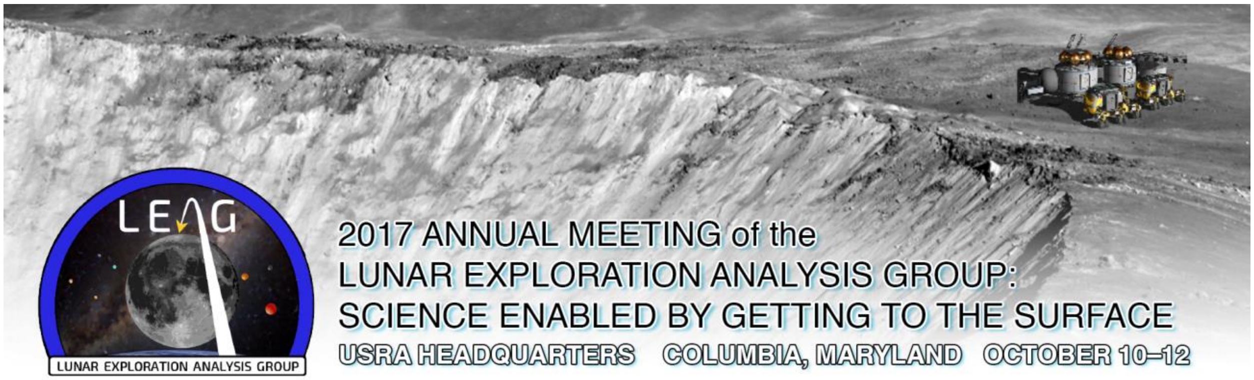

Annual Meeting of the Lunar Exploration Analysis Group

October 10–12, 2017

Meeting Program

LPI

USRA

Annual Meeting of the Lunar Exploration Analysis Group

October 10–12, 2017 • Columbia, Maryland

Institutional Support

NASA Lunar Exploration Analysis Group (LEAG)
Lunar and Planetary Institute (LPI)
Universities Space Research Association (USRA)
National Aeronautics and Space Administration (NASA)
NASA Solar System Exploration Research Virtual Institute (SSERVI)

Organizing Committee

Clive Neal, Convener
University of Notre Dame

Samuel Lawrence, Convener and Program Chair
NASA Johnson Space Center

James Carpenter, *European Space Agency–ESTEC*

Jasper Halekas, *University of Iowa*

Dana Hurley, *Johns Hopkins University/Applied Physics Laboratory*

Kurt Klaus, *Lunar and Planetary Institute*

Stephen Mackwell, *Universities Space Research Association*

Noah Petro, *NASA Goddard Space Flight Center*

Jeffrey Plescia, *Johns Hopkins University/Applied Physics Laboratory*

Louise Prockter, *Lunar and Planetary Institute*

Jerry Sanders, *NASA Johnson Space Center*

Ryan Watkins, *Washington University, St. Louis*

Abstracts for this meeting are available in electronic format via the meeting website at **www.hou.usra.edu/meetings/leag2017/** and can be cited as Author A. B. and Author C. D. (2017) Title of abstract. In *Annual Meeting of the Lunar Exploration Analysis Group,* Abstract #XXXX.
LPI Contribution No. 2041, Lunar and Planetary Institute, Houston.

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The LEAG Bernard Ray Hawke Next Lunar Generation Career Development Awards

Sponsored by:

Recipients

Erica Jawin, *Brown University*

Shuai Li, *University of Hawaii*

Natan Vidra, *Cornell University*

EXHIBITORS

Moon Express, Inc. is a privately funded commercial space company blazing a trail to the Moon to unlock its mysteries and resources beginning with low-cost robotic spacecraft. Driven by long-term goals of exploring and developing lunar resources for the benefit of humanity, the company provides cargo transportation and services to the Moon for private, academic, commercial, and government customers.

Lunar Experiences brings the excitement and wonder of the coming era of lunar exploration via virtual/augmented reality, gaming, and simulations. We will offer cutting-edge virtual reality experiences from lunar missions complemented by a speculative futureverse of games and other media showcasing the lunar technologies of the future. Come see the future of public outreach, education, and engagement made available to anyone with VR and AR and take our "future of VR" survey.

Each of the Apollo lunar landing sites and their predecessor robotic sites are marks of human achievement unparalleled in history. While guidelines to safeguard some of the sites exist, they are not enforceable. Preservation of our common human heritage should not be a choice. **For All Moonkind** is a nonprofit corporation whose mission is to work with the UN to develop a convention to protect all of our human heritage in outer space, starting with the historic lunar landing sites (both human and robotic). As we move into the future, we would do well not to forsake our past.

Technical Guide to Sessions

Tuesday, October 10, 2017

8:30 a.m.	USRA Conference Center	Overview
1:30 p.m.	USRA Conference Center	Ongoing and Proposed Missions
5:30–7:30 p.m.	USRA Education Gallery	Poster Session and Reception

Wednesday, October 11, 2017

8:30 a.m.	USRA Conference Center	Science—Exploration–Commercial Synergies
1:30 p.m.	USRA Conference Center	Resources and the Lunar Economy

Thursday, October 12, 2017

8:30 a.m.	USRA Conference Center	Sample Return and Surface Activities

Program

Tuesday, October 10, 2017
OVERVIEW
8:30 a.m. USRA Conference Center

Chairs: **Samuel Lawrence**
Clive Neal

8:30 a.m. Lawrence S. J. *
Welcome

8:35 a.m. Neal C. R. *
LEAG Update

8:50 a.m. Crusan J. *
Advanced Exploration Systems

9:10 a.m. Williams G. *
HEOMD Update

9:30 a.m. Bussey B. *
ISECG White Paper, KPLO

9:45 a.m. Suzuki N. *
Lunar Volatiles Initiative

10:00 a.m. DISCUSSION

10:15 a.m. BREAK

10:30 a.m. Abbud- Madrid A. *
The 2017 Space Resources Roundtable and New Space Resources Graduate Program at Colorado School of Mines **[#5091]**
For eighteen years, SRR has brought together interested individuals from the space exploration community, the mining and minerals industries, and the financial sector to discuss issues related to the ISRU of lunar, asteroidal, and martian resources.

10:45 a.m. Conley C. *
Planetary Protection and the Moon

11:00 a.m. Ju G. *
Korean Space Program Update

11:15 a.m. Carpenter J. D. *
ESA's Journey to the Moon **[#5009]**
To assure future access to the fundamental capabilities needed to get humans to the Moon in a sustainable way, ESA is developing technologies, planning missions, and building international and public-private partnerships.

11:30 a.m. Hipkin V. J. * Picard M. Haltigin T. Gonthier Y. Lange C. Jean P.
Canadian Space Agency Activities and Science Priorities Related to Lunar Surface Exploration **[#5054]**
Canadian Space Agency activities: Canadian science priorities for lunar surface exploration, rover technology development, mission concept study for rover element of lunar sample return.

11:45 a.m. Wang Q. Xiao L. *
China's Lunar Exploration Programme **[#5092]**
Update on China's lunar program.

12:00 p.m. Masuda K. Sato N.
Japanese Space Program Update **[#5093]**
JAXA's overall Moon exploration scenario, including water utilization.

12:15 p.m. LUNCH

Tuesday, October 10, 2017
ONGOING AND PROPOSED MISSIONS
1:30 p.m. USRA Conference Center

Chairs: **Noah Petro**
Dana Hurley

1:45 p.m. Petro N. E. * Keller J. W.
The Lunar Reconnaissance Orbiter: A Focused Study of Fundamental Solar System Processes at the Moon **[#5045]**
The LRO mission is midway through a two-year extension, to study the fundamental processes recorded on the Moon. LRO's instruments are measuring processes that operate at the Moon and throughout the solar system, especially on airless bodies.

2:00 p.m. Keller J. W. * Petro N. E.
Building on the Cornerstone Mission: Focused LRO Workshops to Support Science Team Synergies **[#5049]**
During the Cornerstone Mission, the LRO instrument teams have identified a number of key science themes that drive their observations during the extended mission. These themes serve as a basis for the identification of the thematic workshops.

2:15 p.m. Blewett D. T. * Hurley D. M. Denevi B. W. Cahill J. T. S. Klima R. L. Plescia J. B. Paranicas C. P. Greenhagen B. T. Tunstel E. W. Anderson B. A. Korth H. Ho G. C. Nunez J. I. Hibbitts C. A. Stanley S. Jozwiak L. Daly T. Johnson J. R. Zimerman M. I. Brandt P. C. Westlake J. H.
Science from the Surface of the Moon: A Rover Traversing a Crustal Magnetic Anomaly **[#5013]**
An *in situ* investigation of a magnetic anomaly would directly address major sets of questions in planetary magnetism, space plasma physics, lunar geology, space weathering, and the lunar water cycle, as well as human exploration SKGs.

2:30 p.m. Kramer G. Y. *
Science Enabled by Getting to a Swirl **[#5027]**
The bright, optically immature, curvilinear, magnomaphile surface features known as lunar swirls should be the target of the next lunar mission.

2:45 p.m. Cohen B. A. *
The Onset of the Cataclysm: In Situ Dating of the Nectaris Basin Impact Melt Sheet **[#5051]**
The impact history of the Moon has significant implications for solar system dynamics and evolution. We are working on a potential Discovery mission concept that would directly constrain the onset of the cataclysm by dating the Nectaris Basin.

3:00 p.m. Anderson F. S. * Levine J. Whitaker T. J.
Pb-Pb Dating for Miller Range 05035, La Paz Icefield 02205, and Northwest Africa 032 Using CODEX **[#5082]**
We have produced new Pb-Pb dates of Miller Range 05035, La Paz Icefield 02205, and Northwest Africa 032 using CODEX, illustrating how *in situ* dating can assess age and isotopic reservoirs.

3:15 p.m. Radebaugh J. Archinal B. * Beyer R. DellaGiustina D. Fassett C. Gaddis L. Hagerty J. Hare T. Laura J. Lawrence S. Mazarico E. Naß A. Patthoff A. Skinner J. Sutton S. Thomson B. J. Williams D.
MAPSIT and a Roadmap for Lunar and Planetary Spatial Data Infrastructure **[#5053]**
We describe MAPSIT, and the development of a roadmap for lunar and planetary SDI, based on previous relevant documents and community input, and consider how to best advance lunar science, exploration, and commercial development.

3:30 p.m. BREAK

3:45 p.m. Clark P. E. * Malphrus B. McElroy D. Schabert J. Wilczewski S. Farrell W. Brambora C. Macdowall R. Folta D. Hurford T. Patel D. Banks S. Reuter D. Brown K. Angkasa K. Tsay M.
Lunar Ice Cube: Development of a Deep Space Cubesat Mission **[#5021]**
Lunar Ice Cube, a 6U deep space cubesat mission, will be deployed by EM1. It will demonstrate cubesat propulsion, the Busek BIT 3 RF Ion engine, and a compact instrument capable of addressing HEOMD Strategic Knowledge Gaps related to lunar volatiles.

4:00 p.m. Hibbitts C. A. * Blewett D. Brandt P. Burke L. Clyde B. Cohen B. Dankanich J. Hurley D. Klima R. Lawrence D. Patterson W. Plescia J. Sunshine J. Westlake J.
The Lunar Water Assessment Transport Evolution and Resource (WATER) Mission Concept Study **[#5031]**
We will describe the Lunar Water Assessment Transport Evolution and Resource mission concept study that is funded under the NASA PSDS3 program.

4:15 p.m. Lucey P. G. * Petro N. E. Hurley D. Farrell W. Sun X. Green R. Greenberger R. Cameron D.
The Lunar Volatiles Orbiter: A Lunar Discovery Mission Concept **[#5048]**
The Lunar Volatiles Orbiter is a discovery-class mission concept which leverages the spacecraft design and operations experience of LRO. LVO is aimed at understanding the current state of volatiles on the Moon with an emphasis on current dynamics.

4:30 p.m. Elphic R. C. * Colaprete A. Andrews D. R.
Resource Prospector, the Decadal Survey, and the Scientific Context for the Exploration of the Moon **[#5076]**
The ISRU-focused Resource Prospector mission will address key questions about lunar polar volatiles set out in the Decadal Survey, as well as goals in the Scientific Context for the Exploration of the Moon.

4:45 p.m. Colaprete A. * Elphic R. Andrews D. Trimble J. Bluethmann B. Quinn J. Chavers G.
Resource Prospector: Evaluating the ISRU Potential of the Lunar Poles **[#5025]**
This talk will provide an overview of the Resource Prospector mission with an emphasis on mission goals and measurements, and will provide an update as to its current status.

5:00 p.m. MacDowall R. J. * Burns J. O.
Science and Antenna Array Trade Studies for Low Frequency Radio Observatories on the Lunar Surface **[#5062]**
A “low-frequency” radio astronomy observatory on the lunar surface would serve to address science goals that cannot be achieved by ground-based observatories. We describe status and plans for such an observatory.

5:15 p.m. DISCUSSION OF PRELIMINARY FINDINGS

Tuesday, October 10, 2017
LEAG ANNUAL MEETING POSTERS
5:30–7:30 p.m. USRA Education Gallery

Gaddis L. R. Boardman J. Malaret E. Besse S. Weller L. Edmundson K. Kirk R. Archinal B. Sides S.
The Status of Restoration of Moon Mineralogy Mapper Data **[#5074]**
We present an update on the status of our geometric and geodetic restoration of the Moon Mineralogy Mapper data.

Nagihara S. Nakamura Y. Williams D. R. Taylor P. T. McLaughlin S. A. Hills H. K. Kiefer W. S. Weber R. C. Dimech J.-L. Phillips D. Nunn C. Schmidt G. K.
Recent Achievement by the SSERVI ALSEP Data Recovery Focus Group **[#5017]**
We report recent research progress made by the SSERVI ALSEP Data Recovery Focus Group.

Horchler A. D. Cunningham C. Jones H. L. Arnett D. Fang E. Amoroso E. Otten N. Kitchell F. Holst I. Rock G. Whittaker W.
Field Test of Route Planning Software for Lunar Polar Missions **[#5041]**
A novel field test paradigm has been developed to demonstrate and validate route planning software in the stark low-angled light and sweeping shadows a rover would experience at the poles of the Moon. Software, ConOps, and test results are presented.

Livengood T. A. Chin G. Mitrofanov I. G. Boynton W. V. Harshman K. P. Litvak M. L. McClanahan T. P. Sagdeev R. Z. Sanin A. B. Starr R. D. Su J. J.
Constructing Lunar Neutron Flux Maps with LRO/LEND Sensor Field of View **[#5078]**
Neutron instrumentation is essential to characterize the quantity and location of hydrogen-rich deposits in lunar regolith as well as iron-group elements. Accurate mapping requires incorporating the spatial resolution of the detection system.

Farrell W. M. Killen R. M. Delory G. T. DREAM2 Team
DREAM2 Studies in Support of Human Exploration of the Moon **[#5036]**
We describe some of the exploration-enabling activities of the DREAM2 team.

Tallaksen A. P. Horchler A. D. Boirum C. Arnett D. Jones H. L. Fang E. Amoroso E. Chomas L. Papincak L. Sapunkov O. B. Whittaker W. L.
CubeRovers for Lunar Exploration **[#5060]**
CubeRover is a 2-kg class of lunar rover that seeks to standardize and democratize surface mobility and science, analogous to CubeSats. This CubeRover will study *in situ* lunar surface trafficability and descent engine blast ejecta phenomena.

Ichikawa R.
ispace and the Lunar Missions Ahead **[#5088]**
The presentation will introduce ispace’s three-step vision beyond GLXP, the technology that ispace is developing for lunar exploration, and opportunities for the scientific community throughout our mission.

Bhaskaran S. Hopkins J. K.
Astrobotic: Peregrine Lunar Lander Technical Program Update **[#5019]**
This paper describes the latest developments in Astrobotic’s lunar lander mission program. Topics addressed here include program updates, technical updates, and a summary of our approach.

Vidra N.
Viability of a Reusable Lunar Lander **[#5004]**
This abstract talks about the viability of a reusable lunar lander and my start-up, Lunar8.

Harris T. H. S.
Transfer and Parse Orbit Momentum Management System Architecture **[#5085]**
Delta V conservative mass transport using orbital tethers at the Moon delivers science and human infrastructure payload mass without need for expendable propulsion as part of the payload platter.

Datta L. V.   Guven U.   Goel E.
A New Approach Towards Deployment of Far Side Lunar SETI Using a Tethered Link to a Near Side Antenna **[#5040]**
Keeping in pace with the recent growth in interest in deployable space telescopes for detection of extrasolar objects, we suggest a feasible approach to make a lunar far side SETI mission a reality with the technology.available today.

Cahan B. B. C.
A Space Commodities Futures Trading Exchange to Grow the Lunar Economy **[#5008]**
This paper proposes to establish a Space Commodities Futures Trading Exchange in order to define and trade essential commodities that, when traded on an open exchange, improve availability, quality, price discovery, financeability, and equal access.

Blair B.   Parr J.   Diamond B.   Pittman B.   Rasky D.
Measuring the Value of AI in Space Science and Exploration **[#5080]**
FDL is tackling knowledge gaps useful to the space program by forming small teams of industrial partners, cutting-edge AI researchers and space science domain experts, and tasking them to solve problems that are important to NASA as well as humanity's future.

Tomic A.   Authier L.   Blanc A.   Foing . H.   Lillo A.   Evellin P.   Kołodziejczyk A.   Heinicke C.   Harasymczuk M.   Chahla C.   Hettrich S.
Growing Plants at a MoonMars Base or/and Dedicated External Space **[#5087]**
We developed an experiment growing plants for the human use, as a food or/and additional oxygen/energy source, that could be adapted on a Moon lander.

Goel E. G.   Guven U. G.
The Future Lunar Flora Colony **[#5016]**
A constructional design for the primary establishment for a lunar colony using the micrometeorite-rich soil is proposed. It highlights the potential of lunar regolith combined with Earth technology for water and oxygen for human outposts on the Moon.

Guven U. G.   Goel E. G.
Interaction of Space Radiation with Agriculture on the Moon **[#5015]**
This paper proposes to understand the effects of GCR and SEP on the plants and agriculture, which is the primary step to colonization at any celestial site. This paper is dedicated to achieve this understanding to aid plantation missions on the Moon.

Poppe A. R.   Farrell W. M.   Halekas J. S.
Charged Particle Weathering Rates at the Moon as Determined from ARTEMIS Observations **[#5007]**
We use a combination of ARTEMIS ion measurements and SRIM simulations to compute the mean ion flux to the Moon and the associated rates of amorphous silicate rim formation on lunar grains. We compare to previous observational and laboratory results.

Hudson D.   De Amici G.
Low-Frequency Moon-Based Radio-Interferometer for Earth Studies **[#5059]**
We suggest that the concept of a Moon-based array of microwave antennas and up-gradable electronics, facing the Earth, to measure soil moisture, sea surface salinity, etc., be matured.

Runyon K. D.
Geological Spacesuit Testing **[#5005]**
Adapting terrestrial field geology techniques for use in a spacesuit is a science-exploration synergistic goal that I am able to support as a qualified spacesuit test subject and geologist.

Authier L.   Blanc A.   Foing B. H.   Lillo A.   Evellin P.   Kołodziejczyk A.   Heinicke C.   Harasymczuk M.   Chahla C.   Tomic A.   Hettrich S.   PMAS Astronauts
MoonMars Astronaut and CapCom Protocols: ESTEC and LunAres PMAS Simulations **[#5071]**
ILEWG developed since 2008 a Mobile Laboratory Habitat (ExoHab) at ESTEC which was tested during a short simulation in July. It was a foretaste of the PMAS mission on 31 July–14 August in LunAres base at Pila, with mission control in Torun, Poland.

McCandless R. S. Burke E. D. McGinley V. T.
Leveraging Virtual Reality for the Benefit of Lunar Exploration **[#5026]**
Virtual reality (VR) and related technologies will assist scientists with lunar exploration and public engagement. We will present the future exponential impact of VR on lunar activities over the coming decades.

Blanc A. Authier L. Foing B. H. Lillo A. Evellin P. Kołodziejczyk A. Heinicke C. Harasymczuk M. Chahla C. Tomic A. Hettrich S.
Logistics for MoonMars Simulation Habitats: ExoHab ESTEC and LunAres Poland **[#5072]**
ILEWG developed within EuroMoonMars research programme since 2008 a Mobile Laboratory Habitat (ExoHab) at ESTEC. Its organization led to logistic concerns our team had to work on. We contributed also to the installation of LunAres in Poland.

Kołodziejczyk A. M. Rudolf A. Gocyła M. Młyńczak M. Wierzejska E. Waśniowski A. Davidova L. Konorski P. Słonina M. Budzyń D. Kuźma J. Ambroszkiewicz G. Harasymczuk M. Foing B. H.
Scientific Outreach of the Lunar Expedition I.0 in the Lunares Habitat in Poland **[#5069]**
Lunares is a chronobiological laboratory to perform advanced studies on humans in controlled MoonMars conditions. Results from The Lunar Expedition I.0 reveal unique properties of the base for future human spaceflight investigation.

Foing B. H. Lillo A. Evellin P. Kołodziejczyk A. Heinicke C. Harasymczuk M. Authier L. Blanc A. Chahla C. Tomic A. Mirino M. Schlacht I. Hettrich S. Pacher T. Maller L. Decadi A. Villa-Massone J. Preusterink J. Neklesa A. Barzilay A. Volkova T.
ILEWG EuroMoonMars Research, Technology, and Field Simulation Campaigns **[#5073]**
ILEWG developed since 2008, "EuroMoonMars" pilot research with a Robotic Test Bench (ExoGeoLab) and a Mobile Laboratory Habitat (ExoHab) at ESTEC. Field campaigns were e.g. in ESTEC, EAC, at Utah MDRS, Eifel, and LunAres base at Pila Poland in 2017.

Evellin P. Foing B. H. Lillo A. Kołodziejczyk A. Authier L. Blanc A. Chahla C. Tomic A.
2017 EuroMoonMars Analog Habitat Preparation at ESTEC **[#5075]**
The 2017 EuroMoonMars analog habitat aims at testing viable concepts of laboratories and habitats to optimize the scientific results of the first crew members of the MoonVillage. The focus is made on developing and testing breakthrough experiments.

Lillo A. Foing B. H. Evellin P. Kołodziejczyk A. Jonglez C. Heinicke C. Harasymczuk M. Authier L. Blanc A. Chahla C. Tomic A. Mirino M. Schlacht I. Hettrich S. Pacher T.
Remote Operation of the ExoGeoLab Lander at ESTEC and Lunares Base **[#5079]**
The ExoGeoLab Lander is a prototype developed to demonstrate joint use of remote operation and EVA astronaut work in analogue lunar environment. It was recently deployed in the new analogue base Lunares in Poland and controlled from ESA ESTEC center.

Neklesa A. Foing B. H. Lillo A. Evellin P. Kołodziejczyk A. Jonglez C. Heinicke C. Harasymczuk M. Authier L. Blanc A. Chahla C. Tomic A. Mirino M. Schlacht I. Hettrich S. Pacher T.
Live from the Moon ExoLab: EuroMoonMars Simulation at ESTEC 2017 **[#5083]**
Space enthusiasts simulated the landing on the Moon having pre-landed Habitat ExoHab, ExoLab 2.0, supported by the control centre on Earth. We give here the first-hand experience from a reporter (A.N.) who joined the space crew.

Snyder K. Amoroso E. Kitchell F. Horchler A. D.
Robust Navigation for Autonomous Exploration of Extreme Environments from a Free-Flying Platform **[#5043]**
Free flying vehicles have the mobility to explore scientifically interesting extreme environments, such as permanently shadowed regions and lava tubes, but require robust and precise navigation to operate safely and autonomously.

Cheetham B. W.
Development of Mission Enabling Infrastructure — Cislunar Autonomous Positioning System (CAPS) **[#5064]**
Advanced Space, LLC is developing the Cislunar Autonomous Positioning System (CAPS), which would provide a scalable and evolvable architecture for navigation to reduce ground congestion and improve operations for missions throughout cislunar space.

Indyk S.   Benaroya H.
Structural Members Produced from Unrefined Lunar Regolith Simulant **[#5032]**
This topic will present data analysis and findings from experimental results from sintered lunar simulant testing for material properties.

Shirley K. A.   Glotch T. D.   Ito G.   Rogers A. D.
Enabling Mid-Infrared Spectral Analysis on the Lunar Surface **[#5033]**
Mid-infrared spectroscopy is a powerful tool in identifying areas of scientific or exploratory interest. Here we demonstrate the necessity of a simulated lunar environment spectral database to be used in conjunction with handheld MIR instruments.

Liu Y.   Retherford K. D.   Greathouse T. K.   Hendrix A. R.   Cahill J. T. S.   Mandt K. E.   Gladstone G. R.   Grava C.   Egan A. F.   Kaufmann D. E.   Pryor W. R.
The Far-UV Wavelength Dependence of the Lunar Phase Curve as Seen by LRO LAMP **[#5038]**
In this study we discuss the Far-UV wavelength dependence of the lunar phase curves for sample mare and highlands as seen by the LAMP instrument, and we report current derived Hapke parameters at far-UV wavelengths for the study areas.

Raut U.   Karnes P. L.   Retherford K. D.   Davis M. W.   Patrick E. L.   Liu Y.   Mokashi P.
Far-Ultraviolet Bidirectional Photometry of Apollo Soil 10084: Laboratory Studies in the Southwest Ultraviolet Reflectance Chamber (SwURC) **[#5050]**
We present new far-ultraviolet bidirectional reflectance spectra of Apollo soil 10084. The FUV spectra this mare soil is featureless, although with a small blue slope. Increased reflectance at high phase imply the grains forward-scatter FUV photons.

Chi P. J.
Magnetic Field Measurements on the Lunar Surface: Lessons Learned from Apollo and Science Enabled by Future Missions **[#5067]**
We discuss the science to be enabled by new magnetometer measurements on the lunar surface, based on results from Apollo and other lunar missions. Also discussed are approaches to deploying magnetometers on the lunar surface with today's technology.

Deitrick S. R.   Lawrence S. J.
Integrating Diverse Datasets to Assess Approaches for Characterizing Mare Basalts **[#5039]**
This research utilizes new LROC data to reevaluate the composition of the mare basalt flows in the Marius Hills Volcanic Complex to provide new insights about the relative ages of the low shields and surrounding flows.

Sehlke A.   Kobs Nawotniak S. E.   Hughes S. S.   Sears D. W.   Downs M. T.   Whittington A. G.   Lim D. S. S.   Heldmann J. L.
The Anatomy of the Blue Dragon: Changes in Lava Flow Morphology and Physical Properties Observed in an Open Channel Lava Flow as a Planetary Analogue **[#5057]**
We present the relationship of lava flow morphology and the physical properties of the rocks based on terrestrial field work, and how this can be applied to infer physical properties of lunar lava flows.

Rader E. L.   Heldmann J. L.
Lunar Volcanic History from In-Situ Morphological Analyses **[#5056]**
We present a new method requiring no sample collection to assess the thermal evolution of lunar volcanic deposits, providing key information on eruptive history of volcanic areas on the Moon.

Curran N. M.   Bower D. M.   Cohen B. A.
Near-Surface Age Distribution of Lunar Impact-Melt Rocks **[#5030]**
Grouping impact-melt rocks from Apollo 16 double-drive tube in preparation for age determination of these samples. The study uses a combination of major-element chemistry, mineralogy, and age to understand impact history of Apollo 16 lunar site.

Bower D. M.   Curran N. M.   Cohen B. A.
Determining the Mineralogy of Lunar Samples Using Micro Raman Spectroscopy: Comparisons Between Polished and Unpolished Samples **[#5047]**
Raman spectroscopy is a versatile non-destructive analytical technique that provides compositional and contextual information for geologic samples, including lunar rocks. We have analyzed a suite of Apollo 16 samples using micro Raman spectroscopy.

Saxena P.   Killen R. M.   Petro N. E.   Airapetian V.   Mandell A. M.
Modeling Sodium Abundance Variations in the Lunar Crust: A Likely Proxy of Past Solar System History and a Potential Guide to Close-In Rocky Exoplanets **[#5034]**
The initial sodium budget of the Moon may have been depleted/transported from the surface post-formation. Abundance variations in crustal samples may be a powerful tool towards exploring conditions on the Moon's surface through solar system history.

Creel R.
Coping with Exposure to Temperature Extremes and Dust for Renewed Lunar Exploration **[#5094]**
Based on thermal experiences during previous Apollo Lunar Roving Vehicle missions, this poster addresses two primary challenges for renewed lunar exploration: coping with lunar temperature extremes and lunar dust.

Wednesday, October 11, 2017
SCIENCE-EXPLORATION-COMMERCIAL SYNERGIES
8:30 a.m. USRA Conference Center

Chairs: **Ryan Watkins**
Georgiana Kramer

8:30 a.m. Sampson M. S. *
Launch Services for the Moon **[#5020]**
One of the next frontiers is the Moon. United Launch Alliance (ULA) has extensive experience with launching delicate, exquisite payloads throughout our solar system, including the Moon. ULA's ACES/XEUS provides lunar surface delivery.

8:45 a.m. Hendrickson D. B. * Thornton J. M.
Astrobotic's Payload Delivery Services Enables Lunar Surface Activities **[#5012]**
This paper describes Astrobotic's lunar payload delivery service, along with the latest program developments toward the company's first demonstration of service.

9:00 a.m. Kitchell J. F. * Horchler A. D. Snyder K. Amoroso E.
Astrobotic Research and Development: New Technology for Lunar Science and Exploration **[#5042]**
Astrobotic will present recent work on a range of space robotics technologies relevant to the lunar science and exploration communities.

9:15 a.m. Spudis P. D. * Richards R. D.
The Robotic Architecture of Moon Express: Exploration, Resources, and Delivery **[#5035]**
Moon Express has recently released a planetary exploration architecture that describes a variety of spacecraft configurations that may be combined and configured to carry out a variety of missions to the Moon and in cislunar and deep space.

9:30 a.m. Zuniga A. F. * Turner M. F. Rasky D. J.
Building an Economical and Sustainable Lunar Infrastructure to Enable Lunar Science and Space Commerce **[#5006]**
A new concept study was initiated to examine and analyze architecture concepts for an economical and sustainable lunar infrastructure system that can extend the life, functionality, and distance traveled of surface mobility missions.

9:45 a.m. Kapoglou A. *
Building the Foundations for a Large-Scale, Cross-Sector Collaboration for a Sustainable and Permanent Return to the Lunar Surface **[#5061]**
This presentation will describe how to build the foundations needed for a large scale, cross-industry collaboration to enable a sustainable and permanent return to the Moon based on system leadership, cross-sector partnership, and inclusive business.

10:00 a.m. BREAK

10:15 a.m. Zacny K. * Indyk S.
Technologies for Lunar Exploration **[#5065]**
Honeybee Robotics, with its partners, developed numerous technologies for lunar exploration. Most of these technologies are at high TRL and have been designed for small landers, rovers, as well as astronauts. This abstract presents several of these technologies.

10:30 a.m. Roux V. G. * Roth M. C.
Developing and Testing Lunar Technologies in a Controlled Simulation Lab Using Simulants Built from the Particle Level Up **[#5029]**
Off Planet Research replicated the natural formation processes on the Moon and then fully characterized regolith formation at the particle level, including agglutinates, so these simulants are very close approximations of true lunar regolith.

10:45 a.m. Pittman R. B. * Rasky D. J.
Commercial Enabled Science **[#5010]**
New commercial space capabilities offer the potential to enable new lunar science and space science missions that can be developed quickly, fly frequently, and at greatly reduced cost.

11:00 a.m. Watkins R. N. * Runyon K. Caswell T. E. Ostrach L. R. Jawin E. R. Meyer H. M. Mitchell J. L.
Strategies for Enabling Lunar Exploration: A NextGen Perspective **[#5003]**
The NextGen is passionate about and committed to continued lunar exploration. Here we outline strategies that NextGen believes are important for enabling future lunar exploration, and what role the NextGen will play in these activities.

11:15 a.m. Green J. *
Planetary Science Division Update

11:35 a.m. DISCUSSION

12:00 p.m. LUNCH

Wednesday, October 11, 2017
RESOURCES AND THE LUNAR ECONOMY
1:30 p.m. USRA Conference Center

Chairs: **Lisa Gaddis**
G. Wesley Patterson

1:30 p.m. Plescia J. B. *
Lunar SKGs: What's Really Needed and What Do We Already Know? **[#5077]**
The distinction between enabling and enhancing SKGs must be maintained. The key unknown is the species, form, and distribution of H in polar regions and it can only be addressed by *in situ* exploration. The commercial role in resource SKGs is unclear.

1:45 p.m. Blair B. *
Modeling PPP Economic Benefits for Lunar ISRU **[#5081]**
A new tool is needed for selecting the PPP strategy that could maximize the rate of lunar commercialization by attracting private capital into the development of critical infrastructure and robust capability. A PPP model under development for NASA-ESO will be described.

2:00 p.m. Greenblatt J. B. *
Quantifying Elements of a Lunar Economy Based on Resource Needs **[#5018]**
We model a simplified lunar economy from human life support, Earth materials consumption, and energy and propulsion requirement estimates, constrained by lunar elemental abundances; estimate likely imports/exports and "gross interplanetary product."

2:15 p.m. Ho K. * Chen H.
Space Transportation Network Analysis for Cislunar Space Economy with Lunar Resources **[#5089]**
This work provides a transportation network analysis of lunar exploration architecture and cislunar mission design with lunar *in situ* resource utilization (ISRU).

2:30 p.m. Schmitt H. H. *
Drilling Regolith: Why Is It So Difficult? **[#5028]**
The Apollo rotary percussive drill system penetrated the lunar regolith with reasonable efficiency; however, extraction of the drill core stem proved to be very difficult on all three missions. Retractable drill stem flutes may solve this problem.

2:45 p.m. Paulsen G. Zacny K. * Kleinhenz J. Smith J. Quinn J. Kim D. Mank Z. Wang A. Thomas T. Hyman C. Mellerowicz B. Yaggi B. Fitzgerald Z. Ridilla A. Atkinson J.
Development and Testing of a Lunar Resource Prospector Drill **[#5066]**
We present update on development and testing of a sampling drill for the Resource Prospector mission.

3:00 p.m. Jordan A. P. * Wilson J. K. Schwadron N. A. Spence H. E.
Synthesizing Surface and Subsurface Measurements of Water Ice in the Polar Regions of the Moon **[#5022]**
Although surface and subsurface data may disagree about the location of water ice near the lunar poles on small scales, we show they are well-correlated on very large scales, with water ice being distributed down to about ±70 degrees latitude.

3:15 p.m. BREAK

3:30 p.m. Cataldo R. L. * Kleinhenz J. E. Sanders G. B.
Technology Demonstration of Extended Operations for Volatile Prospecting and Processing in Lunar Permanently Shadowed Regions Enabled by Advanced Radioisotope Power **[#5063]**
An extended demonstration mission for the purpose of validating advanced radioisotope power system in concert with ISRU systems in a permanently shadowed region.

3:45 p.m. Wilson J. K. * Schwadron N. A. Jordan A. P. Looper M. D. Zeitlin C. Townsend L. W. Spence H. E. Legere J. Bloser P. Farrell W. Hurley D. Petro N. Stubbs T. J. Pieters C.
Diurnal Variation of Lunar Albedo Proton Yield and Hydrogenation **[#5037]**
The quantity of hydrogen or hydrogen-bearing molecules in the top ~10 cm of lunar regolith may vary significantly with local time, according to albedo proton data collected by LRO/CRaTER.

4:00 p.m. Mandt K. E. * Mazarico E. Greathouse T. K. Byron B. Retherford K. D. Gladstone G. R. Liu Y. Hendrix A. R. Hurley D. M. Stickle A. Patterson G. W. Cahill J. Williams J.-P.
LRO-LAMP Observations of Illumination Conditions in the Lunar South Pole Permanently Shaded Regions **[#5023]**
LRO-LAMP is able to observe scattered sunlight within the south pole PSRs. We compare these observations to illumination models and other LRO datasets.

4:15 p.m. Patterson G. W. * Carter L. M. Stickle A. M. Cahill J. T. S. Nolan M. C. Morgan G. A. Schroeder D. M. Mini-RF Team
Mini-RF S- and X-Band Bistatic Radar Observations of the Moon **[#5046]**
Mini-RF is operating in concert with the Arecibo Observatory and the Goldstone DSS-13 antenna to collect bistatic radar data. We will provide an update on science questions being addressed by the Mini-RF team in the current LRO extended mission.

4:30 p.m. Li S. * Lucey P. G. Milliken R. E.
Water in Pyroclastic Deposits and Cold Traps on the Moon: Possible Resources for Future Exploration **[#5055]**
We propose two types of water reservoirs for future exploration of the lunar resources. Both advantages and challenges of exploring the two types of water reservoirs are analyzed.

4:45 p.m. Jawin E. R. * Head J. W. Cannon K. M.
Spectral Unmixing Modeling of the Aristarchus Pyroclastic Deposit: Assessing Eruptive History and Exploration Potential of Glass-Rich Regional Lunar Pyroclastic Deposits **[#5052]**
Spectral modeling of the Aristarchus pyroclastic deposit shows that the Moon's largest explosive volcanic deposit is rich in high-titanium volcanic glass. This lunar pyroclastic deposit is of importance for both scientific and exploration purposes.

5:00 p.m. Kring D. A. *
Conducting Subsurface Surveys for Water Ice Using Ground Penetrating Radar and a Neutron Spectrometer on the Lunar Electric Rover **[#5014]**
Teleoperation of the Lunar Electric Rover can survey large areas of the Moon for subsurface volatile deposits in permanently shadowed regions such as Cabeus and Amundsen craters.

5:15 p.m. DISCUSSION OF PRELIMINARY FINDINGS

Thursday, October 12, 2017
SAMPLE RETURN AND SURFACE ACTIVITIES
8:30 a.m. USRA Conference Center

Chairs: **Kelsey Young**
Kirby Runyon

8:30 a.m. Neal C. R. * Lawrence S. J.
A Moon Sample Return Campaign Will Advance Lunar and Solar System Science and Exploration **[#5068]**
Using private commercial companies to initiate a lunar sample return campaign funded by NASA Planetary Science Division that will advance lunar and solar system science and exploration.

8:45 a.m. Young K. E. * Graff T. G. Bleacher J. E. Coan D. Whelley P. L. Garry W. B. Kruse S. Reagan M. Garrison D. Miller M. Delgado F. Rogers A. D. Glotch T. D. Evans C. A. Naids A. Walker M. Hood A.
Supporting Future Lunar Surface Exploration Through Ongoing Field Activities **[#5011]**
We present results from several ongoing field deployments that are working to explore (1) lunar surface trafficability, (2) radiation shielding, and (3) lunar habitat, life support, and mobility.

9:00 a.m. Heldmann J. L. * Lim D. S. S. Colaprete A. Garry W. B. Hughes S. S. Kobs Nawotniak S. Sehlke A. Neish C. Osinski G. R. Hodges K. Abercromby A. Cohen B. A. Cook A. Elphic R. Mallonee H. Matiella Novak A. Rader E. Sears D. Sears H. Team FINESSE. Team BASALT.
Geologic Exploration Enabled by Optimized Science Operations on the Lunar Surface **[#5024]**
We present detailed geologic field studies that can best be accomplished through *in situ* investigations on the Moon, and the associated recommendations for human and robotic mission capabilities and concepts of operations for lunar surface missions.

9:15 a.m. Kendall J. D. *
Asymmetric Ejecta Emplacement from South Pole-Aitken Basin: 3D Hydrocode Modeling Results **[#5044]**
Using high-resolution 3D impact hydrocodes, we model the ejecta emplacement from the South Pole-Aitken basin-forming impact. We find the Moon's upper mantle material is likely exposed in close proximity to the basin's north rim and farside highlands.

9:30 a.m. Volkova T. V. * Bannova O. K.
Safety and Comfort for Moon and MARS Habitats: Key Design Considerations **[#5086]**
Safety requirements are critical in designing for any extreme environment and especially for habitats in space and on Moon or Mars. But safety alone is not enough when designing for long-term missions in extreme environments on Earth and in space.

9:45 a.m. DISCUSSION

10:00 a.m. BREAK

10:15 a.m. DISCUSSION AND FORMULATION OF FINDINGS

THE 2017 SPACE RESOURCES ROUNDTABLE AND NEW SPACE RESOURCES GRADUATE PROGRAM AT COLORADO SCHOOL OF MINES. A. Abbud-Madrid, Colorado School of Mines, 1310 Maple St., Golden, CO 80401, aabbudma@mines.edu.

For the past eighteen years, the Space Resources Roundtable (SRR) has brought together interested individuals from the space exploration community, the mining and minerals industries, and the financial sector to discuss issues related to the In-Situ Resource Utilization (ISRU) of lunar, asteroidal, and martian resources.

The SRR serves as a communications mechanism between the wide range of people who are and should be involved in a multiplicity of aspects dealing with space resource development. These include fields such as: exploration, mineral extraction, refining, manufacturing, infrastructure development, space transportation, and a host of other technical areas that play an important role in the space resources field. In addition, participation has also included individuals and companies who are developing markets that may be served by space resources products, such as space industrialization, transporation, tourism, space power, and terrestrial uses, as well as from the financial, legal, and entrepreneurial aspects of resource development. In particular, the last five years have seen an increased participation from the private space commercial sector, with companies interested on exploiting the resources from the Moon and asteroids.

In May 2017, the SRR partnered with the Planetary and Terrestrial Mining Sciences Symposium (PTMSS) for the eighth consecutive year and held their joint meeting on May 1-3 in conjunction with the Canadian Institute of Mining (CIM) 2017 Convention in Montreal, Quebec, Canada. A total of 26 papers were presented on a variety of topics, including space mining, resource extraction, construction and fabrication, legal and policy issues, and conducting business in space. This last topic predominently included presentations on business opportunities for robotic exploration, mining, and propellant production on the Moon. The LEAG contributed with a presentation on the economic importance of lunar resources. The Moon was also the focus of other talks on the extraction of lunar volatiles, ISRU manufacturing and fabrication, and regolith processing technologies.

In other developments in space resources, the Colorado School of Mines (CSM) announced a first-of-its-kind graduate program on this field. This multi-disciplinary initiative, which is expected to launch in the Fall of 2018, will offer Post-Baccalaureate certificates and Master of Science and Ph.D. degrees. The proposed program will focus on developing core knowledge and gaining design practices in systems for exploration, extraction, and use of resources in the Solar System. The launch of an educational program of this kind is another indication of the growing interest in this field. This is being driven primarily by an awareness, from space agencies and the private sector, that further development of space travel will be enabled through extraction of materials and production of propellants in space for more affordable and flexible transportation, facilities construction, and life support.

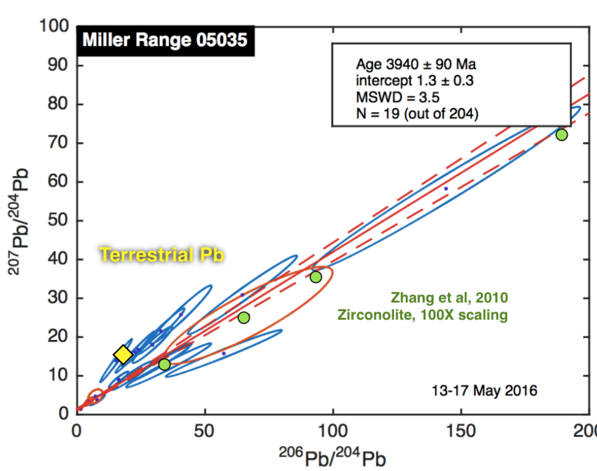
Pb-Pb Dating FOR MILLER RANGE 05035, LA PAZ ICEFIELD 02205, AND NORTHWEST AFRICA 032 USING CODEX. F. S. Anderson[1], J. Levine[2], and T. J. Whitaker[1], [1]Department of Space Operations, Southwest Research Institute, Boulder, Colorado 80303, USA (anderson@boulder.swri.edu), [2]Department of Physics and Astronomy, Colgate University, Hamilton, New York 13346, USA.

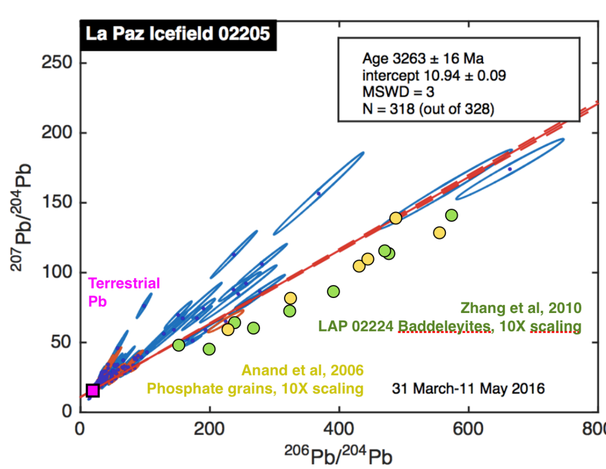
Introduction: Using an instrument called CODEX (Chemistry, Organics, and Dating Experiment) intended for in-situ dating [1-4], we have obtained Pb-Pb dates for Miller Range (MIL) 05035, La Paz Icefield (LAP) 02205, and Northwest Africa (NWA) 032. For MIL 05035 and LAP 02205, CODEX measurements are consistent and concordant with previous measurements, however, NWA 032 appears unusually old. Proposed explanations for this paradox include: a) terrestrial Pb contamination, b) that there are multiple isotopic reservoirs sampled by the impact process, or c) during volcanic emplacement. Using CODEX, we have previously demonstrated Pb-Pb dates for martian meteorites Zagami and NWA 7034, along with Rb-Sr dates for the Boulder Creek Granite, Zagami [5], and the lunar analog Duluth Gabbro. The Pb-Pb measurements of Zagami and NWA 7034, like previous measurements, also illustrate the Pb paradox. We plan to address the interpretational uncertainty caused by the Pb paradox by adding Uranium measurements to the CODEX capability. In the future, we plan to use CODEX to test these hypotheses by making measurements on outcrops in-situ on the Moon and Mars, avoiding terrestrial or impact mixing, and allowing us to assess age and mantle evolution.

Complementary analyses: In our resonance ionization experiments, atoms ablated from the sample surface by a first laser pulse are excited by subsequent pulses of lasers tuned to electronic transitions in the elements of interest, and are finally ionized from the excited states. Turning the post-ablation lasers off altogether converts our instrument into a laser ablation mass spectrometer, and we have used data collected this mode as an aid in identifying the minerals we analyze [6]. Furthermore, tuning the post-ablation lasers to resonantly excite Pb rather than Rb and Sr allows us to gather geochronological data in the Pb-Pb system, which has the advantage that an age may be determined from isotopes of a single element, so that elemental fractionation in our instrument becomes irrelevant. Adding Uranium will allow us to assess the Pb paradox, and more confidently assess whether Rb-Sr, Pb-Pb, and U-Pb dates are concordant, and allow us to provide assessments of the evolution of multiple isotopic reservoirs.

For many planetary specimens, different isotopic systems yield different age estimates [e.g., 9], and each isotopic system provides necessary clues to help interpret the complex geologic history of the specimen. Discrepancies between very old Pb-Pb ages and very young ages from other radioisotopic systems have been previously observed [e.g., 10], and the proposed interpretations have planetary-scale implications for our understanding of geologic history. With all of its complementary modes of analysis, CODEX can assess the composition, chronology, and concordance of contextualized planetary samples collected in situ.

References: [1] F. S. Anderson et al. *LPSC* 1246, 2 (2017); [2] F. S. Anderson et al. *LPSC* 2957, 2 (2017); [3] S. Beck et al., *LPSC,* 3001, 2 (2017); [4] T. J. Whitaker et al. *LPSC* 2328, 2 (2017); [5] F. S. Anderson et al. *RCMS* 29, 191 (2015); [6] S. Foster et al. *LPSC* 47, 2070 (2016); [7]) from Zhang et al, 2010; [8] Anand et al, 2006; [9] D. Papanastassiou et al., LPSC. (1976), vol. 7, pp. 2035-2054.





MOONMARS ASTRONAUT & CAPCOM PROTOCOLS: ESTEC & LUNARES PMAS SIMULATIONS

L. Authier[1,2,4], A. Blanc[1,2,4] , B.H. Foing[1,2,3] , A. Lillo[1,2,4], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Heinicke[2,3], M . Harasymczuk[1,2], C. Chahla[1,2,5], A. Tomic[2], S. Hettrich[6] & PMAS astronauts; [1]ESA/ESTEC & [2]ILEWG (PB 299, NL-2200 AG Noordwijk, Bernard.Foing@esa.int), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] SGAC

Introduction: ILEWG developed since 2008 a Mobile Laboratory Habitat (ExoHab) at ESTEC [1,2]. It was tested as a minimal MoonMars habitat during a short test simulation in July. The simulation was a foretaste of the PMAS mission on 31 July-14 August in LunAres base at Pila [3], with mission control in Torun, Poland. Subsequent LunAres simulation missions Lunex1 on 15-29 Aug 2017 & IcAres in October 2017 will use a mission control from ESTEC.

Protocols simulation: We created various protocols to follow during the ExoHab simulation.

1) We created a voice protocol which aimed to standardize and facilitate communication between the Mission Control and the ExoHab.
2) We created various habitat related protocols: setting up the Habitat communication center, linking the Habitat to sector, shifting the Habitat between work mode and rest mode.
4) We created EVA related protocols: doffing and donning, entering and exiting the Habitat.
5) We created health related protocols: medical check and working out.
6) We uploaded pre-existing protocols for experiments, in particular the handbook of the ExoGeoLander.
7) We wrote a script for the Analog Astronauts to follow during the script. It was thought to test all the possibilities of the habitat.

PMAS CapCom: We have been involved in the PMAS mission as Capsule Communicators (CapCom) in the Mission Controle in Torun, Poland.

Prior-to-the-mission training

As CapComs have a crucial role in the progress of the mission, we had to follow a training program starting 3 weeks before the launch of the mission. It cinsisted in:

1) Getting familiar with the different roles in the Mission Suport
2) Learning the protocols to be used when communicating with the Analog Astronauts
3) Getting familiat with the exeriments to be conducted during the mission.
4) Completing a self-study item.
5) Taking an exam to obtain the CapCom certification.

Role in the Mission Support

CapCom are in charge of communicating with the Habitat. All messages from the Mission Control or from the Principal Investigators (PI) are relayed by our team. We were in charge of communicating the protocols to the crew and make sure they were followed correctly. We were in constant contact with the crew and with the Mission Control and Principal Investigators in order to transmit any questions, answers and/or precisions. As we were the first team to obtain informations from the crew, we acted as a filter to relay the information to the proper team.

Concerning the messages from the Mission Control to the Habitat, we worked with the Flight Director (FD) to select and rephrase the messages.

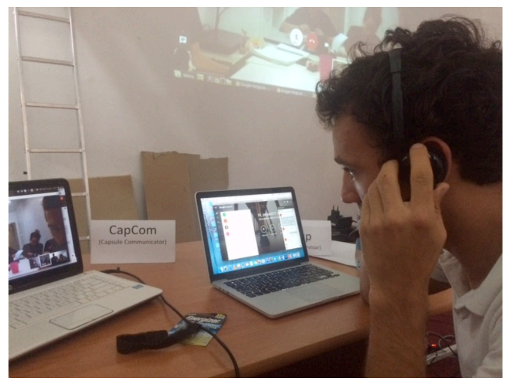


Fig: ILEWG EuroMoonMars trainee Axel Blanc performing a video call from the Mission Control in Torun, Poland with the Analog Astronauts (at LunAres base) during the lunar simulation part of PMAS

Effective communication

We decided to use the *Hangout* chat for written communication with the Habitat. We created a CapCom and a Habitat account. The choice was motivated by the simple use of the software and by the possibility to start video calls. We had a video call with the Habitat every morning and every evening during the Moon simulation, that lasted about half an hour.

Acknowledgements: we thank the LunAres team, PMAS analog astronauts, mission control & support teams, & ILEWG EuroMoonMars programme.

References:

[1] B.Foing et al. Vol. 12, EGU2010-13688, http://meetingorganizer.copernicus.org/EGU2010/EGU2010-13688.pdf;

[2] B.Foing et al Abscicon conference 2010 http://www.lpi.usra.edu/meetings/abscicon2010/pdf/5625.pdf;

[3] http://scienceinpoland.pap.pl/en/news/news,415249,moon-mars-base-lunares-opened-at-the-airport-in-pila-on-saturday.html

ASTROBOTIC: PEREGRINE LUNAR LANDER TECHNICAL PROGRAM UPDATE. S. Bhaskaran[1], J.K. Hopkins[1]. [1]Astrobotic Technology Inc., 2515 Liberty Ave. Pittsburgh, PA 15222, sharad.bhaskaran@astrobotic.com, jeff.hopkins@astrobotic.com.

Introduction: This paper describes the latest developments in Astrobotic's lunar lander mission program. Topics addressed here include program updates, technical updates, and a summary of our approach.

Program Update: Since the last update to LEAG in 2016, Astrobotic has added about 90 years of spaceflight expertise to its team, in the areas of program management, systems engineering, propulsion, GNC and C&DH. The nationwide search for top candidates resulted in key staff positions which now form the nucleus of the Mission Team. The team quickly progressed to a Preliminary Design Review (PDR) in November 2016. Participants in the review included 40 NASA experts representing multiple disciplines and 5 NASA centers; 7 Airbus Defense & Space experts in systems engineering, propulsion and mission design, and 2 Aerojet Rocketdyne propulsion experts. The review comprehensively covered all spacecraft subsystems as well as the mission design. Review feedback was positive – participants recognized the subsystem designs had matured significantly although the design had not closed at the system level. A delta PDR is scheduled for August and September 2017 to demonstrate design closure and compliance with all mission requirements. Again, a large contingent of NASA experts is expected along with the previous Airbus contingent. Joining in the review will be a launch vehicle representative from United Launch Alliance (ULA), building on the recent announcement of the Astrobotic/ULA partnership.

Figure 1: Astrobotic's Peregrine Lunar Lander along with key mission partners.

Following a successful delta PDR, Astrobotic will initiate engineering unit development for component level testing, performance characterization and integrated system testing, and continue refining system design analyses. The schedule moving forward includes key milestones such as a Critical Design Review (CDR), Systems Integration Review (SIR), and Test Readiness Review (TRR). Peregrine will be assembled and integrated at our Pittsburgh facility in a high bay outfitted with a clean room and equipment for component level manufacturing and testing.

Technical Update: A key feature of the ULA partnership is an Atlas V/Centaur launch vehicle offering a higher energy boost to orbit than was previously planned. As a secondary payload aboard Atlas V, Peregrine will benefit from the leftover energy from Centaur's Earth departure burn, which sends Centaur into a hyperbolic disposal orbit. This final burn reduces the delta-V requirement for Peregrine, and decreases the transit time to lunar orbit due to a more favorable direct transfer.

The ULA partnership also includes the development of an expanded payload fairing, increasing Peregrine's axial and lateral growth margins, which increase mass carrying capability and payload volume envelopes. The maximum payload limit on future missions will be achieved with minimal changes to structure, optimization of the performance of the spacecraft's engines, and use of telemetry data from prior missions to optimize spacecraft operations.

Overall, spacecraft design analyses demonstrate all subsystems meet mission requirements with margins of safety consistent with industry standards, and selection of space flight heritage components raised system reliability and increased mission probability of success.

Our Approach: Astrobotic's mission implementation philosophy is derived from government and industry best practices which align with early approaches practiced by the company. Our Guiding Principles consist of strategies which drive tactical implementation across programmatic and technical areas while maintaining an acceptable balance with the company's risk posture. Adherence to these principles enables the team to develop Peregrine as a "Class D", low complexity spacecraft designed with proven spacecraft components, at a fraction of the cost of comparable spacecraft developed by government agencies. We draw on decades of successful spaceflight experience through our partners and suppliers – NASA, Airbus, ULA, Orbital ATK, Honeywell, and the Swedish Space Corporation (SSC) – to design a spacecraft that will have high reliability and high probability of mission success. Repeatability and standardization of payload allocations and interfaces will optimize our payload services offering for future missions.

MODELING PUBLIC PRIVATE PARTNERSHIP ECONOMIC BENEFITS FOR LUNAR ISRU.

B. Blair[1], [1]NewSpace Analytics, Canterbury, New Hampshire, planetminer@gmail.com.

Introduction: The NASA Emerging Space Office (ESO) recently selected a proposal entitled "PPP framework for multi-commodity lunar ISRU" for award under NRA Solicitation NNA15ZBP0001N-B1. The current status of this lunar economic ISRU modeling effort will be presented. Elements of the Public Private Partnership modeling layer will be emphasized, with solicitation of input by the LEAG community.

Relevance to NASA: A robust, private sector, commercial lunar ecosystem will prove invaluable to NASA, provisioning propellant, life support consumables and other materials to NASA as one customer among many. This would increase the robustness of NASA‟s human space exploration missions by providing sustainable, affordable, complementary options that reduce NASA‟s science and spaceflight costs. A commercial-off-the-shelf approach could also lower the risk of NASA program failure and/or requirements creep that typically accompanies cyclical regime change – which is especially troubling for long duration programs (indeed, a lack of fully considering economic factors may be the leading cause of agency regime change).

Public Private Partnerships: A rich set of potential public-private partnership (PPP) tools are available to government. A new tool is needed for selecting the PPP strategy that could maximize the rate of lunar commercialization by attracting private capital into the development of critical infrastructure and robust capability. A successful lunar industrial development program would be good for the country, offering a path to revitalize the US economy by opening up whole new worlds of resources while increasing national employment in aerospace and other high technology sectors.

Project Objectives: The primary objective of this work will be quantitative evaluation of PPP scenarios. This will be done by combining previously developed technical and economic model elements that have been used to simulate various aspects of lunar resource development. Multi commodity ISRU supply (i.e., an aggregate production function) is envisioned that will be combined with a previously developed multi-year Earth-Mars demand forecast as a framework for PPP comparison and scenario analysis.

Modeling Lunar Commercialization: The proposed work would estimate the effect of both supply and demand side stimulation through PPP scenarios, providing a quantitative estimate of the degree of acceleration and/or risk reduction in the emergence of commercial lunar enterprise. This work will also draw upon comparisons to terrestrial mining activities, where byproducts often generate more operating profit than the primary commodity produced. A secondary objective of the proposed work will examine lunar resource byproduct scenarios that may be synergetic or of low incremental cost to obtain high economic benefit. This secondary activity could also create a tool that could facilitate steering near-term prospecting and ISRU technology demonstration missions toward commercially useful results.

References:

[1] Cheuvront, D. (2005) "An Evolvable Approach to Launch Vehicles for Exploration," *AIAA-2005-2603*, http://arc.aiaa.org/doi/abs/10.2514/6.2005-2603. [2] Miller, C., Wilhite, A., Cheuvront, D., Kelso, R., McCurdy, H., Zapata, E. (2015) "Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture that Leverages Commercial Space Capabilities and Public-Private-Partnerships", *NASA Emerging Space Office contract number 14-ECON14–0015*, www.nss.org/docs/EvolvableLunarArchitecture.pdf. [3] Dana M. Hurley, D.M. (2016) "Lunar Polar Volatiles: Assessment of Existing Observations for Exploration", *Presentation to NASA HQ, September 2016*, https://ssed.gsfc.nasa.gov/dream/docs/Polar-Volatiles_HEOMD_Hurley.pdf. [4] Blair, B., (2009) "Quantitative Approaches to Lunar Economic Modeling," *2009 Annual Meeting of LEAG*, http://www.lpi.usra.edu/meetings/leag2009/presentations/Day-1%20PM/02-15_Blair.pdf. [5] Baiden, G., Blair, B. and McKean, M. (2009) SMART STEPS For Canada: Socio-Economic Benefits for Canadians Associated With Mining Expertise for Lunar Outpost Infrastructure Development, *Canadian Space Agency, Contract#9F025-071634/001/SR*, http://enu.kz/repository/2010/AIAA-2010-1548.pdf. [6] Blair, B., Diaz, J., Duke, M., Lamassoure, E., Easter, R., Oderman, M., and Vaucher, M. (2002) Space Resource Economic Analysis Toolkit: The Case for Commercial Lunar Ice Mining, *NASA Exploration Team Contract #1237006*, http://www.isruinfo.com//docs/LDEM_Draft4-updated.pdf.

MEASURING THE VALUE OF AI IN SPACE SCIENCE AND EXPLORATION. B. Blair[1], J. Parr[2], B. Diamond[3], B. Pittman[4] and D. Rasky[4], [1]NewSpace Analytics, Canterbury, New Hampshire, planetminer@gmail.com, [2]NASA Frontier Development Laboratory, Mountain View, California, james@frontierdevelopmentlab.org, [3]SETI Institute, Mountain View, California, [4]Space Portal, NASA Ames Research Center, Moffett Field, California.

Introduction: The Frontier Development Laboratory (FDL) is a hands-on Artificial Intelligence (AI) accelerator that is taking an experimental approach to matching the enormous potential of AI and emerging deep data technology to NASA applications including lunar and planetary science. FDL is tackling knowledge gaps useful to the space program by forming small teams of industrial partners, cutting-edge AI researchers and space science domain experts and tasking them to solve problems that are important to NASA as well as humanity's future.

Partnership with AI Industry: The FDL program is fast-paced, embraces taking risks and trying out emerging cutting-edge AI and deep data tools provided by our industry partners. Corporate sponsors for the 2017 summer program include Nvidia, Intel, IBM, KX, Autodesk and Space Resources Luxembourg, and the research teams this year are hosted by the SETI Institute - located in the heart of Silion Valley.

2017 Program Overview: This year's program organized five research teams that focused on AI-based science opportunities within the fields of Planetary Defense, Space Resources, and Space Weather. The 2017 summer program was an 8-week concentrated R&D deep-dive process that incorporates the latest developments in artificial intelligence and deep neural networks with daily updates on cutting-edge academic research as well as detailed industry partner case studies.

Space Applications of AI: Artificial Intelligence (AI) can help to close key NASA knowledge gaps, but can also shine a light on how developments in the private sector can directly contribute to tackling unresolved challenges in the planetary sciences. Two prior FDL sessions have demonstrated that meaningful progress could be industrialized by bringing together individuals at the doctorate and post doctorate level together to work on connected, but adjacent problems in a shared space mentored by senior scientists with a deep knowledge of the problems. AI is an emergent technology with widespread industrial applications that is generating new tools for making sense of unknowns. Use of AI can help NASA examine unstructured data from multiple sources and wavelengths, and revealing scientific detail as well as informing decisions the moment new discoveries are made.

LOGISTICS FOR MOONMARS SIMULATION HABITATS: EXOHAB ESTEC AND LUNARES POLAND.,

A. Blanc[1,2,4] , L. Authier[1,2,4,] B.H. Foing[1,2,3] , A. Lillo[1,2,4], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Heinicke[2,3], M . Harasymczuk[1,2], C. Chahla[1,2,5], A. Tomic[2], S. Hettrich[6], [1]ESA/ESTEC & [2]ILEWG (PB 299, 2200 AG Noordwijk, NL, Bernard.Foing@esa.int), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] SGAC

Introduction: ILEWG developed within EuroMoonMars research programme since 2008 a Mobile Laboratory Habitat (ExoHab) at ESTEC. Its organization led to logistic concerns our team had to work on. EuroMoonMars 2017 contributed also to the installation of LunAres Analog Reseaech Station in Poland.

Organisation of the ExoHab @ ESTEC:
As a multi-purpose moon habitat, the ExoHab works as a geological laboratory, a communication center and a resting place for the crew.

The ExoHab's compartmentalization

When designing its interior, we had to compartmentalize the space to make it easy to use and efficient. Some places in the ExoHab were well defined (sleeping quarters), we had to organize the rest of the Habitat.
We decided to implement two working zones, one being used as a communication center, the other being separated from the rest of the ExoHab and therefore quiet. The bathroom would be used as an airlock due to its limited and confined space. The working plan would be used as a laboratory, where instruments for sample analysis, microscopes and probes were installed.

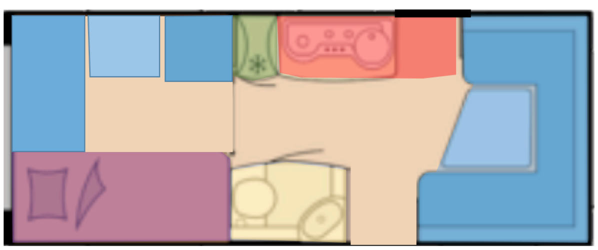


Fig 1: Map of the interior of the ExoHab in work mode. In Blue: working zones (desks). In red: laboratory zones (geology). In green: EVA wardrobe. In yellow: airlock. In purple: sleeping quarters.

The ExoHabs's inventory

In order to ease the work of the astronauts, an inventory of the ExoHab was made. It consisted in:
1) A brief description of every object that could be found in the ExoHab
2) A precise description of the object's location
4) An entry to update its location if the object was to be moved
5) An entry for the object's state
Doing the inventory was also useful to clean the ExoHab and getting rid of overused and/or useless items.

Poland logistics and LunAres Habitat: We have worked on the final installation of building of the Lunares habitat in Pila, Poland for five days.

Travel logistics

We transported some of the ESTEC furniture for its habitat to use them in the Lunares habitat, in order to have them used by Analog Astronauts in longer simulations. They will stay in the Lunares Habitat until the end of October 2017. We also brought the ILEWG ExoGeoLab Lander to be used as an experiment bench during the PMAS , Lunex1 astronaut missions.
Transporting the material required a logistic investment. We used a van and had to organize it efficiently in order to fit the luggage of 5 crew, the Lander and a dozen crates of lab furniture elements.

Installing the LunAres Habitat

We were in Pila as helpers for the working team. We worked on various tasks in and out of the habitat, e.g.:
1) enhancing the outer appearance by hanging posters and cleaning the walls.
2) ensuring the dome was waterproof by applying silicone and tape.
3) installing the laboratories, and adding our furniture.

Fig 2: Lunares Habitat during the day in Pila, Poland.

Acknowledgements: we thank ILEWG EuroMoonMars programme & the LunAres team.

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SCIENCE FROM THE SURFACE OF THE MOON: A ROVER TRAVERSING A CRUSTAL MAGNETIC ANOMALY.
David T. Blewett[1], Dana M. Hurley[1], Brett W. Denevi[1], Joshua T.S. Cahill[1], Rachel L. Klima[1], Jeffrey B. Plescia[1], Christopher P. Paranicas[1], Benjamin T. Greenhagen[1], Edward W. Tunstel, Brian A. Anderson[1], Haje Korth[1], George C. Ho[1], Jorge I. Núñez[1], Charles A. Hibbitts[1], Sabine Stanley[1], Lauren Jozwiak[1], Terik Daly[1], Jeffrey R. Johnson[1], Michael I. Zimmerman[1], Pontus C. Brandt[1], and Joseph H. Westlake[1]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, Md., USA. (david.blewett@jhuapl.edu).

Introduction: The Moon does not presently possess a global, internally generated magnetic field, but the lunar crust contains areas of magnetized rocks ("magnetic anomalies"). Understanding the origin of the anomalies will shed light on major planetary processes. In addition, the anomalies provide a natural laboratory for investigating the interaction of the solar wind with the surfaces of airless silicate bodies. The magnetic fields produce "mini-magnetospheres" that have been detected through analysis of the flux of neutral atoms, electrons, and solar-wind protons.

There are multiple hypotheses for the origin of the magnetic anomalies. Remnant magnetization of basin ejecta or igneous intrusions may be the source of some anomalies. Another hypothesis contends that the anomalies were created by plasma interactions during impact of a cometary coma with the lunar surface.

The crustal magnetic anomalies are often correlated with unusual, sinuous, high-reflectance markings called lunar swirls. There are several hypotheses for the origin of the swirls. One states that the magnetic anomaly limits the flux of solar wind particles that reach the surface, inhibiting normal soil darkening process (space weathering) to which unshielded areas are subjected. Others suggest that impact of a cometary nucleus/coma or meteoroid swarm could disturb the surface to produce the bright swirl markings by changing the structure and particle-size distribution of the uppermost regolith. Alternatively, the magnetic field could alter the trajectories of levitated, charged dust leading to accumulation of high-reflectance dust in the swirls or disturbance of the uppermost regolith structure and thus produce high reflectance.

An in situ investigation of magnetic anomaly regions would directly address at least five major sets of questions in planetary science:

(a) *Planetary magnetism*: What is the origin of the magnetized material? What is the source depth: surficial (comet impact), or deep (magnetized intrusion or basin ejecta)? What are the implications for an ancient dynamo? (b) *Space plasma physics*: What are the fluxes of the particles that actually reach the surface within the magnetic anomaly by energy and species? How does the anomaly interact with the incident plasma to form a standoff region? How does the solar wind/magnetic field/surface interaction change with time of lunar day? (c) *Lunar geology*: What are the nature and origin of lunar swirls? Are swirls ancient or recent? Has levitated dust or cometary material modified the surface? (d) *Space weathering*: Space weathering alters the optical and chemical properties of airless surfaces across the Solar System. What is the relative importance of ion vs. micrometeoroid bombardment and what roles do these agents play in modifying the surface? Lunar magnetic anomalies offer some control on one of the key variables, solar wind exposure. (e) *Lunar water cycle*: How does the OH-H_2O feature at ~2.8 μm vary across spatially and with field strength?

In addition, measurements within a magnetic anomaly could help to address Strategic Knowledge Gaps (SKGs) for human activities on the Moon. SKG Themes include: Theme I, Resource Potential: I-D, temporal variability and movement dynamics of surface-correlated OH and H_2O. Theme II, Lunar Environment: II-B, radiation at the lunar surface. Theme III, Living and Working on the Lunar Surface: III-B-1, lunar geodetic control. III-C-2, lunar surface trafficability. III-E, near-surface plasma environment.

A Rover Mission: A rover traversing one or more of the major magnetic anomalies could provide answers to the important questions listed above. We have named our rover mission concept *Lunar Compass*.

Baseline payload instruments include a vector magnetometer to map the intensity and direction of the local field, allowing the depth of the source to be defined. A solar wind spectrometer (p^+, e^-, α) will directly measure the flux reaching the surface. Mast-mounted instruments include a stereo color imager and a VNIR spot spectrometer for mineralogy and detection of adsorbed OH/H_2O. An arm would carry a microscopic spectral imager to provide particle size distribution, regolith texture, and spectral-compositional properties.

Payload enhancements might include: an XRF/XRD or APXS to determine elemental abundance; a Mössbauer spectrometer to measure soil nanophase iron content; a traverse gravimeter to detect subsurface density variations that could correlate with the magnetized body; a detector for slow-moving dust; and an electric-field meter to assess the role of E-fields in plasma interactions and dust motion.

DETERMINIG THE MINERALOGY OF LUNAR SAMPLES USING MICRO RAMAN SPECTROSCOPY: COMPARISONS BETWEEN POLISHED AND UNPOLISHED SAMPLES. D. M. Bower[1,2], N. M. Curran[1,3] and B. A. Cohen[1], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, dina.m.bower@nasa.gov; [2] Department of Astronomy, University of Maryland, College Park MD, [3] NASA Postdoctoral Program.

Introduction: Raman spectroscopy is a powerful and versatile non-destructive analytical technique that provides compositional and contextual information on mineral phases for a wide variety of geologic samples including lunar rocks [1,2]. Raman istruments have been developed for upcoming planetary missions, and similar instrumentation could be beneficial for the characterization of lunar materials on future lander or for sample return missions [3]. Portable Raman spectrometers can measure mineralogy in situ in a variety of environments, but topographic inconcistencies in natural, unpolished samples still remain problematic. This can make the absolute identification of specific mineral phases difficult. Lunar rocks are composed of a limited suite of minerals, and being able to detect the subtle differences between mineral phases is essential in understaning their origins.

Samples: We have analyzed a suite of Apollo 16 samples from the double drive tube 68001/68002 using micro Raman spectroscopy. Raman spectra were collected from individual polished and unpolished grains using a WITec α-Scanning Near-Field optical microscope that has been customized to incorporate confocal Raman imaging with a 532 nm frequency-doubled solid state laser operating between 0.3 – 1mW power.

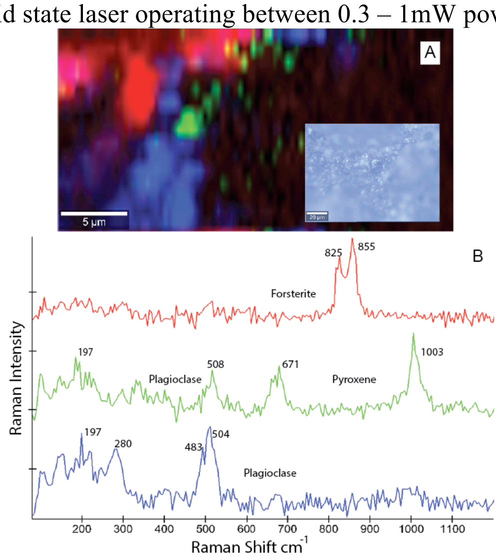

Fig. 1 Raman spectral map and inset image of unpolished grain 68002 1079 (A) and corresponding spectra (B) from unpolished sample grain showing forsterite (red), pyroxene + plagioclase (green), and plagioclase (blue).

Preliminary Results: Comparisons of the scans show we can identify three main phases regardless of polishing: plagioclase (peaks at 197, 283, 483, and 504 cm^{-1}), pyroxene (peaks at 671 and 1003 cm^{-1}), and olivine (forsterite - peaks at 825 and 855 cm^{-1}) (Fig.1). In the polished grains we were able to determine the specific mineral orthopyroxene (peaks at 330, 394, 667, and 1002 cm^{-1}) (Fig.2).

Ongoing Work: As resolution improves, we will be able to extract Fo-Fa compositions and determine specific plagioclase compositions and pyroxene structural types based on subtle shifts in frequencies and the expression of peak doublets. These spectral parameters can be indicators of petrogenic processes and provenance [1, 4, 5]. We are currently adapting a new device to our Raman system that allows us to map the topography of rough surfaces (True Surface ™) and apply the topographic information to the focusing mechanism of the microscope. The system can then adjust the focus the laser on the sample as the topography changes so there is less scatter and a better signal. The goal ultimately is to correlate the compositions and ages of lunar rocks to understand the impact history of the Earth-Moon system.

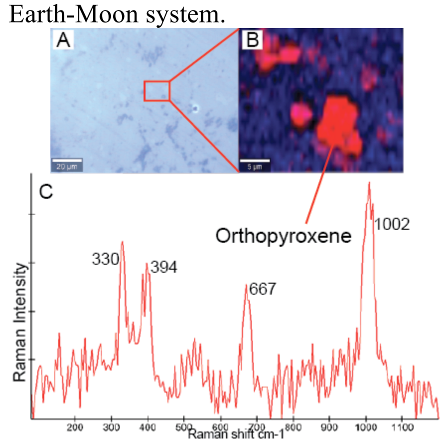

Fig. 2 Example of polished grain with scan area outlined in red box (A), Raman spectral map showing plagioclase (blue) and orthopyroxene (red) (B), and corresponding orthopyroxene spectra including two peaks (330 and 394 cm^{-1}) that were not resolved with the unpolished sample shown in Fig 1.

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Paper Proposal - 2017 Annual Meeting of the Lunar Exploration Analysis Group

Author: Bruce B. Cahan bcahan@urbanlogic.org

Abstract
The lunar economy will supply and demand a diverse range of physical, virtual and financial products and services. A basic subset of these can be standardized as commodities and traded on an exchange to improve availability, quality, price discovery.

Background
Establishing a “space economy” on the lunar surface and in lunar orbit will require a consistency of supply of commodities such as water, oxygen, electricity, telecommunications bandwidth, launch and transport services, food and other natural or synthetic substances that can be consumed or serve as raw materials for ongoing operations and human exploration.

On Earth, commodities markets exist in order to smooth the levels of supply and demand, and to improve the quality and variety of standardized commodities that thriving economic activity requires. Commodities markets operating through regulated exchanges provide commodity sellers and buyers assurance that contracts for future delivery of the commodity will be performed, and allow for the holders of such contracts to sell the contractual rights or to diversity investment in a portfolio of related commodities.

Bold Idea
Given the risk of lunar exploration and its long timeframe for realizing revenues, a Lunar Commodities Futures Trading Exchange (the Exchange) is proposed and described.

The Exchange will permit the lunar economy to dynamically see futures contracts, adding market efficiency and transparency to moderate under-/over-investment and supply of a basket of lunar commodities. The Exchange will support creation of financial derivatives that serve to transfer technology and other risks, and thereby supplement self-insurance and third-party insurance strategies.

Ultimately, the Exchange will allow for a new cohort of investors to hold financial assets that support directly or derivatively a healthy lunar economy.

ESA'S JOURNEY TO THE MOON. J.D. Carpenter[1] for the Directorate of Human Spaceflight and Robotic Exploration, ESA, ESTEC, Noordwijk, The Netherlands (james.carpenter@esa.int).

Moon is the next destination: For ESA the Moon is the next destination for human exploration after Low Earth Orbit, where we have learned to work and operate over decades [1]. ESA is now preparing for a return to the Moon for humans. This new era of lunar exploration must be achieved in a sustainable way that delivers benefits to all of humanity. To do this some fundamental capabilities must be established and delivered through partnerships.

The role of in situ resources: While not on the critical path of a human lunar returnin In Situ Resource Utilisaiton is an important capability. Establishing ISRU as a capability for the future requires; 1) prospecting of deposits, 2) technology demonstration, 3) an ISRU pilot plant, 4) full implementation [3]. Through the missions in ESA's exploration roadmap and coordination with partners these steps are being addressed.

Missions: *Prospecting resources.* PROSPECT is package to assess the resource potential of lunar regolith at any given surface location [4]. It heats samples, thermochemically extracts volatiles and analyses them. It can be used to quantify water ice deposits as well as water and oxygen extraction processes from other regolith sources. PROSPECT is in development for first flight on the Rusian led Luna-27 mission in 2022, along with the PILOT precision landing and hazard avoidance system. ESA is coordinating lunar mission plans with other agencies.

Commercial partnerships. ESA is in a pilot phase with two commercial partners for lunar misisons. These commercially driven missions seek to establish robotic surface access, led by the Part Time Scientists [5], and produce a commercial lunar cubesat deployment and communication relay service at the Moon, led by SSTL and Goonhilly Earth Station [6].

Lunar vicinity as a staging post. ESA is providing the European Service Module [7] for NASA's Orion vehicle, to take humans to lunar vicinity. Once there human explorers will crew the Deep Space Gateway [8], humanity's first spaceship, which is currently in preparation by the agencies of the ISS partnership. This craft could be an enabling infrastructure for sustainable lunar surface access.

Demonstrating in situ resource utilization. ESA is targeting a commercially enabled ISRU demonstration mission not later than 2025. This mission would procure commercial access to the lunar surface and communication services to operate an ISRU demonstration payload. The goal of the mission is to demonstrate the production of drinkable water or breathable oxygen at the lunar surface to prepare for a future pilot plant, implemented in the early human missions.

Human surface exploration demonstration mission: In collaboration with CSA, and JAXA, ESA is studying the HERACLES mission (e.g. [9]), which would use the Deep Space Gateway to teleoperate a rover at the lunar surface, retrieve samples and return them to Earth using Orion via the Deep Space Gateway. NASA supports the study in the interfaces with the Gateway and Orion. The mission would de-risk technologies and prepare for the later human missions. A notional traverse, studied in the preliminary mission studies, would be in the Schroedinger basin [10].

The human mission point of departure. In the context of the International Space Exploration Group (ISECG) [11] a notional scenario for human exploration missions is under discussion. This point of departure is used as a means to coordinate strategic planning and identify potential roles and investments. This scenario includes 5 missions and the first long duration human lunar surface mission (~42 days) with long-range mobility and night operations. This would include the demonstration of re-usability (ascender, pressurized rover) and would offer unprecedented opportunities for science and applications.

Summary: ESA is preparing for the new exploration of the Moon, which will be achieved through agency programmes, international partnerships and new roles for the private sector. Driven by the missions in the ESA mission roadmap ESA is working to assure access to the capabilities needed for lunar explorations. This is achieved through technology development, development of flight systems and the establishment of partnerships with international partnerships and the commercial sector.

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Technology Demonstration of Extended Operations for Volatile Prospecting and Processing in Lunar Permanently Shadowed Regions Enabled by Advanced Radioisotope Power

Robert L. Cataldo, Julie E. Kleinhenz[1], Gerald B. Sanders[2], Kris Zacny[3] and Dan Hendrickson[4]

[1]NASA Glenn Research Center, Cleveland, OH 44135, [2]NASA Johnson Space Center, Houston, TX 77058, [3]Honeybee Robotics Spacecraft Mechanisms Corporation, Pasadena, CA 91103, [4]Astrobotic Technology Inc., Pittsburgh, PA 15222

The adoption of in-situ resource utilization (ISRU) for exploration missions requires robust and long-lived hardware. The Lunar Crater Observation and Sensing Satellite (LCROSS) and Lunar Reconnaissance Orbiter (LRO) missions proved the existence of water in the moon's polar regions. The absence of sunlight in these regions poses a significant challenge for solar/battery systems to perform extensive exploration, prospecting and collection of subsurface water/volatiles and deliver to an ISRU plant. Demonstrating long-term durability of the required systems in a relevant environment on Earth would be a major undertaking. The application of a radioisotope power system (RPS) would enable the demonstration of these technologies in a lunar crater environment. This proposed technology demonstration would include an advanced RPS capable of producing higher electrical power levels than current state-of-the-art and additionally provide heat required for ISRU prospecting and collection processes and also help maintain thermal management for rover/lander systems in the harsh crater environment. A framework for a combined RPS and ISRU technology demonstration will be developed based on the predicted power and energy requirements for volatile extraction while situated within a lunar polar region. The ratio of heat to electricity requirements would be determined to optimize the entire system. A concept of operations analysis will determine the feasibility of such a technology demonstration.

DEVELOPMENT OF MISSION ENABLING INFRASTRUCTURE – CISLUNAR AUTONOMOUS POSITIONING SYSTEM. B. W. Cheetham, CEO/President, Advanced Space, LLC. 2100 Central Ave Suite 102 Boulder CO 80301. cheetham@advancedspace.com

Introduction: As commercial and government mission plans continue to increase in both number and technical maturity, the challenges of operating this fleet of spacecraft throughout cislunar space are coming into focus. Existing ground networks are already stressed and congestion for navigation and data return are increasingly impacting mission operations and planning. Working with NASA's Goddard Space Flight Center, Advanced Space, LLC is developing the Cislunar Autonomous Positioning System (CAPS) which would provide a scalable and evolvable architecture for navigation that has the potential to reduce ground congestion while also providing more frequent and accurate navigation solutions for missions throughout cislunar space.

This program is part of broader development efforts by Advanced Space and others to improve the tools available to support mission planning and operations. In order to realize a future with robust and extensive lunar exploration, development, and settlement, significant improvements must be made in the cost and complexity of mission design, navigation, and overall spacecraft operations.

Technical Summary: The Cislunar Autonomous Positioning System (CAPS) builds on over a decade of research from academia and NASA in autonomous navigation algorithms specifically for dynamic environments such as cislunar space. These algorithms serve as the foundation for a system that can autonomously provide absolute navigation solutions for two spacecraft without ground involvement. This fundamental attribute of the system, complimented by ground tracking, results in a highly responsive navigation architecture that has the potential to reduce ongoing operational costs and ground station congestion. Furthermore, CAPS is being designed to minimize the dedicated space assets required. Similar to communication radio standardization at Mars, CAPS would utilize future mission users as additional nodes in the network so that the system scales organically as the number of participating missions increases.

The fundamental algorithms that enable CAPS have been documented in numerous papers [1][2]. Notably CAPS will support missions orbiting the Earth-Moon Libration (Lagrange) points, orbiting the Moon, traversing space between the Earth and the Moon including low energy transfers (such as GRAIL), as well as lunar surface operations.

Objectives: The proposed talk would be focused on further detailing the opportunity for CAPS to support missions currently in development. It would also seek to spark follow-on discussions related to how technology and process innovations such as CAPS can improve the viability of lunar missions under consideration by both commercial and government entities. Additional discussion may include ongoing developments in mission design, navigation, and control such as those recently proposed by Advanced Space to fly a lunar orbiter that operated continuously below 10 km altitude.

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Additional Information: Advanced Space is developing CAPS under an SBIR with NASA's Goddard Space Flight Center. NASA does not endorse any of the results or projections presented here. Prior technical development of the enabling algorithms has been conducted primarily by the University of Colorado at Boulder. More information about Advanced Space can be found online at www.AdvancedSpace.com

MAGNETIC FIELD MEASUREMENTS ON THE LUNAR SURFACE: LESSONS LEARNED FROM APOLLO AND SCIENCE ENABLED BY FUTURE MISSIONS. P. J. Chi[1], [1]Department of Earth, Planetary and Space Sciences, University of California, Los Angeles, California; pchi@igpp.ucla.edu.

Different from the magnetic field measurements by orbiting spacecraft, magnetometers on the lunar surface can measure at fixed locations on the lunar surface, avoiding the spatiotemporal ambiguity intrinsic to spacecraft observations. The magnetic field measurements on the lunar surface can provide useful information for magnetic sounding of the lunar interior, the electromagnetic waves associated with Moon-plasma interactions, and the space weather environment that can aid the planning of future manned operation on the Moon. The only surface magnetic field measurements made so far are those provided by the U.S. Apollo missions and the Soviet Luna missions in the late-1960s and 1970s, and only the Lunar Surface Magnetometer (LSM) data from the Apollo 12, 15, and 16 missions have been restored for investigations today. This study summarizes the scientific research based on Apollo LSM measurements to shed light on the scientific investigations that can be made by future lunar surface missions, such as the International Lunar Network. Also discussed are approaches to deploying magnetometers on the lunar surface by small landers or impactors.

Lunar Ice Cube: Development of a deep space cubesat mission. Pamela E. Clark[1], Ben Malphrus[2], David McElroy[2], Jacob Schabert[2], Sarah Wilczewski[2], Kevin Brown[2], Robert MacDowall[3], David Folta[3], Terry Hurford[3], Cliff Brambora[3], Deepak Patel[3], Stuart Banks[3], William Farrell[3], Dennis Reuter[3], Michael Tsay[4], Kris Angkasa[1], [1]Jet Propulsion Laboratory, California Institute of Technology (pamela.e.clark@jpl.nasa.gov), [2]Morehead State University, [3]NASA/GSFC, [4]Busek.

Overview: Lunar Ice Cube, a 6U cubesat mission designed for deep space, will be deployed in cis-lunar space by NASA's EM1 mission. Lunar Ice Cube was selected by the NASA HEOMD NextSTEP program to demonstrate cubesat propulsion, via the Busek BIT 3 RF Ion engine, and to demonstrate a cubesat-scale instrument capable of addressing NASA HEOMD Strategic Knowledge Gaps related to lunar volatile distribution (abundance, location, and transportation physics of water ice). We will also demonstrate for the first time in deep space an inexpensive radiation-tolerant flight computer (Space Micro Proton 400K), the JPL Iris Version 2.1 ranging transceiver, a custom pumpkin power system, and the BCT XACT attitude control system, and the AIM/IRIS microcryocooler. In addition, as required at the Preliminary Design Review, we will be delivering science data from the broadband IR spectrometer, as described below, to the Planetary Data System.

Payload: The payload consists of one instrument: BIRCHES [1], Broadband IR Compact High-resolution Exploration Spectrometer. The versatile instrument, being developed by NASA GSFC, is designed to provide the basis for amplifying our understanding [2,3,4] of the forms and sources of lunar volatiles in spectral, temporal, spatial, and geological context as function of time of day and latitude. BIRCHES is a compact version (1.6 U, 3 kg, 10-20 W) of OVIRS on OSIRIS-REx [5], a point spectrometer with a cryocooled HgCdTe focal plane array for broadband (1 to 4 micron) measurements. The instrument will achieve sufficient SNR (>200) and spectral resolution (</= 10 nm @ 3 microns) through the use of a Linear Variable Filter to characterize and distinguish spectral features associated with water. We are also developing compact instrument electronics which can be easily reconfigured to support future instruments with H1RG focal plane arrays in 'imager' mode, when the communication downlink bandwidth becomes available. An adjustable field stop allows as to change the footprint dimension in x or y direction by an order of magnitude, to adjust for variations in altitude and/or incoming signal. The compact and efficient AIM microcryocooler/IRIS controller is designed to maintain the detector temperature below 115K. In order to maintain the cold temperature (<220 K) of the optical system (all aluminum construction to minimize varying temperature induced distortion), a special radiator is dedicated to optics alone.

Investigation: Radiometric models for our instrument configuration indicate that lunar surface emission does not become significant at temperatures within the instrument according to our thermal models until beyond the three-micron band. Emission from detector surfaces remains a minor component regardless of wavelength. These models also allow us to remove thermal emission as a function of wavelength. In addition, for the three-micron band, we should have adequate signal to noise ratio (SNR) to see the absorption features even as we approach the terminator as long as we have water at the hundredths of a percent level or above.

Mission Design: Science data-taking with the BIRCHES payload will occur primarily during the science orbit (100 km x 5000 km, equatorial periapsis, nearly polar), highly elliptical, with a repeating coverage pattern that provides overlapping coverage at different lunations. Between lunar capture and the science orbit, orbits will be used occasionally for instrument calibration and capture of spectral signatures for larger portions of the lunar disk, traversing from terminator to terminator. Particular attention will be paid to systematic or solar activity dependent transient effects resulting from charged particle interactions around the terminators. Science orbit data-taking will last approximately 6 months, 6 lunar cycles, allowing for sufficient collection of systematic measurements as a function of time of day to allow derivation of volatile cycle models.

Output: We will deliver labeled EDRs, derived from packetized dating using AMPCS tools, and, to the extent that resources permit, Level 1 data products, including calibrated data, to the Geoscience Node of the PDS. We will be using SPICE/NAIF tools to capture positioning and pointing information. Such products should become available beginning in 2020. We invite SSERVI node scientists to contact us about leveraging resources to perform higher level processing.

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THE ONSET OF THE CATACLYSM: IN SITU DATING OF THE NECTARIS BASIN IMPACT MELT SHEET. B. A. Cohen, NASA Goddard Space Flight Center, Greenbelt MD 20771 (barbara.a.cohen@nasa.gov)

Introduction: The impact history of the Moon has significant implications beyond simply excavating the surface of our nearest neighbor. The age distribution of lunar impact breccias inspired the idea of a catastrophic influx of asteroids and comets about 4 billion years ago and motivated new models of planetary dynamics [1, 2]. An epoch of heavy bombardment after planets had atmospheres and continents would have influenced the course of biologic evolution [3]. The story of a cataclysmic bombardment, written in the rocks of the Moon, has far-reaching consequences.

Linking lunar samples to specific basins underpins the lunar cataclysm. The inferred age of Imbrium, being the stratigraphically penultimate basin with a distinctive KREEP signature, is well-accepted ~3.96 Ga. Until recently, we thought we also had definitive dates of Nectaris, Serenitatis, and Crisium. Luna 20 samples also yielded ages of 3.85–3.89 Ga [4], but their relationship to the Crisium basin are unknown. Apollo 17 samples contain impact-melt rocks with ages around 3.89 Ga argued to be ejecta from the Serenitatis basin [5]; however, debate continues about the geological relationships at the site and the relative age of Serenitatis [6, 7]. The age of materials thought to originate in Nectaris varies wildly, from 3.9 to 4.2 Ga, with little agreement on what samples in our collection represent Nectaris, if any [8, 9]. The lack of definitive ages for major basins throws the key arguments supporting a lunar cataclysm into doubt. We are therefore working on a potential Discovery mission concept that would directly constrain the onset of the cataclysm by dating a lunar basin age.

The case for Nectaris: The Decadal Survey twice recognized the importance of understanding the cataclysm by recommending sample return from the South Pole-Aitken basin, which would enable high-precision measurements by complementary laboratory methods to resolve sample petrology and ages. However, it may be possible to understand the formation age of individual craters using in situ dating in a Discovery-class package. The Nectaris basin is a defining stratigraphic horizon based on relationships between ejecta units [10]. Although the Nectaris basin itself has experienced both basaltic infill and impact erosion, small "draped" deposits were identified as remnants of the Nectaris basin impact melt sheet [11]. For such a key basin, outcrops of recognizable, datable impact-melt rocks are a significant find.

Assessing the onset of the cataclysm using the age of the Nectaris Basin may require only coarse precision: if Nectaris were 3.9 Ga, we would infer a robust cataclysm; if 4.1 Ga (as suggested by some older samples), a more expansive epoch of bombardment would be allowable; if even older, there may have been no unusual spike in flux but rather a declining rate. These intervals can be recognized with ages ±200 Myr (or less), currently achievable with in situ techniques.

There is no PKT-compositional halo around Nectaris, so the impact-melt sheet should be aluminous and possibly slightly iron-rich. Such samples would be easily distinguished from KREEPy Imbrium and basaltic Mare Nectaris materials, which are likely to be present based on mixing models [12] and Clementine spectral data [11], though no changes were observed near small craters that would suggest compositional variability with depth in these units [11].

Mission Concept: A stationary lander could retrieve tens to hundreds of small (1-3 cm) sized rocks by scooping and sieving the regolith, similar to MoonRise [13]. Sieved samples would be characterized and prioritized using a microscopic imager and Laser-Induced Breakdown Spectroscopy (LIBS), which would be capable of distinguishing between KREEPy, basaltic, and aluminous samples. Samples of interest would be collected in a chamber for geochronology using LIBS to measure the K abundance and to release gases; mass spectrometry to measure the evolved Ar, and optical measurement of the ablated volume. These components have been flight proven and provide essential measurements (complete elemental abundance, evolved volatile analysis, microimaging) as well as in situ geochronology. Multiple laboratories have worked to advance and propose the LIBS-MS technique for planetary missions, including ours [14-16].

This mission concept would constrain the onset of the cataclysm by determining the age of samples directly sourced from the impact melt sheet of a major lunar basin, as well as understand lunar evolution by characterizing new lunar lithologies far from the Apollo and Luna landing sites, and provide ground truth for remote sensing measurements.

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Resource Prospector: Evaluating the ISRU Potential of the Lunar Poles. A. Colaprete[1], R. Elphic[1], D. Andrews[1], J. Trimble[1], B. Bluethmann[2], J. Quinn[3], G. Chavers[4], [1]NASA Ames Research Center, Moffett Field, CA, [2]NASA Johnson Space Center, Houston, TX, [3]NASA Kennedy Space Center, FL, [4]NASA Marshal Space Flight Center, Hunstville, AL.

Introduction: Resource Prospector (RP) is a lunar volatiles prospecting mission being developed for potential flight in CY2021-2022. The mission includes a rover-borne payload that (1) can locate surface and near-subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials. The primary mission goal for RP is to evaluate the In-Situ Resource Utilization (ISRU) potential of the lunar poles.

Mission Goals: While it is now understood that lunar water and other volatiles have a much greater extent of distribution, possible forms, and concentrations than previously believed, to fully understand how viable these volatiles are as a resource to support human exploration of the solar system, the distribution and form needs to be understood at a "human" scale. That is, the "ore body" must be better understood at the scales it would be worked before it can be evaluated as a potential architectural element within any evolvable lunar or Mars campaign. To this end the primary mission goals for RP are to:

- Provide enough information to allow for the next step: e.g., targeted survey, excavation and pilot processing plant demonstration
- Provide ground truth for models and orbital data sets, including:
  - Temperatures at small scales, subsurface temperatures and regolith densities
  - Surface hydration
  - Hazards (rocks and slopes)
- Correlate surface environments and volatiles with orbital data sets to allow for better prediction of resource potential using orbital data sets
- Address key hypothesis regarding polar volatile sources and sinks, retention and distribution, key to developing economic models and identifying excavation sites

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

- Dry: Temperatures in the top meter expected to be too warm for ice to be stable
- Deep: Ice expected to be stable between 50-100 cm of the surface
- Shallow: Ice expected to be stable within 50cm of surface
- Surface: Ice expected to be stable at the surface (i.e., within a Permanently Shadowed Region, PSR)

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

This talk will provide an overview of the RP mission with an emphasis on mission goals and measurements, and will provide an update as to its current status.

COPING WITH DUST FOR EXTRATERRESTRIAL EXPLORATION

Ron Creel

Retired Apollo Lunar Roving Vehicle Team Member

The author worked at NASA on the thermal control system for the Apollo Lunar Roving Vehicle (LRV), America's "Spacecraft on Wheels". This included thermal testing, modeling, and mission support during the Apollo 15, 16, and 17 Moon exploration missions in 1971 and 1972. Coping with Lunar Dust - the Moon exploration challenge that has haunted the author for over 46 years will be presented. This includes discussion of Previous Earth-based Dust Removal /Prevention Testing, Dust Effects on Apollo Lunar Extraterrestrial Missions, Dust Effects on Extended Lunar and Mars Extraterrestrial Missions, Dust Mitigation Options for Future Lunar Exploration, and Experience Based Recommendations for Coping with Dust. Comments on selected Strategic Knowledge Gaps (SKGs) prepared by the Lunar Exploration Analysis Group (LEAG) will also be discussed. The **LU**nar **ROV**ing **A**dventure (LUROVA) simulation game for STEM exploration and analysis will also be described.

NEAR-SURFACE AGE DISTRIBUTION OF LUNAR IMPACT-MELT ROCKS. N. M. Curran[1,2] D. M. Bower[1] and B. A. Cohen[1], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771; [2]NASA Postdoctoral Program

Introduction: The ages and compositions of impact melt rocks, both in lunar meteorites and in the Apollo and Luna sample collections, have been used to address questions related to the impact history in the Earth-Moon system and to investigate regional geology. However, the role of gardening as a possible bias affecting the preservation of impact-melt samples in the near-surface regolith needs further clarification. One way to understand the changes in impact-melt sample populations is to choose samples from depth in the regolith. The Apollo 16 double-drive tube 68001/68002 provides the opportunity to evaluate variations in age and composition of impact materials with depth. Based on composition and the soil maturity parameter I_s/FeO, there are five compositionally distinct units in the core [1]. The fact that each of these horizons can be distinguished from one another implies that each contains a potentially distinct population of impact materials. Additionally, a small inflection in the I_s/FeO profile at 3 cm depth may be related to the nearby South Ray impact, making this horizon similar to the Apollo 12 and 15 soils containing dated spherules, also located near small, young craters. Our intent is to secularly sample particles from each interval, group them according to parent lithology, and then conduct ^{40}Ar-^{39}Ar dating on representatives from each lithology to build a complete picture of the materials contributed to that horizon. While not a perfect analogy for a surface collection mission, it is meant to be illustrative of how we could use a combination of major-element chemistry, mineralogy, and age to understand impact history of a lunar site.

Samples: We received six 0.5-g bulk soil samples from each of the five intervals in 68001/2, plus one near surface sample. We sieved each soil sample into aliquots of size fraction greater than 250 μm, greater than 106 μm, and fines. The approximate mass of each fraction is shown in Fig 1; all aliquots had 50-70 individual particles in the 250+ size fraction that were used for continued analysis. We grouped particles visually using the petrographic microscope, but wanted a more robust method for determining parent lithologies for the groups of particles, and ideally one with the least sample preparation or destruction. First, we mounted each particle on double-sided tape and used micro-XRF to analyze the major-element chemistry, along with several terrestrial K-feldspar grains for calibration. We used Principal component analysis (Fig 2) and hierarchical clustering methods to analyze the dataset, but found that there is not enough variation in major-element chemistry among the particles to form robust groups, though in both methods, the terrestrial K-feldspar readily stood out from the lunar samples.

We tried additional analyses of the unprepared samples using low-vacuum secondary electron microscopy (SEM) and Raman spectroscopy. Unfortunately, the extreme topography and rough surfaces of the particles prevented us from getting robust results with either method. Penetrating analyses such as laser-induced breakdown spectroscopy (LIBS) would be ideal for these samples, but they are too small for reliable LIBS analyses in our laboratory.

Ongoing work: To achieve a more robust association or grouping of particles, we are turning to a mount-and-polish technique. Each particle will be mounted individually using superglue, hand-polished with SiC grinding paper, and analyzed by SEM and Raman spectroscopy to provide texture, major-element composition and mineralogy, to distinguish volcanic, plutonic, and impact-melt samples [2-4]. We will report on these results at the meeting.

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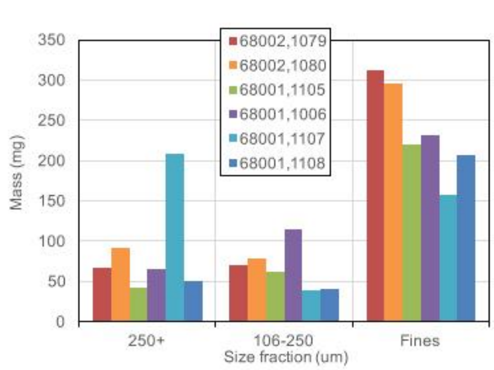
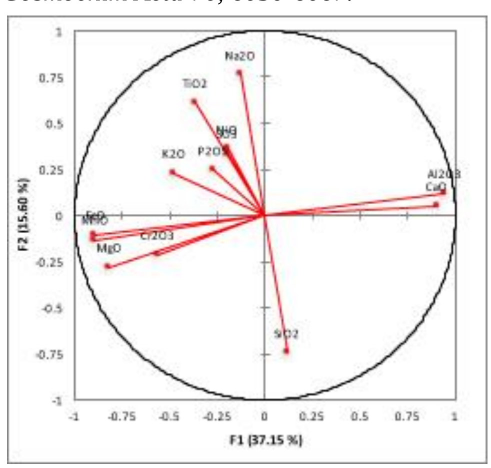


Fig. 1 (left) Mass per size fraction, sorted by depth.

Fig. 2 (right) PCA analysis of all samples shows the primary variability among samples is mafic-felsic (F1) and incompatible-elements (F2).



A NEW APPROACH TOWARDS DEPLOYMENT OF FAR SIDE LUNAR SETI USING A TETHERED LINK TO A NEAR SIDE ANTENNA. L. V. Datta[1], U. Guven[2] and E. Goel[3], 'Technische Universität Berlin, Germany (lakshyavdatta@gmail.com), [2]UN CSSTEAP, United States (drguven@live.com), [3]University of Petroleum and Energy Studies, India (enagoel269@gmail.com).

Introduction: The search for our celestial neighbors has been gaining momentum inexorably in the field of radio-astronomy. Due to a lack of anthropogenic Radio Frequency Interferences, the far side of the moon is perhaps the most pristine location suited for radio astronomy in the near earth environment. Keeping in pace with the recent growth in interest in deployable space telescopes for detection of extra solar Earth-like planets, we suggest a feasible approach to make the SETIMOON mission a reality with the technology available today. This mission was designed in 2000, with the intention of setting up an extendable radio antenna on the far side of the side to detect targets with significantly lower magnitudes and transmitting the data back to Earth using an antenna on the near side of the moon, where communications can be directly established. The data was proposed to be transmitted between the antennae using a fiber optic ‘‘tether’’ / cable. Our approach builds on aspects discussed in the two approaches in the original paper, but is significantly simpler on a systems level, since it separates the two antennae in space and lands them almost simultaneously on the moon, in order to avoid structurally stressing the data line tether, as was an obvious disadvantage of the previous approaches. The idea behind the described trajectory is rooted in the principle of conservation of momentum of the system. Moreover, it is operationally more feasible and shall be lower in cost as well. The paper describes the new approach, and develops it in order to create a feasible model that can finally bring the SETIMOON mission to life and extend our reach in finally establishing contact with our extra-terrestrial neighbors.

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INTEGRATING DIVERSE DATASETS TO ASSESS APPROACHES FOR CHARACTERIZING MARE BASALTS.
S. R. Deitrick[1] and S. J. Lawrence[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, [2]Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX.

Introduction: The Marius Hills Volcanic Complex (MHVC), located on a plateau in central Oceanus Procellarum at 13.4N, 304.6E, is the largest single concentration of volcanic features on the Moon (~35,000 km^2) [1]. The region includes volcanic domes, cones, rilles, and depressions and represents a significant period of lunar magmatism thought to have taken place during the Imbrian (~3.3 Ga) through Eratosthenian (~2.5 Ga) periods [1,2]. Previous studies of the MHVC utilizing the Clementine Ultraviolet/Visible (UVVIS) camera, the Kaguya Multiband Imager (MI), and the Moon Mineralogy Mapper (M^3) aboard the Chandrayaan-1 mission have found that the volcanic domes and surrounding mare basalts are compositionally indistinguishable, indicating similar eruption times [1,2], although the domes are embayed by younger mare basalts [1]. This research utilizes new Lunar Reconnaissance Orbiter Camera (LROC) data to re-evaluate the composition of the volcanic domes and surrounding mare basalt flows in the MHVC. Through this, the compositions and relative ages of the domes and the surrounding flows can be determined, improving our understanding of the volcanic history of this region.

Methods: Color unit boundaries were mapped using the LROC Wide Angle Camera (WAC) 7-band multispectral [3] and Clementine 5-band color ratio [4] basemaps. The boundaries were iteratively compared to each other to assess any differences between them and were then compared to the WAC hillshade and morphology data to assess the quality of correlations between color unit boundaries and topographic features. Next, five LROC Narrow Angle Camera (NAC) featured mosaics were analyzed in order to associate the WAC color unit boundaries with morphologies that are evident in the high resolution NAC frames. The correlated morphologies were mapped and confirmed by taking elevation profiles of NAC Digital Terrain Models (DTMs) in the LOC featured mosaic area. The WAC color unit boundaries in that same area were then compared with the Clementine TiO_2, FeO, and OMAT data as well as the mare basalt units mapped by [2] to evaluate the differences between them.

Results: It was discovered that some of the volcanic domes are outlined or crosscut by the WAC color unit boundaries. It can also be seen that a large majority of the color unit boundaries mapped from the WAC basemap correlate with morphologies that are evident in the NAC frames. Evidence of morphology changes were found to correlate with the color unit boundaries near the flanks of the domes that were observed and show possible embayment of the mare basalt flows on the flanks.

The color units derived from the WAC basemap almost exactly parallel units evident in the Clementine TiO_2 map and also matched well with the Clementine FeO map, but not as well as with the OMAT map. The color unit boundaries mapped from the WAC also correlated very well with the mare basalt units mapped by [2], but in general are more detailed and complex than those from [2].

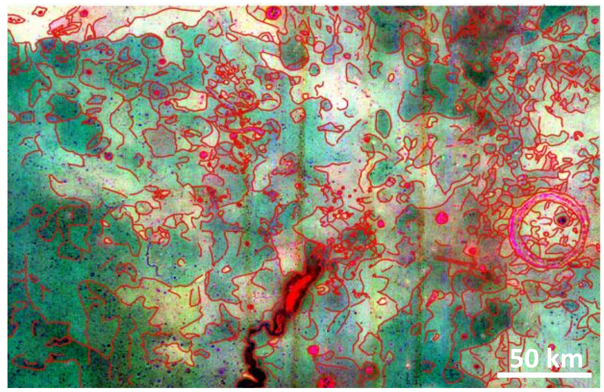

Figure 1. WAC color unit boundaries (red lines) overlain onto the WAC 7-band multispectral basemap.

Discussion: The morphologies seen in the NAC featured mosaics that parallel the color unit boundaries indicates that WAC color has great potential for identifying mare basalt units. When confirmed with elevation profiles from the NAC DTMs, the morphologies show embayment of the observed domes, indicating that the mare basalts were erupted after dome formation. This implies that the domes are older than the flows and the volcanic activity on the plateau was a complex process, as described by [1].

Conclusions: Color unit boundaries derived from WAC data correlate well with morphologies that are seen in the high resolution NAC featured mosaics. These results indicate that the domes are embayed by the surrounding mare basalt flows, a conclusion supported with elevation profiles from the NAC DTMs. This indicates that not only are the techniques used in this study useful for mapping distinct mare basalt units with the LROC WAC data, but will also be helpful in determining the relative stratigraphy and relative ages of the volcanic domes and surrounding mare basalts in the MHVC.

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LUNAR, CISLUNAR, NEAR/FARSIDE LASER RETROREFLECTORS FOR THE ACCURATE: POSITIONING OF LANDERS/ROVERS/HOPPERS/ORBITERS, COMMERCIAL GEOREFERENCING, TEST OF RELATIVISTIC GRAVITY AND METRICS OF THE LUNAR INTERIOR

S. Dell'Agnello[1], D. Currie[2], E. Ciocci[1], S. Contessa[1], G. Delle Monache[1], R. March[1], M. Martini[1], C. Mondaini[1], L. Porcelli[1], L. Salvatori[1], M. Tibuzzi[1], G. Bianco[1], R. Vittori[1], J. Chandler[3], T. Murphy[4], M. Maiello[1], M. Petrassi[1], A. Lomastro[1]

[1] National Institutte for Nuclear Physics – Frascati National Labs (INFN-LNF), via E. Fermi 40, Frascati (RM), 00044, Italy, simone.dellagnello@lnf.infn.it
[2] University of Maryland (UMD), Regents Drive, College Park, MD 20742-4111, USA, dgcurrie@verizon.net
[3] Harvard-Smithsonian Center for Astrophysics (CfA), 60 Garden Street, Cambridge, MA 02138, USA, jchandler@cfa.harvard.edu
[4] CASS, University of California, San Diego, La Jolla, CA 92093, USA, tmurphy@physics.ucsd.edu

Abstract: Since 1969 Lunar Laser Ranging (LLR) to Apollo/Lunokhod laser retroreflector (CCR) arrays supplied accurate tests of General Relativity and new gravitational physics: possibile changes of the gravitational constant Gdot/G, weak and strong equivalence principle, gravitational self-energy (PPN parameter beta), geodetic precession, inverse-square force-law [1][2][3]; it cal also constraints gravitomagnetism. Some of these measurements also allowed for testing extensions of General Relativity, including spacetime torsion, non-minimally coupled gravity (that may explain the gravitational universe without dark matter and dark energy)[4]; in principle, although technically and programmatically very challenging, also effective quantum gravity exploting the L1 lagrangian point. LLR has also provided, and will continue to provide, significant information on the composition of the deep interior of the Moon, complementary to the GRAIL mission of NASA. LLR first provided evidence of the existence of a fluid component of the deep lunar interior, confirmed also by lunar seismometry data [1].

In 1969 CCR arrays contributed a negligible fraction of LLR error. Since laser stations improved by >100, now, because of lunar librations, current arrays dominate the error. We developed a next-generation single large CCR, MoonLIGHT-NGR[1] unaffected by librations that supports an improvement of the space segment of the LLR accuracy up to x100. INFN also developed INRRI (INstrument for landing-Roving laser Retroreflector Investigations), a microreflector to be laser-ranged by orbiters. MoonLIGHT/INRRI, characterized at SCF-Lab [5] of INFN-LNF, Italy, for their deployment on the lunar surface or the cislunar space, will accurately position landers-rovers-hoppers-orbiters of GLXP/agency missions, thanks to LLR observations from select ground station of the International Laser Ranging Service (like APOLLO in the USA, GRASSE in France and MLRO in Italy).

INRRI was launched with the ESA ExoMars EDM 2016 mission, deployed on the Schiaparelli lander [6]. INRRI is also proposed for the ESA ExoMars 2020 Rover. Based on a NASA-ASI Implementing Arrangement signed in July 2017, a similar INFN payload (LaRRI, Laser RetroReflector for InSight) has been delivered to JPL and integrated on the NASA InSight 2018 Mars Landers in August 2017. Following a separate NASA-ASI Implementing Arrangement (already signed by NASA) a microreflector (LaRA, Laser Retroreflector Array) will be delivered by INFN to JPL in 2019 for deployment on the NASA Mars 2020 Rover.

The first opportunities for the deployment of MoonLIGHT-NGR will be from early to late 2018 with commercial missions, followed by opportunities with space agency misions, including the proposed deployment of MoonLIGHT/INRRI on NASA's Resource Prospectors and its evolutions.

LLR data analysis is carried out since the Apollo days with PEP, the Planetary Ephemeris Program developed and maintained by CfA. New LLR data, will provide useful input to improve the lunar models that PEP needs [7], as already shown by the implementation of data collected by GRAIL into LLR analysis.

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RESOURCE PROSPECTOR, THE DECADAL SURVEY AND THE SCIENTIFIC CONTEXT FOR THE EXPLORATION OF THE MOON. R. C. Elphic[1], A. Colaprete[1], and D. R. Andrews[1], [1]NASA Ames Research Center, Moffett Field, CA 94035 USA.

Introduction: The Inner Planets Panel of the *Planetary Exploration Decadal Survey* [1] defined several science questions related to the origins, emplacement, and sequestration of lunar polar volatiles:

1. What is the lateral and vertical distribution of the volatile deposits?
2. What is the chemical composition and variability of polar volatiles?
3. What is the isotopic composition of the volatiles?
4. What is the physical form of the volatiles?
5. What is the rate of the current volatile deposition?

A mission concept study, the *Lunar Polar Volatiles Explorer (LPVE),* defined a ~$1B New Frontiers mission to address these questions.

The NAS/NRC report, *"Scientific Context for the Exploration of the Moon"* [2] identified he lunar poles as special environments with important implications. It put forth the following goals:

- Science Goal 4a—Determine the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and depth) of the volatile component in lunar polar regions.
- Science Goal 4b—Determine the source(s) for lunar polar volatiles.
- Science Goal 4c—Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions.
- Science Goal 4d—Understand the physical properties of the extremely cold (and possibly volatile rich) polar regolith.
- Science Goal 4e—Determine what the cold polar regolith reveals about the ancient solar environment.

Resource Prospector: In 2014, HEOMD Advanced Exploration Systems initiated a Phase A study of Resource Prospector, a lunar polar mission that would address many of the open science and engineering questions surrounding lunar polar volatile deposits. Resource Prospector would, like LPVE, use a mobility system to explore the physical form, composition, spatial distribution scales, and likely origins of polar volatiles. The primary mission requirements focus on characterizing lunar polar volatiles as an ISRU resource. But the RP objectives also address Decadal and SCEM questions and goals, as shown in the following two tables:

Decadal Science Questions	Resource Prospector Capability
1. What is the lateral and vertical distribution of the volatile deposits?	Lateral: Neutron spectroscopy of water-equivalent hydrogen concentration in top 1-m of regolith throughout entire traverse; Imaging and NIR spectra of surface while roving.
	Vertical: Neutron spectroscopy of water-equivalent hydrogen concentration in top 1-m of regolith; NIR spectra of drill cuttings, GC/MS of samples from different depths
2. What is the chemical composition and variability of polar volatiles?	Chemical: Imaging and NIR spectra of surface and subsurface materials (drill cuttings), GC/MS of volatile vapor from samples, including isotopic analysis.
	Variability: NIR spectra and GC/MS analysis of drill samples acquired at multiple locations separated by 10 - 100's meters.
3. What is the isotopic composition of the volatiles?	GC/MS of volatiles driven off of samples provides isotopic analysis.
4. What is the physical form of the volatiles?	Imaging and NIR spectra of surface and subsurface materials (drill cuttings), GC/MS of volatile vapor from samples.
5. What is the rate of the current volatile deposition?	No direct measurements

SCEM Goals	Resource Prospector Capabilities
Science Goal 4a-Determine the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and depth) of the volatile component in lunar polar regions.	GC/MS analysis of surface and subsurface volatiles reveals chemical and isotopic composition; NIR spectra reveal mineralogy; Neutron spectroscopy provides lateral and approximate depth distribution; NIR spectra of extracted drill cuttings provides vertical distribution, as does GC/MS analysis of samples from depth.
Science Goal 4b-Determine the source(s) for lunar polar volatiles.	Chemical and isotopic composition reveal sources; imagery of physical state and NIR spectra inform emplacement mechanism.
Science Goal 4c - Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions.	Drilling/sampling within PSRs: Chemical and isotopic composition reveal likely sources; imagery of physical state and NIR spectra inform emplacement mechanism.
Science Goal 4d-Understand the physical properties of the extremely cold (and possibly volatile rich) polar regolith.	Rover slip vs slope, drill penetration force and augering torque with depth, and imaged rover wheel/surface interaction provide geotechnical info.
Science Goal 4e-Determine what the cold polar regolith reveals about the ancient solar environment.	Not directly addressed by RP.

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2017 EUROMOONMARS ANALOG HABITAT PREPARATION AND SIMULATION AT ESTEC

P. Evellin[1,2,5], B.H. Foing[1,2,3], A. Lillo[1,2,4], A. Kołodziejczyk[1,2], L. Authier[1,2,4], A. Blanc[1,2,4], C. Chahla[1,2,5], A. Tomic[2], [1]ESA/ESTEC & [2]ILEWG (PB 299, 2200 AG Noordwijk, NL, pierre.evellin@community.isunet.edu), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg

Introduction: The 2017 EuroMoonMars analog habitat was intended to provide a knowledge about what is the minimum and necessary equipment needed when arriving on the Moon using off the shelf and cheap components and where the focus should be put on. Even though the purpose is neither to test new equipment and technologies nor to perform some human and psychological experiments, high technologies experiments are developed and tested to increase the coherence of the data collected.

Context: ILEWG has developed, since 2008, "EuroMoonMars", an evolving pilot research programme starting with a Robotic Test Bench (ExoGeoLab) and a Mobile Laboratory Habitat (ExoHab) at ESTEC. An autonomous Laboratory (ExoLab) has been added later [1].

Technical improvements: For EuroMoonMars 2017 ESTEC tests, the ExoHab, ExoLab and ExoGeoLab are located in different areas adding complexity to the simulations. An efficient communication system is developed to cope with this issue, using mainly walky-talkies and Wi-Fi. A collaboration with former Google Lunar XPrize participant PuliSpace provides a Rover to connect with ExoGeoLab so it can be operated either locally or from a dedicated mission control in Hungary.

The ExoHab has been rearranged so that it could be possible to work simultaneously at 5 people at least thanks to the clear definition of functional areas. ExoHab represents the "first house" of the MoonVillage. As such, it is used to centralize every aspect of the mission (communication, science, life) [2].

The ExoLab has been rearranged into ExoLab 2.0 with a redefinition of the functional areas. Keeping in mind that it should be a modular laboratory based on standard space container, the whole layout has been thought to be dismountable and reusable in similar containers. Thus, highly modular magnetic walls capable of supporting heavy charges have been developed using off the shelf components as well as modular furniture.

All those improvements made possible the EuroMoonMars simulation on the 21st of July 2017.

EuroMoonMars Simulation: In the frame of the simulation, the participants of the EuroMoonMars workshop held at ESTEC contributed by taking different roles from Astronauts in ExoHab, ExoLab, in the Lunar Orbiter, as well as Ground Controllers at the Mission Control Centre.

Some protocols have also been developed to clarify each task [3]. What was planned for the workshop was:

- Landing on the Moon, setting of the Astronauts in ExoHab and ExoLab.
- Medical check of crew members.
- Biological experiments.
- EVA including interactions with ExoGeoLab lander and sample gathering.
- Geological experiments.
- Medical experiments.
- Leaving the Moon Base

In-between, incidents have been triggered by the Mission Control Centre to test the emergency protocols and equipment.

Figure 1: Mission control of the EuroMoonMars 2017 simulation at ESTEC

Acknowledgements: we thank ILEWG EuroMoonMars programme and the participants to EuroMoonMars 2017 workshop and simulation.

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DREAM2 STUDIES IN SUPPORT OF HUMAN EXPLORATION OF THE MOON. W. M. Farrell[1], R. M. Killen[1], G. T. Delory[2], and the DREAM2 team, 1. NASA/Goddard Space Flight Center, Greenbelt, MD, 2. University of Californian at Berkeley, Berkeley, CA (William.M.Farrell@nasa.gov)

DREAM2 is a modeling, laboratory, and data center that examines the space environment at airless bodies, including the Moon. Many of tasks in this center focus on new exciting science findings, but many of these topics also have direct applicability to the advancement of human exploration of the Moon.

In this poster, we present a gallery of topics addressed by DREAM2 since 2014. These exploration-supporting topics include astronaut and rover charging, the complex electrical environment in polar craters, Earth-shine, dust cohesion, polar cold trapping, the lunar hydrogen cycle, radiation and astronaut safety, deep dielectric discharge, spacecraft outgassing, and support of the HEOMD funded Resource Prospector mission.

ILEWG EUROMOONMARS RESEARCH, TECHNOLOGY & FIELD SIMULATION CAMPAIGNS

B.H. Foing[1,2,3] , A. Lillo[1,2,4], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Heinicke[2,3], M. Harasymczuk[1,2], L. Authier[1,2,4], A. Blanc[1,2,4], C. Chahla[1,2,5], A. Tomic[2], M. Mirino[1,2], I. Schlacht[2,3,6], S. Hettrich[7], T. Pacher[8], L. Maller[2,4,9], A.Decadi[7,10], J. Villa-Massone[7], J. Preusterink[2], A. Neklesa[2], A. Barzileye[2], T. Volkova[2], [1]ESA/ESTEC & [2]ILEWG EuroMoonMars 2017 (PB 299, 2200 AG Noordwijk, NL, Bernard.Foing@esa.int), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] Extreme Design, [7] SGAC, [8] Puli team, [9] EAC European Astronaut Centre, [10] ESA HQ

Introduction: ILEWG developed since 2008, "EuroMoonMars" an evolving pilot research programme starting with a Robotic Test Bench (ExoGeoLab) and a Mobile Laboratory Habitat (ExoHab) at ESTEC . They can be used to validate concepts and external instruments from partner institutes. Field campaigns have been conducted in ESTEC, EAC, at Utah MDRS station , Eifel, Rio Tinto, Iceland, La Reunion, Hawaii, and LunAres base at Pila Poland in summer 2017.

Goals of EuroMoonMars & ExoGeoLab: We integrated instruments integrated in an ExoGeoLab test bench, along a methodic hands-on research:

1) We procured and adapted instruments to equip a small ExoGeoLab demo lander. Some instruments can also be used on a small or mid-size Rover. some instruments can be brought for field site campaigns.

2) This terrestrial payload (instruments, sensors, data handling) has been deployed, operated and used as collaborative research pilot facility (ExoGeoLab), first tested and operated at ESTEC & transportable

4) We have implemented the possibility of remote control of instruments from an adjacent mobile laboratory, and a remote science desk.

5) The suite of measurements includes a comprehensive set with telescopic imaging reconnaissance and monitoring, geophysical studies, general geology and morphology context,geochemistry (minerals, volatiles, organics), subsurface probe, sample extraction and retrieval, sample spectroscopy analysis.

6) We have reproduced some simulation of diverse soil and rocks conditions (mixture of minerals, organics, ice, penetrations of water, oxydant, organics, living organisms & plants) and diagnostics

7) We used these instrument packages to characterise geological context, soil and rock properties

8) Science investigations include geology, geochemistry, mineral, oxydant, organics, volatiles & biomarker diagnostics.

9) After first validations we started to exploit the facility for collaboration with partners that have provided some additional guest instruments, and performed specific investigations,

10) We can make use of the mobile lab habitat ExoHab for logistics support and local operations.

11) An additional ExoBiology Laboratory module (ExoLab) has been equipped to support related technical research. A new version ExoLab 2.0 was developed over summer 2017

12) From this test bench and kit of ExoGeoLab instruments, we plan to operate comprehensive instruments packages that could help in the technical research and science preparation of future lander/rover missions.

This research can benefit Science, Exploration or Application programmes, and isc used in support of International Tasks Groups such as ILEWG, IMEWG, ISECG, space agencies, and research partners.

EuroMoonMars field campaigns: We have organised field campaigns using selected instruments from ExoGeoLab suite in specific locations of technical, scientific and exploration interest. Field tests have been conducted in ESTEC, EAC, at Utah MDRS station, Eifel vocano region, Rio Tinto, Iceland, La Reunion, Hawaii. These were organised by ILEWG in partnership with ESTEC, VU Amsterdam, NASA Ames, GWU in Utah MDRS (EuroGeoMars 2009, and then yearly for EuroMoonMars 2010-2013).

EuroMoonMars field tests 2017 were at ESTEC in July and at LunAres base at Pila Poland from August.

We thank ILEWG EuroMoonMars 2017 campaign crew at ESTEC (here in figure with ExoGeoLab lander & Puli Rover) & teams at simulation campaigns (PMAS, LUNEX1, IcAres) at LunAres base, Poland.

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THE STATUS OF RESTORATION OF MOON MINERALOGY MAPPER DATA. L. R. Gaddis[1], J. Boardman[2], E. Malaret[3], S. Besse[4], L. Weller[1], K. Edmundson[1], R. Kirk[1], B. Archinal[1], and S. Sides[1]. [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, USA (lgaddis@usgs.gov). [2]Analytical Imaging and Geophysics, LLC, Boulder, CO, USA. [3]Applied Coherent Technologies, Herndon, VA, USA. [4]European Space Astronomy Centre, Madrid, Spain.

Introduction. An important dataset for the mapping and characterization of lunar surface resources was acquired by the NASA Moon Mineralogy Mapper (M^3) instrument [1-4]. Our work continues on geospatial restoration of the M^3 data, improving the geodetic control of these hyperspectral data covering >95% of the Moon. Using Global and Targeted imaging modes (at 140 and 70 m/pixel spatial resolution, respectively) with spectral resolution of 20-40 nm in 85 channels between 460 and 3000 nm, the M^3 data are uniquely valuable for characterizing surficial water [2, 5], soil and rock mineralogy [6-9], and water in lunar pyroclastic deposits [10]. Our goal is to use the high spatial resolution (~100 m/pixel) and improved horizontal geodetic accuracy of the Lunar Reconnaissance Orbiter Wide Angle Camera (WAC) stereo-derived topographic model [i.e., the GLD100 digital terrain model or DTM, 11] to improve the positional accuracy of M^3 frames tied to the 3D lunar surface.

This project has 7 goals: (1) Reprocess M^3 data with the mission's Level 1B (L1B) processing pipeline and the GLD100 to improve selenolocation accuracy; (2) Develop USGS Integrated Software for Imagers and Spectrometers (ISIS3) software to ingest and process M^3 data [12, https://isis.astrogeology.usgs.gov/]; (3) Control the global M^3 dataset with better geodetic accuracy and update L1B products; (4) Reprocess improved L1B data through the mission's Level 2 (L2) pipeline to improve thermal and photometric accuracy; (5) Update the photometric modeling; (6) Create orthorectified frame and mosaicked (Level 3) data products; and (7) Deliver interim and final products, including NAIF SPICE kernels [13] and restored M^3 frames to the Planetary Data System (PDS). Goals 1 to 3 are completed, and work on 4 to 7 is underway.

Improved Geodetic Control. The M^3 L1B IDL pipeline was used to reprocess the data through ray tracing and geometric modeling, creating a full-mission orthorectified product. The improvement of geodetic control of M^3 frames makes use of ISIS3 software [12], which allowed us to model rigorously the physics and geometry of image formation by the M^3 camera. We used the M^3 camera model in ISIS3, added tie points to the lunar surface with automated and manual procedures, and bundle-adjusted the frames [13]. To develop a control solution for the M^3 data, we orthorectified the images and evaluated the positional consistency of overlapping images in map coordinates. The final M^3 control network is based on 859 images, 102,547 points (including 39,024 constrained points), and 379,412 measurements. The largest offsets (up to ~5 km) from original image placements were observed in M^3 data from Optical Period OP2C.

Photometric Correction: The Level 2 [L2] pipeline has been updated for newer hardware and is being used to compute normalized reflectances from the Level 1B radiances and improved LOC and OBS files [14]. The initial Lommel-Seeliger photometric correction was updated for the improved M^3 data and correction coefficients for each wavelength are being applied to thermally corrected [15] L2 data.

Our major products are improved hyperspectral frames (including all M^3 Global and Target Mode data, L1B and L2) closely tied to the 3D lunar surface, along with updated kernels and metadata. Late in 2017, we will deliver these products to PDS and make them publicly available. These data will be important for new research on lunar resources, mapping of volatiles, surface compositions, etc.

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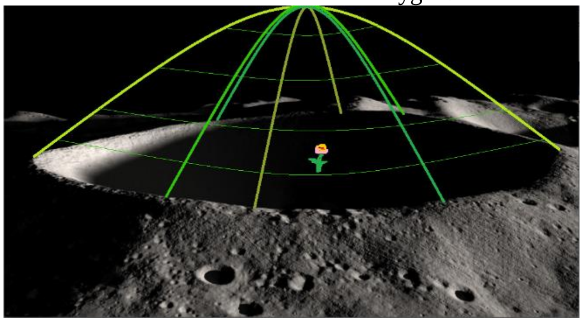
THE FUTURE LUNAR FLORA COLONY. E. Goel[1] and Dr. U. Guven[2], [1]University of Petroleum and Energy Studies, India (enagoel269@gmail.com), [2]UN CSSTEAP, United States (drguven@live.com).

Introduction: Missions of sample extraction to those of manned landings have been proposed since man extended its outreach to the Moon. The Moon offers a varying landscape and environment with no atmosphere or magnetic field unlike the Earth. The lunar regolith varies throughout the surface of the moon with depths and composition. A site nearby the poles, receiving adequate amount of sunlight throughout the year, holding adequate amount of micrometeorites on the surface will be good choice to start a lunar colony, setting up a flora community primarily. Micrometeorite rich surface will fuel the Iron oxide and Hydrogen ion reaction to produce water vapor, sunlight directed and stored in the right amount will drive the photosynthesis and close to poles site will ensure water availability in case of emergencies. This paper lays out a constructional design for the establishment of a lunar colony using the micrometeorite regolith and space technology input from Earth. Near pole craters covered with an inner concave surface dome such as those used on Earth's greenhouse buildings will be useful to store sunlight for the process of photosynthesis. The dome will be required to sustain condensation of the water vapors produced by the Iron and Hydrogen reactions taking place on the regolith. The utilization of the iron oxide and hydrogen reaction to extract water has also been discussed. Stored sunlight, condensed water and bio-manure from Earth will complete the ingredients for setting up the flora colony. The oxygen thus produced can be channeled to a human base. This set up will help future colonization missions on the moon and can be viewed as a potential source of water and oxygen for the human outpost on the Moon, the celestial body closest to home. If established, a colony based on this design shall be capable of making Moon self-sufficient in terms of water and oxygen.



Iron Oxide and H^+ ion Reaction: The Solar wind implants hydrogen ions on and into the regolith. Processing and reworking of regolith rich in micrometeorites triggers a melting reaction on the surface itself. This reaction employs the already present iron oxide to react with the hydrogen ions and produces water vapor. Sub microscopic metallic iron grains are formed thereafter in the resulting agglutinate. This output can be used to extract the water vapor. The Luna 16 and Luna 20 missions reveal that FeO is the second most abundant compound by mass when the regolith was tested for chemical composition.

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QUANTIFYING ELEMENTS OF A LUNAR ECONOMY BASED ON RESOURCE NEEDS. J. B. Greenblatt[1], [1]Emerging Futures, LLC, 2726 Eighth St., Berkeley, CA 94710, jeff@emerging-futures.com.

Introduction: A lunar economy will be built upon *in situ* resource utilization and trade with other solar system locations. Elements must include human life support commodities (water, air and food that is maximally recycled) and basic structural and functional materials including metals, concrete, glass, plastics and industrial chemicals (H_2SO_4, NaOH, etc.). Propellant (e.g., H_2/O_2, etc.) will be essential for surface propulsion and material export, while solar photovoltaic (PV)-grade silicon will enable a lunar economy to expand by harnessing more power. Rare earth elements, uranium, and ^{3}He could be obtained with additional effort, enabling sophisticated metallurgy, catalysis, and nuclear fission and fusion capabilities.

Si, Ca, Mg, Al, Fe, Ti and O are abundant in lunar regolith, so materials containing them could be exported, along with ^{3}He. By contrast, H- and C-containing materials would be limited due to low lunar abundances, and may need to be provided from elsewhere, along with other elements in low abundance, as well as sophisticated products such as electronics, etc.

Approach: We use a combination of resource estimates for human life support, basic materials consumption on Earth, and energy and propulsion requirements to build a simple resource consumption model that is then constrained by lunar elemental abundance estimates to identify materials that could be imported or exported. We also constrain the area covered by solar PV to 0.1% of the lunar farside (~19,000 km^2), and consumption of the estimated lunar water resource (2.9 Gt) to ~0.01%/year (8,000-year lifetime). While this approach does not represent a rigorous economic assessment, it forms a starting point for planning a lunar economy. For details, see [1].

Reclamation of 99.5% of water is assumed, or ~10 times the current recovery rate on the International Space Station; advanced water purification approaches on Earth can already achieve >99% reclamation [2], so this goal is not unreasonable. Lower recycling rates of air, organics, surface propellant and other materials are assumed. Because aluminum represents an important part of the lunar economy but requires fluorine for processing, which is found in low abundances in regolith (~20-120 ppm), a recycling rate of 99.9% is required, along with inert, non-carbon anodes that are not consumed during aluminum production [3].

Results: We find that 50,000 people can be supported on the lunar surface, constrained primarily by lunar water. However, because of abundant solar energy and mineral resources, a large industrial capacity is feasible, providing exports to other solar system locations of ~300 Mt/yr of inorganic materials (metals, glass, solar PV, and raw regolith for shielding), sufficient for >170 million people in our simple assessment. The lunar surface population would consume ~17 Mt/yr of concrete, metals, industrial chemicals, fertilizers (N, P, K), air (O_2/N_2), carbon-containing products (food, plastics, structural plants), potable water, and H_2/O_2 propellant for surface mobility and energy storage during the ~14-day lunar night.

Propellant limitations. One key limitation is the lack of sufficient water for long-term space launch capability required for the assumed levels of exports. Instead, ablation of raw regolith is assumed using ground-based lasers to provide energy. This technology has been explored in the laboratory, with an estimated thrust coefficient of 500 μN/W at laser intensities of 10 MW/m^2 [4], resulting in a specific impulse of 121 s. Thus, for a delta-v budget of 2.7 km/s (sufficient to escape the Moon and reach the Earth-Moon L1 point or similar location), 21 kg of regolith and ~100 MJ of electricity are required per kg of exported material.

Gross Interplanetary Product (GIP). Based on the ratio of final energy consumption on the Moon (1.34 TW) to estimated 2015 global electricity consumption (12.4 TW) and Gross World Product ($76 trillion) (see [1]), we estimate an annual GIP of $8 trillion. In addition, the energy that would be produced in space from exported solar PV adds another 3.9 TW or $24 trillion.

Beyond the Moon. For sustaining human life and industrial activity in space, exports of food, air, water and chemical propellants would be required from other locations than the Moon, presumably asteroids and/or Mars. We have done similar calculations for Mars and determined that less than 0.1% of its surface area would be sufficient to produce these items from *in situ* resources for export to >170 million people.

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INTERACTION OF SPACE RADIATION WITH AGRICULTURE ON THE MOON. Dr. U. Guven[1] and E. Goel[2], [1]UN CSSTEAP, United States (drguven@live.com), [2]University of Petroleum and Energy Studies, India (enagoel269@gmail.com).

Introduction: The Moon has been a celestial body of immense interest since the Luna 2 landed on it in 1959. Experiments, findings and our understandings about the Moon have long persuaded scientists for colonization plans on the Moon. With the Chandrayaan mission, we have even come to discovering presence of water on the Moon. Devoid of atmosphere, the Moon is mostly vacuum and funds a channel for the Galactic Cosmic Radiations (GCR) and the Solar Energetic Particles (SEP). These radiations have drastic impacts not only in the region above the surface but also deep into the soil of the lunar crust. The effects of these radiations need to be addressed in order to establish an agricultural layout to support colonization missions on the Moon. Since the Moon has no magnetic field, there is no magnetic blanket or channel to deviate the solar radiations. This has affected the regolith to depths. This paper proposes to understand the effects of GCR and SEP on the plants and agriculture which is the primary step to colonization at any celestial site. Light is an important ingredient for this process and looking at the albedo on the lunar regolith, a smart balance in exposure as well as shielding of plants against the sun's rays is critical to understand. This paper is dedicated to achieve this understanding in order to aid plantation missions on the moon. This endeavor shall encourage smart manifestation of solar technology for settlement missions on celestial spheres.

GCR and SEP: These are the energetic charged particles travelling at a fraction of the speed of light. They are much faster than the ambient particles in space plasma [3]. GCR are remnants of a supernova and contain various element ions and high energy gamma rays. "SEP" refers to protons usually. They are born are the flares and coronal mass ejections in the Sun. They have severe effects on biological, satellite and other systems. The flux and hence effective dose rate on the Moon from these sources in space are about half of that in deep space due to the self-shielding by the Moon [2].

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TRANSFER AND PARSE ORBIT MOMENTUM MANAGEMENT SYSTEM ARCHITECTURE.
T. H. S. Harris, Dynamicist, Orbit Analyst, Lockheed Martin retired (THSHarris@mindspring.com)

Introduction: The campaign to revisit the Moon has become exactly that, a far reaching, multi-functional enterprise. As various entities take interest in any one of many stages and settings of the overall paradigm, the cost of safe, reliable transport to the moon is purvasive above all other factors. As mission demand increases and the list of points of interest on the lunar surface become diverse and potentially dynamic, many trajectory architectures will be considered. Ultimately a semi-consolidated transport architecture to service many different mission types and payload mass requirements may reduce the overall cost of bulk transport for lunar missions. Architectural elements of Earth-Moon system mass transport "structure" are developed for lunar orbital residence.

A system of one or more orbital tethers is suggested to capture generic payload containers out of transfer orbit from Earth and divert them to their reqiured parking or pre-landing trajectories. The perferred system is one that absorbs a portion of the transfer orbit energy for maintenance of its own orbit and orbit parsing delta V requirements (solar electric powered for guidance and actuation). Benefits and drawbacks or risks are considered in the context of Human Exploration and Operations in the Earth-Moon System (EMS), while the conceptual framework is applicable for destinations beyond the Moon, with hardware & control commonality as potential benefits for such additional uses.

Context: A coordinated approach to mass transport in the EMS for both transfer orbit to the Moon and then parsing orbits at the moon has the potential to optimize both specific angular momentum and total mechanical energy. Reduced specific delivery cost vs. chemical rockets for soft landing would have to exceed the system cost of viable solutions within the EMS mass transport system architecture.

When not ferrying human payload, mass transport costs may be reduced via any EMS mass transport system that is more conservative and reusable than the large "human-rated" chemical boosters. Humans are a very small fraction of all of the infrastructure and robotoc mass we would like to provide at the lunar surface. What is needed is some sort of "on-station conveyor" around the Moon that can be adapted, controlled and/or configured to accept incoming mass from transfer orbit and parse it to a pre-landing orbit.

Top Level Requirements: We assume soft landing capability on the lunar surface is a requirement for payload survivability. We know that areas of interest on the Moon could be anywhere from equatorial to polar, so we would like access to all latitudes. We would also like the ability to place mass on the lunar surface without need of expendable propellant or thrster to do so. Using a rotating tether to place a payload on the surface during flyby, delta V is conserved during the delivery, and the tether delivery vehicle extracts payload energy by accelerating itself in a controlled fashion for orbit upkeep. The challenge is mainly divided into control/actuation and orbit determination for the tether vehicle/system. Tight constraints on transfer orbit definition are also required, offset by improved tether control performance.

Recievers and Workers: A larger, higher orbiting tether may be used to match or "receive" higher incoming velocity transfer orbit requirements [1]. The reciever tether then parses the payload to a smaller "worker" or "delivery" tether (fleet), at a lower, near surface orbit [2]. This two tier system can theoretically reach stated requirements. Choice of delivery tether would depend somewhat but not completely on target latitude. Ultimately the entire tether system can derive its required delta V by strategic choice of transfer delivery condition depending on current vs. desired tether states, before payload launch from Earth [3].

Discussion & Conslusion: Proposed EMS mass transport architecture allows for a resident delivery conveyor within the EMS environment, alleviating delta V requirements during science and coeval support infrastructure build-up to human arrival.

Single point failure sensitivity of this EMS mass transport system architecture may be reduced by multiple active orbital tether units in each of an upper or "reciever" tier, and a lower or "delivery" tier.

The preferred workup to this architecture starts with smaller scale tethers to handle low mass science payloads such as "CubeSat" scale, for survivable placement on the lunar surface at various latitudes. Larger scale tether devices for larger mass payloads may then be successively deployed to expand the mass/time capacity of the overall system. A varsatile and delta V conservative mass transport system should be delivered early in the modern lunar campaign to aid in the entire exploration process. This system has the added advantage of possible fast resupply after human occupation.

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GEOLOGIC EXPLORATION ENABLED BY OPTIMIZED SCIENCE OPERATIONS ON THE LUNAR SURFACE.
J.L. Heldmann[1], D.S.S. Lim[1,2], A. Colaprete[1], W.B. Garry[3], S.S. Hughes[4], S. Kobs Nawotniak[4], A. Sehlke[1], C. Neish[6], G.R. Osinski[6], K. Hodges[7], A. Abercromby[8], B.A. Cohen[3], A. Cook[1,5], R. Elphic[1], H. Mallonee[4], A. Matiella Novak[8], E. Rader[1], D. Sears[1,2], H. Sears[1,2] and the FINESSE and BASALT teams. [1]NASA Ames Research Center Moffett Field, CA, [2]Bay Area Environmental Research Institute, Petaluma, CA, [3]NASA Goddard Space Flight Center, Greenbelt, MD, [4] Idaho State University, Pocatello, ID, [5]Millennium Engineering, Moffett Field, CA, [6]Western University, London, Ontario, Canada, [7]Arizona State University, Tempe, AZ, [8]Johns Hopkins University / Applied Physics Lab, Laurel, MD.

Introduction: Humanity's return to the lunar surface will enable unprecedented studies of science on, of, and from the Moon. Of great interest are in situ studies with human and robotic explorers of volcanism and impacts as the dominant planetary processes shaping the Moon. We've conducted such research in terrestrial analog environments, and both the science and exploration research is placed in the context of optimizing the scientific return from upcoming lunar surface missions. This paper presents detailed geologic field studies that can best be accomplished through in situ investigations, and the associated recommendations for human and robotic mission capabilities and concepts of operations for lunar surface missions.

To this end, NASA's FINESSE (Field Investigations to Enable Solar System Science and Exploration), partnered with NASA's BASALT project has conducted numerous field campaigns to field sites as lunar analogs. The scientific investigations are directly correlated to the related science applicable to the Moon, and the concepts of operations and capabilities required to conduct these investigations are tested, validated, and used to inform human architecture planning through NASA's human spaceflight program.

Field Sites: Our work is focused at three locations.

Craters of the Moon (COTM) National Monument and Preserve. COTM is a dominantly basaltic volcanic system with a variety of well-exposed analogs to volcanic formations on the Moon [1]. Field research topics include, but are not limited to, comparative planetology to understand the geologic history of volcanic landforms (e.g., cinder cones, lava tubes, different lava flow types, rilles and vent structures) similar to features within the Marius Hills region [2], measuring surface roughness with implications for emplacement of lava flows and impact melt [3], understanding phreatic craters and ballistic ejecta field formation [4], and testing various techniques such as thermoluminescence for age dating volcanic flows [5].

West Clearwater Impact Structure (WCIS). WCIS is located in northern Quebec, Canada and possesses one of the best records of impact melt rocks and breccias among impact craters on Earth. Science research at WCIS includes constraining the age of the impact through geochronology [6], assessing shock metamorphism and complex crater collapse [7], studying impact induced geothermal activity, and characterizing unique impact features such as lineaments and melt veins [8].

Kilauea Volcano, Hawai'i. Kīlauea presents a basaltic terrain with a variety of surficial features analogous to lunar features. The historically active volcanoes enable the investigation of relatively sterile, recently-erupted lava as well as basaltic substrates and fumaroles. Hawai'i has also served as a key field site for past and current surface exploration research.

Exploration Investigations: Exploration research is conducted within the context of enabling bona fide scientific investigations. This research focuses on operational concepts such as the structure and functions of extra-vehicular activity, intra-vehicular activity, mission control and science backroom teams [9]. New technologies are incorporated into the deployments and evaluated for efficiency and utility including, but not limited to, portable field instrumentation (VIS-NIR spectrometer, portable XRF, portable LIBS, FLIR cameras, LiDAR, UAV systems, etc.) to identify capability requirements for future instrument development, comparison of lab versus field data, ergonomics and instrument use considerations for science output and decision making pathways [10]. We have also assessed science training required for astronaut explorers and provide recommendations regarding subject matter, approaches, instrumentation, and follow-up laboratory work in conjunction with active duty astronaut participation [11].

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ASTROBOTIC'S PAYLOAD DELIVERY SERVICE ENABLES LUNAR SURFACE ACTIVITIES. D. B. Hendrickson, Vice President of Business Development, J.M. Thornton, CEO, Astrobotic, 2515 Liberty Ave. Pittsburgh, PA 15222, dan.hendrickson@astrobotic.com.

Introduction: This paper describes Astrobotic's lunar payload delivery service, along with the latest program developments toward the company's first demonstration of service.

Overview of Astrobotic's Service: Astrobotic is a lunar logistics company that delivers payloads to the Moon for companies, governments, universities, and nonprofits using its Peregrine Lunar Lander. Peregrine is a modular spacecraft that delivers a collection of payloads to lunar orbit or surface on a single mission for the historic low price of $1.2 million per kg. The vehicle will serve as a product line for Astrobotic's first five delivery missions.

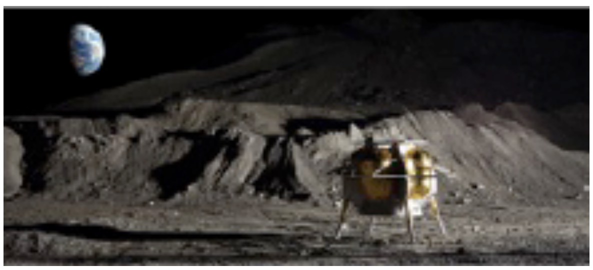

Figure 1: An engineering mock-up of the Peregrine Lander at a lunar analogue site.

Peregrine's first flight in 2019 will be a demonstration of service that carries 35 kg of customer payload to the lunar surface. Following this first mission, Peregrine will be capable of carrying up to 265 kg of payload optimizing the trajectory and increasing the quantity of propellant carried. Payloads are integrated onto either the top or bottom of Peregrine's payload decks using a standard bolt pattern.

For Peregrine's first mission, the vehicle will fly as a secondary payload on a United Launch Alliance (ULA) launch vehicle to either low Earth orbit or geosynchornous transfer orbit. After deployment in Earth orbit of ULA's primary payload, Peregrine will be propelled toward the Moon using the launch vehicle's upper stage. Peregrine then separates and its onboard propulsion system carries out course correction burns, lunar orbit insertion, and powered descent to the surface. Upon landing, Peregrine will commence an 8-Earth day surface mission, and provide payloads power (0.5 W per kg of payload) and communications bandwidth (2.8 kbps per kg) for the duration. The first mission will land at Lacus Mortis, a mid-latitude location at 45 degrees North, 25 degrees East. Future missions will be capable of landing at any latitude on the Moon, including the lunar poles.

Peregrine for Surface Activities: Peregrine is ideally suited to carry small (1-5 kg) to medium-sized (5-10 kg) science, exploration, and technology demonstration payloads to lunar orbit or the lunar surface on its first mission. CubeSats (from 1U to 6U), small rovers, resource instruments, seismometers, retroreflectors, and telescopes could all make use of this mission and advance the state of the art in lunar exploration for a fraction of the typical cost. As of this writing, Astrobotic has 11-deals in place, representing 6-nations for its first delivery mission.

Following a successful demonstration of low cost delivery service to the Moon, Peregrine will be ready to serve the landscape of lunar surface activities that are planned for the near term. To date, Astrobotic has 108 deals in its sales pipeline for Peregrine. This pipeline is indicative of space agency plans and private sector business cases that are enabled with foundational low cost lunar delivery. Peregrine's design will be ready to serve and compliment exploration architectures such as Orion and SLS, the Cislunar Gateway, or the ESA Lunar Village with regular large cargo shipments. Missions focused on resource prospecting, harvesting, and insitu resource utilization at the lunar poles will also be flown by Peregrine. Development of the technologies needed to land and operate at the poles (such as Terrain Relative Navigation) are well underway in Astrobotic's Future Mission and Technology Department, which has 23-past or ongoing NASA technology contracts to date.

Laser Communications on the Surface: At the Paris Air Show this past summer, Astrobotic announced that it had signed a payload agreement with ATLAS Space Operations to carry the first-ever laser communications terminal to the surface of the Moon. In addition to ATLAS carrying out a technology demonstration at the surface, this new terminal will be made available for Astrobotic's payload customers, providing them gigabit per second data bandwidth. This is a thousand-fold increase over radio communications from the Moon. Thanks to this new service offering, Astrobotic's payloads can now broadcast live streaming, high definition video, among other high speed data intensive activities. This service will be available for purchase by payloads as live bandwidth or data packages. Laser communication services on the Moon is indicative of the new era in lunar surface activities enabled by commercial lunar services like Astrobotic.

The Lunar Water Assessment Transport Evolution and Resource (WATER) Mission Concept Study.
C. A. Hibbitts[1], D. Blewett[1], P. Brandt[1], L. Burke[2], B. Clyde[1], B. Cohen[3], J. Dankanich[4], D. Hurley[1], R. Klima[1], D. Lawrence[1], W. Patterson[1], J. Plescia[1], J. Sunshine[5], J. Westlake[1], [1]JHU-APL (11100 Johns Hopkins Rd., Laurel, Md 20723; karl.hibbitts@jhuapl.edu), [2]GRC, [3]GSFC, [4]MSFC, [5]Univ. of Maryland

Introduction: Over the last decade, many lunar measurements have revealed that water is more ubiquitous on the Moon than previously thought. With this new knowledge, there is a clear need for a focused lunar orbital mission to better understand this water and related processes at the Moon. The science objectives – e.g., understanding water-related volatiles in the inner solar systems – are high-priority objectives in the 2014 NASA Science Plan, the 2013-2022 Decadal Survey, and directly address Lunar Strategic Knowledge Gaps.

While a Discovery-class mission could conduct the full set of science objectives, large subsets of the objectives can be accomplished using small-sats. These low-cost missions can be enabled by leveraging rideshare launch options (e.g., EELV Secondary Payload Adapter), implementing innovative propulsion technology (e.g., solar electric propulsion), miniaturizing instruments, and using more efficient communications compared to interplanetary missions. The associated trade studies will consider orbital requirements, instrument payload, and mission duration.

Science Rationale and Approach: Previous missions have made ground-breaking discoveries about lunar water but also have been dramatically limited in their subsequent investigation by not obtaining both a global perspective of the Moon with a wide range of terrains seen at once at different local times of day, and also by not being able to observe inside and outside of permanently shadowed regions (PSRs) with the appropriate measurements at the appropriate spatial scales to characterize the water/geologic/temperature dependencies. Within PSRs, high spatial resolution (~10 km/pixel) neutron mapping correlated with surface frost imaging (UV and/or active IR) and archived temperature maps within PSRs could resolve complex relationships of the chemistry and distribution of water to provide insight into the origin and evolutionary processes that led to the current distribution of water at the poles. Spectral mapping of the 3-μm feature on the illuminated Moon across a range of local times will determine its chemical composition and unambiguously characterize any diurnal variation for possible accumulation of H_2O at the poles. Combined with neutron observations, the 'water cycle' that may transport H_2O globally and within the near surface could potentially be understood. Quantitative estimates of the global distribution and variability of solar-wind-proton implantation rates and simultaneous observations of OH band depth will provide insight into the source and loss of OH in the lunar surface. Other measurements would greatly increase the science return to include radar sounding the PSRs to search for subsurface ice deposits. Additionally, in-situ sampling of possible water molecules released from the surface would help quantify specific source mechanisms. The payload capability of a smallsat is extremely limited; thus, the scientific value of a measurement will be traded against the available spacecraft resources.

Technical Approach: A goal of this study is to determine a feasible payload suite from a variety of possible instruments. A highly eccentric orbit is essential for the science and instrument measurements. A duration of greater than one lunation is the minimum time needed to separate exogenous inputs and loss mechanisms. A high apoapsis (1000s of km) enables global correlations between surface 'water' chemistry, abundance, surface temperature, and solar wind input. A low-altitude polar perilune will enable high-spatial-resolution measurements of polar volatiles such as with a neutron spectrometer (NS), an active IR multispectral imager, a multispectral UV imager to characterize the water in the PSRs, and/or a low-resource radar sounder to characterize subsurface ice. At apolune, global information is obtained on the formation, loss mechanisms, and evolution of OH and H_2O on the illuminated Moon using a Faraday cup to measure the solar-wind proton flux impinging on the surface, a neutral atom imager to understand the reflected portion of the solar wind, and a single channel mass spectrometer for quantifying molecular water production. An IR spectral imager can investigate the OH and any H_2O formed.

The general orbital approach is straightforward; it will be either drop-off from a spacecraft passing the Moon or will require a transfer orbit from, for instance, geosynchronous orbit to spiral into lunar orbit. A gradual transition from either GEO, combined with the need for constant input to maintain a low periapsis requires significant deltaV and makes this mission suited for solar electric propulsion. It also provides ample time to execute global observations of the Moon

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CANADIAN SPACE AGENCY ACTIVITIES AND SCIENCE PRIORITIES RELATED TO LUNAR SURFACE EXPLORATION.
V. J. Hipkin[1], M. Picard[1], T. Haltigin[1], Y. Gonthier[1], C. Lange[1] and P. Jean[1], Canadian Space Agency, 6767 Route de l'Aeroport, St Hubert, Canada, J3Y8Y9; Email: Victoria.Hipkin@Canada.ca.

Introduction: The Canadian Space Agency (CSA) is engaged in preparing for a role in human exploration beyond Low Earth Orbit. Studies are underway to determine potential significant contribution(s) of similar visibility and impact to Canada's Mobile Servicing System on the International Space Station. These studies include concepts and technology development for lunar surface mobility.

In parallel, in the context of Canada's Innovation Agenda, the CSA is renewing its planetary science priorities through consultation with the Canadian community, to better understand potential instrument and secondary payload contributions to robotic science as well as human exploration missions. In November 2016, 204 scientists, engineers and students from Canadian academia, industry and government gathered in Montreal for a workshop entitled 'Canadian Space Exploration: Science and Space Health priorities for next decade and beyond' [1]. Along with similar exercises for space astronomy and space health, four planetary science Topical Teams (*Astrobiology; Planetary Atmospheres; Planetary Geology, Geophysics and Prospecting; and, Planetary Space Environment*) were convened to take input from the workshop and develop reports detailing the community's priority science objectives and potential instrument, mission and human exploration investigations. A similar Canadian community workshop was held in 2008 [2], where the community was asked to develop specific priorities for the Moon, Mars and asteroids within the context of the Global Exploration Strategy. A number of new instrument investigation concept studies are planned for 2017 as well as small mission (secondary payload) concepts and investments to further mature concepts that were previously developed and for which the priority has been reaffirmed by Topical Teams in 2017.

Canadian science priorities for lunar surface exploration: This paper will present a summary of priorities from Topical Teams relevant to lunar surface exploration. Universally, the planetary topical teams chose to organize science objectives as broad questions applied to the solar system. With exception of the planetary atmospheres group, all topical teams identified lunar surface investigations amongst their 2017 priorities. An updated Canadian science priorities report is in preparation at the time of LEAG abstract submission.

Recent studies related to lunar surface exploration: This paper will present results from recent studies. Since 2009, the Canadian Space Agency has funded several studies related to lunar surface exploration, from small rovers designed for scientific exploration to 'moon buggy' systems for human exploration, building Canadian expertise in surface mobility systems, drilling, and in analogue mission deployments using prototype systems [3]. Requirements for compact rovers were developed in the context of NASA's Resource Prospector and ESA's HERACLES [4] mission concepts. A major technology development study that has recently completed is the Lunar Rover Platform and Drivetrain Prototype (LRPDP), a TRL-6 prototype derived from the CSA's Artemis Jr platform [5] tested under lunar-representative environmental conditions of 'dirty' T-VAC using CHENOBI regolith simulant. A TRL-4 Small Planetary Rover Prototype (SPRP) was also developed in 2016 to advance low cost solutions to surface exploration. Weighing in at 95kg it uses the same drivetrain as the LRPDP to ensure portability of the TRL-6 solution.

Current studies: CSA remains an active partner with JAXA in ESA's HERACLES mission concept development, leading the lunar surface rover component, with interest in using HERACLES to demonstrate technology solutions which could be scaled to a potential lunar surface human pressurized rover chassis contribution. Current CSA studies are described that include twin industry studies that will each develop a detailed lunar surface mobility concept for two main assets: (1) Precursor to Human And Scientific Rover (PHASR) (2) Lunar Pressurized Rover Core (LPRC). A CSA Lunar Demonstrator Mission Science Maturation Study is also underway which will provide input to a strawman rover payload for PHASR that will select samples for sample return.

It is anticipated that should an ESA-led HERACLES mission go forward with international partners, an international science definition study would confirm payload and landing site.

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SPACE TRANSPORTATION NETWORK ANALYSIS FOR CISLUNAR SPACE ECONOMY WITH LUNAR RESOURCES. K. Ho[1] and H. Chen[1], [1]University of Illinois at Urbana-Champaign, (Talbot Laboratory, 104 South Wright Street, Urbana, IL, 61801, kokiho@illinois.edu, hchen132@illinois.edu).

Introduction: This work provides a transportation network analysis of lunar exploration architecture and cislunar mission design with lunar in-situ resource utilization (ISRU). This analysis is performed using a mathematical model for space transportation network analysis for cislunar resource economy. We propose a campaign-level integrated optimization framework that can (1) design a sequence of (potentially interdependent) missions concurrently with lunar resource as a potential propellant source; (2) select the ISRU architecture and/or technologies; (3) select the potential vehicles from a reslistic set; (4) provide an economic analysis of lunar resource. The proposed analysis method can be used to advance our quantitative and qualitative understanding about mission design for profitable cislunar space economy with lunar resource, and thus support design of a more self-sustained resource economy in cislunar space.

Methods: Our methods are based on the time-expanded mixed-integer generalized multi-commodity network flow (GMCNF) model [1-3]. In our model, space transportation map is converted into a network, where the nodes correspond to planets, celestial objects or orbits, and the arcs correspond to trajectories. With this conversion, space mission design problem can be considered as a mathematical network flow optimization problem. The formulation can take different objective functions; one example would be the campaign lifecycle cost including technology development, vehicle production, launch, and operations over all missions, while it can also include other metrics such as risk or robustness. In order to consider multiple missions concurrently, a time-expended network is considered that can effectively integrate the time dimensions into our analysis. By approximating the existing ISRU infrastructure design models, our method can also consider ISRU infrastructure sizing as part of the tradespace. With a set of vehicles we can use, we can optimize the routing of each vehicle trading off the associated cost and benefits in the campaign. The resulting model can be formulated as a mixed-integer linear programming (MILP) problem, which can be solved computationally efficiently with commercial software such as Gurobi or CPLEX.

In addition to optimizing the mission planning and vehicle design, the proposed method can also be used to evaluate the impact of different technologies to the systems architecture. For example, we can evaluate the pros and cons of lunar ISRU at a campaign level considering both its development/deployment cost and its benefits during the operation. Our past studies have shown an effective deployment plan of ISRU plants is critical to maximize the value of ISRU technologies [1-2]. This rigorous analysis method can fairly evaluate the value of ISRU technology and can be integrated into decision making for technology roadmapping.

Using the above methods, we introduce optimized transportation architectures for robotic and human lunar exploretaion missions and discuss the impact of lunar ISRU to various cislunar missions and campaigns. In addition, a preliminary analysis about propellant transportation after ISRU deployment is also introduced to provide an estimate of economic value of ISRU. The influences of mission scenarios, ISRU system architecture (i.e. concentrated ISRU system or distributed ISRU system), and launch vehicle capacity to the space transportation system are also analyzed.

Conclusions: With the proposed methods and the case study in lunar missions, we aim to demonstrate the capability of our method to analyze the cislunar space resource economy. We also aim to identify the bottleneck of the cislunar transportation network as well as the potential opportunities for commercialization and/or public-private partnerships.

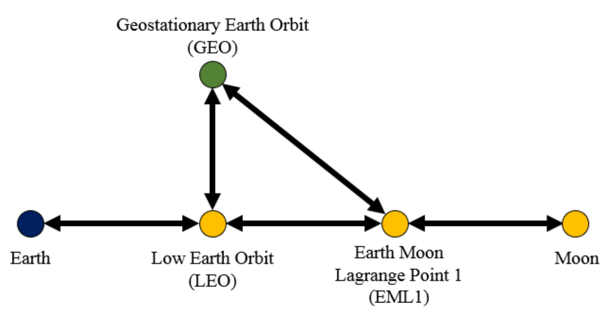

Figure. Example network for cislunar transportation.

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FIELD TEST OF ROUTE PLANNING SOFTWARE FOR LUNAR POLAR MISSIONS. A. D. Horchler[1], C. Cunningham[2], H. L. Jones[2], D. Arnett[2], E. Fang[2], E. Amoroso[1], N. Otten[2], F. Kitchell[1], I. Holst[2], G. Rock[1], and W. Whittaker[1,2]. [1]Astrobotic Technology. 2515 Liberty Ave, Pittsburgh, PA 15222. andrew.horchler@astrobotic.com [2]Carnegie Mellon University Robotics Institute. 5000 Forbes Ave, Pittsburgh, PA 15213. red@cmu.edu

Introduction: Limited time, power, and communication constrain rovers that explore and conduct science operations on planetary surfaces. At the lunar poles, this is complicated by the way illumination and communications availability vary across time and space. To make best use of rovers in these difficult environments, efficient planning and sequencing tools are essential.

Spatiotemporal path planning software that accounts for illumination, communications availability, hazard avoidance, and energy usage during route generation has been developed [1], [2]. This software enables mission planners to develop efficient trajectories and sequence multiple science targets. Imprecision in environmental or rover models can be mitigated by risk-tolerant planning, e.g., velocity margins or requiring a minimum distance from shadows. The planning software relies on a physics-based simulation tool, AVOI [3], that uses digital elevation models to render ephemeris-accurate illumination and communications-availability maps.

We have developed a novel field test paradigm to demonstrate and validate planning for a lunar polar environment. An interactive user interface (Fig. 1) was also developed to help users effectively generate and understand plans.

Methods: Simulating the stark low-angled light and sweeping shadows a rover would experience at the poles of the Moon in a relevant environment field test depends on many factors. An artificial lunar landscape, consisting of several 1–2-m high mounds of fine aggregate, was created. Tests were run at night with a 1,000-W spotlight simulating the Sun. To mimic the Sun during the course of a lunar day, the light was towed at a steady pace along a semicircular path.

A LiDAR survey of the 80×80-m field test site was rasterized to 1 cm/pixel and then downsampled to obtain a 0.5-m/pixel elevation map. The properties of the simulated Sun and its approximate position in time were used by the AVOI tool to generate illumination maps (Fig. 2). These were then used in conjunction with the planning software to generate spatiotemporal paths visiting one or more waypoints. Planned paths were uploaded to an AutoKrawler (Fig. 3), a custom 13-kg, 500-W, highly maneuverable rover that operates autonomously, logs data, and transmits live telemetry [4].

Field experiments were designed to demonstrate the software's ability to generate spatiotemporal paths and the ability of risk-tolerant plans to compensate for low resolution maps and imperfect rover control. Test runs

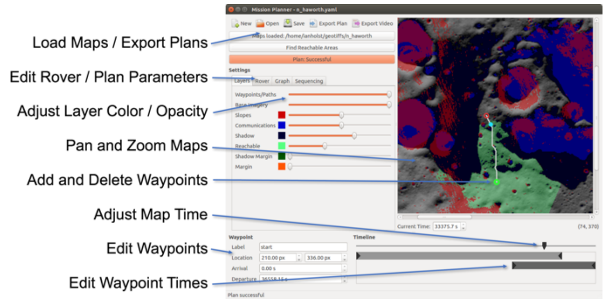

Figure 1. Route planning software user interface.

Figure 2. (Left) Overhead drone images of the field test site and simulated Sun. (Right) Renderings approximating the drone's view and light position.

Figure 3. AutoKrawler rover lit by low angle light.

(N=18) were evaluated based on the percentage of time the rover remained in the light. The rover never entered shadows during risk-tolerant plans, whereas nominal plans sometimes caused the rover to enter shadows when it lagged the intended trajectory or when the light timing was deliberately shifted. Field testing successfully demonstrated and validated our algorithms and software in a realistic lunar polar mission scenario.

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LOW-FREQUENCY MOON-BASED RADIO-INTERFEROMETER FOR EARTH STUDIES

Derek Hudson[1] and Giovanni De Amici[1]
[1]NASA Goddard Space Flight Center, code 555, Greenbelt, MD 20771
Derek.L.Hudson@nasa.gov, Giovanni.DeAmici@nasa.gov

We suggest that the concept of a Moon-based array of microwave antennas and up-gradable electronics, facing the Earth, to measure soil moisture, sea surface salinity, etc. be matured.

Measurements of the water cycle provide essential information for an important climate variable. The capabilities of the measuring instruments lags somewhat behind the development of the models, and the existing blueprints cannot be easily scaled to provide the spatial (5 km footprint, Nyquist –sampled) and temporal (1 day revisit time or shorter) resolutions that are needed to validate the details of the models. Improvement in radiometric sensitivity would be welcome, but the advantage from any technological advance in the performance of front-end amplifiers is limited by the inevitable thermal noise in the scene being measured.

The study of soil moisture content and temporal evolution requires fine spatial resolution and frequent revisit. There is no conceivable architecture that can better deliver the low-frequency (for soil penetration) long baseline (for spatial resolution) and daily revisit than an instrument sited on the Earth-facing surface of the Moon.

Although the Earth science community has long sought the means to perform high-spatial-resolution measurements in the 1 GHz range of geophysical phenomena, this need has historically been satisfied with more complex missions flown in Low Earth Orbit. It is conclusive that such an approach is capable of producing a modest factor of improvement within the next decade. And it will succeed if public interest (funding) is high enough. Beyond that next step, the antennas or antenna arrays would have to be so large that it raises the question of whether it is more practical to build them on the surface of the Moon -- even with the factor of 500 distance penalty -- rather than trying to construct them in LEO (whether as enormous real apertures which upscale NASA's SMAP mission or as constellations of antennas in which the exact relative positions of the elements must be precisely known and somewhat controlled, similar to ESA's successful SMOS interferometer mission).

The advantage of an interferometer on the surface of the Moon to Earth studies are evident and remarkable. - Continuous and unbroken temporal coverage. - Spatial resolution that is only limited by the (easily-adjustable) separation of the antennas, - Sensitivity which is limited by the number of antennas (also easily scalable).

The drawbacks are also evident. - Any evolving weather situation can go out-of-sight for 14 hours as the Moon sets. - Look angle and beam footprint are modulated by the lunar orbit and libration. – Radiometric performance must account for extreme monthly temperature excursions on the electronics and mechanical components. But these difficulties should be seen as engineering challenges, rather than scientific limitations.

The art of building long-baseline interferometers is well proven on the earth's surface (radio astronomy arrays), and the usefulness of this facility can be proven even with a small array, making the instrument easily up-scaleable in size and performance. Even a better-than-1-km resolution is achievable.The hardware would be semi-permanent: after the problems of first construction are overcome, it becomes relatively easy to replace any component that fails from age or exposure to the space environment (e.g. meteorite hit). This architecture is in line with business plans to extend the commercial sphere of humanity to the Moon. We envision assisting private industry, academia, and possibly other nations to be the principle actors, with U.S. government playing only a supportive role.

Antenna arrays on the Moon would also be well suited for other applications – such as communications with Earth and with deep space; and very long baseline interferometry (VLBI) in which Earth antennas and Moon antennas combine to form baselines which are much longer than those achieved on Earth alone, with applications to astrometry and other areas of radio astronomy and to spacecraft tracking.

From an emotionless technological perspective, the answer to the question of LEO versus lunar surface is not easy to foresee. Though the answer could be explored, we note that the public are not emotionless system engineers. Building things on the Moon adds additional facets of public interest and enthusiasm. Coupling that with public desire for better Earth science can create a win-win situation, uniting the passions for Earth science, planetary exploration/science, and human exploration. It therefore seems plausible that a Moon-based microwave instrument is more likely (than LEO instruments) to be funded sufficiently to achieve long-term Earth science objectives.

ispace and the lunar missions ahead R. Ichikawa, ispace inc., 1-3-6 Azabudai, Minato-ku, Tokyo, 106-0041 r-ichikawa@ispace-inc.com

Introduction: This presentation will introduce ispace, a lunar exploration company headquartered in Tokyo, Japan, and Team Hakuto, a front-running team participating in the Google Lunar XPRIZE (GLXP) competition. The presentation will begin by introducing ispace's vision and the technology that ispace is developing for lunar exploration. Next, the presentation will outline ispace's mission plans and rover capabilities. The presentation will conclude by explaining the three-step plan to utilize resources on the lunar surface, while discussing opportunities for the scientific community.

ispace & Water on the Moon: ispace technologies is the commercial arm that manages Team Hakuto in the GLXP Mission. Founded in 2013, its mission is to find the resources necessary to extend human life into outer space. ispace's primary goal is to locate and utilize water on the lunar surface. Observations from the Moon Mineralogy Mapper aboard India's Chandrayaan-1, and measurements from NASA's Lunar Reconnaissance Orbiter, each provide strong evidence for the presence of water ice on the Moon [1]. The water may originate from endogenous sources, delivery by comets or asteroids, or implantation by solar wind [2]. While extracting hydrogen and oxygen from lunar regolith will require significant amounts of energy and infrastructure, the higher concentrations of lunar ice which have been discovered at the Southern Lunar Pole and more recently in the skylight could offer an energy-efficient alternative. In 2009, LCROSS impacted the permanently shadowed crater Cabeus and measured a water ice concentration of 5.6-2.9 wt% [3]. Ground truthing missions are needed in order to further verify the distribution of lunar ice in permanently shadowed and other regions.

ispace has a three-step plan that will demonstrate its technology, locate, map and measure resources, and finally utilize those resources on the lunar surface. ispace will have its first attempt to demonstrate its rover technology during the GLXP mission. Secondly, in the early 2020's, ispace will develop a number of future prospecting missions that will improve our understanding of how and where to mine lunar resources. In this phase ispace plans to partner with space agencies and the scientific community for sensor and technology development to better detect and understand water ice deposits. ispace has been working closely with multiple exploration and science payload developers in the United States, Europe and Japan. In March of 2017, ispace created a new office in Luxembourg under the auspices of the Space Resource Initiative. As a part of this program, ispace is teaming up with the Luxembourg Institute of Science and Technology who will develop a Mass Spectrometer. Finally, depending on the location, distribution, quality and quantity of the lunar ice, ispace will develop extraction, processing, and utilization techniques with interested industrial partners. An ultimate goal is to convert the ice to fuel and deliver it to private companies such as the United Launch Alliance, who recently offered to purchase fuel on the lunar surface for $500/kg [4].

Team Hakuto: ispace owns and operates Team Hakuto, the only Japanese Team competing for the 30M GLXP competition. During this first mission we will join team Indus on a trip to Mare Imbrium. Team Indus's lander will deploy the 4kg rover will attempt to survive one lunar day. The rover will travel at least 500m to achieve the required objectives of the GLXP. In order to further test and demonstrate new technologies, the rover will attempt long distance travel. The traverse will be executed in a flower petal pattern, repeatedly circling back toward the host lander to be photographed. The mission will provide a low cost opportunity to demonstrate our technology. In the future this technology can be further used to investigate promising regions for potential resource deposits.

Supporting Science: 2017 is the beginning of a new era of exploration with cost-efficient opportunities for scientists on commercial missions. Japan Aerospace Exploration Agency is partnering with ispace and Team Hakuto to send a dosimeter to measure cosmic rays and solar wind for future human missions. By decreasing the overall mass of the rover, ispace is able to accommodate future opportunities for scientific payloads and offer the scientific and space technology community unprecedented economical opportunities to gather data and test instruments, algorithms, and equipment during our missions.

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STRUCTURAL MEMBERS PRODUCED FROM UNREFINED LUNAR REGOLITH SIMULANT

S. Indyk[1], H. Benaroya[2], [1]Honeybee Robotics, 398 W. Washington Ave, Suite 200, Pasadena, CA 91103, indyk@honeybeerobotics.com. [2]Rutgers University, 98 Brett Rd, Piscataway, NJ 08854, benaroya@soe.rutgers.edu.

Introduction: The potential of utilizing lunar regolith as the raw material for manufacturing structural members is very appealing for future exploration of the Moon [1,2]. Future lunar missions will depend on in-situ resource utilization (ISRU) for structural components. Manufacturing structural components directly from unrefined lunar regolith would have the advantage of needing less specialized material processing equipment in comparison with refining the lunar regolith for its raw elements. Sintering lunar regolith has been proposed as a structural material by previous researchers but has not been evaluated for its elastic material properties. Sintering can be a highly variable process and only with the material constants can a structure be designed from this material.

Background: Sintering of actual lunar regolith has been accomplished by Taylor and Meek [3] using microwaves. However, there is not enough lunar regolith available for destructive testing to accurately quantify the mechanical material properties of sintered regolith. Lunar simulant substituted for lunar regolith in experiments then becomes the commonplace. The lunar simulant JSC-1A has become the standard for researchers in the topic of structural ISRU. Through a geothermic reaction produced by the inclusion of additives, JSC-1A has been used to fabricate bricks for constructing a voissoir dome as performed by Faierson et al. [4]. In addition, Balla et. al. [5] has utilized JSC-1A, filtered for particle size, as the base material in a selective laser sintering (SLS) machine to prove the simulants additive manufacturing potential. As a proof of concept, fabrication of small solid cylinders was performed and the parameters for the SLS machine were evaluated. Focusing on developing an optimal method of sintering lunar simulant, Allen, et al. [6] compared the fabrication of bricks with two unrefined simulants, JSC-1and MLS-1.

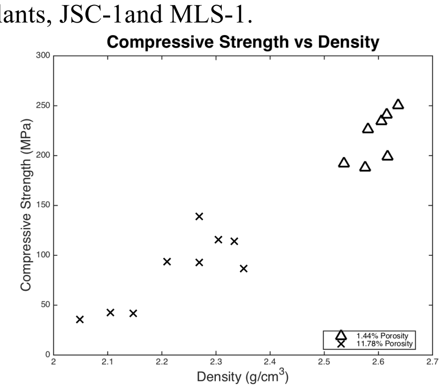

Figure 1. Compressive Strength Vs Density of the sintered specimens.

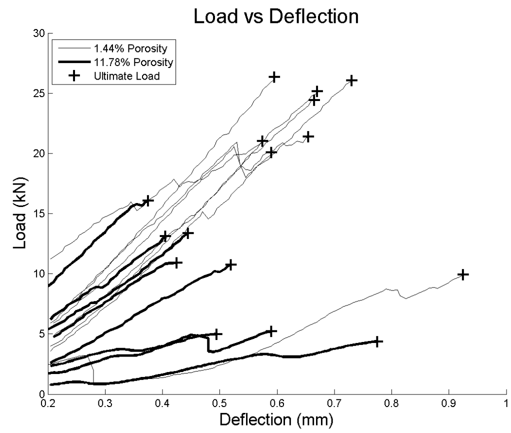

Figure 2. Load vs deflection for all compression tests.

Test Results and Data Analysis: Two batches of sintered lunar regolith simulant, JSC-1A samples with porosities 1.44% and 11.78% underwent compression testing. This is a followup of last years presented research work for quantification of the material properties. Analysis of the data sets continued and were reevaluated based on the comparative material density. Compressive strength compared to the density as shown in Figure 1 shows two clear classes of material quality. The average compressive strengths of the 1.44% porosity material were 219 MPa, and 85 MPa for the 11.78% porosity material. Material properties were evaluated from the load vs. deflection data acquired. Stress, strain, modulus of elasticity, toughness, the compression strength, bulk modulus. Figure 2 shows the load vs deflection until failure of each specimen. By comparing these values with other ISRU derived structural materials, sintered lunar regolith is expected to be one of the strongest material derived from lunar sources.

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SPECTRAL UNMIXING MODELING OF THE ARISTARCHUS PYROCLASTIC DEPOSIT: ASSESSING ERUPTIVE HISTORY AND EXPLORATION POTENTIAL OF GLASS-RICH REGIONAL LUNAR PYROCLSTIC DEPOSITS. Erica R. Jawin[1], James W. Head[1], and Kevin M. Cannon[2], [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI 02912 USA, (Erica_Jawin@brown.edu), [2]Planetary Sciences Group, University of Central Florida, Orlando, FL 32816.

Introduction: The Aristarchus Plateau in central Oceanus Procellarum is viewed as the most diverse volcanic complex on the Moon [*1*], containing the largest pyroclastic deposit [*2*] which is understood to be ~20 m thick and rich in volcanic glass [*1–5*]. Pyroclastic deposits are of interest for future exploration potential due to the concentrations of easily extractable in-situ resources such as O, Fe, Ti, H^3, and H_2O [*6–8*].

While many authors have reported the glass-rich nature of the Aristarchus pyroclastic deposit, the interpreted color (and therefore composition) of the glass varies between analyses, including orange (high-Ti) [*1*, *2*], green (low-Ti) [*9*], and yellow glass (intermediate-Ti) [*10*]. In addition, previous spectral analyses of the Aristarchus pyroclastic deposit have been performed using lower resolution data than are currently available. In this work, high-resolution spectral data from the Moon Mineralogy Mapper (M^3) [*11*] are applied to investigate the nature of the Aristarchus pyroclastic deposit, with four objectives: (1) What is the degree of mineralogic variability of the pyroclastic deposit? (2) What kind (color) of volcanic glass is present, and how does it vary in abundance across the deposit? (3) What can we determine about the eruption conditions on the Aristarchus Plateau from this analysis? (4) What is the exploration and in-situ resource utilization (ISRU) potential of the Aristarchus pyroclastic deposit?

Methods: We apply Hapke theory of radiative transfer modeling [*12*, *13*] to nonlinearly unmix M^3 data. The approach (modeled after [*14*, *15*]) models a spectrum as a five-component mixture where three components are laboratory mineral endmembers, the fourth component is a flat line approximating lunar space weathering effects, and the fifth is a laboratory spectrum of a returned Apollo volcanic glass or a synthetic lunar glass (modeled glasses include green, orange, yellow, red, and black) [*16*]. Reflectance between is converted to single-scattering albedo (SSA) and a spectrum is mathematically inverted to give relative abundances of each endmember.

Results: The Aristarchus pyroclastic deposit is very low albedo and the pyroclastic materials contain very shallow absorption bands centered at approximately 1000 nm and 1800 nm. Preliminary results of the M^3 unmixing suggest that spectra of the pyroclastic deposit can be modeled by a mixture composed predominantly of a featureless endmember (indicating a space weathered target) and a smaller component of glass. Various glasses were able to give relatively good fits, but the most accurate fit was generated by using a synthetic orange glass endmember.

Discussion: The results shown here confirm that there is a detectable component of glass in the Aristarchus pyroclastic deposit which may be similar to the high-Ti orange glass seen in other regional pyroclastic deposits [*17*], with minimal contributions of other crystalline mineral components, suggesting that soil is dominating the spectral fraction. These results are in agreement with several previous analyses [*1–5*].

The presence of volcanic glass in the pyroclastic deposit, with the low abundance of crystalline material, supports the model that the Aristarchus pyroclastic deposit formed in a long-duration, hawaiian-style fire fountain eruption [*18*, *19*]. Glass abundance did not vary significantly across the deposit, and there was no significant detection of devitrified black beads (as was observed at the Apollo 17 landing site in the Taurus-Littrow pyroclastic deposit [*17*]) in the modeling results. These observations suggest that the eruption optical density remained low throughout the eruption [*5*].

The confirmation of abundant glass that may be rich in titanium in the Aristarchus pyroclastic deposit has implications for the future exploration and in-situ resource potential of this region. Spectral analyses, combined with other data sets such as radar CPR (e.g., [*3*]) and mapped water content [*8*] can help to identify regions where the pyroclastic deposit is thickest and most abundant in useful resources. Regional pyroclastic deposits such as that on the Aristarchus plateau therefore represents a key region of scientific and exploration potential, and should be of high priority when considering future human exploration destinations.

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SYNTHESIZING SURFACE AND SUBSURFACE MEASUREMENTS OF WATER ICE IN THE POLAR REGIONS OF THE MOON. A. P. Jordan[1,2*], J. K. Wilson[1,2], N. A. Schwadron[1,2], and H. E. Spence[1,2], [1]EOS Space Science Center, University of New Hampshire, Durham, NH, USA (*email: a.p.jordan@unh.edu), [2]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, CA, USA.

Introduction: Knowing how water is distributed in the Moon's polar regions helps determine the origin of the water and how it can be accessed for in situ resource utilization. Yet it is unclear why some permanently shadowed regions (PSRs) lack ice and why surface and subsurface measurements seem to disagree regarding the locations of deposits of water ice. We show how to synthesize these disparate measurements—ultraviolet (UV), infrared, neutrons, and albedo protons—into a result that tightly constrains the origin of water ice on the Moon.

Surface Data: We first consider three instruments that can remotely measure even within PSRs. First, the Lyman Alpha Mapping Project (LAMP) on the Lunar Reconnaissance Orbiter (LRO) measures UV emitted by stars and the interplanetary medium and subsequently reflected off the lunar surface. LAMP's off-band to on-band signal ratio indicates the presence of surficial water ice. This ratio increases with increasing latitude, at least poleward of -75° and is independent of large PSRs [1]. Extrapolating beyond what the authors show suggests that water ice maybe detected as far equatorward as about -70°.

LRO also carries the Lunar Orbiter Laser Altimeter (LOLA), which can actively measure surface albedo with a 1064 nm laser. Regions of anomalously high albedo can be due to exposed water ice. The albedo as a function of latitude shows, in the authors' words, "upticks" above latitudes of ±70° [2], indicating an increasing fraction of water ice.

The third instrument is the Moon Mineralogy Mapper (M3) on Chandrayan-1. M3 has detected the specific absorption features of water ice in PSRs that are indirectly illuminated [3]. All detections occur poleward of ±70°.

Subsurface Data: Both the Neutron Spectrometer on Lunar Prospector (LPNS) and the Lunar Exploration Neutron Detector (LEND) have found similar trends with latitude due to hydrogen in the upper ~50 cm of regolith. Away from the poles, both datasets are fairly flat with latitude, but they show clear poleward decreases beginning near ±70° [4, 5]. Even when large regions of neutron suppression are removed from LEND data, the trend remains [6].

The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on LRO measures protons ejected from regolith by cosmic rays. Cosmic ray collisions create protons and neutrons. The same hydrogen that suppresses neutrons leaving the regolith also enhances the "albedo" protons [7]. Although the current resolution in latitude is too low to determine whether a rollover occurs at ±70°, the data do show that albedo protons increase with increasing latitude. We are creating a new data product with improved statistics and background correction; perhaps it will show the same trend as the other datasets.

Modeling Cold Traps: The similarity between all the datasets, including one which unambiguously detects water ice spectra, strongly suggests that all are measuring water ice and not just various forms of hydrogen. This is further confirmed by simulations showing that surface and subsurface cold traps become important with increasing latitude [8]. Although the published results of these simulations do not extend equatorward of ±75°, the trends are consistent with what is observed by most of the instruments above. And because subsurface cold traps can extend to lower latitudes than surface cold traps, subsurface ice can be present to lower latitudes than subsurface ice. This difference could be revealed by comparing more carefully the above surface and subsurface measurements.

Conclusion: These measurements indicate that water ice is distributed throughout the polar regions of the Moon down to about ±70° latitude. This distribution may aid in situ resource utilization. Furthermore, the consistency across these datasets and simulations suggests an ancient cometary impact or impacts deposited the water. If the majority of the ice were created more constantly in time via the solar wind, we would expect most craters to be similar. An ancient impact or impacts, on the other hand, could create the above large scale correlation that would be disrupted on smaller scales, i.e., large PSR scales, by subsequent impacts. This could explain why the above datasets are correlated on large scales but may disagree on smaller scales. The above synthesis thus strongly constrains the possible origins of water ice on the Moon.

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BUILDING THE FOUNDATIONS FOR A LARGE SCALE, CROSS-SECTOR COLLABORATION FOR A PERMANENT AND SUSTAINABLE RETURN TO THE MOON SURFACE. Angeliki Kapoglou[1], [1] Moon Village Association.

Introduction: An increasing number of credible, governmental and private sector efforts are currently underway to bring a sustained human presence to the Moon. However, particularly in the private sector, these organizations are not well coordinated or actively collaborating to the detriment of all. The challenge for the lunar exploration community? How can we collectively prepare for novel, cost-efficient and agile programs for lunar settlement and allow for space agencies, commercial space, philanthropists and citizens to create an integrated, mutually reinforcing strategy? To explore together we also need to design new ways of working together.

This challenge arises from the broad mix of expertise common on cross-industry teams. Enabling a permanent and sustainable return to the Moon will require building trust and collaboration between leaders in the private and public sectors unused to working together. Participants will often live in different intellectual worlds and have distinct technical languages. Thus when cross-industry teams come together, they might suffer from culture clash. However, to make real progress we have to harness the best thinking and judgment of our best innovators, experts and decision makers out there— especially when they don't agree. In practice, this means creating value for the overall system but also actively surfacing and resolving tension within the system. Our stakeholders' many differences— of role, of mindset, of culture, and more— can be rich sources of insight. But these differences have to interact with one another in the right ways to create value. Orchestrating this kind of collective effort is possible but it requires a new scale of leadership: System Leadership. Too often collaboration is thought to be driven by alignment to formal project plans, investment memos, and impact metrics. What's also needed is the informal sense of shared values, common language, and trust in others' intentions to tackle the issues and problems that emerge "off-plan". Therefore, we advocate that there are two major and parallel design challenges for the lunar exploration community:

1. **The Design of the technical artifacts:** the infrastructure needed for a permanent and sustainable human return on the Moon and its key technical and scientific elements.
2. **The Design of the intervention that brings the vision to life:** the international partnership; the introduction and integration into the status quo and the acceptance by the stakeholders.

To date, much of the dialogue in the space sector has focused on engineering and science and less on the intervention that is needed to ensure an effective, large scale and cross industry collaboration on the Moon surface. However, one of the biggest differentiators between success and failure in implementing large scale system innovations is whether the emotional dynamics of what it takes for people to trust each other are factored into the strategy. In order to design effective interventions, we must pay attention not just to formal procedures, but also to culture. During this transition phase, we need to properly account for the fact that we are asking the people in the system to change—people with pride in what they do, knowledge of subtle details about how things work, and personal relationships with colleagues who help them solve problems.

A permanent and sustainable human presence to the Moon is ambitious, but we believe it is achievable in the coming decade if all the key actors in the ecosystem collaborate effectively. Therefore, this presentation will describe five key practices that we perceive as the most critical in building the foundations needed for large scale system design and cross-industry collaboration.

BUILDING ON THE CORNERSTONE MISSION: FOCUSED LRO WORKSHOPS TO SUPPORT SCIENCE TEAM SYNERGIES. J. W. Keller and N. E. Petro, NASA Goddard Space Flight Center, Solar System Exploration Division (John.W.Keller@nasa.gov; Noah.E.Petro@nasa.gov).

Introduction: The Lunar Reconnaissance Orbiter (LRO) mission is now in its 8th year of operations. In that time the mission has evolved from it's focused ESMD exploration mission to a SMD science mission, and on to extended science missions [1, 2]. As part of that evolution the LRO project and science teams continue to look for ways to improve and enhance the mission. During the current "Cornerstone Mission" phase of the LRO mission [3] we have instituted a new approach to foster both inter-team collaborations as well as solicit input from scientists outside of the LRO science teams. In the first half-year of the Cornerstone Mission, LRO has supported four workshops that have brought together all of the science teams to collaborate on new analyses. Here we highlight these workshops and their outcomes, and briefly discus their impact.

Focused Workshops: During the Cornerstone Mission the LRO instrument teams have identified a number of key science themes that drive their observations during the extended mission [3]. These themes serve as a basis for the identification of the thematic workshops.

Young Lunar Volcanism: With the identification of possible recent lunar volcanism [4], a serious re-examination of our assumptions of the timing of volcanic activity has occurred. While the possibility of volcanism as recently as 50 mya is compelling, several questions about how to sustain such long-lived volcanism have been raised. This workshop brought together all of the seven LRO instruments as well as experts from outside the science teams to discuss the implications for such volcanism and future observations that may confirm or refute these findings.

Diurnally Varying Surface Hydrogen: The surprising pre-LRO discovery of varying surface hydration [5] has become a key question in the continued LRO observations at the Moon [e.g., 2, 6]. However, several possible alternate explanations for this observation have been made [7, 8] that do not support mobile hydrogen. With the ongoing LRO mission, a number of instruments can contribute to this question, while constraining either the amount of hydrogen that may be moving [9] or the spatial (both lateral and vertical) scales at which they migrate [2].

Rock-breakdown and Regolith Formation: A number of LRO observations have called-into-question long-held assumptions on the rate at which the regolith forms and rocks breakdown into regolith [10-12]. This workshop aimed at identifying lunar features that would serve as calibration points to best constrain what can observed remotely for understanding regolith formation.

Bombardment History: A number of recent publications have questions the long-held assumptions of when particular basins formed [13, 14]. These highlight the uncertainties in timing for a number of pre-Necartian aged basins, as well as a suite of uncertainties in the impactor flux and source of the impactors. This particular workshop not only highlighted the work to be done in identifying basin stratigraphic relationships between basins, but also how LRO data may be used to constrain the impactor populations in the earliest history of the Moon.

Outcomes: These workshops have acted to enhance existing LRO science team collaborations, and have lead to the development of new collaborations. During the remaining Cornerstone Mission, these interactions will improve the quality of the already high-quality LRO science. We also anticipate that these workshops will lead to the development of many new science questions for LRO to address in several future extended missions.

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ASYMMETRIC EJECTA EMPLACEMENT FROM SOUTH POLE-AITKEN BASIN: 3D HYDROCODE MODELING RESULTS. J. D. Kendall[1], [1]Purdue University, Department of Physics and Astronomy, 525 Northwestern Ave, West Lafayette, IN 47907 (email: jordan.d.kendall@gmail.com).

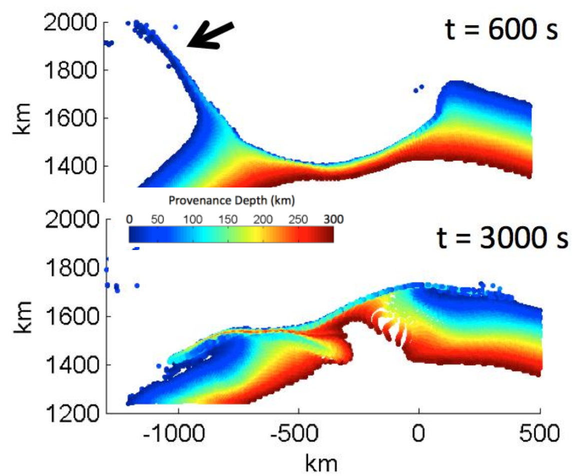
Introduction: The largest known impact on the Moon formed the South Pole-Aitken (SP-A) basin and excavated material as deep as the mantle. From crater scaling laws [1], the impact that formed the SP-A basin likely excavated material onto the surface that likely originated from the crust and upper mantle. Thus, SP-A is of great interest for future space missions and possible sample return missions [2,3]. Using the latest hydrocode modeling techniques and the highest resolutions yet achieved for SP-A, we find the SP-A impact ejected enough material to deeply cover the lunar farside. The SP-A basin, a ~2500 km diameter farside basin, is the largest and oldest observable lunar impact structure. The basin's elliptical shape is indicative of an oblique impact (around 30° to 45° to the horizontal) by an asteroid greater than 200 km in diameter traveling from South to North [4,5,6]. During the impact process, ejecta leave the crater and travel well beyond the transient crater rim (Figure 1) before emplacement upon the surface.

Numerical Model: We use iSALE-3D, an impact shock physics hydrocode capable of three-dimensional (3D) simulations [7,8], to determine the ejecta distribution, volume, and thickness for an obliquely-approaching impactor. We calculate the trajectory of ejecta that leave the crater and return to the lunar surface. Our work also incorporates the curvature of the lunar surface in 3D (entirety of Moon is modeled) for both the impact and ejecta models.

Results: In these simulations, an ejecta blanket forms (Figure 1), with a thickness of kilometers, over the entire lunar farside. The ejecta deposit primarily in a distorted annulus along the northern region of the SP-A basin and the nearby lunar farside highlands. Although the nearside-farside dichotomy is too large to be attributed entirely to SP-A ejecta deposition, the basin ejecta have nevertheless made a substantial contribution to the farside mass anomaly. In addition to ejection of crustal material, we predict that an impact of this scale also excavates and ejects upper mantle material beyond the transient crater rim and final basin rim.

We determined the thickness and original depth (or provenance depth) of the debris deposited for each point on the Moon's farside. The ejecta extends mainly downrange from the basin rim: very little is deposited uprange due to the obliquity of the impact (Figure 1). The range of the ejecta is inversely related to its initial depth. Crustal material (<50 km depth) travels farthest and blankets the largest area of the farside. Upper mantle material (>50 km depth) occupies a distorted annulus downrange of the transient crater rim. The ejecta volume and area decrease with increasing excavation depth.

Figure 1: We illustrate the evolution of mantle material as the crater opens and collapses. A 200 km diameter impactor strikes at 15 km/s and a 45° angle from the horizon (down and to the left). We plot only the tracers along the plane of impact with the center of the Moon at the origin. The tracer colors represent initial depth from the surface (dark blue) to an initial 300 km depth (red).



Conclusion: We find that the debris underlying the lunar farside highlands mainly consists of material excavated by the SP-A basin-forming impact. The Moon's upper mantle material is most likely to be exposed in close proximity to the SP-A basin's north rim. Our model and results will be useful for any future misisons to the South Pole-Aitken basin or large scale impact structures on the Moon.

Acknowledgements: We give special thanks to the developers of iSALE: Kai Wünnemann, Tom Davison, Gareth Collins, Dirk Elbeshausen, and Boris Ivanov.

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ASTROBOTIC RESEARCH AND DEVELOPMENT: NEW TECHNOLOGY FOR LUNAR SCIENCE AND EXPLORATION.
J. F. Kitchell[1], K. Snyder[1], E. Amoroso[1], and A. D. Horchler[1].
[1]Astrobotic Technology, Inc. 2515 Liberty Ave, Pittsburgh, PA 15222. research@astrobotic.com

Introduction: In March of 2016, Astrobotic created the Future Missions and Technology department, tasked with turning the company's current technologies into products and pursuing novel research contracts focused on space robotics applications. This focused effort builds upon the company's history of broad technology development for NASA through over 20 SBIR, STTR, and NIAC contracts. Here we present recent work on a range of space robotics technologies relevant to the lunar science and exploration communities and that will enable future missions to the Moon.

Terrain Relative Navigation for Precision Landing: In 2014, Astrobotic demonstrated visual terrain relative navigation (TRN) and LiDAR hazard detection to guide a rocket-propelled Masten Xombie to a safe landing (*https://youtu.be/kK-LwUcj2r8*). In 2017, the group has continued to refine our navigation system to minimize size, weight, power, and cost by leveraging space-tested COTS parts and hardware accelerated vision processing, for the purpose of providing precision navigation to a robotic lander. As NASA mission planners and Astrobotic's payload customers increasingly express interest in exploring the most challenging destinations on the Moon, Astrobotic sees a growing need for an affordable and effective TRN solution.

Navigation for Lunar Free-Flyers: Under a Phase II NASA STTR, Astrobotic is developing robust, GPS-denied navigation to allow free-flying robots to explore lunar skylights and lava tubes [1], [2]. The system fuses inertial measurements with stereo vision and 360° LiDAR scans for precision navigation, enabling free-flyers to safely and autonomously enter, map, sample, and exit from a cave or lava tube to a lander or roving base. Astrobotic will continue to develop these techniques to enable a multi-sortie lava tube mapping and sample collection mission incorporating a high degree of system autonomy.

Route Planning for Lunar Missions: In early 2017, Astrobotic, in collaboration with CMU, completed a Phase II NASA SBIR to develop software to plan safe rover missions at the poles of the Moon [3], e.g., Resource Prospector. The software extends mission durations, provides knowledge of safety margins, and maximizes science gain. Robust route planning optimization algorithms take into account time varying conditions, rover capabilities, risk specifications, and sequencing of science objectives. Astrobotic intends to further refine these tools to aid lunar mission planning and, eventually, volatile prospecting, infrastructure emplacement, and human settlement at the poles.

Lunar CubeRover: In May of 2017, Astrobotic was awarded a NASA SBIR to develop CubeRover, a concept for a 2-kg robot built to survive the harsh environment of the Moon while performing science aligned with NASA's lunar strategic knowledge gaps. The impetus behind CubeRover is to standardize and democratize surface mobility, analogous to the transformation CubeSats brought to the domain and economics of Low Earth Orbit. This will drive the space community to commoditize systems, components, and instruments. The first CubeRover will model blast ejecta and characterize terrain trafficability for small rovers.

Lunar Rendering: The Astrobotic Virtual Orbital Imager (AVOI) is a physically accurate lunar renderer to assist in precision landing, route planning, and landing site selection [4]. Using topography and ephemeris data, AVOI determines lighting and line-of-sight communication conditions at any date and location, and produces high-quality renderings and time-lapses. AVOI can be used for TRN by producing accurate georeferenced maps for a landing spacecraft.

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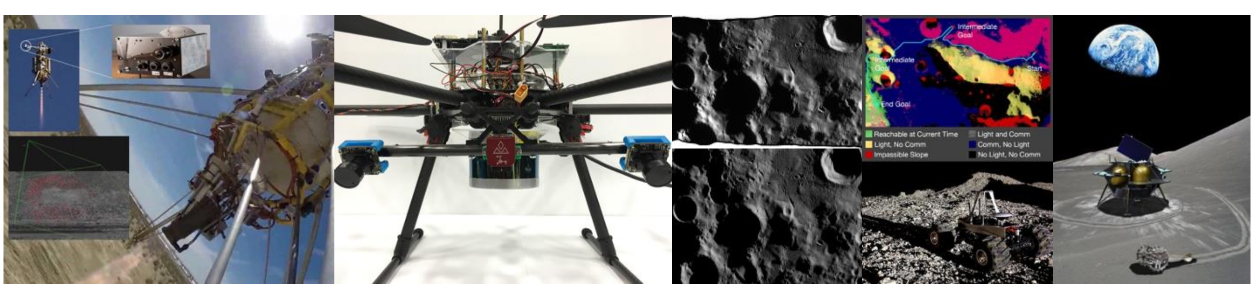

Figure 1. Astrobotic technologies: TRN demo, drone navigation, lunar rendering, route planning, CubeRover.

SCIENTIFIC OUTREACH OF THE LUNAR EXPEDITION I.0 IN THE LUNARES HABITAT IN POLAND. A. Kołodziejczyk[1,2,7], A. Rudolf [7], M. Gocyła[7], M. Młyńczak[5,7], I. Schlacht[2], E. Wierzejska[6,7] ,A. Waśniowski [6,7] ,L. Davidova[7,], P. Konorski[7], M. Słonina[7], D. Budzyń[7], J. Kuźma[7], G. Ambroszkiewicz[7], M. Harasymczuk[1,2,7], B.H. Foing[1,2,3] ([1]ESA/ESTEC & [2]ILEWG PB 299, 2200 AG Noordwijk, NL, Bernard.Foing@esa.int , [3] VU Amsterdam, [4] Institute INAF-IAPS, [5] Warsaw University of Technology, [6] Medical University in Poznań, [7] Lunares)

Introduction: Habitat Lunares is a simulated space base and chronobiological laboratory to perform advanced studies on humans in controlled conditions [1]. With common effort of Medical University in Poznań, Lunares became the first in Poland laboratory of extreme medicine. People living in this base are constantly monitored by telemedical devices. Additionally, the base is monitored regarding O_2 levels, temperature, humidity, radiation and light intensity. The habitat is equipped with automated lighting system controlled by Mission Control Center, where specific ranges of solar spectrum can be administrated selectively (Fig.1). It's the only facility of its kind in Europe, where conditions of the future base both on the Moon and Mars can be simulated. The habitat is located at the former military airport in Piła, north of Poland. Four analog missions were planned for 2017, among them the Lunar Expedition I.0. During two weeks of isolation from external world, analog astronauts were completely cut off from UTC time, sunlight and urban noise. They could leave the hab only to an airplane hangar where the surface of the Moon was simulated.

Fig. 1. The Lunares habitat is equipped with 3 types of automated lighting systems: circadian lighting, hydroponic lighting, EVA terrain lighting.

Scientific objectives of the Lunar Expedition I.0 studies: The main objective of this analog mission was to perform chronobiological studies and subjective time perception experiment. It is well known, that astronauts are isolated from natural sunlight during stay in space, what implies desynchronization of metabolic circadian cycles, decreases immunity, sleep quality and concentration. In this experiment we tested the influence of developed lighting systems on circadian rhythms in analog astronauts, also during EVAs (Fig.2). Moreover, specific non-intrusive experiment detected the effect on stress.

Fig. 2. During EVAs analog astronauts were monitored with prototypes of non-invasive telemedical devices to measure respiratory signal, ECG and motion.

The second objective of the mission was to investigate biological life support systems. Multispecies ecological relations were implemented in the bioloab and hydroponic system (Fig.3) to generate oxygen, recycle wastes and water.

Fig. 3. Hydroponic system with multispecies bioreactors including algae, cyanobacteria, Kombucha, Hermetia, Drosophila and cockroaches.

This work presents the main results from the simulation and opens future perspectives for extermal partners invited to collaborate with Lunares Team.

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Additional Information: www.lunares.space

SCIENCE ENABLED BY GETTING TO A SWIRL. G. Y. Kramer[1], [1]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058 (kramer@lpi.usra.edu).

Introduction: The bright, optically immature, curvilinear surface features known as lunar swirls should be the target of the next lunar mission. The swirls are not only a fascinating feature of the Moon, they are a laboratory to study the solar wind, space weathering, and complex electromagnetic interactions in space. A robotic or human mission to a swirl will help answer questions of interest to planetary science as well as the broader scientific community.

Lunar Magnetic Fields. Every swirl is associated with a magnetic anomaly. In addition, it has been shown that the optically brightest part of a swirl or group of swirls correlates with the location of peak magnetic field intensity [3, 4]. Models of the distributions of the magnetic source material, when constrained by the observed albedo patterns produce fields that are consistent with magnetometer measurements [5]. Specifically, strongly horizontal surface fields generate the bright swirls, while vertical surface fields result in off-swirl features called dark lanes. The more intricate swirl morphologies could be used to infer small-scale structure in the near-surface magnetic field as well as the depth and orientation of the magnetic source material.

Space Weathering. The optical properties of the on-swirls surfaces compared with off-swirl (adjacent or between swirls) and non-swirl surfaces (locations not associated with magnomalies) demonstrate the specific ways the surface material is altered by solar wind ions versus micrometeorite impacts [2, 6] - the two agents of space weathering. Not only is space weathering on-swirl retarded, the dark lanes mature much faster than a non-swirl surface [2].

Since the swirls are weathered almost exclusively by micrometeorites, in situ analysis and returned samples can be used to study their isolated effect on the maturation process. This would also benefit asteroids studies. Retardation of the weathering process on-swirl indicates that the solar wind is the dominant form of weathering at the Earth-Moon distance. However, at the Asteroid Belt it may be micrometeorites that dominate due to the decreased solar wind flux. Spectroscopic differences between asteroid and lunar surfaces due to composition and proximity to the Sun have kept this controversial [7].

Sampling Fresh Material. Since space weathering is retarded on-swirl, while normal (and possibly accelerated) space weathering rates are occurring off-swirl, even a lander or rover of limited mobility could sample materials of the same *absolute* age, but different *apparent* age (maturity) and vice versa. In a small area one can sample material formed at the same time (e.g., by volcanism, by impact), and/or exposed by impact gardening at the same time, while also sampling fresh material and its weathered counterpart.

Lunar water. Moon Mineralogy Mapper data show that the optically bright swirls are depleted in OH/H_2O relative to their surroundings [6] - consistent with the solar wind deflection model for the swirls [1]. The creation of OH and H_2O is spatially controlled by the magnetic anomalies, making swirls ideal places to study the surface hydration phenomenon and potentially providing locations for extracting this resource.

Electrical potential. Models and spacecraft data show [e.g., 10, 11, 12] that in a plasma wake, such as on the nightside of a planetary body or the shadowed side of a crater bowl, there is a dearth of positive ions to counteract the buildup of negative static electricity on an astronaut's suit or robotic equipment, and thus pose a danger to sensitive instrumentation. However, such a phenomenon may be controlled by the geometry of the magnetic anomalies in useful ways; either through protection and/or as an energy resource. The strength of such an electric field is not dependent on the overall size of the magnetic anomaly, but is related to the local gradient in the magnetic field strength. Locations where the gradient is steep, identified by a sharp bright swirl/dark lane interface, may be a small, but still viable voltage potential to exploit for surface operations.

Plasma physics. The swirls are a place to observe charged particle interactions with a magnetic field involving complex geometries. In particular, the swirls provide a laboratory for studying these interactions in a vacuum on a unique scale, larger than a vacuum chamber [13], yet smaller than a global magnetic field.

Heliophysics. How effective the magnetic anomalies are at deflecting the bulk solar plasma can be studied for both light and heavy ions and for a range of particle fluxes (from the change in incident solar wind angles with latitude) with instruments placed at lunar swirls. Variations in the magnetic field intensities, even at regional magnetic anomaly locations, provide an opportunity to determine whether there are conditions in which only electrons are deflected or other specific controls on particle mass [2, 14]. If the magnetic anomalies formed at an early age and have been protecting the surfaces from the solar wind ever since, the swirls may be a great location to sample the ancient solar wind.

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CONDUCTING SUBSURFACE SURVEYS FOR WATER ICE USING GROUND PENETRATING RADAR AND A NEUTRON SPECTROMETER ON THE LUNAR ELECTRIC ROVER. David A. Kring[1,2], [1]LPI-JSC Center for Lunar Science and Exploration, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058 (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute.

Introduction: Hufenbach *et al.* [1] introduced a design reference mission architecture that utilizes the space launch system (SLS), Orion crew vehicle, a service module, exploration deep space habitat (eDSH) or gateway in lunar orbit, two small pressurized rovers (SPR), 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 five times. The landing sites in this scenario are Malapert massif, the south pole, Schrödinger impact basin, Antoniadi crater, and the center of the South Pole-Aitken impact basin. A study of that traverse [2] indicates the traverse is 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

Instrumentation on rover: For crewed operations, the LER was outfitted with high-visibility windows, a ForeCam, AftCam, port and starboard cameras, docking cameras, and a GigaPan camera (Fig. 1) to support both intravehicular and extravehicular activities (*e.g.*, [3,4]). 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 (Fig. 1) 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. 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).

Surveying for subsurface water: Kamps *et al.* [2] pointed out that the LER could prospect for water and related volatiles while being driven telerobotically between crew landing sites. The GPR, already tested on the LER, and a neutron spectrometer, already tested on a 1-g mockup of RP, would be a powerful instrument suite for that type of survey. Two important targets along the route of the LER in the design reference mission of [1] is the permanently shadowed regions of Cabeus, which LCROSS demonstrated has volatiles, and Amundsen, which is an excellent site for volatile deposits with the characteristics needed to address the scientific goals of the National Research Council (2007) report *The Scientific Context for Exploration of the Moon* [5].

Fig. 1. A GPR unit installed beneath the aft deck of an LER.

Conclusions: Teleoperational driving of an LER between crew landing sites can be used to explore the ISRU potential of permanently shadowed regions and, thus, map the locations of ice deposits that could be used to support a sustainable exploration program on the Moon.

Acknowledgements: Tests of the LER were conducted by the NASA Desert Research and Technology Studies program 2008–2011 and would not have been possible without the input of vehicle crews and the science, mobility, communication, health and safety, human factors, and mission operational teams that supported them. The JSC mobility team built an incredibly capable vehicle. The GPR unit was installed as an LPI contribution, led by Essam Heggy and the author.

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Water in pyroclastic deposits and cold traps on the Moon: Possible resources for future exploration

Shuai Li[1], Paul Lucey[1], and Ralph Milliken[2]

[1] University of Hawaii; [2] Brown University

Two possible water (OH/H_2O) reservoirs on the lunar surface were identified using the Moon Mineralogy Mapper (M^3) data that can be exploited in future exploration of the Moon. Significant amount of water (OH/H_2O) has been detected in the lunar pyroclastic deposits at the equatorial region corresponding to a surface abundance of 0.01 - 0.05 wt. % in volcanic glass beads. The thickness of these relatively OH/H_2O rich pyroclastic deposits is 4-7 m based the sizes of craters identified in the NAC data that penetrated the deposits. Assuming that the water abundance observed on the surface can represent the entire layer of pyroclastic deposits, we estimated 10^5 – 10^7 tons of water at individual deposits depending on their sizes, which is equivalent to 100 – 1000 tons of water per square kilometer. Water and other resources of pyroclastic deposits in the equatorial region are much easier to be accessed than those in the polar regions. However, the low water abundance at pyroclastic deposits means that mining such low abundance of water from lunar regolith is challenging, especially when most of the water could be in the form of strongly chemically bounded OH.

Alternatively, the possible ice deposits in the lunar polar region recently verified using M^3 may have much higher abundances of water. Our modeling results suggest that the water ice abundance could reach over 50% by area at the surface. However, we cannot tell the thickness of the ice deposits using the reflectance data. Our detected ice deposits could be very thin (i.e. ~mm) or the ice particle is very small (deposits could be thick). The Mini-RF circular polarization ratio (CPR) data did not suggest large blocks of ice. In addition, the possible ice deposits are located at relatively small individual discrete cold traps, which is not like the pyroclastic deposits expanding thousands of square kilometers. The patchy distribution of ice deposits is a challenge for exploitation owing to the extreme thermal environment.

In summary, exploiting water (possibly in the form of OH) in the large pyroclastic deposits at the equatorial region and water ice in the cold traps near the poles both have exploration potential. Exploring water in the pyroclastic deposits is challenged by its low abundance, while it shows advantages in easy access, concentrated distribution of water bearing materials, and availability of solar energy for rovers. On the other hand, the local abundance of water in the ice deposits in the polar region is much higher than in pyroclastic deposits. However, the volume of water ice in the polar region is still unknown. Mining water from the polar region is challenged by the patchy distribution of ice deposits and the extreme temperature environment.

Exploiting water in the large pyroclastic deposits at the equatorial region and water ice in the cold traps near the poles both has scientific significance. The former is critical for understanding the magmatic activities in the early history of the Moon, the volcanic process, and the process of water retention, while the latter is important for revealing the formation and deposition processes of water ice in the polar region.

REMOTE OPERATION OF THE EXOGEOLAB LANDER AT ESTEC & LUNARES BASE

A. Lillo[1,2,4], B.H. Foing[1,2,3], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Jonglez[1,2,4], C. Heinicke[2,3], M . Harasymczuk[1,2], L. Authier[1,2,4], A. Blanc[1,2,4], C. Chahla[1,2,5], A. Tomic[2], M. Mirino[1,2], I. Schlacht[2,3,6], S. Hettrich[7], T. Pacher[8], [1]ESA/ESTEC & [2]ILEWG (PB 299, 2200 AG Noordwijk, NL, arthurlillog@gmail.com), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] Extreme Design, [7] SGAC, [8] Puli team

Introduction: The ExoGeoLab lander is a project at ESA/ESTEC initiated in collaboration with ILEWG task groups [1-5]. It is a structure with a rover deployment hatch, that can be equipped with several instruments such as UV-VIS, NIR and Raman spectrometers, environmental sensors, cameras and a telescope. Those payloads can be remotely operated from a laptop connected via a Wi-Fi to the Lander.

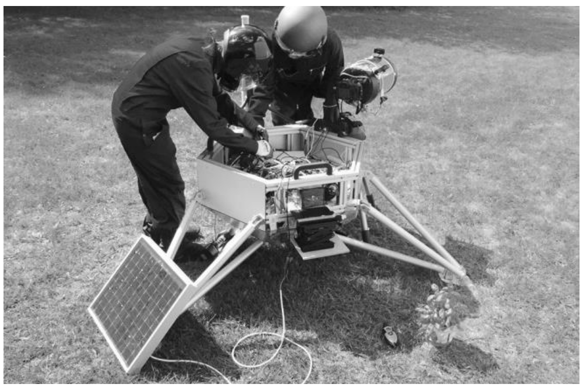

Figure 1 Manipulation of ExoGeoLab instruments by analogue astronauts during EuroMoonMars Workshop 2017 at ESTEC

Goals: The ExoGeoLab Lander is intended to demonstrate on a small class prototype and with off-the-shelf technology how remote operation of scientific instruments can be used jointly with Extra-Vehicular Activities (EVA) on the Moon or Mars. The Lander is thus made to be operated in analogue conditions from close or distant stations. The three main goals are science (spectrometry and astrophotography), technology (remote control), and ergonomics (joint operation with astronauts).

Technical improvements: Over 2016 and 2017, a database of minerals was established at ESTEC to calibrate the spectrometers, and the former Arduino+laptop architecture was replaced by a centralised Raspberry-Pi architecture [6,7], allowing development of a robust, modular, user-friendly and community-supported interface for remote control based on the software K-Stars Ekos. The computerized telescope allows now to make astrophotography and take pictures of remote geological features, and the webcam mounted on its motorized mount can be used for panoramic context or to remotely follow the rover or astronauts' activities with 360 degrees rotation, or for visual check of the Lander's subsystems.

EuroMoonMars campaigns at ESTEC and Lunares: the Lander was deployed on an analogue simulation conducted at ESTEC for EuroMoonMars Workshop 2017. The spectrometer, the telescope and an electric drill were remotely operated from the ExoHab module while astronauts brought rock samples and calibrated the instruments. In August, the Lander was deployed in the Moon/Mars analogue environment of the new LunAres base in Piła, Poland. It has been operated by the astronauts of the PMAS mission and remotely from ESTEC, where spectral and environmental data are being processed, along with videos of the EVAs captured by the cameras onboard. The Lander is also expected to be used during Lunar Expedition 1 at LunAres base after PMAS.

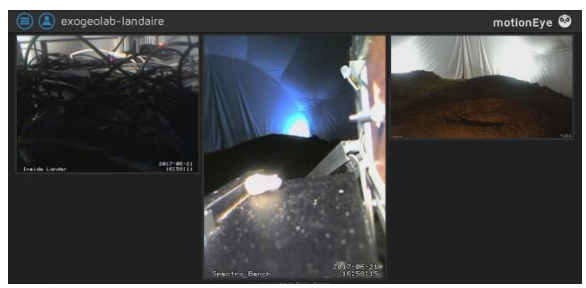

Figure 2 Livestream recorded at ESTEC during remote operation, showing Lander's interior, spectrometer bench and LunAres analogue environment from Lander's cameras

Acknowledgements: we thank ILEWG EuroMoonMars programme, the LunAres support team & analog astronauts.

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THE FAR-UV WAVELENGTH DEPENDENCE OF THE LUNAR PHASE CURVE AS SEEN BY LRO LAMP.
Y. Liu[1], K. D. Retherford[2], T. K. Greathouse[2], A. R. Hendrix[3], J. T. S. Cahill[4], K. E. Mandt[4], G. R. Gladstone[2], C. Grava[2], A. F. Egan[5], D. E. Kaufmann[5], W. R. Pryor[6]; [1]Lunar and Planetary Institute, Houston, TX (liu@lpi.usra.edu), [2]Southwest Research Institute, San Antonio, TX, [3]Planetary Science Institute, Tucson, AZ, [4]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [5]Southwest Research Institute, Boulder, CO, [6]Central Arizona University, Coolidge, AZ

Introduction: The Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) provides global coverage of both nightside and dayside of the Moon in the far ultraviolet (FUV) wavelengths between 57 and 196 nm [1]. The nightside observations use roughly uniform diffuse illumination sources from interplanetary medium Lyman-α sky glow and UV-bright stars so that traditional photometric corrections do not apply. In contrast, the dayside observations use sunlight as the illumination source where bidirectional reflectance is measured. The bidirectional reflectance is dependent on the incident, emission, and phase angles as well as the soil properties. Thus the comparisons of dayside mapping and nightside mapping techniques offer a method for cross-comparing the photometric correction factors because the observations are made under different lighting and viewing conditions.

In this study, we discuss the FUV wavelength dependence of the lunar phase curves as seen by the LAMP instrument in dayside data. Sample mare and sample highlands have been selected for our investigation. Our preliminary results indicate that the reflectance in the FUV wavelengths decreases with the increasing phase angles. This is similar to the phase curve in the UV-visible wavelengths as studied by Hapke et al. [2] and Sato et al. [3] using the LRO Wide Angle Camera (WAC) data, among other visible-wavelength lunar studies. Also, phase reddening at FUV wavelengths was observed; at UV-visible wavelengths, such phase reddening has been attributed to interparticle multiple scattering as the albedo increases [2, 3]. Finally, we report current derived Hapke parameters at FUV wavelengths for our study areas.

Data and Method: The LRO LAMP instrument is a push-broom style FUV imaging spectrograph with a spectral resolution of ~2 nm and standard spatial resolution of ~250 m/pixel. Nominally pointed nadir, LAMP provides repeated observations of the Moon, enabling accumulation of FUV signal and higher data quality over the regions of interest. LAMP data were radiometrically calibrated to give the radiance factor $I/F(i,e,g)$ (i.e. the radiance relative to a perfectly diffusing Lambert surface illuminated and viewed normally). Then the I/F values were divided by the Lommel-Seeliger (LS) function to get the reduced reflectance, where *LS* is a common factor in the radiative transfer equation for the theoretical photometric functions of particulate media. To further improve signal/noise, we use 10 nm bandpasses combining five bins in the normal 2 nm products and lower spatial resolution (i.e., 10 km/pixel as compared to the standard 250 m/pixel) such that more photon events can be captured at each pixel for a given wavelength. Finally, we used the Hapke equation to fit the phase curves for each wavelength to derive the single scattering albedo *w* and asymmetric factor *b*.

Results: For both sample mare and highlands, the reflectance decreases with increasing phase angles. Phase reddening at FUV wavelengths was observed. The wavelength dependent single scattering albedo and asymmetric factor in the single-particle phase function for the sample mare and highlands were derived, which are listed in Table 1. These parameters will be used to perform better photometric corrections for LAMP FUV dayside reflectance data. Future work includes deriving Hapke parameters for more refined mare and highlands areas and testing shadow hiding and coherent backscattering effects in FUV wavelengths when small phase angles are available in the areas investigated.

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Table 1. Retrieved wavelength dependent Hapke parameters for sample mare and sample highlands (*w* is the single scattering albedo, and *b* is the asymmetric factor for single-particle phase function)

λ (nm)		134	144	154	164	174	184
Mare	*w*	0.092±0.002	0.085±0.001	0.078±0.001	0.065±0.001	0.059±0.001	0.055±0.001
	b	0.483±0.023	0.467±0.023	0.484±0.023	0.476±0.023	0.483±0.023	0.501±0.023
High lands	*w*	0.086±0.002	0.082±0.002	0.074±0.002	0.059±0.002	0.056±0.002	0.058±0.002
	b	0.478±0.023	0.471±0.023	0.478±0.023	0.468±0.023	0.452±0.023	0.446±0.023

CONSTRUCTING LUNAR NEUTRON FLUX MAPS WITH LRO/LEND SENSOR FIELD OF VIEW.

T. A. Livengood[1], G. Chin[2], I. G. Mitrofanov[3], W. V. Boynton[4], K. P. Harshman[4], M. L. Litvak[3], T. P. McClanahan[2], R. Z. Sagdeev[5], A. B. Sanin[3], R. D. Starr[6], J. J. Su[5]. [1]CRESST/U. of Md, Code 693, NASA/GSFC, Greenbelt, MD 20771, timothy.a.livengood@nasa.gov, [2]NASA/GSFC, [3]Institute for Space Research, Moscow, Russia, [4]Lunar and Planetary Lab, U of Az, [5]Dept. of Physics, U. of Md, [6]Dept. of Physics, Catholic U. of America.

Neutron detection rates within the Lunar Reconnainssance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) have been mapped globally as well as targeted on the Moon's polar regions [1–4]. Similar mapped measurements were acquired with the earlier Lunar Prospector Neutron Spectrometer (LPNS) [4,5]. Maps are constructed by identifying a measurement of neutron flux with its lunar coordinates, building up a map of detection rates over each location. Spatial smoothing can be applied to the mapped measurements due to finite spatial resolution in the detector system, which convolves emissions from a broad region into detections at a particular coordinate. Defining the convolution function to apply to a map poses challenges, as the function changes with orbit altitude and the energy of the detected neutrons. Reconstructing the field of view (FOV) for individual measurements is far too computationally expensive. We have had success with developing finely-sampled maps to which a psf corresponding to the average spacecraft altitude at each coordinate for each neutron detector can be applied to construct a global map of neutron flux from the Moon in distinct energy intervals.

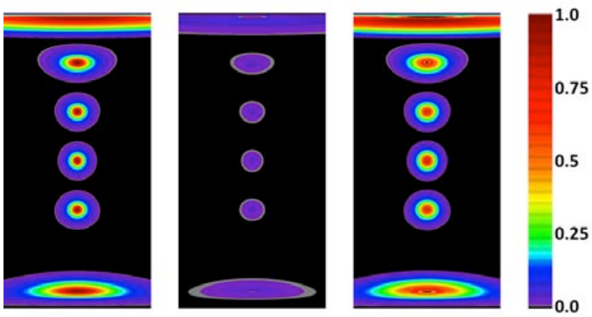


Fig. 1: Point-spread function (psf) on the Moon for (*left*) uncollimated detector, (*center*) LEND collimated detector CSETN, and (*right*) uncollimated component of collimated detector, at latitudes from equator to pole in cylindrical Mercator projection. Each psf peaks at unity. The displayed strips are ±90° latitude and 90° in longitude (width), sampled at 0.125°/pixel.

The natural spatial resolution of an uncollimated neutron detector is dominated by anisotropic emission from the surface into free space (Fig. 1). The detector is sensitive to emission all the way out to the horizon, which distance varies according to the altitude of the spacecraft. Emission intensity declines with increasing slant angle relative to the surface normal, approximately proportional to cosine raised to a small power of order 1-1.5. Collimation can further restrict the effective FOV, as with the CSETN detector of LEND, for which detected neutrons include the narrow collimated FOV as well as neutrons out of collimation that penetrate the finite opacity of the collimator wall [6]. Neutrons that penetrate the collimator wall to reach the detector originate from the lunar surface at greater average energy than the population in collimation [7].

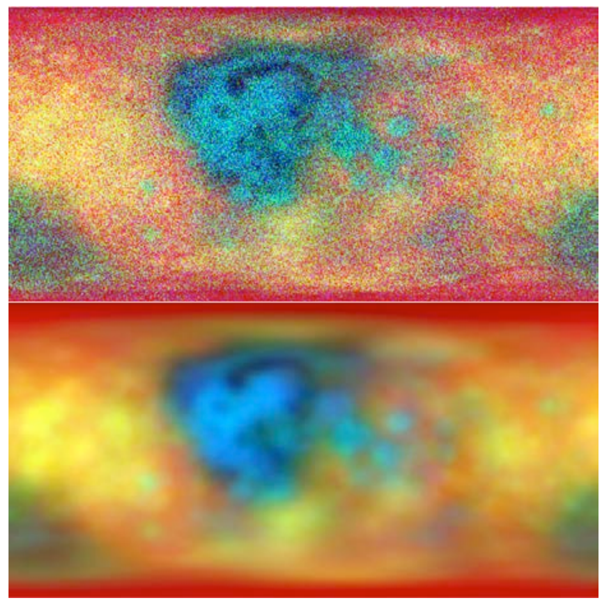


Fig. 2: Global map of lunar neutron emission. Red = thermal, E<0.4 eV; green = epitherml, 0.4 eV < E < 10 keV; blue = high-energy epithermal, 0.4 eV < E < 1 MeV; minus estimated background [4]. (*top*) Flux assigned directly per 0.5° pixel; (*bottom*) flux convolved with estimated psf for altitude and latitude.

The LRO data used here were acquired in 2009–2011, while the spacecraft was in circular orbit at 50 km altitude. The smoothing method should work for the elliptical orbit that LRO has occupied since 2011 by constructing maps for intervals during which the orbit is stable, combining maps from differing periods.

References: [1] Mitrofanov *et al.* (2010) *Science* **330**, 483–486.s [2] Sanin *et al.* (2012) *JGR-Planets* **117**, E00H26. [3] Litvak *et al.* (2012a) *JGR-Planets* **117**, E00H22. [4] Livengood *et al.* (2017) *P&SS*, in review. [5] Maurice *et al.* (2004) *JGR-Planets* **109**, E07S04. [6] Litvak *et al.* (2012b) *JGR-Planets* **117**, E00H32. [7] Livengood *et al.* (2015) *Icarus* **255**, 100–115.

The Lunar Volatiles Orbiter: A Lunar Discovery Mission Concept. P. G. Lucey[1], N. Petro[2] D. Hurley[3], W. Farrell[2], X. Sun[2], R. Green[4], R. Greenberger[4], and D. Cameron[4] [1]University of Hawaii at Manoa, 1680 East-West Rd, Honolulu, HI 96822, lucey@higp.hawaii.edu, [2]NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [3]The Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, [4]Jet Propulsion Laboratory, Pasadena CA 91109.

Introduction: The Lunar Volatiles Orbiter (LVO) is a Discovery-class mission concept which leverages the spacecraft design and operations experience of the Lunar Reconnaissance Orbiter. LVO is aimed at understanding the current state of volatiles on the Moon with an emphasis on current dynamics. The mission will carry both surface and atmospheric composition instruments that will definitely answer questions regarding volatile flows to and from the Moon, and their propagation in the lunar environment. A particular emphasis is to use the Moon as a natural laboratory to understand volatile interactions of all airless bodies.

All planetary bodies are exposed to and interact with the solar wind and continuous infall of meteorites. The surfaces of those without atmospheres are directly exposed to this flow and diverse evidence shows can respond differently to this stimulus. Most of the inferences regarding the influence of exposure to space are indirect and researchers invoke differential response of known inputs to explain often conflicting observations. The Moon offers the opportunity to fully understand the response of an airless body to these inputs, providing insights into the general process of space-surface interaction applicable from Mercury to exoplanets. Despite the wealth of sample and remotely obtained data the response of the lunar surface to the solar wind and mass infall of volatiles is only partly understood. A single mission can provide the linkages necessary to form a coherent understanding of the interaction of the Moon and its volatile rich sources.

LVO plans six instruments to address its science objectives: 1) Spectroscopic Infrared Reflectance LIDAR (SpIRRL), a laser spectrometer developed by Goddard Space Flight Center operating in the 3 micron region; 2) the Lunar Volatiles Imaging Spectrometer (LVIS), an infrared imaging spectrometer operating in the 3 micron region; 3) Surface Water Mapper (SWAM), an infrared spectrometer operating at 6 microns; 4,5) Ion and neutral Mass Spectrometers (IMS, NMS), developed by Goddard Space Flight Center aimed at detection of water and other species in the lunar atmosphere; and 6) Gamma-Ray/Neutron Spectrometer (GRNS) by APL for high spatial resolution measurement of the abundance and distribution of hydrogen in the polar regions and other proposed hydrogen-rich regions.

Mission and Science Objectives: The objective of the LVO mission is to determine how volatile elements and compounds are distributed, transported, and sequestered in near-surface environments on the surface of the Moon. The mission will determine the current state of surface volatiles including whether the Moon is in net loss or accumulation, and address issues related to interior water with a powerful remote sensing suite.

The first science objective is to inventory the surface and subsurface volatile content, and determine the extent of dynamic changes to this inventory. LVO instrumentation can definitively separate water from hydroxyl, and distinguish the various forms of water and hydroxyl in ice, minerals and glasses. The instrument suite is also sensitive to organics as has been suggested to be present at locally high abundances on Mercury. The second science objective is to globally characterize the lunar atmosphere, detect vertical and horizontal flows, and determine if the present day Moon is in equilbrium, loss or accumulation. The third objective is to characterize interior water with targeted observations of known water related anomalies using the extensive spectroscopic capabilities of the mission. Low altitude GRNS passes will characterize huydrogen contents to about 1-m depth. The fourth objective is to identify flows of volatiles from low latitudes to the polar region and determine if the polar inventory is consistent with modern or ancient deposition. The fifth objective is to characterize how the Moon reacts to brief high intensity volatile sources including solar storms and meteorites, and how these contribute to the overall volatile inventory and cycle.

Relevance to Exploration: LVO contributes to resolving several Strategic Knowledge Gaps including: The Composition, Form and Distribution of Polar Volatiles; Temporal Variability and Movement Dynamics of Surface- Correlated OH and H2O deposits towards PSR retention; and Composition, Volume/Distribution and form of pyroclastic/dark antle deposits and characteristics of associated volatiles.

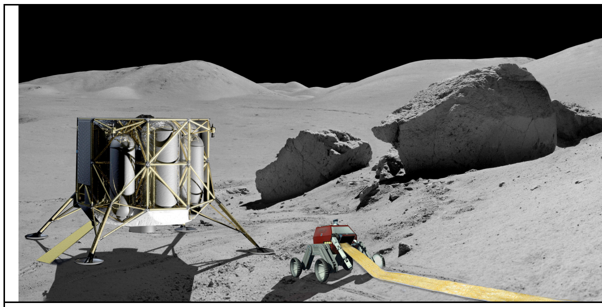
SCIENCE AND ANTENNA ARRAY TRADE STUDIES FOR LOW FREQUENCY RADIO OBSERVATORIES ON THE LUNAR SURFACE. R. J. MacDowall[1] and J. O. Burns[2], [1]NASA Goddard Space Flight Center (robert.macdowall@nasa.gov), [2]University of Colorado, Boulder (Jack.Burns@colorado.edu)

Introduction: A "low-frequency" radio astronomy observatory on the lunar surface would serve to address science goals that cannot be achieved by ground-based observatories, because the radio emission occurs at frequencies below the terrestrial ionospheric cutoff (~10 MHz) or because the sources of radio frequency interference (RFI) must be blocked by placing the Moon between the RFI and the observatory.

Solar Radio Burst Imaging: To image solar radio bursts at frequencies less than ~10 MHz requires an array of antennas somewhere outside the terrestrial ionosphere. The capability to do so is compelling, because 10 MHz corresponds to the plasma frequency (f_P) at a distance from the Sun of about 2 solar radii (R_s). Outside of the sphere ~2 R_s in radius, the plasma frequency is lower and cannot be observed from the ground. Consequently, radio bursts produced inside most of the inner heliosphere have neve been imaged. The capability to image the radio bursts as their emitting sources (flare or shock-accelerated electrons) move away from the Sun would be valuable for understanding the emission mechanisms better, useful for tracking shock particles and coronal mass ejections from the Sun to 1 AU, and valuable for space weather prediction. We discuss the current status and plans for a radio observatory designed to image these bursts.

Detection of the Radio Signature of Cosmic Dawn and Habitable Exoplanets: Cosmic Dawn is a transformative event when the first stars and galaxies formed in the early Universe (35<z<10). The first ~0.5 billion years after the Big Bang are largely unexplored because we lacked theoretical insights and instruments to probe this epoch. We now have the modeling tools and technology to investigate this era using the highly redshifted 21-cm (1420 MHz in rest frame) signal from neutral hydrogen. The Moon's farside is uniquely shielded from terrestrial RFI and free from ionospheric effects that will permit these redshifted observations at <100 MHz. An observatory capable of Cosmic Dawn measurements could also provide a capability to detect magnetospheric radio emissions from exoplanets, which indicate that the surface of the planet is protected from energetic particles by a magnetosphere and consequently more habitable.

Teleoperated Systems to Facilitate Observatory Deployment: A small lunar array with a limited number of antennas could be deployed from a small lander, such as those being proposed by commercial companies. Larger arrays, to provide greater angular resolution or greater sensitivity, might well be deployed by rovers teleoperated by astronauts on Orion and/or Habitat missions in cis-lunar orbits. Such activities would serve as an important proving ground for future exploration missions in deep space.



Surface teleoperation of rovers from orbiting facilities is a key technology for astronaut-assisted deployment of a lunar farside antenna array.

The Network for Exploration and Space Science (NESS): NESS is a newly-selected team of the NASA Solar System Exploration Research Virtual Institute (SSERVI) with goals that address these topics. Our team will conduct trade studies to advance the design of a low frequency radio array, wide-band receivers, and new calibration techniques. Ideally, we will find a scaleable design that can serve for a small to medium-sized solar radio observatory, as well as a larger observatory for "astrophysical" radio sources. It is also our goal to complete a design for a radio observatory pathfinder that will be ready for proposal to a flight opportunity in the near future.

The NESS website http://www.colorado.edu/ness/ provides an indication of the multifaceted, multidisciplinary, and innovative investigation by NESS in the space sciences, including the areas of astrophysics and heliophysics that are enabled through human and robotic exploration of the Moon.

LRO-LAMP OBSERVATIONS OF ILLUMINATION CONDITIONS IN THE LUNAR SOUTH POLE PERMANENTLY SHADED REGIONS. K. E. Mandt[1], E. Mazarico[2], T. K. Greathouse[3], B. Byron[4,3], K. D. Retherford[3,4], G. R. Gladstone[3,4], Y. Liu[3], A. R. Hendrix[5], D. M. Hurley[1], A. Stickle[1], G. W. Patterson[1], J. Cahill[1] and J.-P. Williams[7]; [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, Kathleen.Mandt@jhuapl.edu; [2]Goddard Space Flight Center, Greenbelt, MD; [3]Southwest Research Institute, San Antonio, TX; [4]University of Texas at San Antonio, San Antonio, TX; [5]Planetary Science Institute, Boulder, CO; [6]University of California at Los Angeles.

Introduction: The south pole of the Moon is an area of great interest for exploration and scientific research. Many low-lying regions are permanently shaded and are likely to trap volatiles for extended periods of time, while adjacent topographic highs can experience extended periods of sunlight. A goal of the Lunar Reconnaissance Orbiter (LRO) mission [1] is to characterize illumination variability of the lunar polar regions for future exploration. We compare far ultraviolet (FUV) observations made by the Lyman Alpha Mapping Project (LAMP) [2] with a model that uses topographic data [3] to evaluate illumination at the lunar south pole (within 5° of the pole).

Mapping the South Pole in Ultraviolet: LAMP observations are made through passive remote sensing in the FUV wavelength range of 57-196 nm using reflected sunlight during daytime observations and reflected light from the IPM and UV-bright stars during nighttime observations [2,4]. We show in Fig. 1 several maps produced using nighttime data taken between Sept. 2009 and Feb. 2014.

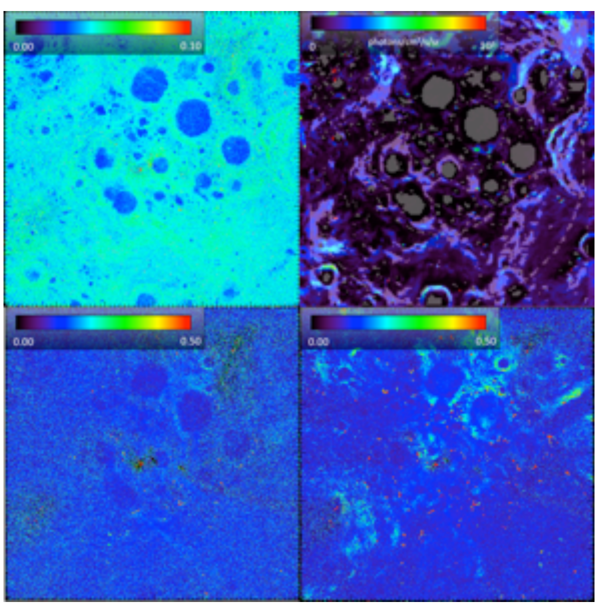


Figure 2: LAMP Lunar south pole region maps: (top left) daytime average 155-190 nm brightness. (top right) Average night time Lyman-α albedo with sza restricted to > 91°. PSRs are shaded in gray. (bottom left) Average 155-190 nm albedo with sza restricted to > 91° and (bottom right) using no sza restriction.

To isolate scattered sunlight observed by LAMP we subtract the albedo measured with a solar zenith angle (sza) > 91° from the albedo mapped using all observations. LAMP observes the highest rate of scattered sunlight in Haworth and Shoemaker.

Comparison with Model and LRO Datasets: As Fig. 2 shows for Haworth, the LAMP maps do not correlate well with the model. However, preliminary results comparing LAMP maps with other LRO datasets show a correlation with Diviner measurements for maximum temperature.

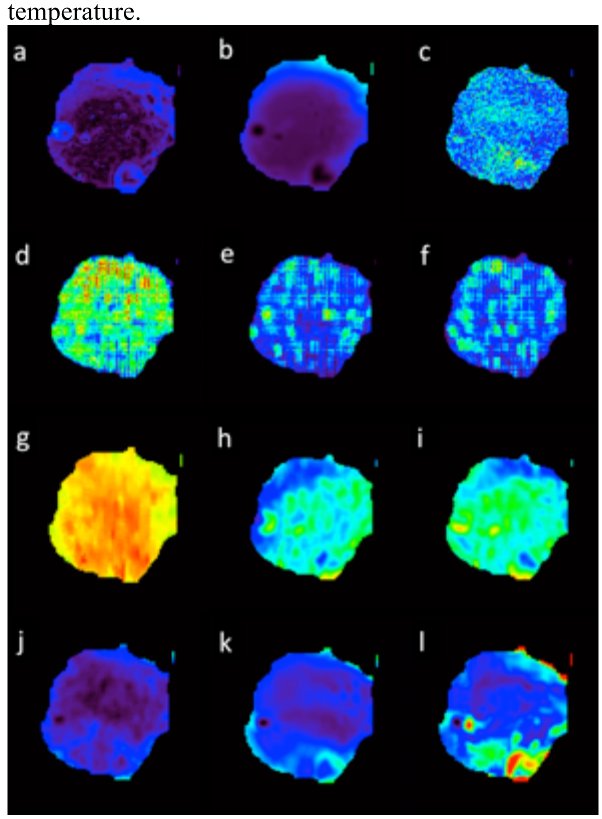


Figure 5: Comparison of LRO datasets for Haworth: (a) slope from LOLA topography, (b) elevation from LOLA topography, (c) LAMP excess albedo showing scattered sunlight, (d-f) illumination model, (g) LOLA normal albedo, (h) & (i) mini-RF circular polarization ratio, and (j) minimum, (k) average, and (l) maximum temperature measured by Diviner.

References: [1] Chin et al. (2007) SSRv, 129, 391-419. [2] Gladstone et al. (2010) SSRv, 150, 161-181. [3] Mazarico et al. (2011) Icarus, 211, 1066-1081. [4] Gladstone et al. (2012) JGR, 117, E00H04.

JAPANESE SPACE PROGRAM UPDATE

K. Masuda and N. Sato, Japan Aerospace Exploration Agency (ohtake.makiko@jaxa.jp)

The Space Exploration Promotion Team was formed at JAXA in 2015, and has conducted a comprehensive study for Japan's space exploration scenario, which was very recently proposed at the ISS/Space Exploration sub-committee on June 28, 2017. One of the most important outcomes of this study is that the overall architecture could change if there is some amount of water at the lunar surface and can be utilized as the fuel by electrolyzing to LOX/LH2 . (Water on the moon could be the game changer!)

Per our preliminary assessment, if there is water ice more than 0.5% of the lunar soil, the initial cost of transporting the ISRU plant for collecting the regolith, extracting water, and electrolysis to the LOX/LH2 to the lunar surface will be paid in case more than seven times of human lunar surface mission. The LOX/LH2 can be utilized not only for the fuel for roundtrip of human lander between lunar surface and the Gateway on the lunar orbit, but also for the fuel of transportation on the moon and for the fuel for transportation in the deep space including journey to Mars.

We will present the JAXA's overall moon exploration scenario, including the water utilization.

LEVERAGING VIRTUAL REALITY FOR THE BENEFIT OF LUNAR EXPLORATION. R. S. McCandless[1], E. D. Burke[2], and V. T. McGinley [1]Lunar Experiences, [2]Nova Realities, [3]Lunar Experiences

Introduction: Lunar exploration, whether for scientific, economic, or other purposes, is in a stage of infancy. Even with several missions scheduled, only a tiny fraction of the lunar surface will be visited in the next few years. Surface coverage can be done from orbit (e.g., LRO) but detailed vetting for science, habitation, or resource extraction is best done on the surface. What combinations of technologies will enable widespread exploration? We propose a set of intersecting and collaborating technologies that will exponentially increase scientific and exploration productivity starting with simulated environments.

Leveraging Virtual Reality: One such set of emerging technologies is collectively called immersive reality (IR) – virtual (VR), augmented (AR), and mixed (MR) – which will give us new opportunities for exploration, collaboration, outreach, and much more in ways we are just starting to imagine, especially for space generally and specifically lunar scientific exploration. Of the IR technologies, VR has the earlirest near-term use and strong long-term potential. Today's state of VR technologies gives us a hint of where they will be in just a few years that will dovetail with our increased ability to reach and operate on the lunar surface. Most think of VR in terms of games, yet VR has a multitude of industry uses. Venture Radar has identified 25 major use cases for VR for both consumer and workplace tasks. VR hardware is getting rapidly cheaper and more capable, which will drive how it can be used both here on Earth and in space missions. For instance, lightfield technology will give the user a much clearer and realistic look anywhere the camera goes, which is very useful for remote exploration. Camera components are getting smaller, weighing less, and provide higher quality data. For upcoming robotic lunar exploration missions, including some associated with the Google Lunar X Prize, VR data will be sent back from rovers and stationary payloads, which will require ground processing ("stitching") into usable video for researchers and eventually for public consumption. These data will provide much improved simulated environments for upcoming mission training and concept of operations validation. Additionally there are coming technologies, not only in VR but in other supporting areas, that will dramatically enhance our ability to explore the Moon in near real-time and involve more people in the scientific process.

Emerging Technology Infrastructure: What if we could cover large surface areas with instruments, provide data back to Earth and cis-lunar space in near-real time, and involve trained citizen scientists to help with analysis? VR and collaboration technologies have the potential to accomplish this, which is orders of magnitude better than today's situation. There is a set of enabling technologies that are needed to make VR effective for lunar surface exploration. They include improved cameras, better data storage and transmission, practical teleoperation, use of swarm devices, and advanced artificial intelligence (AI). Lightfield technology in small, lightweight cameras in space VR applications will give the user unprecedented views of the lunar terrain and conditions near operational sites. Collecting massive amounts of high quality data will be very useful, but how will that data reach humans in a timely manner? Laser communications technology that is being pioneered by NASA and companies such as ATLAS will be needed to collect and transfer data in real time for viewing. As this technology improves, it will open up the possibility of near real-time teleoperations where operators on Earth or even from lunar orbit (e.g., NASA's Deep Space Gateway) can not only analyze data, but can control devices on the lunar surface for further investigation. Small, agile, smart, rechargeable lunar drones outfitted with VR cameras such as those under development by SpaceTREx Lab could be deployed to areas for closer exploration of sites of interest, provide support to humans and rovers on expeditions, and monitor ongoing operations (e.g., drilling) to provide status, health, and safety functions [1]. SpaceTREx drones will utilize advanced AI that learns from errors and helps organize swarm activities for specified exploration objectives. Large swarms of drones can be used to quickly gather data in specific lunar regions. Having vast amounts of near real-time VR data will provide opportunities for citizen scientists to get involved in analysis in the spirit of today's Moon Zoo and Galaxy Zoo projects. VR and the aforementioned companion technologies will exponentially improve our ability to explore the Moon.

Broader Impact: With the coming ubiquity of VR (>100 million headsets by 2020), bringing the Moon to anyone will not only be possible, but probable, through science, educational outreach, entertainment and games, film, and other experiences. Making the Moon a VR destination will help popularize space and lunar exploration, enabling even more scientific endeavours.

References: [1] Thangavelautham, J., Robinson, M., and McCandless, R. S. (2016), NASA RFI NNH17ZCQ001L.

RECENT ACHIEVEMENT BY THE SSERVI ALSEP DATA RECOVERY FOCUS GROUP. S. Nagihara[1], Y. Nakamura[2], D. R. Williams[3], P. T. Taylor[3], S. A. McLaughlin[3], H. K. Hills[4], W. S. Kiefer[5], R. C. Weber[6], J.-L. Dimech[6], D. Phillips[7], C. Nunn[8], and G. K. Schmidt[9]. [1]Department of Geosciences, Texas Tech University, Lubbock, TX 79409 (seiichi.nagihara@ttu.edu), [2]Institute for Geophysics, University of Texas at Austin, Austin, TX 78758, [3]Goddard Space Flight Center, Greenbelt, MD 20711, [4]ADNET Systems, NSSDC, Greenbelt, MD 20711, [5]Lunar and Planetary Institute, Houston, TX 77058, [6]Marshall Space Flight Center, Huntsville, AL 35805, [7]Department of Physics and Astromony, University of Alabama in Huntsville, Huntsville, AL 35899,[8]Department of Earth and Environmental Sciences, Ludwig Maximilian University of Munich, [9]Solar System Exploration Virtual Research Institute, Ames Research Center, Moffett Field, CA 94035.

Introduction: The ALSEP Data Recovery Focus Group was founded in 2010 under NASA's Lunar Science Institute and continues under the Solar System Exploration Research Virtual Institute (SSERVI). ALSEP (Apollo Lunar Surface Experiment Package) is a collective name for the ground-based science instruments deployed by the astronauts at the Apollo 12, 14, 15, 16, and 17 sites. The ALSEP instruments operated from November 1969 to September 1977, and 15 types of experiments were carried out [1]. At the conclusion of the ALSEP program, only portions of the data were archived at the National Space Science Data Center (NSSDC). The ALSEP Focus Group's primary mission is to recover/restore the missing data and metadata, and make them available in formats that are user-friendly to contemporary researchers. The Focus Group (FG) also serves as a forum for communication between the original ALSEP investigators and contemporary researchers who want to use/re-analyze the data. Here we summarize some of the group members' recent achievement made possible by the support from NASA's Planetary Data Archving, Restoration, and Tools program.

Recovery of Raw ALSEP Data: From April 1973 to September 1977, raw ALSEP data received from the Moon were recorded on digital open-reel magnetic tapes for archival purpose at Johnson Space Center (JSC) and University of Texas at Galveston. However, these tapes were not delivered to NSSDC in 1977, and many of them were later lost. When the ALSEP FG was founded, only copies of the tapes generated in March 1976 to September 1977 had been archived. In 2010, we recovered at the Washington National Records Center 440 original archival tapes generated in April through June of 1975. We recently finished extracting data from these tapes (*Level-0* Data). Because of degraded quality of the tapes, the extracted binary files contained numerous bit errors. We have cleaned up most of such errors and have recovered more usable data. The raw data and cleaned-up raw data (*Level-0* and *Level-0a* Data) for April through June 1975 are now available from the National Space Science Data Coordinated Archive (NSSDCA). The raw data files from March 1976 through September 1977 are also available.

Higher Order Data and Derivative Products: The files from the archival tapes contain data from various experiments intermeshed [2], and thus they do not readily conform to the specfications of the Planetary Data System (PDS). We are now extracting individual data packets, experiment by experiment, from our *Level-0* and *-0a* products for archving with PDS (*Level-1* Data). Some of these products are now available from NSSDCA.

Because *Level-1* data are not readily usable for scientific data analysis, they are now being further processed according to the scheme and the instrument calibration data used by the original ALSEP investigators (*Level-2* Data).

Derivative data products are also being generated from *Level-1* and *-2* data. For example, the currently used lunar seismic event catalog, compiled in 1981 [3], is now being updated and expanded with additional moonquake information extracted from the recently restored data for the Lunar Seismic Profiling and the Lunar Surface Gravimeter experiments [4].

Digital Metadata Catalog: The *Level-2* data processing requires metadata, most of which were never published by the original ALSEP investigators. At the conclusion of the Apollo program, voluminous documents containing important information on the data processing, instrument design, and calibration experiments were moved from JSC to the Lunar and Planetary Institute (LPI) in Houston, TX and the National Archives storage facility in Fort Worth, TX. Our group has been conducting an inventory and optical scanning of these documents. Digital copies of these documents are being made available through LPI's web portal:
https://repository.hou.usra.edu/handle/20.500.11753/2

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A MOON SAMPLE RETURN CAMPAIGN WILL ADVANCE LUNAR AND SOLAR SYSTEM SCIENCE AND EXPLORATION. C. R. Neal[1] and S. J. Lawrence[2]. [1]Dept. Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA (neal.1@nd.edu), [2]ARES, NASA-Johnson Space Center, Houston TX 77058, USA (samuel.j.lawrence@nasa.gov).

Introduction: There have been 11 missions to the Moon this century, 10 of which have been orbital, from 5 different space agencies. China became the third country to successfully soft-land on the Moon in 2013, and the second to successfully remotely operate a rover on the lunar surface [1]. Later in 2017, China is set to become only the second nation to robitically return samples from the lunar surface. There are now significant global datasets that, coupled with the 1990s Clementine and Lunar Prospector missions, show that the sample collection is not representative of the lithologies present on the Moon [2]. The M^3 data from the Indian Chandrayaan-1 mission have identified lithologies that are not present/under-represented in the sample collection [3,4]. LRO datasets show that volcanism could be as young as 100 Ma [5] and that significant felsic complexes exist within the lunar crust [6]. A sample return campaign is the next logical step in advancing our understanding of lunar origin and evolution as well as Solar System processes.

Current Decadal Survey (DS) [7]: South Pole-Aitken (SPA) Basin Sample Return has been a named New Frontiers class mission in the last two DSs [7,8]. The currental decadal survey [7] also states (p. 133) "*Other important science to be addressed by future missions include the nature of polar volatiles, the significance of recent lunar activity at potential surface vent sites, and the reconstruction of both the thermal-tectonic-magmatic evolution of the Moon and the impact history of the inner Solar System through the exploration of better characterized and newly revealed lunar terrains. Such missions may include orbiters, landers,* ***and sample return***." It is difficult to conduct a lunar sample return mission under the current Discovery cost cap; international cooperation and/or commercial partnersips are ways to propose a Discovery nearside lunar sample return. Recent developments in commercial lunar capabilities (e.g., [9]), a new and innovative lunar science (and exploration) program could be initiated.

Sample Return Targets: Given the wealth of orbital information now available for the Moon, we can propose targeted sample return missions beyond what is outlined in [7]. Multiple nearside and farside targets are proposed (**Fig. 1a,b**). Note that these locations are examples of locations for the the types of samples that would greatly advance our understanding of the Moon *and* the inner Solar System. **Figure 1** is not meant to be an all-inclusive compilation of potential sample return sites. These sites will need to be adjusted on the basis of landing safety, accessibility, etc. ***Here, science is the only driver for these locations***.

Olivine/Orthopyroxene- and Spinel-rich lithologies (OOS) were discovered using M^3 data [3,4]. These are not well represented in the current sample collection (Apollo and Luna, as well as lunar meteorites), although a small clast in ALHA81005 is spinel-rich [10]. Such lithologies are vital for understanding the composition of the lunar crust and possibly the upper mantle, and to test the lunar magma ocean (LMO) hypothesis.

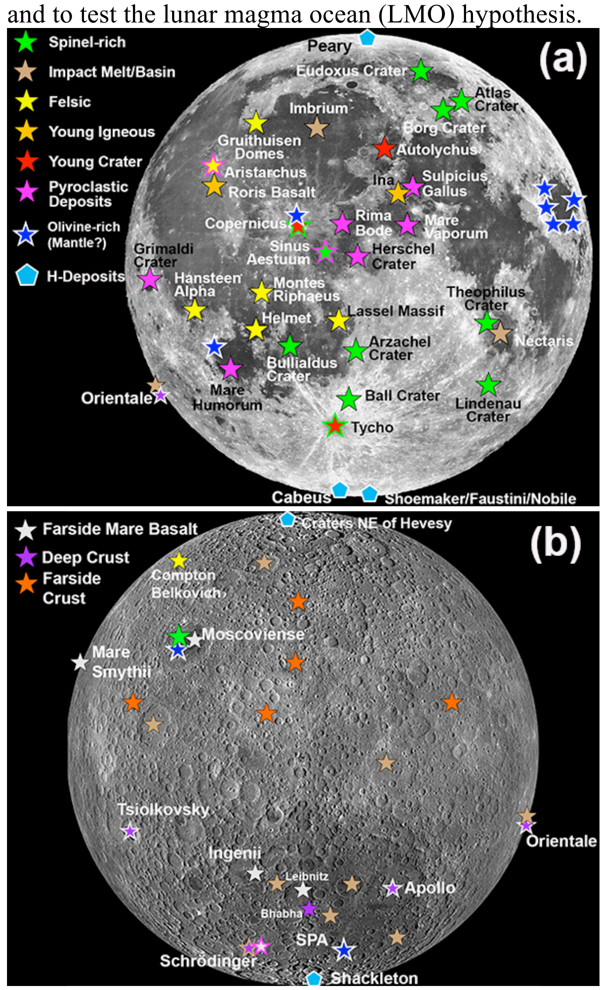

Figure 1: Examples of sample return locations: (a) nearside, (b) farside. Where >1 sample type can be obtained from a single site, symbols = multiple colors.

The locations for "**Impact Melt/Basin**" are intended to represent returning impact melts from such basins to constrain the impact history of the inner Solar System. This activity also includes "**Young Craters**" are also included in an attempt to constrain the impact flux at times older and younger than the 3.8-3.9 Ga ages of impacts that dominate the samples returned by Apollo.

"**Felsic**" locations are those that have been ideintifed from orbital datasets to be silica-rich (and contain high Th abundances and a distinct peak in the Moon's thermal emission near 8µm, the Christiansen feature, associated with Si-O stretching vibration [11,12]). Felsic lithologies are present in the sample collection, but are relatively small (a few grams at the most). Orbital data demonstrate the presence of massifs at the Gruithuisien Domes, Hansteen Alpha, Aristarchus, Lassell, Compton Belkovich [6,13]. Sampling these massifs will enable tests of granite/rhyolite petrogenesis through silicate liquid immiscibility [14] and/or LMO processes.

Young Igneous samples include the young basalts defined by crater counts [15], as well as irregular mare patches [4]. The composition of these young basalts has important implications for understanding the composition of the mantle as well as the thermal evolution of the Moon. Sampling of **Farside Mare Basalts** will also address these science issues.

Pyroclastic Deposits are critical for understanding the volatile budget of the deep lunar interior. Experimental petrology on the glasses returned by Apollo suggest they are derived from greater depths than the crystalline mare basalts [16]. The presence of volatiles in the Apollo 17 orange and Apollo 15 green glasses [17,18] make pyroclastic deposits important for science and exploration (i.e., *in situ* resource utilization - ISRU).

Hydrogen (volatile) Deposits are identified from orbit to be present in and around some permanently shaded regions (PSRs) (e.g., [19]). We know very little about these deposits and landed missions such as Resource Prospector and far more capable follow-on missions are required. Sample return of such materials could contain ancient materials that address Solar System science questions (building blocks of life, source signature of inner solar system volatiles, etc.). Understanding the nature, distribution, and accessibility will be important for ISRU and human exploration.

Deep Crust and possibly lunar mantle can potentially be sampled around central peaks and deep areas within SPA. Having a sample of the deep crust or even the upper mantle will help constrain the Apollo geophysical data as well as the more capable and globally distributed Lunar Geophysical Network, a named New Frontiers mission for the NF-5 call later this decade [7].

Farside Crust (highlands): example locations are given (Fig. 1b). Comparing these samples with Apollo, Luna and lunar meteorite highlands lithologies is important for understanding crustal heterogeneity. It will also test if ferroan anorthosites are the dominat crustal lithology, as predicted from the LMO hypothesis.

Outcrop Sampling: None of the samples in the collection were collected from unequivocal in situ outcrops. Properly oriented samples are required from various terrains and of different ages to truly test the whether the Moon ever established a core dynamo [20].

Technology Development. Sample return has become a next step for studying many planetary bodies (Moon, Mars, asteroids). For the return of rock and regolith samples, very little technology development is needed. However, *cryogenic sampling, return, and curation will require investment*.

A New Paradigm for Getting To & From the Moon. 2017 could be the year that a private commercial company visits (robotically) the lunar surface, to be followed by others in 2018. With these companies planning sample return capabilities, there is an opportunity to change the paradigm of lunar science and exploration to implement a potentially cheaper robotic program that has a regular cadence of flight opportunities. It is obvious, from a business case, that a regular cadence of missions to the Moon would be required for private commercial companies to build a business case to potential investors. In terms of the Moon, we are now at the stage where these companies have evolved to the point where NASA could transition to being a customer and, in effect, get the the lunar surface more cheaply. This in turn allows NASA to be a regular customer and implement at least some of the objectives listed in [21,22]. This in turn could allow a Lunar Science & Exploration Program (LSEP) Office to be established that would involve the lunar community in mission planning and research. This really could be faster, cheaper and better.

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LIVE FROM THE MOON EXOLAB: EUROMOONMARS SIMULATION AT ESTEC 2017

A. Neklesa[2] A., B.H. Foing[1,2,3], A. Lillo[1,2,4], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Jonglez[1,2,4], C. Heinicke[2,3], M . Harasymczuk[1,2], L. Authier[1,2,4], A. Blanc[1,2,4], C. Chahla[1,2,5], A. Tomic[2], M. Mirino[1,2], I. Schlacht[2,3,6], S. Hettrich[7], T. Pacher[8], [1]ESA/ESTEC & [2]ILEWG (PB 299, 2200 AG Noordwijk, NL, Bernard.Foing@esa.int), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] Extreme Design, [7] SGAC, [8] Puli team

Introduction: The 8th year of the ILEWG EuroMoonMars programme [1] was celebrated by the workshop and the analogue mission 2017. The team of space enthusiasts simulated the landing on the Moon having pre-landed Habitat ExoHab, ExoLab 2.0, and the Storage Unit on the Moon and the control centre on Earth. We give here the first-hand experience from a reporter (A.N.) who joined the space crew.

Figure 1 ExoLab 2.0 interior equipped for sample analysis and storing

Goals: Our goal was to face astronaut’s daily routine and to experience the life on the Moon at its raw. The EuroMoonMars mission simulation 2017 [2] intended to collect and analyse samples from the Moon surface along with the evaluation of ergonomics of the units and the brought equipment needed to complete the mission. The new voice protocol aimed to standardize and facilitate the communication between the Mission Control and the ExoLab was the subject of a training program.

Overview: After successful arrival from Earth onboard a Deep Space Shuttle; and landing near the Habitat to the ExoLab, the team has conducted the following protocol: health & safety check; measured blood pressure, explored body and psycho for trauma and the lab unit for a possible damage damage as it has arrived before. The EVA related protocols were tested: doffing and donning, entering and exiting the ExoLab.

Later the same day the signal from the Lander [3] was received by the team leading one of the ExoLab astronauts outside to explore the surface where he joined the ExoHab crew member to collect samples. After several hours spent on the Moon surface they safely made their way back.

It was the most amazing journalist experience you could ever imagine! The report from the Moon, being a part of the space crew and getting into the secrets of protocols and mission routine is absolutely outstanding! I hope one day each of us can experience the same thrilling sensation as the very first journalist on the Moon.

Figure 2 Astronauts conducting bio experiments at the ExoLab.

Acknowledgements: we thank ILEWG EuroMoonMars programme, the Lunares team and PMAS astronauts

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MINI-RF S- AND X-BAND BISTATIC RADAR OBSERVATIONS OF THE MOON. G. W. Patterson[1], L. M. Carter[2], A. M. Stickle[1], J. T. S. Cahill[1], M. C. Nolan[2], G. A. Morgan[3], D. M. Schroeder[4], and the Mini-RF team, [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD (Wes.Patterson@jhuapl.edu), [2]Lunar and Planetary Laboratory, Tucson AZ, [3]Smithsonian Institution, Washington D.C., [4]Stanford University, Stanford CA.

Introduction: NASA's Mini-RF instrument on the Lunar Reconnaissance Orbiter (LRO) is currently operating in concert with the Arecibo Observatory (AO) in Puerto Rico and the Goldstone deep space communications complex 34 meter antenna DSS-13 to collect bistatic radar data of the Moon. These data provide a means to characterize the scattering properties of the upper several meters of lunar materials, as a function of bistatic angle, at S-band (12.6 cm) and X-Band (4.2 cm) wavelengths. We will provide an update on science questions being addressed by the Mini-RF team in the current LRO extended mission.

Background: The transmitters for Mini-RF bistatic observations is the 305 m Arecibo Observatory radio telescope in Puerto Rico or the 34 m DSS-13 radio antenna at the Goldstone deep space communications complex. For each observation, a transmitting antenna is pointed at a target location on the moon and illuminates a fraction of the lunar surface around that location with a circularly polarized chirped signal. The data returned provide information on the structure (i.e., roughness) and dielectric properties of surface and buried materials within the penetration depth of the system (up to several meters for Mini-RF) [1-4]. The bistatic architecture allows examination of the scattering properties of a target surface for a variety of bistatic angles. Laboratory data and analog experiments, at optical wavelengths, have shown that the scattering properties of lunar materials can be sensitive to variations in bistatic angle [5-7].

Observations: In the current LRO extended mission, Mini-RF is targeting a variety of lunar terrains to address LRO science objectives related to fundamental, evolutionary, and contemporary processes involving the Moon. They include collecting data of: the floors of south polar craters to search for signatures indicative of the presence of water ice [8]; Copernican crater ejecta blankets to characterize rates of regolith breakdown/weathering [8,9]; the ejecta of newly-formed craters to characterize the size-distribution and density of wavelength-scale scatters as a function of distance from the impact; mare materials within the Imbium and Serenitatis basins to identify flow units and establish stratigraphic relationships; and irregular mare patches (IMPs) and pyroclastic deposits to characterize their radar properties.

Results: The first Mini-RF bistatic campaign (2012-2015) included 28 AO S-band observations of the lunar surface, polar and nonpolar. Those observations provided data used to suggest the presence of water ice within floor materials of the crater Cabeus [8] and to characterize the weathering of Copernican crater ejecta [8,9]. In the first 9 months of the current LRO extended mission, Mini-RF has acquired 4 additional AO S-band observations and 10 DSS-13 X-band observations of the lunar surface, polar and nonpolar.

Initial analysis of south polar targets acquired at X-band (4.2 cm) do not appear to show the possible water ice signature detected at S-band (12.6 cm). This would indicate that, if water ice is present in Cabeus crater floor materials, it is buried beneath ~0.5 m of regolith that does not include radar-detectible deposits of water ice. Observations of Copernican crater ejecta materials at S- and X-band wavelengths continue to show variations that can be attributed to variations in the age of the crater. Differences between S- and X-band observations of the same crater are also present, providing new insight into the size-distribution of radar scatters within the ejecta. S- and X-band Observations of mare materials in the Imbrium basin have been acquired and, combined with ground-based P-band observations, are providing important information on the locations, extents, and depths to individual flow units within the basin. Recent X-band observations have imaged the ejecta of 2 craters that formed during the LRO mission. Analysis of the ejecta deposits is ongoing.

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DEVELOPMENT AND TESTING OF A LUNAR RESOURCE PROSPECTOR DRILL. G. Paulsen[1], K. Zacny[1], D. Kim[1], Z. Mank[1], A. Wang[1], T. Thomas[1], C. Hyman[1], B. Mellerowicz[1], B. Yaggi[1], Z. Fitzgerald[1], A. Ridilla[1], J. Atkinson[1], J. Quinn[2], J. Smith[2], J. Kleinhenz[3], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com, [2]NASA Kennedy Space Center, FL, [3]NASA Glenn Research Center, Cleveland, OH.

Introduction: The goal of the Lunar Resource Prospector (RP) mission is to capture and identify volatiles species within the top one meter layer of the lunar surface [1]. The RP drill has been designed to 1. Generate cuttings and place them on the surface for analysis by the Near InfraRed Volatiles Spectrometer Subsystem (NIRVSS), and 2. Capture cuttings and transfer them to the Oxygen and Volatile Extraction Node (OVEN) coupled with the Lunar Advanced Volatiles Analysis (LAVA) subsystem.

Figure 1: Resource Prospector Rover with the Drill

RP Drill: The RP drill is based on the TRL4 Mars Icebreaker drill and TRL5 LITA drill developed for capturing samples of ice and ice cemented ground on Mars, and represents over a decade of technology development effort [2-4]. The TRL6 RP drill weighs approximately 15 kg and is rated at just over 500 Watt. The drill consists of: 1. Rotary-Percussive Drill Head, 2. Sampling Auger, 3. Brushing Station, 4. Feed Stage, and 5. Deployment Stage.

To reduce sample handling complexity, the drill auger is designed to capture cuttings as opposed to cores. High sampling efficiency is possible through a dual design of the auger. The lower section has deep and low pitch flutes for retaining of cuttings. The upper section has been designed to efficiently move the cuttings out of the hole. The drill uses a “bite” sampling approach where samples are captured in ~10 cm depth intervals.

The first generation, TRL4 Icebreaker drill was tested in Mars chamber as well as in Antarctica and the Arctic. It demonstrated drilling at 1-1-100-100 level (1 meter in 1 hour with 100 Watt and 100 N Weight on Bit) in ice, ice cemented ground, soil, and rocks. The second generation, TRL5 LITA drill was deployed on a Carnegie Mellon University rover, called Zoe, and tested in Atacama, Antarctica, the Arctic, and Greenland. The tests demonstrated fully autonomous sample acquisition and delivery to a carousel. The modified LITA drill was tested in NASA GRC’s lunar vacuum chamber at <10^-5 torr and <200 K [5]. It demonstrated successful capture and transfer of volatile rich frozen samples to a crucible for analysis. The modified LITA drill has also been successfully vibration tested at NASA KSC. The drill was integrated with RP rover at NASA JSC and successfully tested in a lab and in the field, as well as on a large vibration table and steep slope.

The latest TRL6 RP drill has successfully underwent testing at NASA GRC lunar chamber facilities.

Figure 1: TRL6 Resource Prospector Drill

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THE LUNAR RECONNAISSANCE ORBITER: A FOCUSED STUDY OF FUNDAMENTAL SOLAR SYSTEM PROCESSES AT THE MOON. N. E. Petro and J. W. Keller, NASA Goddard Space Flight Center, Solar System Exploration Division (Noah.E.Petro@nasa.gov; John.W.Keller@nasa.gov).

Introduction: The Lunar Reconnaissance Orbiter mission (LRO) is midway through a two-year extension, running through September 2018, to study the fundamental processes recorded on the Moon. LRO's instruments are measuring processes that operate not only at the Moon but also generally throughout the Solar System, especially on bodies without a significant atmosphere.

This "Cornerstone Mission" (CM) employs all seven LRO instruments in a mission-wide approach to constrain focused science questions. This synergistic approach allows processes to be constrained at distinct spatial (both lateral and vertical) and temporal scales. These processes are divided into three eras of lunar history.

Contemporary Processes [2009 – Today]: LRO has been at the Moon for over 8 years, making it NASA's longest duration lunar mission. This unprecedented baseline of observations enables fundamentally new science, especially in observations of changes to the lunar surface and its environment. In addition to the detection of new impact craters and surface changes [e.g., 1] we also examine the possibility of volatile transport on diurnal timescales [e.g., 2, 3, 4] and constrain the presence of dust in the exosphere [5, 6].

These contemporary processes are observed the Moon, but applicable to any airless body, and are best detected by continuous observations by LRO. With the growing baseline of measurements the detection of changes across all spatial scales is possible. As LRO continues operations the chances of larger impacts being detected grows.

Evolutionary Processes [~1 Ga – ~2009]: LRO is looking to the geologic past to study processes taking place within the interior of the Moon and their reflection on the surface, such as those that provide evidence of the Moon's recent volcanism, and the evolution of the regolith over longer periods of time. These observations include constraining Copernican era volcanism [7] with additional observations of the Irregular Mare Patches as well as the constraining the regolith formation at several locales [8, 9].

These observations also include constraining the distribution of volatiles at and near the surface using multiple instruments at various sensing depths [4, 10].

Fundamental Processes [> 1 Ga]: Reaching farther back in time, LRO will employ new observations to determine the relative timing and duration of basin-forming impacts during the proposed period of Late Heavy Bombardment, the formation and evolution of the early crust, and the styles of early volcanism. These observations help constrain the evolution of volcanism as well as clarify stratigraphic relationships between basin units [e.g., 11].

Science Focus During the CM: The LRO science teams identified three science themes for the CM, which build on Decadal-relevant science questions: 1) Volatiles and the Space Environment, 2) Volcanism and Interior Processes, and Impacts and 3) Regolith Evolution.

Each theme has a corresponding theme lead, responsible for cross-team collaborations. In addition a number of focused workshops have been held in order to facilitate integrated analyses of the LRO data [12].

PDS Data Deliveries: LRO will continue to deliver data to the PDS at a three-month cadence. Currently over 800 Tb of data has been delivered to the PDS, the largest data volume of any NASA Planetary Science Division mission. A number of higher-level data products are in the PDS archive, including mosaics, topographic products, and derived products (*e.g.*, rock abundance from Diviner, local slope). These products are available on the LRO PDS archive (http://pds-geosciences.wustl.edu/missions/lro/) and on individual teams websites.

LRO Support for Future Lunar Missions: LRO data is critical for future surface missions and several outstanding science questions derived from LRO observations could be addressed by orbital observations [e.g., 13]. A number of derived data products have been generated by the LRO science teams in support of future surface exploration. These tools enable safe exploration of the lunar surface [14-16], and with continued operations LRO can continue to collect targeted observations of potential landing sites, a resource unavailable from any other asset.

Conclusions: LRO remains a highly productive, scientifically compelling mission. During its Cornerstone Mission LRO will continue to advance the leading edge of lunar and Solar System science. The LRO mission looks forward to many more years of providing critical data for the revolution in our understanding of the Moon, and by association the Solar System.

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Commercial Enabled Science

. R.B. Pittman[1] and D.J. Rasky[2], [1]NASA Space Portal Office/Wyle, NASA Ames Research Center, Moffett Field CA. 94035, bruce.pittman@nasa.gov, [2] NASA Space Portal Office, NASA Ames Research Center, Moffett Field CA. 94035, daniel.j.rasky@nasa.gov.

Introduction: The rapid rise of new space companies and capabilities, exemplified by companies such as SpaceX, Made in Space, Nanoracks, Astrobotic, Moon Express and Blue Origin, provides a wide range of new capabilities and opportunities for advancing space science. The most obvious potential benefit is lower cost and more responsive options for launch of payloads to low-earth-orbit, geosynchronous transfer orbit, to the Moon and beyond. But there are a number of other options and opportunities as well. These include:

- On-orbit assembly and manufacturing for large space structures and complex spacecraft
- On-orbit repair and upgrades of space science missions
- Indefinite life upper stages and on-orbit refueling to enable deep-space missions not possible or affordable using standard single launch approaches
- Use of extraterrestrial resources, including spent stages and Earth orbital debris, to manufacture spacecraft components and systems, and propulsion fuel
- Establishment of multi-purpose, multi-use, long duration infrastructure for transportation, power, comm and navigation to significantly reduce the risks and costs of future missions.
- Purchase rides to the lunar or Mars surface on commercial landers

This paper will detail a variety of these new space companies and briefly describe their current capabilities and future plans. With this foundation, several potential new science missions will be discussed that could leverage these capabilities to pursue exciting and beneficial future science missions.

LUNAR SKGs: WHAT'S REALLY NEEDED AND WHAT DO WE ALREADY KNOW? J. B. Plescia[1],[1] The Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD 20723 (jeffrey.plescia@jhuapl.edu).

Introduction: Strategic Knowledge Gaps (SKGs) consist of information of the environment, characteristics and processes active on a target body that at present are unavailable and that are considered as necessary to conduct specific operations on that target body. Depending upon the operation, the list of SKGs or the detail to which they must be understood vary. Lunar SKGs for different exploration scenarios were established several years ago. Since that time, a variety of international missions have been conducted, including LRO and LCROSS. Given the huge influx of recent data, it is appropriate to evaluate the current list of SKGs and to consider not only those that can be retired, but to consider new SKGs that were not previously identified. Recently, a review of SKGs in light of the new data was conducted by Shearer et al. [1].

SKGs are considered to be *enabling* or *enhancing*. *Enabling* SKGs are those that must be resolved in order to safety and effectively carryout a particular activity. *Enhancing* SKGs are those whose resolution will increase the effectiveness of an activity. Lunar SKGs were divided into three themes: Understand the lunar resource potential, Understand the lunar environment and its effects on human life, and Understand how to work and live on the lunar surface.

With respect to the resolution of SKGs, a somewhat platitudinous analogy is that if one wants to understand annual rainfall in Columbia MD, one can develop a complete understanding the Earth's climate system on the relevant spatial and temporal scales, or one can deploy a rain gauge. It is the *what* that is of consequence with respect to the SKGs, not the *why*.

Understand the lunar resource potential: This theme is associated with the exploitation of *in situ* resources to support exploration at the Moon and beyond. *In situ* resources are those that can be used for life support and fuel – hydrogen and oxygen. While the use of *in situ* resources has been discussed, its economic viability is undemonstrated. It is the use of in situ resources as fuel that present the greatest challenges.

H and O are present everywhere, respectively as trapped solar wind gas and as mineral oxides. Neutron data indicate increased H abundance in polar regions in both permanently shadowed regions (PSRs) and illuminated areas. The H species (e.g., H_2O, H_2, C_2H_6O) remains unknown as well as its form, lateral and vertical distribution. For example, as H_2O, it could be distinct ice lenses, regolith cement, or scattered blocks.

The species, form and distribution of H in polar regions, in terms of fuel production, are enabling and the most critical. Of particular note is enhanced H outside of PSRs. The limit of remote sensing data has probably been reached. Resolution will require *in situ* data. Such data does not require sample return.

Mobile robotic platforms capable of extended traverses (kms) in both sunlight and permanent shadow, acquiring and analyzing samples from depth (1-3 m), and mapping the spatial distribution over km-scales are required to evaluate whether such exploitation is possible and economically viable. Static landers and penetrators can provide some data, but it will not be definitive.

Understand the lunar environment and its effects on human life: The environmental conditions in terms of high-energy particles and radiation as well as the presence of dust are largely understood. The methodology for meliorating these issues with respect to human health and safety remain and must be addressed. However, there are no obvious requirements for additional *in situ* data. Spacecraft radiation sentinel systems (e.g., at L5) would be required during long-term operations but are not necessary as a precursor.

Understand how to work and live on the lunar surface: Once the distribution and form H are established, the extraction and processing for fuel must be demonstrated on the appropriate scale. If H is present is significant quantities in illuminated polar regions, it might make exploitation considerably easier than in PSRs. Transport, storage and use of the fuel must also be demonstrated. Only then would be the economic viability be demonstrated. Significant technology developments are required to conduct such demonstrations.

Conclusions: It is critical that the distinction between *enabling* and *enhancing* SKGs be maintained and understood such that a return to the Moon is not precluded. The role of commercial enterprises in this endeavor is not clear. Establishing the viability of lunar resources would appear to fall to NASA. Once its value is demonstrated and an architecture established that exploits the resources [2], the long-term production could become a commercial activity.

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CHARGED PARTICLE WEATHERING RATES AT THE MOON AS DETERMINED FROM ARTEMIS OBSERVATIONS. A. R. Poppe[1], W. M. Farrell[2] and J. S. Halekas[3], [1]Space Sciences Laboratory, Univ. of California at Berkeley, Berkeley, CA, USA, [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Dept of Physics and Astronomy, Univ. of Iowa, Iowa City, IA, USA

Introduction: The weathering of airless bodies exposed to space is a fundamental process in the formation and evolution of planetary surfaces. At the Moon, space weathering induces a variety of physical, chemical, and optical changes including the formation of nanometer sized amorphous rims on individual lunar grains. These rims are formed by vapor redeposition from micrometeoroid impacts and ion irradiation-induced amorphization of the crystalline matrix [e.g., 1, 2]. For ion irradiation-induced rims, however, laboratory experiments of the depth and formation timescales of these rims stand in stark disagreement with observations of lunar soil grains. In particular, 1 keV proton and 4 keV alpha (He^{++}) irradiation from the solar wind, presumably the dominant flux to lunar grains, should penetrate lunar soil grains on the order of 10-20 nm. While most observations of amorphous rims on lunar grains are consistent with this, observations have also shown rims with thicknesses up to and over 200 nm [3]. Furthermore, [4] have shown a positively-correlated relationship between rim thickness and surface exposure age that is not fully understood and conflicts with laboratory measurements of surface weathering rates for 10-20 nm rims [5].

Methodology: In order to quantify the rate of space weathering of lunar grains, we have analyzed over five years of observations by the ARTEMIS spacecraft [6] in orbit around the Moon to compute the mean ion flux to the lunar surface and have convolved this flux with ion irradiation-induced vacancy production rates calculated using the Stopping Range of Ions in Matter (SRIM) model [7]. From this, we have calculated the formation timescales for amorphous rim production as a function of depth and compared to laboratory experiments and observations of lunar soil.

The mean ARTEMIS flux shows that while the solar wind proton flux near 1 keV is indeed the largest source of charged particle flux to the lunar surface, there is an extended range of ion energies up to 5 MeV (and potentially greater) with appreciable flux to the Moon. These higher energy ion fluxes originate from several sources, including the terrestrial ion foreshock region, the terrestrial magnetosheath and magnetotail current sheet, and occasional solar energetic particle events. In turn, SRIM simulations show that these higher energy charged particles penetrate and induce silicate amorphization in lunar grains at greater depths than the 1 keV solar wind particles.

Thus, we will show that this analysis resolves two outstanding issues: (1) the provenance of >100 nm amorphous rims on lunar grains and (2) the nature of the depth-age relationship for amorphous rims on lunar grains. We also present the hypothesis that ion beam-induced epitaxial crystallization [e.g., 8] is responsible for the discrepancy between observational and experimental results of the formation time of <100 nm amorphous rims. Future laboratory experiments with both a 1 keV charged particle beam and a secondary, higher energy beam should be able to test this hypothesis.

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MAPSIT AND A ROADMAP FOR LUNAR AND PLANETARY SPATIAL DATA INFRASTRUCTURE. J. Radebaugh[1], B. Archinal[2], R. Beyer[3], D. DellaGiustina[4], C. Fassett[5], L. Gaddis[2], J. Hagerty[2], T. Hare[2], J. Laura[2], S. Lawrence[6], E. Mazarico[7], A. Naß[8], A. Patthoff[9], J. Skinner[2], S. Sutton[4], B. J. Thomson[10], and D. Williams[11]; [1]Brigham Young Univ., Provo, UT, USA (janirad@byu.edu), [2]USGS, Flagstaff, AZ, USA, [3]SETI/NASA/Ames, Mountain View, CA, USA, [4]Univ. of Arizona, Tucson, AZ, USA, [5]NASA/MSFC, Huntsville, AL, USA, [6]NASA/JSC, Houston, TX, USA, [7]NASA/GSFC, Greenbelt, MD, USA, [8]DLR, Berlin, Germany, [9]PSI, Tucson, AZ, USA, [10]Univ. of Tennessee, Knoxville, TN, USA, [11]Arizona State Univ., Tempe, AZ, USA.

Introduction: Lunar and planetary spatial data continue to rapidly increase in volume and complexity. Maintaining these data using accessible formats and standards for all scientists is essential for the success of past, present, and future lunar and planetary missions. As an update to the lunar community, we describe here the Mapping and Planetary Spatial Infrastructure Team. MAPSIT is a group of planetary community members tasked by the Planetary Science Subcommittee and NASA Headquarters to identify and prioritize the infrastructural spatial data needs for research and analysis for NASA's past, current, and future lunar and planetary science and exploration missions, but with science-exploration-commercial synergies as well.

Planetary Spatial Data and MAPSIT: The extraction of scientific knowledge from lunar and planetary mission data relies on several steps of refinement of the raw data from instruments. Creating scientifically useful information is often a major research and development effort in itself. To complete this process, goals need identified, missions need to be properly designed, and instruments need to be appropriately developed and calibrated. The models, software tools and content distribution platforms required for scientists to obtain, process, and analyze planetary mission data need continuing development and maintenance. For these reasons, community coordination and strategic planning for the use of lunar and planetary spatial data are essential for the success of planetary exploration, as well as the commercial development of space.

To this end, MAPSIT has been established with a mission to ensure that lunar and planetary spatial data are readily available for any scientific investigations, now and in the future. Some of its functions include the following: provide community findings, in the form of a roadmap, or Planetary Geospatial Strategic Plan, concerning the scientific rationale, objectives, technology, and long-range strategic priorities for accessing and using planetary spatial data, and engaging in software development (e.g., [2]) and mapping [1]; encourage the development of standards for present and future lunar and planetary missions and research activities; help define community needs for critical research and planetary mission infrastructure [e.g., 3]; provide findings on the accuracy and precision required for spatial technologies and products; and coordinate and promote the registration of data sets from international missions and US missions to optimize their combined utility.

MAPSIT will help enable the broad spectrum of planetary spatial data and programmatic capabilities required to effectively achieve robotic precursor and human exploration of the Solar System. These include (but are not limited to) the analysis of planetary surfaces, the identification of safe landing sites, the down-selection of sample acquisition locations, hazard assessment, and the spatial characterization of in-situ resources [4, 5, 6]. In particular it will help address the issues raised in the lunar Strategic Knowledge Gaps.

Planetary Geospatial Strategic Plan: To build a roadmap, MAPSIT will solicit broad stakeholder input through community surveys and town hall meetings. A goal is to recommend and prioritize the needed data products and infrastructural developments, following a process much like that of the Lunar Exploration Roadmap. A Planetary Spatial Data Infrastructure (PSDI) has been created as a theoretical scaffold [7] which outlines and defines all aspects of planetary spatial data and lays out the needs, capabilities and tasks of the community. This builds on a similar document for the U.S., the National SDI [8]. A knowledge inventory, communication with the community about goals, and the initial development of a plan for realizing a lunar SDI is now needed. It is envisioned that the roadmap will be a living document that evolves as milestones are met and the state of the art advances.

For the Moon in particular, the roadmap will consider previous documents such as the Lunar Exploration Roadmap, to see where key recommendations regarding PSDI can best advance lunar science, exploration and commercial development. This will include recommendations for mission planning, standards, identifying current foundational data products, and what data and products are needed in the future.

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LUNAR VOLCANIC HISTORY FROM IN-SITU MORPHOLOGICAL ANALYSES. E. R. Rader[1,2] and J. L. Heldmann[1], FINESSE team. [1]NASA Ames Research Center Moffett Field, CA, , [2]NASA Postdoctoral Program, USRA (Erika.rader@nasa.gov).

Introduction: Nearly all analyses revealing the thermal and geochemical history of volcanoes on Earth require large volumes of material to be retrieved, prepared, and analyzed in a laboratory setting. To obtain the same level of information for lunar volcanoes, new techniques that require little to no sample collection must be developed. The presented project has expanded a method to determine emplacement temperature and accumulation rate of volcanic deposits, which only requires measurements of outcrops [1] to be applicable to lunar conditions. Thermal constraints for volcanic eruptions on the Moon will allow for better understanding of the thermal evolution of the lunar crust and mantle, as well as the loss of gasses from the lunar mantle [2].

Methods: The empirical relationship between measurable characteristics (clast shape, connections and voids between clasts, and vesicularity) of volcanic deposits and thermal conditions during emplacement were developed by making experimental spatter piles at the Syracuse Lava Project (Fig. 1), tracking the thermal evolution of each clast, and then measuring morphological characteristics, such as the amount of connection and void space between clasts, and the vesicularity, shape, and size of each clast. The relationship was tested using a 1-D numerical model, and then applied to natural spatter clasts at Craters of the Moon in Idaho, a lunar analogue studied extensively by the FINESSE project [3].

Results: The morphology of volcanic spatter correlates to eruption temperature and time spent above 700°C, which is approximately the glass transition temperature for experimental basalt at the Syracuse Lava Project. Higher temperatures and longer times correlate to more connections and fewer void spaces between clasts. Furthermore, lower interior vesicularity and more oblate clasts were formed at higher temperatures and longer durations above the glass transition temperature. The range of conditions in which spatter forms include emplacement temperatures of 840°C-950°C and sintering times of 25-90 minutes. Numerical modeling can be used to match these emplacement temperatures and cooling trends and estimate accumulation rates, which range from 2-6 m/hr for experimental clasts.

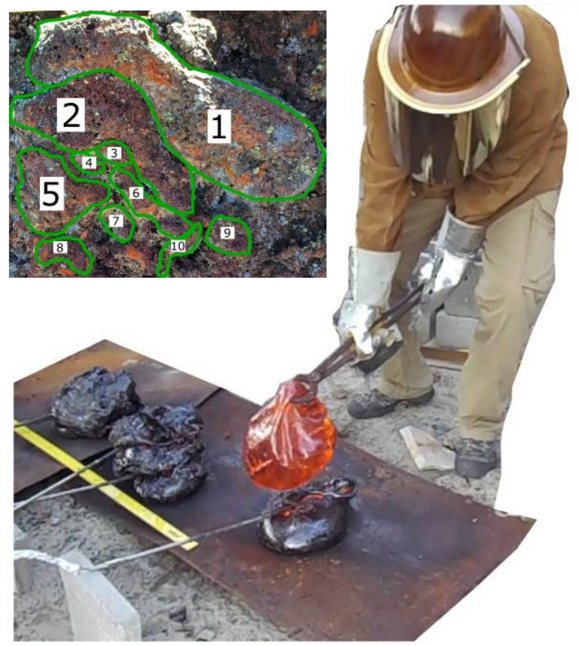

Figure 1. **Experimental spatter bombs are shown being stacked with thermocouples between each clast, the cooled product mimicked the appearance of natural spatter clasts (insert) from Craters of the Moon National Monument, Idaho.**

Implications: We present a new method requiring no sample collection to asses the thermal evolution of lunar volcanic deposits, providing key information on eruptive history of volcanic areas on the Moon. There is currently no way to remotely sense these data from satellite imagery, therefore, landing on the Moon is critical to gain more understanding of the eruptive processes that shaped our nearest neighbor. With the correct measurements, the eruption duration, explosivity, and eruptive column height can be garnered from outcrops of scoria or spatter clasts. This type of material has been hypothesized to exist in several locations on the Moon, including the Marius Hills [4].

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Acknowledgments: Funding for this project comes from Universities Space Research Association (USRA) through the NASA Postdoctoral Program. FINESSE is supported by NASA's SSERVI (Solar System Exploration Research Virtual Institute).

FAR-ULTRAVIOLET BIDIRECTIONAL PHOTOMETRY OF APOLLO SOIL 10084: LABORATORY STUDIES IN THE SOUTHWEST ULTRAVIOLET REFLECTANCE CHAMBER (SwURC). U. Raut, P.L. Karnes, K.D. Retherford, M.W. Davis, E.L. Patrick, Y. Liu, P. Mokashi. Southwest Research Institute, Space Science and Engineering Division, San Antonio, Texas 78238.
(uraut@swri.edu)

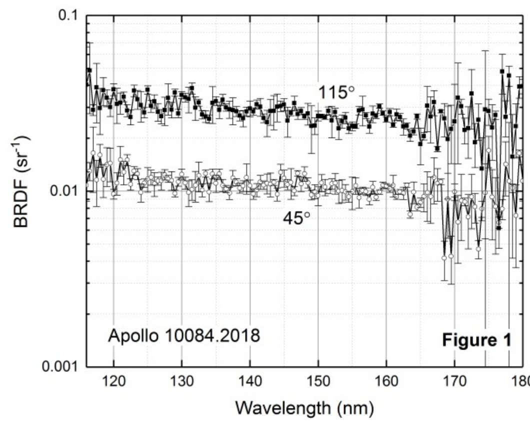
Introduction: A detailed understanding of the physico-chemical properties of the lunar volatiles and an accurate assessment of its abundance and distribution are critical to the in-situ utilization of these resources in future explorations. Our understanding of the nature, abundance, and distribution of these volatiles emerges mainly from remote-sensing spectroscopy. For instance, observations of the several permanently shadowed regions (PSRs) of the moon by LRO-LAMP showed relative reddening (> 155 nm) in their far ultraviolet (FUV) spectra that is best explained by the presence of < 2% water frost mixed with the lunar regolith [1]. Similarly, LAMP dayside observations reveal variations in the FUV spectral slopes attributed to the diurnal/latitudinal variation of hydration at the lunar surface. However, the water abundance needed to produce the spectral signatures remains poorly constrained, estimated at < 1% [2].

Such estimates, derived from photometric modeling of observed FUV albedo, would benefit from laboratory measurements and verification. Some key laboratory measurements that would improve/constrain previous estimates are FUV bidirectional reflectance and optical constants of Apollo soils, water frosts, and ice-soil aggregates. To this end, we report new measurements of FUV bidirectional reflectance distribution function (BRDF) of mare soil 10084. To the best of our knowledge, the only existing FUV measurement of lunar soil was performed decades ago [3]. We improved over this existing dataset, specifically with respect to the vacuum conditions, counting statistics and sampling intervals, and geometry (i.e. BRDF measurements at multiple phase angles).

Experimental Setup: The measurements reported here were conducted in the SwURC [4], a high-vacuum (base pressure ~10^{-8} Torr) ultraviolet reflectance chamber. We filled a rectangular trough (13 mm *L* x 13 mm *W* x 0.5 mm *D*) on our anodized aluminum sample tray with ~ 0.2 g of Apollo soil 10084.2018 obtained from CAPTEM. This is a mature mare soil (I_s/FeO = 78) containing nanophase Fe and enriched rich in Ti content, returned by the Apollo 11 mission. The soil sample was subject to a ~ 250 °C, 24 hours vacuum bake-out prior tray assembly.

A 30 W deuterium lamp illuminates a grating monochromator which provides monochromatic light that is collimated with a pair of reflective cylindrical mirrors, prior to illuminating our sample at a fixed 45° incidence. A channeltron detector (Photonis 5901 Spiraltron, CsI-coated) is rotated in the principal plane over emission angles of -70° to + 90° with respect to the surface normal to collect diffuse light reflected by the Apollo soil. The angular steps can be as small as 0.01°. We also measure the incident beam intensity by retracting the sample tray and directly intercepting the beam with the detector positioned at 135°. The intensity of the reflected light at a particular emission or phase angle is divided by the incident beam intensity (plus geometrical corrections) to yield the BRDF.

Results: Figure 1 shows the BRDF spectra of Apollo soil 10084 collected at 45 and 115° phase angles (phase angle is the angle between incidence and emission). The Apollo soil BRDF is featureless, except for a small blue slope. The soil appears brighter at higher phase angles, implying the lunar soil anisotropically scatters FUV photons in the forward direction.



We will present additional BRDF spectra obtained at various phase angles and discuss the fits of Hapke's model to the angular distribution of BRDFs at Ly-α and 160 nm. Future plans will include BRDF measurements of several mare and highland soils of varying maturity index (I_s/FeO) and lunar soil-ice aggregates, to directly compare to LRO-LAMP datasets to constrain the lunar water ice abundances.

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DEVELOPING AND TESTING LUNAR TECHNOLOGIES IN A CONTROLLED SIMULATION LAB USING SIMULANTS BUILT FROM THE PARTICLE LEVEL UP. Vincent G. Roux[1] and Melissa C. Roth[2], [1,2]Off Planet Research, LLC 5000 Abbey Way SE, Lacey, Washington 98503, [1]Vince@OffPlanetResearch.com. [2]Melissa@OffPlanetResearch.com.

Introduction: With the renewed urgency of returning to the moon and the resulting need to conduct testing of moon-bound technologies, the natural urge is to repeat past patterns and buy a batch of “good enough” simulant that is similar to, but not the same as previously produced simulants. The additional commitment of building and operating the required testing facility has often been forsaken in favor of something that was again, “good enough”. This pattern emerged due to missions that were one-off and underfunded.

Manufacturing very high fidelity simulants and operating a large scale environmentally controlled simulation laboratory can only happen when the motivation arises from a long-term commitment focused on the success of the missions rather than the occasional sale of the simulant. Off Planet Research (OPR) does not sell its simulants for reasons discussed later.

Background: Making lunar regolith simulant for sale is not a sustainable business. Despite good intentions, existing simulants of limited quality were produced quickly, and were disbursed and compromised.

The simulation lab is equally important. It is well known that a large quantity of high quality lunar regolith, maintained and held in a controlled laboratory environment is needed. This lab needs to be large enough for multiple lunar landscapes with appropriate simulants. The environments in the simulation labs at OPR are very tightly controlled.

The overwhelming majority of the surface of the moon is highland, while almost all of the simulant ever made is lowland. Because of this need, OPR is producing over 30 tons of highland simulant for use in its labs.

Almost all available simulants lack actual agglutinates which are a critical component that makes up to 90% of lunar regolith. There is simply no way that any simulant without agglutinates can realistically behave like actual lunar regolith. Crushed melt product added to simulant is better than nothing but it is not agglutinate just as croutons are not bagels.

Particle-up Production Method: Most simulants are produced in a top-down manner where large scale sintering, modification, and milling is performed followed by inspection of the product and adjustment of the processes until available time and funds run out. This method tends to produce adequate simulants given the conditions under which they are made, although the products retain many decidedly Earth-like qualities.

OPR was not constrained by the time and budget limitations of previous efforts, so each component within these simulants can be built from the particle level up. For each type of particle within the lunar regolith, OPR replicated the natural formation processes on the moon and then fully characterized regolith formation at the particle level. The rate of formation was then meticulously scaled up so that the particles that make up OPR’s simulants are very close approximations of true lunar particles. This includes crushed minerals with the correct morphology, and the formation of glass spherules, breccia, and of course, true agglutinates.

OPR manufactures true agglutinates by replicating the natural formation process by micro-meteorite strikes that occur on the moon, which produces simulated lunar agglutinates that are mechanically nearly identical to the real thing.

After building the individual simulant components, OPR mixes them in the correct ratios to create the simulants. The result of this particle-up effort is simulants which are superior to those that currently exist. What this means is that simulants made by OPR are much closer to lunar regolith with fewer Earth-like characteristics than other current simulants.

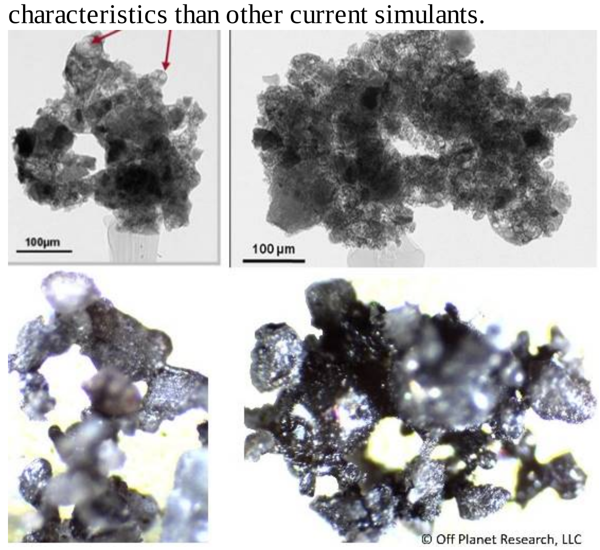

Figure 1 : Upper images used by permission from *An X-ray Ultra microscopy Study of Apollo 11 Lunar Regolith* paper by Kiely, C and Kiely, C.J. (2010). Lower images are simulated highland agglutinates produced by Off Planet Research, LLC. All particle sizes are similar.

GEOLOGICAL SPACESUIT TESTING. K. D. Runyon[1], [1]Johns Hopkins University Applied Physics Laboratory, 11101 Johns Hopkins Road, Laurel, MD, USA, 20723. kirby.runyon@jhuapl.edu

Introduction: Astronauts' scientific tasks on lunar and planetary surfaces will largely be the geological exploration of their site. Pressurized rovers proved a valuable tool for geologic exploration during previous Desert RATS (Research and Technology Studies; e.g., [1;2;3]). While spacesuits keep crew alive during missions, the suits also allow mobility so as to maximize scientific return from geological field studies. Thus, spacesuits are a geological tool in their own right.

Spacesuited test subjects on Earth provide valuable feedback for spacesuit design. With their knowledge base, geologists serving as spacesuit test subjects are uniquely positioned to adapt terrestrial field geological techniques for use on the Moon and elsewhere.

I was recently sized for the Mark 3 Spacesuit as a geologic spacesuit test subject. This involved body measurements and adjusting gloves, suit harness tightness, and pant sizings. This laid the groundwork for my future participation in adaptation of terrestrial field geology techniques for use in a spacesuit on the Moon.

Spacesuit Impressions: My ears popped as the spacesuit was pressurized to 4.6 psi above ambient conditions. Even with the suit supporting some of its own weight, I was struck with how heavy it felt; most of the weight was supported via internal backpack-like shoulder straps. While the weight wouldn't be an issue on the Moon, the inertia is: the suit "tried" to move my center of gravity away from over my feet, and this necessitated slow, thoughtful movements.

While I could not kneel, I could assume a lunge position with legs apart to allow picking up an object from the ground (Figure 1). However, my ability to "crunch" my abdomen to pick up the object was curtailed. This meant that I sometimes had to stand up, walk forward or back by a fraction of a step, and lunge again to pick up the object. A walking stick was a valuable asset, which [2] also discovered to be useful.

Finger and hand mobility was quite good. The current Phase 6 gloves allows a wide range of easy hand positions even when pressurized. Grasping and holding onto objects was not a problem.

Future Work: As a qualified geologist spacesuit test subject with NASA/JSC's Crew and Thermal Systems Division (CTSD), I am poised for inclusion on SSERVI teams, PSTAR grants, RATS, and other funded investigations.

Acknowledgements: Much thanks to the CTSD staff (Amy Ross, Kevin Groneman, Kris Larson, and others) for accommodating me; and to Dean Eppler for mentoring a new generation of crash test dummies.

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Figure 1. *Top Left:* Simple walking. *Top Right:* I could not reach the object by squatting. *Middle Left:* Lunging down allowed me to grasp the object on the ground, though sometimes multiple tries were needed to get my forward-backward distance correct to be able to reach the object. *Middle Right:* Considering a sample of vesicular basalt. *Bottom*: Getting my fingertips to exactly touch the glove tips is necessary for a nearly perfect glove fit.

Launch Services for the Moon. Melissa Sampson[1], [1]United Launch Alliance, 9501 East Panorama Circle, Centennial, CO, 80112, Melissa.sampson@ulalaunch.com

Introduction:

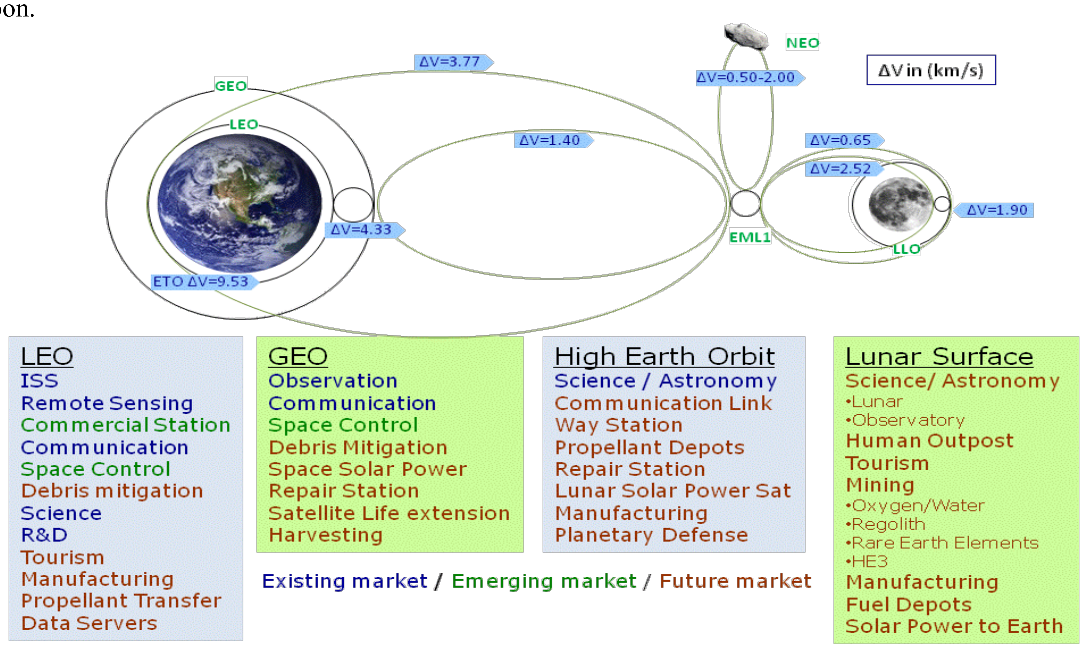
One of the next frontiers is the Moon. United Launch Alliance (ULA) has extensive experience with launching delicate, exquisite payloads throughout our solar system, including the Moon.

ULA is developing a next generation second stage, ACES (Advanced Evolved Cryogenic Stage), which will greatly increase payload capacity to many orbits and locations. It is currently in development and builds on flight proven Centaur heritage. ACES can deliver payloads throughout the Earth Moon system, including to any lunar orbit.

In addition to ACES, ULA is also developing XEUS (eXperimental Enhanced Upper Stage), which is a mission kit added to ACES. XEUS can deliver large payloads, both crew and cargo, to the Moon's surface.

A unique benefit of ACES/XEUS is the ability to utilize distributed launch. Distributed launch significantly increases the amount of payload that can be delivered to the lunar surface. Distributed launch consists of two launches. The first launch puts propellant in Earth orbit. The second launch delivers the payload with ACES. Once both payload and propellant are in orbit, ACES is refueled from the propellant. Now the second stage is largely fueled and out of the majority of Earth's gravity well.

ULA offers a variety of launch services, including ACES/XEUS with lunar surface delivery, in addition to multiple options to deliver other customers to the Moon.



MODELING SODIUM ABUNDANCE VARIATIONS IN THE LUNAR CRUST: A LIKELY PROXY OF PAST SOLAR SYSTEM HISTORY AND A POTENTIAL GUIDE TO CLOSE-IN ROCKY EXOPLANETS.

P. Saxena[1], R. M. Killen[1], N.E. Petro[1], V. Airapetian[1], and A. M. Mandell[1], [1]Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD, United States (prabal.saxena@nasa.gov)

Introduction: While the Moon and Earth are generally similar in terms of composition, there exist variations in the abundance of certain elements among the two bodies. These differences are a likely consequence of differing physical evolution of the two bodies over the solar system's history. We describe how our past and current modeling efforts indicate that a significant fraction of the initial sodium budget of the Moon may have been depleted and transported from the lunar surface since the Moon's formation. Using profiles of sodium abundances from lunar crustal samples may thus serve as a powerful tool towards exploring conditions on the Moon's surface throughout solar system history. Conditions on the Moon immediately after formation may still be recorded in the lunar crust and may provide a window towards interpreting observations from some of the first rocky exoplanets that will be most amenable to characterization. Potential spatial variation of sodium in the lunar crust may be a relevant consideration for future sample return efforts.

Sodium Depletion in the Lunar Crust: Lunar samples indicate the Earth and the Moon are generally very similar in composition, but that there exist significant depletions in elements that possess condensation temperatures less than 1300 K (at a pressure of 10^{-4} bar)[1]. Sodium appears to be approximately five times more abundant in the Bulk Silicate Earth versus the Bulk Silicate Moon, with significant variation depending on the particular lunar sample chosen. [2] Some of these abundance variations have been attributed to incomplete accretion during the formation of the Moon immediately after a hypothesized giant impact on the Earth. [2] However, processes operating after accretion of the Moon may also have influenced sodium abundance and spatial variation on the Moon.

Post-Formation Depletion and Transport Mechanisms: We examine two mechanisms that may have influenced sodium abundances:

A Primordial Lunar Atmosphere. Given a canonical Moon formation hypothesis where the Moon accreted quickly from a disk created when a planetary sized impactor hit the Earth, the Moon may have possessed a short-lived largely hemispheric metal dominated atmosphere immediately after it tidally locked to the Earth. Sodium would have been a significant (and potentially dominant) constituent of this atmosphere. Such an atmosphere was characterized by moderate pressures, high atmospheric temperatures, strong supersonic winds and large atmospheric scale heights. [3] Estimates of atmospheric (and consequently sodium) escape from such an atmosphere range from 5-25% of the initial sodium content of the global lunar magma ocean. [3] Additionally, sodium would have been transported rapidly to regions of the Moon near or just beyond its' terminator with respect to the Earth. This transport would have occurred right up to and during the beginning of lid formation and may have produced sodium depletions from sub-Earth zones while producing significant sodium abundance enhancements on rockbergs [4] that were advected towards the far side.

Effects of Past Solar Activity. Sodium may also have been depleted due to solar activity in the past. Recent research based on Kepler observations of solar analogues at different stages in their evolution indicate the Sun may have experienced an enhanced period of flare and CME activity earlier in its history. [5] This enhanced CME activity may have resulted in a frequency of geoeffective high energy CMEs on the Earth-Moon system of >1/day in the first 500 million years of the Solar Systems history. Using a previously developed exosphere generation model that includes the effect of an incident CME [6], we are able to estimate the potential loss of sodium from the regolith due to solar wind and CME effects. Depending on the choice of composition (LPUM versus TWM), even with a conservative model of sputtering yields, this enhanced solar activity may explain anywhere from 10-100% of the observed sodium depletion. Additional modeling considering other physical mechanisms that may effect sodium abundance and spatial variations should be a focus of future work. Eventually, connecting vertical profiles of sodium abundances in lunar samples to physical mechanisms may be a potential means of exploring lunar surface history.

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Introduction: The Apollo lunar EVAs demonstrated success in many different ways – trained crew observations, sample documentation, experiment deployment, and roving vehicle operation to name a few. Drilling into the lunar regolith, however, was not an unequivocal success. Although heat-flow probes were successfully employed on Apollo 15 and 17 and deep drill cores were returned on Apollo 15, 16 and 17, the cores were obtained only at the cost of significant physical effort and exploration time. Although the rotary percussive drill system used by Apollo astronauts penetrated into the lunar regolith with reasonable efficiency, extraction of the drill core stem proved to be very difficult on all three missions.

The Problem: The problem with drill stem extraction probably lies in two aspects of the geotechnical character of the regolith. First of all, even though it is a heterogeneous mixture of particle sizes, the regolith is very closely packed and provides little or no space for sideways particle movement during drilling. The fluted design of the outer wall of the drill stem (figure 1) provided a path for the drill cuttings to move upward and out of the way of down-hole movement. Secondly, the regolith contains numerous jagged particles large enough to catch on the flutes during extraction but too large to be easily pushed into the densely packed walls of the drill hole. As the fluted drill stem begins to move upward, some of these larger particles catch on the flutes and work to retard that upward movement. This will be a problem whether robotic or human energy is available for extraction.

The Solution: A potential solution would be to employ flutes that can be retracted into the drill stem wall so that the outer drill stem wall becomes a smooth surface. Alternatively, a gas-flow system might be devised to removed cuttings during drilling, allowing a smooth wall to be used on the outer drill stem.

Figure 1 Apollo deep drill stem showing outer spiral flutes.

THE ANATOMY OF THE BLUE DRAGON: CHANGES IN LAVA FLOW MORPHOLOGY AND PHYSICAL PROPERTIES OBSERVED IN AN OPEN CHANNEL LAVA FLOW AS A PLANETARY ANALOGUE.

A. Sehlke[1], S.E. Kobs Nawotniak[2], S.S. Hughes[2], D.W. Sears[1,3], M.T. Downs[4], A.G. Whittington[5], D.S.S. Lim[1,3], J.L. Heldmann[1] and the FINESSE Team. [1]NASA Ames Research Center Moffett Field, CA (alexander.sehlke@nasa.gov), [2]Idaho State University, Pocatello, ID,[3]Bay Area Environmental Research Institute, Petaluma, CA, [4]NASA Kennedy Space Center, Titusville, FL, [5]University of Missouri, Columbia, MO.

Introduction: Lava terrains on other planets and moons are abundant, with morphologies similar to those found on Earth, such as flat and smooth pāhoehoe, which can transition to rough, jagged \`a\`ā terrains based on the viscosity – strain rate relationship of the lava [1]. Therefore, the morphology of lava flows is governed by eruptive conditions such as effusion rate, underlying slope, and the fundamental thermo-physical properties of the lava, including temperature (T), composition (X), viscosity (η), the volume fractions of entrained crystals (ϕ_c) and vesicles (ϕ_b), as well as bulk density (ϱ). These textural and rheological changes were previously studied and quantified for Hawaiian lava through field and laboratory work [2,3]. In this case, the lava flow started as channelized pāhoehoe and transitioned into a rough \`a\`ā flow, demonstrating a systematic trend in $T, X, \eta, \phi_c, \phi_b$, and ϱ.

NASA's FINESSE (Field Investigations to Enable Solar System Science and Exploration) focuses on Science and Exploration through analogue research. One of the field sites is Craters of the Moon (COTM) National Monument and Preserve, Idaho, a dominantly basaltic volcanic system erupted ~2000 years ago, exposing a variety of well-preserved volcanic features. In this study, we present field work done at a ~3.0 km long open channel lava flow belonging to the Blue Dragon (BD) lavas erupted from a chain of spatter cones, which then coalesced into channelized flows.

Methods: We acquired Unmanned Aerial Vehicle (UAV) imagery along the entire length of the lava flow, and generated a high resolution Digital Terrain Model (DTM) of ~5 cm per pixel (Fig. 1), from which we derived height profiles and surface roughness values [4,5]. Field work included traversing the flow from vent to toe, mapping the change in surface morphology while samples were collected approximately every 150 meters from the channel interior and the levees. In the laboratory, we measured ϕ_c, ϕ_b, and ϱ for all these samples. Viscosity measurements were carried out by concentric cylinder viscometry at subliquidus temperatures between 1310ºC to 1160ºC to study the rheology of the lava, enabling us to relate changes in flow behavior to temperature and crystallinity.

Results: Our results are consistent with observations made for Hawaiian lava. In particular, we observe an increase in bulk density towards the flow terminus, while porosity changes from connected to isolated pore space. Crystallinity increases downflow, and the transition from pāhoehoe to \`a\`ā is prompted by nucleation and growth of plagioclase microcrystals, strongly increasing the viscosity of the lava several orders of magnitude. The transition of the lava from pāhoehoe to \`a\`ā occurs in a temperature interval from 1230ºC to 1150ºC, based on rheology experiments.

Conclusions: The results of this study allows us to correlate $T, X, \eta, \phi_c, \phi_b$, and ϱ to the lava flow morphology expressed as surface roughness, which can then be used as a tool to infer these physical properties of the rocks for open channel lava flows on on the Moon , such as lava flows documented near the Marius Hills and Lunar Mare, based on Digital Terrain Models.

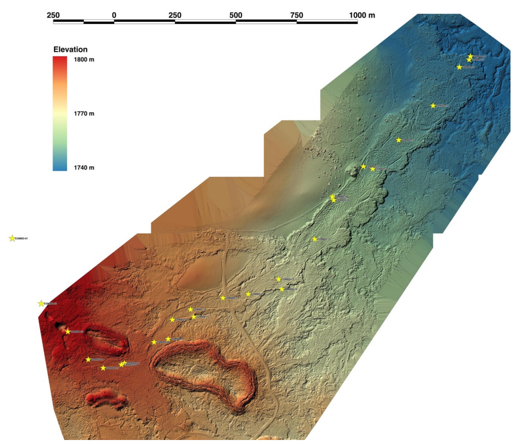

Fig 1: High-resolution (5 cm per pixel) Digital Terrain Model (DTM) of the studied Blue Dragon lava flow at the Craters of the Moon National Monument and Preserve, Idaho, generated by UAV imagery. Star symbols represent sample locations along the flow.

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ENABLING MID-INFRARED SPECTRAL ANALYSIS ON THE LUNAR SURFACE. K. A. Shirley[1], T. D. Glotch[1], G. Ito[1] and A. D. Rogers[1], [1]Geosciences Department, Stony Brook University, Stony Brook, NY 11794. katherine.shirley@stonybrook.edu.

Introduction: The lunar environment is harsh, with extreme thermal gradients in the top few hundred microns of regolith. However, the Moon is the most likely potential target for near-term exploration by crewed missions. When we return, we will need to determine locations of scientific or resource value, and while we will utilize orbital data for surface exploration, handheld instruments for astronaut use will be invaluable. Additionally, we will need the ability to accurately analyze results from such instruments taking the lunar environment conditions into account.

The use of handheld instruments by humans at the lunar surface aids astronauts' ability to characterize what they see and identify regions of interest. Handheld visible/near-infrared (VNIR) equipment has long been in use in terrestrial field work, and scientists are continuing to create and test new field tools for the mid-infrared (MIR). Ito et al. [1] have done extensive field tests in Hawaii and New Mexico on the utility of a handheld thermal IR camera, and have demonstrated its ability to identify regions of interest in a scene, as well as differentiate geological units invisible to the human eye.

Analysis of spectra acquired by a hand-held instrument on the lunar surface would require a database of spectra acquired under lunar-like conditions [2]. In the lab, we can simulate the thermal environment on the Moon at low pressure to measure VNIR and MIR spectra for comparison with data from remote sensing instruments like the Moon Mineralogy Mapper and the Diviner Lunar Radiometer Experiment. The Planetary and Asteroid Regolith Spectroscopy Environmental Chamber (PARSEC) at Stony Brook University is one such instrument capable of measuring samples under simulated lunar environment (SLE). The SLE spectral libraries we are developing are already useful for analysis of orbital data and will be even more so, when humans or rovers on the surface make measurements at the same frequencies. Additionally, information we can gather from the surface, such as a direct thermal gradient readings would greatly enhance our ability to accurately simulate environmental conditions in the lab.

Our previous work has involved measuring the spectra of pure minerals, mixtures, simulants, and simulated space weathered samples to understand how a simulated lunar environment affects MIR spectra and necessity of measuring under SLE to compare to lunar spectra.

Methods: PARSEC achieves SLE conditions by passive liquid nitrogen cooling under ~10^{-6} mbar vacuum, and heating samples from above and below to create a lunar-like thermal gradient. Chamber temperatures reach <150 K and the sample is heated to reach surface brightness temperatures of ~350 K. Emissivity spectra are calibrated via the methods of [3&4]. The samples used in the experiments were ground, cleaned, and sieved into varying size fractions.

Results: Particle size influences MIR spectra, notably by shifting the position of the Christiansen feature, and the spectral contrast of the Reststrahlen bands [5].

Mineral mixtures of <32 um also show a change in spectral shape, but a Christiansen feature position shift that is consistent with that observed under terrestrial conditions with varying the weight percent of the mineral constituents.

Simulated space-weathered material also shows a shift in Christiansen feature position from that measured under terrestrial conditions and further experiments show a correlation between sample albedo and CF position.

Discussion: The SLE experiments performed here demonstrate the power of environmental conditions to alter MIR spectra from those measured on Earth and the necessity for a SLE spectral library to characterize material sensed remotely and measurements performed on the lunar surface. Additionally, these experiments highlight the importance of variables previously unstudied or only understood as they affect spectra on Earth.

When used in concert with handheld MIR instruments [e.g., Ito et al., 2016], these spectral analyses and the development of an SLE spectral library will allow future astronauts to identify geologic interests within a region. Efficiency of these measurements will allow astronauts to quickly assess a scene to recognize areas useful for both science and exploration purposes.

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ROBUST NAVIGATION FOR AUTONOUMOUS EXPLORATION OF EXTREME ENVIRONMENTS FROM A FREE-FLYING PLATFORM.
K. Snyder[1], E. Amoroso[1], F. Kitchell[1], and A. D. Horchler[1]
[1]Astrobotic Technology, Inc., 2515 Liberty Ave., Pittsburgh, PA 15222. kerry.snyder@astrobotic.com

Introduction: Permanently shadowed regions and lava tubes on the Moon are sites of considerable geological interest, and hold the potential for in-situ resource utilization and future human habitation. However, these domains present daunting challenges to exploration and sampling. Free flying vehicles have the mobility to explore such environments but require robust and precise navigation for advanced autonomy. Astrobotic is developing these capabilities under a Phase II NASA STTR contract to enable high impact science and exploration on the Moon (Fig. 1).


Figure 1: Free-flyer exploration concept for extreme environments.

Sensing: Robust, high-rate GPS-denied navigation is required for autonomous exploration of lava tubes and caves and presents unique challenges. On the surface, detailed maps are unavailable, but the surrounding terrain is illuminated and allows for visual navigation. Conversely, underground there is little-to-no light, but the craft will be surrounded by rich geometric surfaces. Astrobotic is developing a solution that fuses LiDAR and visual sensing such that precision navigation is maintained during the transition from light to dark and back. A sensor package combining stereo global shutter image sensors and a Velodyne VLP-16 LiDAR is used to develop and test these capabilities, and sensor measurements are precisely synchronized and collected with a custom sensor interface controller.

Navigation: With a factor graph-based simultaneous localization and mapping (SLAM) formulation, these different navigation modalities are robustly fused. A requirement for drift of < 5% of distance traveled ensures that the free-flyer can safely exit after exploring the cave. Image feature observations are triangulated with stereo cameras and tracked between images with optical flow. LiDAR scan features are registered using LOAM [1] and then processed to generate relative pose measurements. An iSAM2 [2] incremental smoothing backend efficiently fuses these measurements into a coherent, low-drift pose estimate.

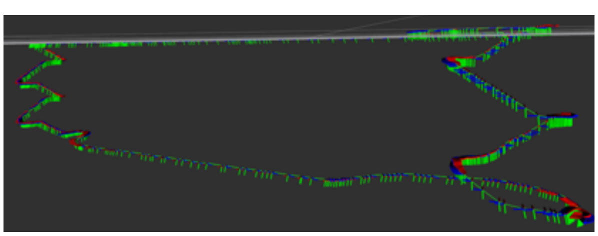
Figure 2: Example indoor navigation capability: side view of a 130-m path that travels down and back up one story.

Field Testing: Robust navigation is being tested with indoor, urban, and cave datasets (Fig. 2). Continuous testing ensures robustness while accuracy and performance are improved. A navigation drift rate of less than 1% has been achieved in a variety of scenarios with LiDAR, visual, and combined LiDAR-visual navigation [3]. For field validation, these algorithms are being deployed on a terrestrial hexcopter (Fig. 3). With integrated high performance computing, all navigation, exploration, and mapping is performed onboard.

Future Work: By Fall 2018, navigation algorithms will be field tested in a realistic skylight entry scenario. The terrestrial hexcopter, with an onboard sensing and computing payload, will autonomously take off from a base station, navigate to a cave entrance, and enter, map and explore the cave, before returning to the base station. Future tests may also incorporate lightweight sampling equipment and validate the full free-flyer mapping and sample collection concept of operations.

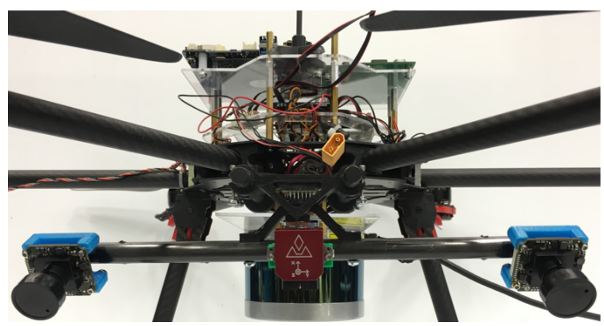
Figure 3: Hexcopter sensing and computing platform.

Acknowledgement: This work was supported by Phase I and Phase II NASA STTRs (NNX15CK15P and NNX16CK16C) and is completed in conjunction with Nathan Michael at Carnegie Mellon University. CMU is developing state of the art information driven exploration guidance [4] and multi-modal mapping [5] that complements Astrobotic's robust navigation.

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THE ROBOTIC ARCHITECTURE OF MOON EXPRESS: EXPLORATION, RESOURCES AND DELIVERY

Paul D. Spudis[1,2], Robert D. Richards[2] 1. Lunar and Planetary Institute, Houston TX 77058 2. Moon Express Inc., Cape Canaveral FL 32920

Moon Express has recently released information on a planetary exploration architecture that describes a variety of spacecraft configurations and missions. The spacecraft may be used singly or combined and configured to carry out a variety of missions to the Moon and in cislunar and deep space.

Moon Express Spacecraft. The MX-1 spacecraft is self-propelled, having a 250 kg wet mass with a total delta-v of 5.8 km/s. Depending upon the launch vehicle selected, it is capable of carrying up to 30 kg of payload to the surface and provide up to 200 W of electrical power to serve a variety of payloads. The MX family of spacecraft are capable of being combined and configured in a modular fashion to accomplish a wide variety of deep space missions. Two MX-1 can be stacked to create a single, two-stage vehicle (MX-2) for orbital maneuvers, translunar injection, and various trans-LEO operations. Depending on the mission, this spacecraft enables orbiters, landers, and deep space (planetary) probes. Five MX-1 units can be employed in a platform configuration (MX-5) for missions to the lunar surface. Such an arrangement provides the capability to land 300 kg on the Moon from GTO or 50kg from LEO. The MX-9 consists of nine MX-1 stages, arranged in a cluster of 8 outboard and 1 inboard that can land 500 kg on the lunar surface, including the option of landing a fully fueled single MX-1 ascent stage for a sample return journey [1].

Moon Express Missions. We have devised several missions designed to address a variety of exploration and scientific goals. The first mission will likely orbit the Moon to validate the basic spacecraft design, refine its operational properties and test our custom propulsion system in real space operations. Payloads are still being evaluated but among the possibilities is a multispectral imaging system designed to map the global spatial and temporal distribution of the 3 micron hydroxyl and water spectral absorptions discovered by the Moon Mineralogy Mapper (M^3) on the Chandrayaan-1 orbiter [2]. This feature is important for understanding the nature and conditions of lunar water deposition and migration, a crucial aspect of the lunar water cycle. We are evaluating a spectral imager designed by APL (MIMSI) for compatibility with this mission [3]. An MX-1 in polar orbit could map the water band over the entire Moon, with emphasis on its distribution at high latitudes and implications for this water as a source for polar volatiles.

For the first lander mission, we have tentatively selected an area of regional dark mantling deposits near Rima Bode. This material appears to be rich in Fe and Ti and is optically mature. Because the concentration implanted solar wind gas is positively correlated with fine grain size and Fe- and Ti-rich compositions, we expect this deposit to be rich in adsorbed solar wind hydrogen [4]. Recent work on M^3 spectra indicates that juvenile water from the lunar interior might also be present [5]. We plan to directly measure the bulk hydrogen content of the Rima Bode pyroclastics while also mapping any 3 micron spectral feature associated with surface water. Payload is a spectral mapper and neutron spectrometer, possibly the neutron instrument being tested for NASA's Resource Prospector mission [6]. These data provide ground truth for orbital measurements. We will select a near-polar landing site, probably between 70° and 85° latitude.

An early landed mission will emplace the International Lunar Observatory telescope [7], a privately designed and operated instrument designed to conduct observations of the galactic center from the south pole of the Moon. We are in process of selecting a landing site that gives an unobstructed view of the galactic center and southern sky, undergoes near-constant solar illumination to power the spacecraft and maintains a constant or near-constant line of sight for communication with Earth. Two sites meet these requirements, both on peaks near the south pole of the Moon.

The robust capability provided by the modular MX-1 spacecraft can be adapted to a variety of missions for government, commercial, educational and international users. Likely future missions include the return of lunar samples to Earth for both scientific and operational uses, the emplacement and delivery of surface networks, rovers and instrument packages, and the exploration and prospecting of polar ice deposits using hard landers, fixed stations and surface rovers.

Conclusions. The advent of inexpensive access to deep space locales means that they will not remain exotic much longer. The Moon Express line of services and systems enable a variety of activities in cislunar and deep space for many diverse users.

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CUBEROVERS FOR LUNAR EXPLORATION. A. P. Tallaksen[1], A. D. Horchler[2], C. Boirum[1], D. Arnett[1], H. L. Jones[1], E. Fang[1], E. Amoroso[2], L. Chomas[1], L. Papincak[1], O. B. Sapunkov[1], W. L. Whittaker[1,2].
[1]Carnegie Mellon University Robotics Institute. 5000 Forbes Ave, Pittsburgh, PA 15213. aptallak@andrew.cmu.edu
[2]Astrobotic Technology, Inc. 2515 Liberty Ave, Pittsburgh, PA 15222. andrew.horchler@astrobotic.com

Introduction: CubeRover exploration offers a new paradigm for robotic planetary missions in which small landers and small rovers operate as precursors to larger primary missions to explore a planetary body. Small rovers can potentially explore greater area more efficiently than large rovers, because several can operate in parallel, and they can be deployed widely from multiple landers. These rovers can act as scouts, identifying safe paths into regions that would otherwise be considered too risky. This enables follow-on missions to accomplish goals that would not otherwise have been attempted. Finally, CubeRover exploration offers the prospect for standardization, democratization, and broad applicability analogous to the transformation that CubeSats brought to the domain and economics of Low Earth Orbit.

For the specific context of this project, CubeRover is specialized to address a few of NASA's Strategic Knowledge Gaps (SKGs), in particular, In-situ Lunar Surface Trafficability (topic III-C-2) and Descent Engine Blast Ejecta Phenomena (topic III-D-4) [1].

Methods: Rover mechanical design will consider at minimum a four-wheel skid steer drive body averaging suspension and an invertible two-wheel differential drive tail dragger, shown in Figure 1. The four-wheel design has superior mobility, but the two-wheeled design has a higher chance of recovering from tip-over. In addition to mobility, mass and effects on 3D imaging capabilities will determine the final design.

Requirements for battery capacity and solar power generation will be investigated and a thermal analysis performed to choose between solar powered, lander-rover recharging, or strictly battery powered designs. This thermal analysis will be based on regolith temperature and incident solar radiation on the lunar surface at appropriate latitudes and times of the lunar day.

An avionics system will be developed similar to the single board computer in development by Carnegie Mellon University (CMU). A high-resolution camera will be included to facilitate simultaneous localization and mapping (SLAM) and ejecta characterization. A Wi-Fi radio will be integrated to provide communications with a lander, along with wheel encoders and an IMU. High bandwidth communication, high performance processing, and the use of COTS components will all be investigated for use on the CubeRover.

During the mission, after deployment from the landed spacecraft, the rover will perform a visual survey of the landing site while driving in a spiral pattern out to a radius of 20 meters. A 3D model of the terrain will be created using structure from motion (SfM), a method of deriving three-dimensional structure in the world from camera images up to scale. This method is robust to changes in camera parameters, does not need explicit calibration, and can be performed using a single monocular camera. Open source SfM algorithms that may be employed include the OpenMVG Algorithm [2] and the Multi-View Environment (MVE) [3].

Field testing will occur at the LaFarge Duquesne Slag Heap just outside of Pittsburgh, PA where lunar analog terrain will be constructed. Early tests will evaluate a monocular camera on one of CMU's preexisting rovers, which will aid in the modification of software and parameters that may impact later design decisions. Other tests will evaluate slip detection, maximum travel distance, obstacle surmounting height, climbable slope angle, and rollover angles. The software will be evaluated based on its ability to produce a 3D model that provides meaningful information regarding terrain trafficability for small rovers and for characterizing lander descent blast ejecta.

Figure 1. Early concept two-wheeled rover design.

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Numerical models of volatiles loss during Lunar Resource Prospector Mission Sample Acquisition

L. F. A. Teodoro,[1] A. Colaprete,[2] T. Roush,[2] R. Elphic,[2] A. Cook,[3] J. Kleinhenz,[4] E. Fritzler,[3] J. T. Smith,[5] K. Zacny,[6] [1]BEARI/NASA Ames Research Center, Moffett Field, CA 94035 (luis.f.teodoro@nasa.gov), [2]NASA Ames Research Center, Moffett Field, CA 94035, [3]Milliennum Engineering, NASA Ames Research Center, Moffett Field, CA 94035, [4]NASA Glenn Research Center, Cleveland, OH 44135, [5]NASA Kennedy Space Center, Cocoa Beach, FL 32899, [6]Honeybee Robotics Pasadena, Pasadena, CA 91103

Introduction: Here we report on our latest effort to model the volatiles transport in lunar regolith. This research has been performed in the context of the NASA's Resource Prospector (RP). The main aim of this NASA mission to the high latitudes and permanently shadowed regions of the Moon is the identification and extraction of volatile species in the top meter of the lunar regolith layer. Briefly, RP consists of five elements: *i)* The Neutron Spectrometer System (NSS) will search for high hydrogen concentrations and in turn select optimum drilling locations; *ii)* The Near Infrared Volatile Spectrometer System (NIRVSS) will characterize the nature of the surficial and subsurface water ice; *iii)* The Drill Subsystem will extract samples from the top meter of the lunar surface for examination by NIRVSS and deliver them to the Oxygen and Volatile Extraction Node (OVEN); *iv)* The OVEN will heat up the sample and extract the volatiles therein, that will be *v)* transferred to the Lunar Advanced Volatiles Analysis (LAVA) instrument.

Over the last few years a series of vacuum experiments have been taking place at NASA's Glenn Research Center with the aim of quantifying volatile loss during the RP drilling/sample acquisition phase and sample delivery to the crucibles steps. Outputs of these experiments include: *i)* Pressure measurements of several chemical species (e.g. H_2O, OH, CO_2, N_2, Ar); *ii)* Temperature measurements within and on the surface of the lunar simulant using thermocouples; *iii)* Surficial temperature NIRVSS measurements; *iv)* Temperature measurements at the tip of the drill, and a *v)* post-test water distribution within the lunar simulant.

We report on the numerical modeling we have been carrying out to understand the physics underpinning these experiments. Given the measured temperature field and the low volatile density our modeling employs the Knudsen's (sublimation of volatile molecules at the grain surface) law. Furthermore, we also mimic the soil porosity in randomly allocating 75 micron particles.

To model the molecular diffusion of volatiles we have implemented a 3-D numerical code that track one 1 billion macro-particles (each macro-particle represents a large number of water molecules) within the computational volume. At each instant, we compute a time-step that takes into account the relevant local time scale. The Knudsen's law has the following time scale which depends strongly on temperature: Knudsen's law *residence time*: $\tau_K \alpha \exp[-Q/(KT)] * T^{1/2}$, where K and Q are the Boltzmann's constant and sublimation enthalpy. As the temperature field is not uniform throughout the simulation volume and changes during the duration of the experiment, one chooses the time-step, Δt, at a given instant in time, t, as the largest of the $\tau_K(\mathbf{r},t)$ within the simulation volume, where r and t denote position and t, respectively.

The initial conditions of each numerical model is a constant 5 wt. % water ice concentration throughout the simulation domain. This corresponds to ~3000 water ice monolayers on the surface of each grain. At each time step, the number of particles leaving is proportional to the number of particles present at the grain surface with a "half-time" given by the local residence time. The fraction of molecules going in one given direction is drawn using a Monte Carlo procedure. A grain that presents less than fifty monolayers on its surface is considered dry and molecules are not allow to leave.

Conclusions: We present the numerical results of large scale molecular simulations of water molecules during Resource Prospector sample acquisition. The current model when compared to the post-test results show a better agreement than previous models. Figure 1 presents the final water distribution profile: *i)* dark blue denote the experimental points, *ii)* grey region represents the numerical models in which a fraction of 0.01 departed from the surface in average, while *iii)* cyan line denotes the old model in which only a few monolayers were allow to leave the surface.

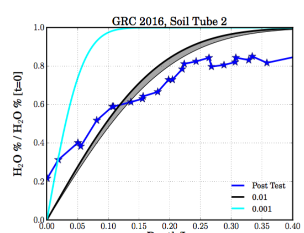


Figure 1. Final water distribution profile. Dark blue denotes the experimental measurement, the grey regions represent the latest model, and the cyan line shows the model presented at LEAG 2016.

GROWING PLANT(S) AT A MOONMARS HABITAT OR/AND DEDICATED EXTERNAL SPACE.
A. Tomic[2.] .L. Authier[1,2,4], A. Blanc[1,2,4] , B.H. Foing[1,2,3] , A. Lillo[1,2,4], P. Evellin[1,2,5], A. Kołodziejczyk[1,2], C. Heinicke[2,3], M . Harasymczuk[1,2], C. Chahla[1,2,5], , S. Hettrich[6], [1]ESA/ESTEC & [2]ILEWG (PB 299, 2200 AG Noordwijk, NL, Bernard.Foing@esa.int), [3] VU Amsterdam, [4] Supaero Toulouse, [5] ISU Strasbourg, [6] SGAC

Introduction: We developed an experiment growing plants for the human use, as a food or/and additional oxygen / energy source, that could be adapted on a Moon lander.

Phases of research and simulation:

1) In the specially created simulant copy of Moon soil, which we got from ESTEC team, we planted 3 different seeds. Seeds were couted in the mixture of clay and minerals.

2) The Moon soil was treated in the first two weeks only with a water and LED red-blue light in the daily rhymical way to support and accelerate plants grow.

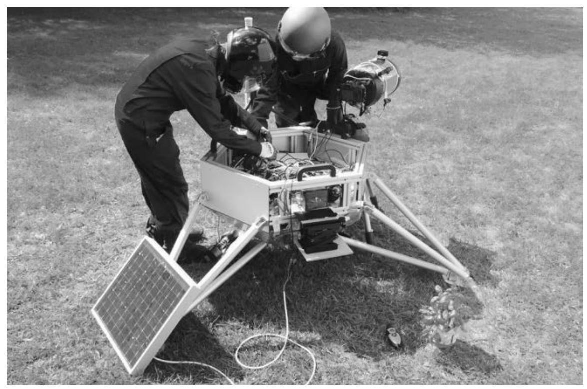
3) After two weeks on the top of water-light, soil was treated with the additional minerals:
   a. 2.7% nitrogen organic (N)
   b. 1.3% anhydride phosphoric (P2 O5)
   c. 5.9% potassium oxide (K2 O)

Plant growth Experiment at the Moon Lander:

During the EVA at the Euro Moon Mars – Moon short simulation at the ESA-ESTEC, astronauts have performed spectrometric reading of the plants leaf with the USB4000 device located at the Moon Lander.

The spectrometer was remotely controlled from the Habitat controlled by Habitat CapCom in the synchonised action and communication with the astronautls outside.

In addition of collection more data, we performed also remote reading of Moon Lander thermometer and hygrometer.



Data collected in this process first was stored at the Habbitat local data server, and than transferred to the Mission Control for the further analyses.

Acknowledgements: we thank ILEWG EuroMoonMars programme, and participants to the ESTEC EuroMoonMars 2017 workshop and simulation.

Viability of a Reusable Lunar Lander. Natan Vidra[1], [1] Co-Founder of Lunar8 and Student of Applied and Engineering Physics at Cornell University [1]. 100 Ridgewood Road, Ithaca, NY, 14850. nv78@cornell.edu

With the utilization of insitu resources, the creation of a Moon Village, and the completion of Google LunarX Prize all potentially in store, sustainability and economic feasibility are needed now more than ever. The development of ports in LEO and LLO, the creation of a Lunar Lander, and the making of a hub and spoke network for flights are essential for the colonization of the Moon and beyond. In order to realize this vision, it is essential that we create a safe and synchronized model of transportation to get cargo and modules to LLO and lunar surface.

Lunar8 [2], an aerospace startup founded by a group of Cornell Engineers, intends to help create this mode of transportation. Our goal is to build a Reusable Lunar Lander (RLL) that will travel from lunar orbit to lunar surface, helping deliver cargo and modules to the Moon's surface. In creating this cargo delivery service, we tackle a major limitation to the Moon Village Initiative by allowing more entities to access the Moon at an affordable price. The reusability of our lander would save millions of dollars of materials that would have otherwise been thrown away into the vacuum of space after a single use.

An RLL will require in-situ resource utilization in order to create a sustainable retropropulsion lander, which will reduce inhibiting cost drivers of lunar transportation. Companies that use our RLL can also dedicate the space usually reserved for a lander to other cargo, and save the time, materials, and capital required to develop one. More importantly, the technological innovations that Lunar8 will strive for has the potential to revolutionize our economy, shifting gears from a rocket-centered space industry towards an industry willing to invest in technologies necessary for extraterrestrial expansion.

An African Proverb States: “If you want to go far, go alone. If you want to go fast, go together.” With this comes a paradigm shift in the fundamental logistics of space exploration. In order to enable rockets to fly to Saturn, Uranus, Neptune and beyond, we must first work together to create a sustainable means of getting to the lunar surface.

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[1] http://nextgenlunar.weebly.com/featured-member.html (see month of June for my bio)

[2] http://www.lunar8.space

SAFETY AND COMFORT FOR MOON AND MARS HABITATS: KEY DESIGN CONSIDERATIONS.

T.V.Volkova[1] and O. K. Bannova[2], [1]Bauman Moscow State Technical University, Ecole polytechnique, Markhi/ENSAPLV, Paris, France (tatiana.volkova@polytechnique.edu), [2]SICSA, Cullen College of Engineering University of Houston, Houston, USA (obannovaa@central.uh.edu).

Introduction: Safety requirements are critical in designing for any extreme environments and especially for habitats in space and on Moon or Mars. However, safety alone is not enough when designing for long term missions in extreme environments on Earth and in space. Comfortable and functional design that accommodates crew's physical and psychological needs can help to improve their everyday life and work performance. Currently, a common habitat design approach is based on a linear process satisfying technical requirements of the mission and providing necessary life support for the crew. Nevertheless, to ensure crew members' wellbeing and productivity, aesthetics and other architectural design aspects have to be given equal attention throughout the whole design process. In addition, it is important to examine habitat safety and comfort requirements from a broader than only technical perspective.

Habitats in extreme conditions need to satisfy exceptional requirements for construction, environmental protection, and maintenance, they have to ensure life safety, crew's physical and psychological health, productivity, and emergency response protocols.

Key design aspects of planning a Moon/Mars base or settlement emerge from answering the following questions:

- Where is better to locate Moon or Mars bases and why?
- How to integrate life support systems into the base design?
- How to provide safety in emergency situations?

Exemples of effective architectures and technologies in extreme environments: Advancing crew working performance while reducing base maintenance costs is the major concern that determines habitat design requirements and design overall efficiency. In particular, architecture of the whole structure or facility has to provide systems and inhabitants security, sustainability and good living standards. Such strategy fundamentally changes the approach to designing habitats and equipment for extreme conditions on Earth and in space.

Pleasing, yet comfortable and easy-to-use interior design combined with the latest technology allows multiple options for efficient use of habitat's compartments. That increases functional and operational flexibility of habitats and other modules interior spaces. Elegant design with unobtrusive design elements can help the crew to relax mentally and rest. Consequently, comfortable conditions for life and work contribute to improvement of crew's health and well-being stimulating better psychological and physical conditions of every crewmember who works under extreme conditions. With the new approach to habitat design habitat structures become more efficient due to their compactness, modularity and flexibility.

These assumptions are based on our research of the best practices and recommendations derived from experience on the International Space Station as well as polar research stations in the Antarctica and Arctic.

In addition, selected key results from international studies on innovative technologies and structures for habitats, radiation protection, and regenerative life support systems are summarized and reviewed.

The paper summarizes with definition of current major problems in the habitat design and proposes a new methodological architectural approach to creating innovative and effective habitation systems for Moon and Mars applications.

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STRATEGIES FOR ENABLING LUNAR EXPLORATION: A NEXTGEN PERSPECTIVE. R. N. Watkins[1,2], K. Runyon[3], T. E. Caswell[4], L. R. Ostrach[5], E. R. Jawin[4], H. M. Meyer[6], J. L. Mitchell[6], and the NextGen Group. [1]Washington University in St. Louis, Department of Earth and Planetary Sciences, St. Louis, MO 63130, USA, rclegg-watkins@psi.edu, [2]Planetary Science Institute, Tucson, AZ 85719, [3]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, [4]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA 02912, [5]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ 86001, [6]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA 85282.

Introduction: The Next Generation Lunar Scientists and Engineers ("NextGen") Group consists of graduate students, post-docs, and early career professionals who will lead future lunar science and exploration efforts [1,2]. Returning to the lunar surface will begin a new era of lunar science; however, there are many critical investigations that must be carried out beforehand to enable future lunar exploration activities. Here we outline critical strategies for enabling future lunar exploration and the crucial role that NextGen will play in their implementation.

Defining Exploration Priorities: While the expertise of senior researchers is essential for planning future missions, it is imperative to include early career scientists/engineers when defining priorities for future lunar exploration. NextGen provides fresh perspectives on destinations, scientific objectives, and exploration strategies. Actively including NextGen in discussions centered around future exploration (e.g., on strategic action teams and on SSERVI teams) will safeguard institutional knowledge, and ensure that the next generation is prepared to lead the way back to the Moon.

Integrating Science and Engineering: NextGen recognizes the value of bringing scientists and engineers together in a way that optimizes the planning and implementation of future lunar missions. The integration of science and engineering is enhanced by increasing effective communication between scientists and engineers, and by providing opportunities for cross-training between the two fields. JPL's TeamX and APL's ACE Runs [3] exemplify science-engineering synergy, and the JPL Planetary Science Summer Seminar is one program that provides cross-training between the two fields, producing a generation of scientists/engineers who can navigate the balance between science and engineering and can apply this practical knowledge to mission planning.

Field Training and Analog Studies: Developing techniques for planetary field geology is vital for human exploration of any planetary body. Advanced sampling tools and protocols have progressed significantly in recent years [4]; however, further work remains to be completed: e.g., the functional equivalents of a Brunton Compass or a hand lens have not been developed, yet these tools are essential in characterizing rock orientations and textures and for placing samples in geologic context. NextGen members are currently working to fill these capability gaps.

NextGen will actively preserve and extend institutional knowledge of planetary field geology beyond the current knowledge base; a strategic investment, especially if further delays occur in sending astronauts back to the Moon. NextGen envisions this investment taking the form of new, high-fidelity analog field campaigns, building off the experience gained from Desert RATS 2010 [5,6] and involving NextGen members in astronaut field geology and spacesuit testing (e.g., [7]).

Support for Exploration Science Research: Grant funding is difficult to obtain, especially for early career researchers, and few programs exist solely to provide support for exploration science-focused research. Though exploration science projects are often included within extended mission proposals, having programs focused on exploration science would broaden the scope and improve the quality of such investigations. A program that *does* support this – and that we believe should be nurtured by NASA HQ – is Planetary Science and Technology through Analog Research. Funding for exploration science investigations would provide opportunities for early career and senior researchers who are not active mission team members to carry out exploration research studies. Additionally, targeted exploration science funding for early career researchers would ensure NextGeners have the resources necessary to contribute fresh perspectives and innovative methods to exploration science questions.

Commercial Partnerships: Partnering with commercial companies (such as NASA's current ISS resupply contracts with SpaceX and Orbital/ATK) will lower costs and accelerate technology development, while building strong relationships with private industries. Similarly, the Google Lunar X-Prize competition may soon result in commercial companies successfully landing on the Moon. Partnerships with such companies (NextGen already has established ties with Moon Express) will promote science/engineering integration, which will in turn enable continued lunar surface exploration at lower costs and with higher scientific return.

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DIURNAL VARIATION OF LUNAR ALBEDO PROTON YIELD AND HYDROGENATION. J. K. Wilson[1], N. A. Schwadron[1], A. P. Jordan[1], M. D. Looper[2], C. Zeitlin[3], L. W. Townsend[4], H. E. Spence[1], J. Legere[1], P. Bloser[1], W. Farrell[5], D. Hurley[6], N. Petro[5], T. J. Stubbs[5], C. Pieters[7], [1]University of New Hampshire, Space Science Center and Inst. of Earth, Oceans and Space, Morse Hall, 8 College Rd, Durham, NH 03824, USA (jody.wilson@unh.edu), [2]The Aerospace Corporation, El Segundo, CA 90245-4609, USA, [3]Leidos, Houston, Texas 77042, USA, [4]University of Tennessee, Knoxville, TN, 37996, [5]Goddard Spaceflight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, [6]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [7]Brown University, Planetary Geosciences Group, Dept of Earth Environmental and Planetary Sciences, 324 Brook St, Providence, Rhode Island, 02912.

Summary: The CRaTER instrument on LRO has detected a diurnal variation in the yield of ~100 MeV albedo protons being emitted from the lunar surface. We use a new type of horizon-viewing observation, and find that the proton yield is higher over the dawn terminator than the dusk terminator. The simplest physical explanation is that mobile hydrogen or hydrogen-bearing molecules are more concentrated at the pre-dawn lunar surface; forward-scattering knock-on collisions of grazing-incidence galactic cosmic rays (GCRs) and albedo neutrons with protons (hydrogen nuclei) in the lunar regolith will increase the yield of protons relative to the GCR source, qualitatively consistent with our observations.

New Observing Mode: CRaTER is normally oriented vertically, with one end of the telescope facing the Moon and the other end pointed at the zenith. During periods when the polar orbit of LRO was over the lunar terminator, LRO was rotated to point the edge of CRaTER's field of view to within 1° of the lunar horizon, allowing for direct detection of albedo protons leaving the surface at nearly horizontal angles. (See Figure 1.) We have been collecting 10s of hours of such observations every year starting in 2015.

Data reduction: To accurately calculate the yield of lunar albedo protons at different local times, we carefully subtract the background signal in the instrument, as well as account for systematic variations in the actual or measured GCR flux. We use all six detectors in CRaTER to distinguish albedo protons from GCR protons, and then fit an exponential function to the background LET spectrum in one detector to isolate and count the protons. We also detect and account for a small difference in the dawn vs. dusk flux of incident GCRs due to streaming along interplanetary magnetic field lines. (details in Schwadron et al. 2017[1])

Implications: The size of the dawn yield enhancement suggests that a significant population of hydrogen or hydrogen-bearing molecules are mobile over or within the surface of the Moon. Schwadron et al.[2] found a 1% high-latitude enhancement in the nadir-viewing proton yield using CRaTER, and concluded that the small signal required ~1% H by mass (~10% H_2O equivalent) at depths of 10-20 cm in the regolith, which is on the high side of the range found by other studies. The dawn grazing-angle enhancement seen here suggests a portion of the global H population is concentrated towards the dawn sector of the Moon; this is reminiscent of Schorghofer's [3] model of mobile lunar H2O which predicts a dawn H2O regolith concentration that is orders of magnitude larger than that just prior to sunset.

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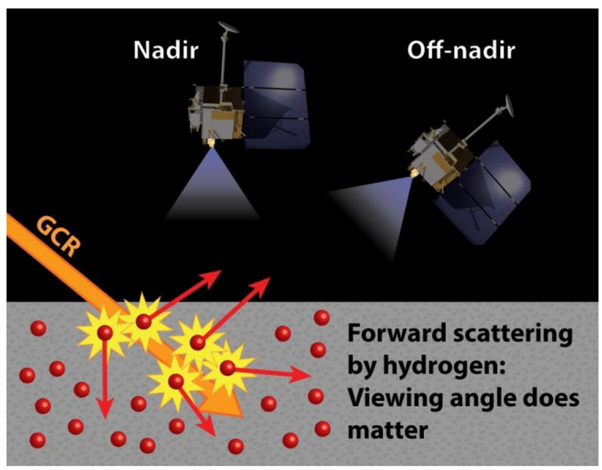

Figure 1. The orientation of CRaTER's fieid of view relative to the lunar horizon affects CRaTER's sensitivity to the products of forward-scattering (knock-on) collisions of GCRs with

CHINA'S LUNAR EXPLORATION PROGRAMME. Q. Wang[1], and L. Xiao[2], [1]Lunar Exploration and Space Engineering Center, CNSA, Beijing, China (isabellaw_q@163.com). [2]China University of Geosciences, Wuhan, China (longxiao@cug.edu.cn),

Introduction: China has a long-term lunar exploration strategy. The first round of luanr exploration is named as Chang'E Lunar Exploration Programme. It includes three steps missions: orbiting, soft landing and sample return. China has succefully completed orbiting and soft landing missions to the Moon in the past 10 years. Lunar sample return mission will be launched soon. The second round of lunar exploration will target on the polar region and explore the potentail resources. The third round of luanr exploration aims to establish a research station.

Chang'E Lunar Exploration Programme: This three-step lunar exploration programme started from the first step of two orbiting missions named as Chang'E-1 launched in Oct. 2007 and Chang'E-2 launched in Oct. 2010. Chang'E-1 orbited the Moon for 494 days, carred out global and general survey by remote sensing, obtained lunar global image and elevation map with 120m in resolution, mapped the abundance and distribution of various chemical elements on the lunar surface. Chang'E-2 validated key technologies for moon landing and obtained obtained the map of entire lunar surface with resolution of 7m, high resolution (1.7m/pix) image of Sinus Iridium in preparation for Chang'E-3's soft landing, carried out extensive tests at Sun-Earth L2 point, and successfully conducted flyby detection of asteroid 4179 Toutatis in its extended mission. Chang'E-2 is now orbiting the Sun as an artificial satellite with a distance of more than 200 million km from Earth. Chang'E-3 mission, the second step exploration, was successfully soft landed and roved (Yutu Rover) on the designated area of norther Imbrium. It was the first soft landing on the Moon since the Soviet Union's Luna 24 mission in 1976. The Chang'E-3 spacecraft touched down on the northern Mare Imbrium of the lunar side, a region not directly sampled before. Yutu Rover drove 114 meters on the ejectoa blanket, detected the surface composition and subsurface geology. The lunar penetrating radar detection identified multilayered subsurface structure in landing region, suggesting that this region has experienced complex geological processes and is compositionally distinct from the Apollo and Luna landing sites [1][2][3]. Chang'E-4, the back-up spacecraft of Chang'E-3 will explore the farside of the Moon and will be launched in 2018. It includes a relay satellite, a lander and a rover. The third step sample return mission Chang'E-5 will be lanched soon once the Long March-5 rocket passed testing. The candidate landing and sample return region is located at the Mons Rumker region, northern Oceanus Procellarum. It plans to take up to 2000 grams lunar regolith from surface and subsurface by gripping device and drill. Chang'E-6 will probably to take samples return from the polar region once the Chang'E-5 succeed.

Lunar Polar Region Exploration: China Space Agency (CNSA) plans to carry out 3 missions to study the geological structure, mineral composition, volatile content in permanent shadow areas of polar regions before 2030. One of the missions will return samples.

Lunar Research Station: The far-reaching plan is to establish a long-term energy supply, autonomous controlled infrastructures. It could conduct robotic/manned scientific research and technology tests. In-situ resource utilization and the significant lunar science problems will be comprehensively studied.

International Cooperation Opportunities: China welcome international cooperations on its long-term lunar exploration strategy. All data from Chang'E-1 to Chang'E-3 have been released for scientific research and public outreach. Several payloads for Chang'E-4 mission will collaborate with Eruope counties. China is coordinating with ESA about future cooperation in lunar exploration, and the science of sample analysis. China and Russia are on track to sign a bilateral agreement on joint space exploration from 2018 to 2022, with an emphasis on future missions to the moon and other deep-space destinations. China's middle- to long-term lunar exploration provide extensive opportunities for international cooperations in different levels.

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SUPPORTING FUTURE LUNAR SURFACE EXPLORATION THROUGH ONGOING FIELD ACTIVITIES.
K. E. Young[1], T. G. Graff[2], J. E. Bleacher[3], D. Coan[4], P. L. Whelley[5], W. B. Garry[3], S. Kruse[6], M. Reagan[7], D. H. Garrison[2], M. Miller[8], F. Delgado[7], A. D. Rogers[9], T. D. Glotch[9], C. A. Evans[7], A. Naids[7], M. Walker[7], and A. Hood[7]; [1]UTEP/Jacobs at NASA JSC, Houston, TX, 77058; [2]Jacobs at NASA JSC, Houston, TX, 77058; [3]NASA GSFC, Greenbelt, MD, 20771; [4]Aerospace at NASA JSC, Houston, TX, 77058; [5]University of Maryland, College Park at NASA GSFC, Greenbelt, MD, 20771; [6]University of South Florida, Tampa, FL, 33620; [7]NASA JSC, Houston, TX, 77058; [8]Georgia Institute of Technology, Atlanta, GA, 30332; [9]Stony Brook University, Stony Brook, NY, 11794; corresponding author email: kelsey.e.young@nasa.gov.

Introduction: The return of humans to both lunar orbit and the lunar surface will greatly enhance the ability of the scientific community to answer some of the highest priority science questions about the history and evolution of the Moon. Understanding how humans will live and work on the lunar surface is of utmost importance in thinking about a return to the Moon and has been identified by LEAG (Lunar Exploration Analysis Group) as one of the three primary SKG (strategic knowledge gap) themes for current investigation [1]. This submission highlights ongoing activities designed to close these SKGs, specifically in the categories of 1) surface trafficability, 2) radiation shielding, and 3) habitat, life support, and mobility.

TubeX - Lava Tube Exploration: Lava tubes have been identified since the 1970's as potential safe havens for humans and life support equipment on the lunar surface [2]. In order to use these features as a resource, we must first understand how a surface mission would find and characterize a tube-rich environment and select one tube for habitation and/or exploration. The TubeX project is working at Lava Beds National Monument, CA, to explore technologies and strategies for mapping and exploring lunar lava tubes. Our team has deployed LiDAR (light detection and ranging), GPR (ground penetrating radar), magnetometry, seismic arrays, and handheld XRF (x-ray fluorescence) to understand which instruments might be used by an exploration mission and how they should be used to select a tube for habitation. Preliminary results indicate that this suite of surface geophysics instruments can indeed identify and quantify lava tube properties at depth. This submission will detail ongoing results of the TubeX project and provide recommendations for exploration of these potential radiation safe havens.

Scientific Hybrid Reality Environments (SHyRE): Several proposed lunar exploration modes place humans in habitats either in cislunar space or on the lunar surface for extended stays. Regardless of which mode is chosen, the presence of humans near or on the Moon presents exploration opportunities including teleoperation of robotic assets, extended periods of scientific observation, and potentially the ability to work with samples collected from the surface of the Moon in a habitat laboratory [3]. All of these capabilities rely on the development of novel visualization concepts, which will bring real-time surface data to the astronaut in the habitat. The SHyRE project explores hybrid reality (HR, i.e. the combination of virtual reality with unique physical characteristics of the environment) as a capability that could be used to train crewmembers, develop operational protocols and a decision-making support system, or allow a crewmember to view and manipulate data collected by a surface asset. SHyRE uses data collected over the past several years by the RIS^{4}E SSERVI (Remote, In Situ and Synchrotron Studies for Science and Exploration) team on the Big Island, HI. We will present initial results and a path forward for developing this capability for future exploration, and discuss how HR can be used to investigate SKGs pertaining to the utility and design of habitats either in cislunar space or on the lunar surface.

NASA Extreme Environments Mission Operations (NEEMO): An important part both of the Apollo missions and any future lunar exploration is the science support team providing input and recommendations on sampling/traverse execution to the crew. Future science support, however, will differ from the Apollo era model of using near real-time science backrooms to direct astronauts on the Moon. With the advancements in technology over the decades since the 1970's come complexities in data assimilation and visualization that benefit from increased science support. Understanding how this support should be structured to maximize utility of habitation on the Moon is critical to mission success and is being explored in the NEEMO analog missions. Also tested during NEEMO was how a crew would transport equipment and samples over long distances away from a habitat, directly addressing the mobility LEAG SKG. This submission will discuss lessons learned from NEEMO that might influence mission design architecture for future lunar exploration.

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TECHNOLOGIES FOR LUNAR EXPLORATION. K. Zacny, S. Indyk, Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com

Introduction: Honeybee Robotics with its partners developed numerous technologies for lunar exploration. Most of these technologies are at high TRL and have been designed for small landers, rovers, as well as astronauts. This abstracts presents several of these technologies.

Heat Flow Probe: The probe uses pneumatic (gas) approach to lower the temperature and thermal conductivity sensors attached to a lenticular (bi-convex) tape to >3 meters [1, 2]. The system weighs approx. 1 kg and reached 2 m in 2 minutes in compacted NU-LHT-2M during vacuum chamber tests. The probe is at TRL 4/5.

Resource Prospector Drill: This 1 m class rotary-hammer drill captures and delivers samples to instruments [3]. The drill weighs 15 kg and it is at TRL6.

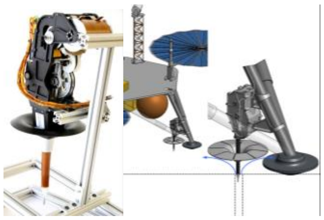

Figure 1. Heat flow probe.

Figure 2: Resource Prospector Drill

Pneumatic sample acquisition and delivery: This technology has been designed to capture and pneumatically deliver regolith samples to an instrument [4]. It's an end to end system and it has been tested in vacuum and lunar gravity in reduced gravity flights. The sampler is integrated in the lander footpads and requires just one solenoid actuator to deliver sample to an instrument. The system is at TRL 5/6.

Geotechnical Tool: Stinger is a geotechnical tool that is integrated with a rover. It measures bearing capacity and shear strength of soil to provide cohesion and friction angle. These two parameters are required for mobility, mining, and ISRU systems. The system is at TRL 4/5.

Figure 3. PlanetVac: sample acquisition and delivery.

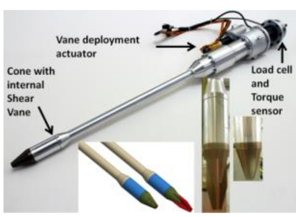

Figure 4. Stinger geotechnical tool.

Hand held coring tool: This astronaut deployable coring tool is used to capture core samples from lunar rocks and deposits them in a hermetically sealed canisters. The tool is at TRL4.

Corner Cube Reflector: This robotic system deploys corner cube reflector and anchors it at approx. 50 cm below the surface in a thermally stable ground [5]. Anchoring allows achieving of extremely high resolution. The system is at TRL 4/5.

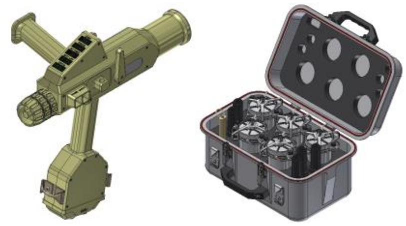

Figure 5. Astronaut coring tool.

Figure 6: Corner Cube

Planetary Volatiles Explorer (PVEx): PVEx is a volatile mining system built around rotary-percussive drill. It can therefore penetrate formations with significant water-ice content [6]. PVEx achieves >80% volatile extraction efficiency and is at TRL 4/5.

Seismic Sensor: The system is designed to emplace seismic sensors at least 50 cm below the surface and in turn decouple the thermal-wave induced noise. The system is at TRL 4.

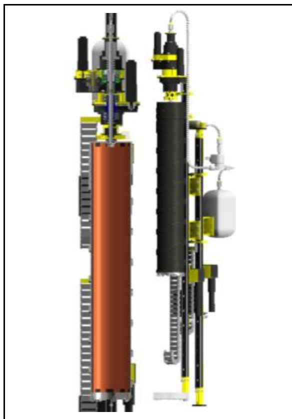

Figure 5. ISRU system.

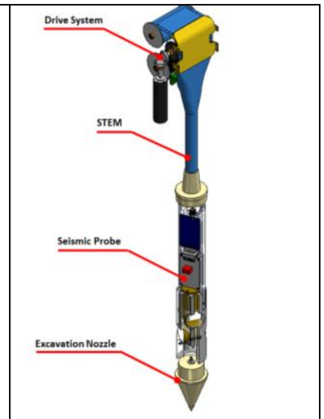

Figure 6: Seismic Sensor

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Building an Economical and Sustainable Lunar Infrastructure To Enable Lunar Science and Space Commerce. A. F. Zuniga,[1] M. F. Turner[1] and D. J. Rasky[1], [1]NASA Ames Research Center, 555 McCord Ave., Moffett Field, CA (allison.f.zuniga@nasa.gov).

Introduction: A new concept study was initiated to examine the framework needed to gradually develop an economical and sustainable lunar infrastructure using a public/private partnerships approach. This approach would establish partnership agreements between NASA and industry teams to develop cis-lunar and surface capabilities for mutual benefit while sharing cost and risk in the development phase and then allowing for transfer of operation of these infrastructure services back to its industry owners in the execution phase. These infrastructure services may include but are not limited to the following: lunar cargo transportation, power stations, energy storage devices, communication relay satellites, local communication towers, and surface mobility operations.

The public/private partnerships approach for this plan leverages best practices from NASA's Commercial Orbital Transportation Services (COTS) [1] program which introduced a new affordable and economical approach to partnering with industry to develop commercial cargo services to the International Space Station. Similarly, this concept study, named Lunar COTS (Commercial Operations and Transport), aims to: 1) demonstrate commercial and affordable cis-lunar and surface capabilities and services; 2) encourage creation of new space markets to share cost and risk with industry; and 3) enable development of a sustainable and economical lunar infrastructure to support lunar science and new commercial ventures.

The primary goal of the lunar infrastructure development is to extend the life, functionality and distance traveled of surface mobility missions and to reduce cost, complexity, mass and volume of all surface missions. Presently, surface mobility or rover missions are heavily constrained by power demands, battery life, direct line-of-sight communications with Earth, extreme thermal conditions, traverse distances, landing conditions and 14 lunar day/night cycles. To date, there have not been any US surface mission that have survived a full 14 lunar day/night cycle primarily due to the extreme cold temperatures that exist during the lunar night (approx -250C). Therefore, the mission life of lunar surface missions is typically limited to less than 14 lunar days. The traverse distances are also severely limited primarily due to batteries not surviving the extreme cold temperatures in dark craters and throughout the 14-day lunar night.

A lunar infrastructure system with power, communication and navigation elements as well as a self-contained mobility system designed properly will have the capability to extend mission life to several years by providing power generation, storage, recharge and thermal control functions to the surface mobility system(s) and other payloads. In addition the communication tower will be able to increase communication links to the rover systems and not be limited to direct-line-of-sight to Earth communications. The local navigation aids located on the top of the communication tower will also aid the rover systems to navigate in dark areas, such as craters, where visibility is limited. A mobile infrastructure system will also have the added capability to extend the traverse distances of the mission to hundreds of kilometers. Therefore this new infrastructure system together with surface mobility systems have the potential to provide valuable and extensive scientific data over several years and cover numerous lunar sites over hundreds of kilometers. By partnering with industry to develop and own the infrastructure services using the COTS model, this plan will also result in significant cost savings and increased reliability and mission probability of success

A phased-development approach is also planned under this concept to allow for incremental development and demonstration of capabilities gradually over time. During the initial phase, a small-scale infrastructure is planned together with small mobility systems to collect ground truth data to identify valuable resources and assess its composition, distribution and accessibility. These data will be important not only to the science community but also the commercial space community for future planning of potential lunar industries.

This presentation will describe the Lunar COTS concept goals, objectives and approach for developing an economical and sustainable lunar infrastructure. It will also describe the technical challenges and advantages of each infrastructure element towards supporting future lunar science missions and lunar industrialization, such as lunar mining and space manufacturing. Finally, the presentation will also look forward to the potential of a robust lunar commercial economy supporting science missions and lunar industries and its potential effect on the next 50 years of space exploration

References:

[1] "A New Era in Spaceflight," NASA Commercial Operations and Transportation Services Program, U.S. Government Printing Office, Washington, DC, Feb 2014.