in this energy range with unprecedented precision in terms of energy, composition and short and long term time variations, profiting from the unique orbit and the expected long lifetime of the DSG. PAN will open up a new window of observation for multiple disciplines of space science, including solar physics, space weather and cosmic ray physics, and their interplay in the interstellar radiation environment. For example, the precise flux and composition measurements of the GCR at 100 MeV/n – 20 GeV/n will help to resolve fundamental questions concerning the GCR production, acceleration and propagation in the Galaxy. However, solar modulation effects on these measurements should be evaluated and corrected. Another example is detailed studies of the rare "GeV" solar storms (solar flares that produce GeV particles), an interesting topic for solar physics, space weather and radiation protection.

Energetic particle monitoring for deep space human travel: Energetic particles above about 100 MeV/n, in particular proton and nuclei, cannot be shielded easily, thus become "penetrating". At LEO, the geomagnetic field is a natural shield for particles up to 20 GV. In deep space however, without the geomagnetic shield, penetrating particles represent a serious radiation hazard for long term space travelers. The precise and long term measurements of the flux and composition of these particles are indispensable for the assessment of the related health risk, and the development of an adequate mitigation strategy. PAN will also provide valuable experience for the crew to operate a real-time penetrating particle monitoring tool.

Detection principle: Magnetic spectrometer (MS) is a proven detection technology for particles between 100 MeV/n and 20 GeV/n (e.g. Pamela and AMS-02). In this energy range, the classical ΔE – E method (e.g. ACE) is not optimal, because a very thick and heavy calorimeter is needed to measure the total energy of the particle. In a MS, the momentum resolution, thus the energy resolution, has 2 contributions: one, related to the magnetic field (strength and length) and the tracker precision, increases with momentum; the other, due to the multiple Coulomb scattering (MCS), decreases with momentum. With appropriate instrument design, it is possible to mitigate these two effects to achieve a good energy resolution over the desired energy range. Figure 1 shows the energy resolution obtained with the baseline PAN design described below, estimated with the Gluckstern formulas [5]. For protons, the energy resolution is ~5% between 1-5 GeV, and ~15% at 100 MeV and 20 GeV. Note that a 20 GV rigidity is equivalent to ~9 Gev/n for nuclei heavier than proton.

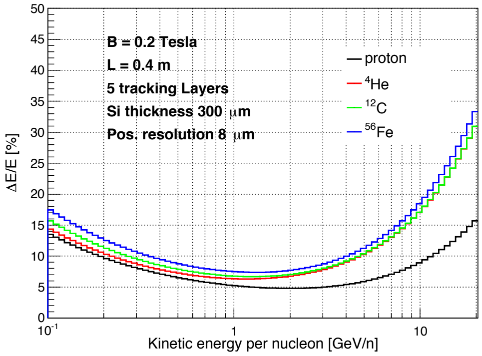

Figure 1. Energy resolution as a function of energy per nucleon for proton, Helium, Carbon and Iron nuclei from 100 MeV/n to 20 GeV/n, with the baseline PAN design.

The charge (Z) of the particle can be determined by measuring the energy deposited in the tracking layers and in the Time-of-Flight detector, using the dE/dx method. A large dynamic range is needed to measure the dE/dx for Z up to ~30. Also at 100 MeV/n, the βγ of the particle is only ~0.5, which leads to a dE/dx that is ~3 times of the Minimum Ionization. A possible option to optimize charge measurement is to add a dedicated charge detector, using e.g. silicon pixel detectors. On the other hand, the low βγ value can provide isotope identification for low energy particles with the dE/dx – E method. The identification of electrons is straightforward since they bend in the MS to a direction opposite to that of the nuclei.

Baseline instrument design concept: The baseline design concept of PAN is shown in Figure 2. It consists of a cylindrical MS, with a TOF detector at each end to determine the entering direction of the particle. The instrument is symmetric, effectively doubling the geometrical acceptance. The data processing of the MS is straightforward, allowing for real-time calculation and display of particle fluxes that can be monitored by the crew, who can decide to point the PAN to a particular direction if the situation requires.

The MS consists of a magnet made from blocks of NdFeB permanent magnets arranged according to the Halbach scheme. The baseline layout uses a magnet assembly weighing below 10 kg to provide a dipole magnetic field of 0.2 Tesla, in a cylindrical cavity of 15 cm in diameter and 40 cm long. The total geometrical acceptance is about 2x18 cm^{2}sr.

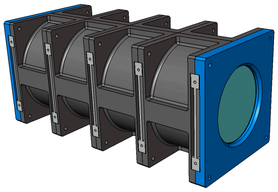

Figure 2. Sketch of the baseline design concept of PAN.

The MS is instrumented with 5 equal-distance tracking planes made of 300 μm thick Si micro-strip sensors, with 50 μm readout pitch, to provide a position resolution of ~8 μm. This layout achieves the energy resolution shown in Figure 1. A plastic scintillator TOF with SiPM readout can achieve a time resolution of 150 ps, sufficient for determining the particle entering direction in the energy range of interest.

A preliminary estimate of resource requirements is given in Table 1. The baseline design uses technologies with high TRL. It can easily be scaled up or down depending on available resources. More recent technology such as silicon pixel detector can also be adopted. By design the instrument is highly modular, with replaceable modules, to provide an extra safety margin for very long operation period.

Resources	Requirement
Mass	~20 kg
Power	~20 W
Cost	~10 M$
Volume	~25 cm×25 cm×50 cm
Crew intervention	Setup and monitoring

Table 1. Preliminary estimated resource requirements.

PAN should be mounted at an external site that facilitates maximal sky coverage. The operation mode includes automatic full sky scan and pre-programmed pointing observation, but the crew can take control of the instrument for instantaneous monitoring in specific directions.

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UTILIZING THE DEEP SPACE GATEWAY TO CHARACTERIZE DNA DAMAGE DUE TO SPACE RADIATION AND REPAIR MECHANISMS.

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Introduction: The Deep Space Gateway (DSG) in cislunar orbit will be beyond the protection of the Van Allen Belts, providing an ideal environment for characterizing the DNA damage that can be expected in missions around and on the Moon, and on a journey to Mars. Similarly, these conditions provide a unique setting for the study of different DNA damage repair mechanisms, providing insight into differences in their efficiency in space.

Science Enabled by the DSG: Ionizing radiation (IR) refers to X-rays, gamma rays and cosmic rays, as they can ionize molecules [1]. IR can cause double-strand breaks, which are dangerous to organisms as it does not leave an intact template to use as a basis for repair. This can translate to loss of genes when the cell divides [2]. For repairing IR-derived DNA damage, the two main mechanisms used are (*i*) nonhomologous end joining and (*ii*) homologous recombination. The first one refers to the re-joining of the broken sides via DNA ligation, which usually means the loss of nucleotides. The second, homologous recombination, uses a sister chromatid as template and yields a more accurate, albeit slower, repair.

While humans have lived on the International Space Station (ISS) in low Earth orbit (LEO) for years, the ISS does not provide a representative radiation environment of what is expected beyond LEO, where the Earth's magnetosphere does not provide protection from cosmic and solar radiation [3]. In order to best prepare for future human missions around and on the surface of the Moon, and to Mars, we need to know what magnitude of cellular (DNA) damage can be expected.

Bacteria (e.g. *E. coli*) and humans share DNA repair mechanisms such as the SOS response. DNA double-strand breaks from IR yield single-stranded DNA (ssDNA), which in turn elicits the formation of RecA filaments around these ssDNA regions. The increase in the presence of the RecA protein decreases the amount of LexA, which is a repressor of the SOS response. This makes *recA* and *lexA* (which have homologous genes in the human genome) [4] potential target genes to interrogate under an initial experiment performed on the DSG. While over 1,000 genes are involved in DNA damage response in *E. Coli* [5], target genes can be down-selected by choosing those with human homologs and/or that have corresponding molecular pathways in eukaryotic cells, as described in Ref [6].

Required Instruments: Our group recently proposed the development of the High Altitude Research Pressurized Instrument Enclosure (HARPIE) for implementation on a high altitude Antarctic balloon that operates in a high radiation environment, and it consists of (*i*) the core experiment hardware, and (*ii*) a system that administers power and control/data logging functionalities, as well as provides temperature control.

The core experiment hardware consists several sets of well plates. Each set of plates supporting dozens of samples and capable of providing an initial inoculum, several media changes, and an experiment-terminating fixation/preservation. HARPIE has the ability to autonomously perform media changes to prolong the effective lifetime of the culture, which is critical to performing a multi-generational study to identify effects of radiation exposure. The plates themselves are easy to redesign to support other experiment schedules (e.g. less samples with more media changes) depending on other studies' science requirements.

The experiment can be executed (started or finished) at any point during the mission. The length of the experiment is limited by the number of media changes that occur, the effective dilution ratio between the wells of the inoculum plate and the media/fixative plate, and the growth rate of the selected microorganism or cell. The container includes insulation, heaters, computers, batteries, sensors, and other electronics to operate the core experiment hardware, provide a viable environment for the biology housed within it, and log parameters relevant to the experiment such as temperature, radiation exposure, and HARPIE's health status data. HARPIE's principle of operation is based on hardware we have previously operated on board the Space Shuttle and ISS with updated electronics that are robust against radiation effects.

Needed Resources.

- Mass: 4.1 kg
- Power: average: 7.6W, peak: 11.9W
- Cost: TBD
- Volume: 0.005 m^3
- Crew time: none
- No specific requirement regarding cislunar orbit

Conclusions: The DSG can enable radiation studies, namely DNA damage and repair investigations, in a way that the ISS or Earth laboratories cannot replicate. These type of investigations may serve to determine the likelihood and consequence of the high-radiation risk to human exploration of space beyond

LEO. HARPIE enables the performance of this type of research while consuming minimal resources such as volume, mass, power, and data transmission. This hardware may also enable different types of investigations using unicellular organisms, such as drug effectiveness and multigenerational studies.

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