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Lunar and Planetary Institute

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Preface

This volume contains abstracts that have been accepted for presentation at the Annual Meeting of the Lunar Exploration Analysis Group, October 14–16, 2013, Laurel, Maryland.

Administration and publications support for this meeting were provided by the staff of the Meeting and Publication Services Department at the Lunar and Planetary Institute.

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AN UPDATE TO THE ORION/MOONRISE MISSION CONCEPT STUDY. L. Alkalai[1], J. Hopkins[2], A. Trebi-Ollenu[1], J. Mueller, Ben Solish[1], Tim McElrath[1]
[1]Jet Propulsion Laboratory, Caltech; [2]Lockheed Martin Corporation

Introduction: The Orion/MoonRise mission concept was first proposed and discussed in an open forum at the LEAG meeting in Greenbelt, Maryland in October 2012, and subsequently published at the IEEE Aerospace Conference in March 2013 [1]. The proposed mission concept utilizes the Sample Return Vehicle (SRV) proposed as part of the MoonRise New Frontiers proposal to return samples from the South Pole-Aitken Basin (SPAB) on the lunar far side. However, instead of returning samples directly back to Earth, the Lunar Ascent Vehicle (LAV) takes the sample canister to the EM-L2 destination where the pre-deployed crewed Orion vehicle captures the canister and returns the samples safely back home. The Orion/MoonRise mission concept has multiple strengths worth noting:

a) It provides for significant contributions and tasks for the astronauts to demonstrate and train at the EM-L2 destination including: i) providing critical communications coverage for the SRV landing on the Moon; ii) surface operations including tele-operations; iii) critical coverage for the LAV ascent from the Moon; iv) proximity operations with regards to the LAV in EM-L2; v) sample canister capture in EM-L2; vi) sample handling and return.
b) The Orion/MoonRise approach to the return of samples to Earth allows for up to 30 kg of samples to be returned versus only 1 kg using a robotic only approach. This is a major value added compared to a purely robotic approach. In other words, the Earth entry vehicle mass of the SRV can be traded for additional sample mass.
c) Orion/MoonRise provides an opportunity for a major demonstration of a human/robotic symbiotic mission with key roles for each (human and robotic) with clear contributions by each. Moreover, this mission provides an opportunity for NASA's SMD and HEOMD to define a common mission of high value to each. Returning samples from the SPAB is a high priority by NASA's SMD as evidenced by multiple Decadal Surveys. Demonstrating deep-space human operations by Orion in EM-L2 is of high value to HEOMD [2].

Overview of Paper:
This paper describes results since the LEAG 2012 meeting by a joint team at JPL and LM and is based on questions raised during the LEAG meeting including:

1) Does the Orion/MoonRise sample return approach support Mars Sample Return (MSR)?
2) What is the surface sampling approach to collect more than 1kg of samples?
3) What is the LAV/Orion proximity operations approach?
4) What is the approach to capture the sample canister by Orion in EM-L2 and bring it inside Orion?

The study team has addressed all the 4 questions:

a) The team has picked an approach that is consistent with MSR. This includes the deployment of the passive sample canister by the LAV in EM-L2 halo orbit at a safe distance from Orion, and the subsequent tracking and capture of the canister.
b) Several innnovative surface sampling approaches have been studied indicating a possible rich set of options, depending on the ultimate shape of the canister and its location on the LAV. Figure 1 shows one such approach in the canister.
c) A proximity operations approach has been studied and simulated using the specified capabilities of the LAV and the Orion vehicle relative navigation and rendezvous capabilities. A proximity operations approach will be presented.
d) A sample canister capture approach compatible with Orion has been defined. This uses a small sample airlock susbtituted for the Orion docking system. It can be opened to capture the canister into an unpressurized chamber, then closed and repressurized so that it is accessible to the astronauts who stow the canister inside Orion for reentry. No EVA is required. .

Figure 1. MoonRise robotic arm places multiple small sample modules into the sample canister

Acknowledgements: This study has been supported by a joint task between JPL, California Institute of Technology and by the Lockheed Martin Corporation.

References: [1] L. Alkalai et. al. "*Orion/MoonRise: A Proposed Human & Robotic Sample Return Mission from the Lunar South Pole-Aitken Basin*," IEEE Aerospace, Big Sky Montana, March 2013. [2] Hopkins, J.B. *Early Telerobotic Exploration of the Lunar Farside Using Orion Spacecraft at Earth-Moon L2*, Global Space Exploration Conference May 2012.

OBTAINING NEW IN-SITU CONSTRAINTS ON THE AGE OF THE MOON, CRATERING FLUX, ELEMENTAL CHEMISTRY, AND POTENTIAL ORGANICS USING LASER DESORPTION RESONANCE IONIZATION. F. S. Anderson[1], T. Whitaker[1], J. Andrews[1], [1]Southwest Research Institute, 1050 Walnut, Suite 300, Boulder, CO 80302 (anderson@boulder.swri.edu).

Introduction: We have developed a portable, fast, laser desorption resonance ionization mass spectrometer (LDRIMS) that can currently produce Rb-Sr isochrons (while avoiding interferences) good to ±60-90 Ma. The instrument can also be operated in a two-step laser mass spectrometry (L2MS) mode that can measure elemental chemistry and detect and characterize aromatic organic compounds. This instrument could be carried to the Moon on a small rover similar in size to the Mars Exploration Rover (MER), or on a fixed lander with an arm or fetch rover, filling a triage role and providing a science preview that could help compel future sample return.

The Need for Lunar Dating, Chemistry, & Organics: Such a mission could address three uncertainties in the current chronology of the Moon: a) the duration and timing of the period of heaviest bombardment of asteroids and/or comets onto the Moon, known as the Late Heavy Bombardment (LHB) [1], b) the lack of timing constraints from the lunar cratering record for the period from ~1-3.5 Ga, and c) the non-unique constraints provided by Copernicus and Tycho on cratering rate estimates from the most recent era. Improving dates on the Moon has proven to be so pressing a goal that the Decadal Survey (DS) lists missions to return lunar samples as a top priority: "The exploration and sample return from the Moon's South Pole-Aitken (SPA) basin is among the highest-priority activities for solar system science." with a primary goal of: "Determin[ing] the chronology of basin-forming impacts and constrain[ing] the period of late heavy bombardment in the inner solar system, and thus address[ing] fundamental questions of inner solar system impact processes and chronology" [2]. In addition, the Scientific Context for Exploration of the Moon [3] calls for "Establish[ing] a precise absolute chronology" and "inventory[ing] the variety, age, distribution, and origin of lunar rock types" and "determin[ing] the age of the youngest and oldest mare basalts." To achieve these goals, NASA's integrated technology roadmap for Science Instruments, Observatories, and Sensor Systems [4] specifically calls for "Surface Chronology" [TA08-2] and "Age Dating [to] ±200 Myr on surface" [Table 5. Summary of Planetary Science Technology Needs, TA08-13].

While evidence for lunar organics are scarce [5], models of meteoric influx [6], and polar organic cold trapping [7], suggest that organics should be detected. And intriguing hints of organic compounds such as benzene, phenol, naphthalene, phenanthrene and pyrene appear indigenous and are present at concentrations of < 1 ppm [6, 8].

Dating Method: The LDRIMS technique can be miniaturized and avoids the Rb-Sr mass interference issues requiring unwieldy chemical separation for traditional geochronology techniques [9-12]. With LDRIMS, a sample is placed in a time-of-flight (TOF) mass spectrometer and surface atoms, molecules, and ions are desorbed with a 213 nm laser. Ions are suppressed by an electric field and the plume of expanding particles is present for many µs, during which it is first illuminated with laser light tuned to ionize only Sr, and then 1-3 µs later, Rb [9-11, 13, 14]. This eliminates isobars for Rb and Sr, insures that the measured atoms come from the same ablation event, and hence target materials, and reduces the total number of measurements required. To obtain a LDRIMS date, we measure hundreds of spots with a ~300 µm spacing (**Fig. 1**), producing microscopic pits ~75 µm wide by ~0.5 µm deep. We also acquire interleaved measurements of a glass calibration standard, MPI-DING-T1-G [15]. We reduce the data using standard line-fitting techniques for error in both axes [16], and apply standard linear $^{86}Sr/^{88}Sr$ corrections. TIMS analyses can take 1-6 months to measure enough spots to generate an isochron, as compared with the LDRIMS data, for which hundreds of points were collected in <4.5 hours, with

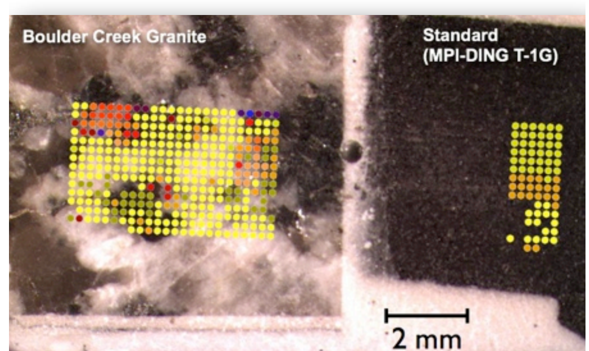

Figure 1: LDRIMS spot locations colorized by spectral shape.

no sample preparation other than rough cutting. Assuming 300 spot measurements, and 3000 shots, approximately one million shots are required per date; the LDRIMS diode laser design lifetime is typically billions of shots, allowing for 1000 or more dates.

Organics Method: L2MS is a subset of the full LDRIMS capability. L2MS uses high-power IR laser ablation to desorb neutral organic molecules, followed by a second, UV laser beam for ionization. Advantages of L2MS include the measurement of a wide array of elements, and it is one of the most sensitive available organic detection methods, with demonstrated detection to 10^{-18}.

Results: The results have an average of 1.766 Ma±0.147 Ga for an MSWD=1, well within the age measured using TIMS techniques. Commonly, a MSWD of up to ~2.7 is considered acceptable for geochronology; for an MSWD=2, the precision is ±0.105 Ga; both measurements have a precision and accuracy exceeding that called for by NASA [4]. If we assume the offset between the average LDRIMS value and the TIMS value is due to instrumental bias, and correct the runs for this bias, the accuracy of an individual run can be improved to 1.727±0.087 Ga (MSWD=1; ±0.062 for MSWD=2, e.g **Fig. 2**).

Finally, we have demonstrated ppm-level detections of organics in the Murchison meteorite using L2MS that closely match previously results (**Fig. 3**).

Discussion: We have developed bench-top and portable versions of a LDRIMS/L2MS instrument, and are working on a one cubic-foot flight design. Ultimately, we seek to enhance the characterization of landing sites on the Moon by providing in-situ triage of potential samples for Earth return. Sample triage will improve the odds of returning relevant samples, and significantly enhances near-term science return should the sample return portion of future missions be delayed.

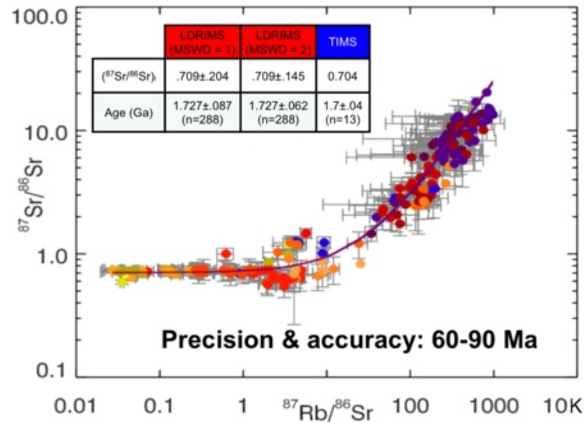

Figure 2: Log-log isochron of BCG #10 using the average of other measurement runs as a calibration. Linear fit to the data (red line) vs TIMS (blue line). Error bars exceeding 100% are not shown.

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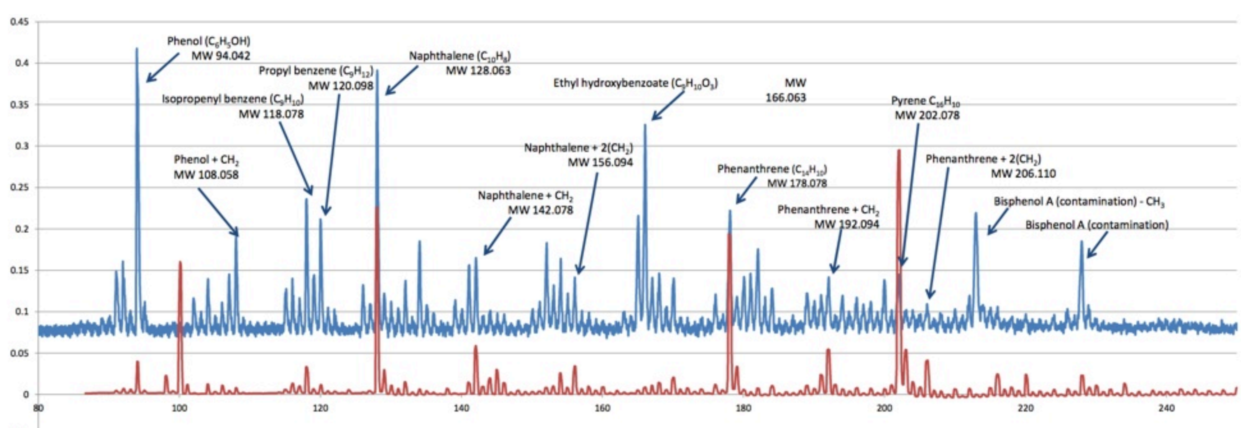

Figure 3: L2MS spectrum taken with dating instrument (blue) compared with previous results (red).

VOIDS IN LUNAR MARE AND IMPACT MELT DEPOSITS — A COMMON-SENSE EXPEDIENT TO THE EXPANSION OF HUMANS INTO SPACE.

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Introduction: Apollo exploration of the Moon was a high-risk enterprise that only the courageous would dare undertake. While the extravehicular activities of Apollo operations regarded radiation, micrometeorites, solar wind, temperature extremes, and the vacuum of space as acceptable occupational hazards, any long-term human presence on the Moon will require a more active risk mitigation posture. Fortunately, protection from most surface hazards may be found naturally and inexpensively inside accessible subsurface voids (i.e. caverns) when shielding from a few meters of ceiling rock is present [e.g., 1]. Long regarded as possibilities [2-5], candidates for subsurface planetary voids and their systems have been appearing in new high-resolution imagery of both the Moon [6-8] and Mars [9], and have become a topic of general interest [e.g., 10]. While Mars candidate voids have an astrobiological component to their attraction, lunar speleology is motivated more by what subsurface voids represent to 1) basic lunar science, and 2) lunar engineering.

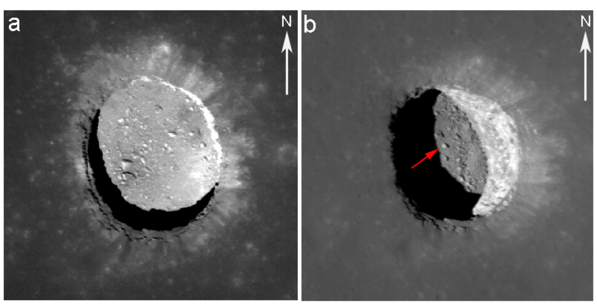

Figure 1. The 90 meter-diameter Tranquillitatis pit; 1a shows a nadir view, NAC frame M155016845R, image is ~175m wide; 1b is an oblique image (M152662021R; emission angle 26°) revealing a minimum of 20 meters of subsurface floor space (surface east of three conspicuous rocks at shadow's edge, red arrow).

Basic Lunar Science: Open voids provide access to the subsurface and therefore represent exploration potential of high value to science. Lava tubes likely contain records of magma source compositions, evolution, and flow morphologies, protect delicate minerals, and afford access to paleo-regolith layers (which could preserve ancient samples of implanted solar wind). However, geothermal temperatures [11,12] within cavernous environments should hold constant and probably exceed the sublimation temperatures of most likely volatiles. Voids located near surface features of high scientific interest could serve as convenient bases of operation for their exploration. Two types of subsurface voids, one in mare deposits and the other in ponded impact melt deposits, were identified from lunar orbit [6,13]. Preliminary studies suggest that visible openings in both types are the result of ceiling collapse. However, precise modes of deposit emplacement, cavern formation, entrance formation, lateral extent and subsurface connectivity remain speculative without further evaluation. Depending on the type of void under consideration, improved insights into volcanic or impact melt emplacement processes are anticipated from their exploration.

Lunar Engineering: In addition to surface hazard protection, subsurface environments would conserve resources and reduce engineering costs by providing "ready-made" structures requiring a minimum of retrofitting to become useful as habitations or caching supply depots. Indeed when considering facilities suitable for the long-term habitation and exploration of the Moon, such natural voids would be difficult to improve upon.

Voids in mare deposits: To date eight pits have been identified in Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) [14] images within mare deposits having the potential for subsurface access. These are located in Mare Tranquillitatis, Oceanus Procellarum (Marius Hills area), Schlüter crater, Lacus Mortis, Mare Ingenii, and Mare Fecunditatis [13]. Most pits are well-removed from mare margins, and many show fine layering in their walls that could provide valuable insights on the nature of mare emplacement. Oblique NAC frames of the two features in the Marius Hills and Mare Tranquillitatis confirm subsurface extents of at least 12 and 20 meters from the pit margins, respectively. Additional passage is considered likely if the voids are lava tubes.

Lunar rilles form either by surface erosion or by tube collapse [e.g., 15]. The Marius Hills pit is located within a lunar rille and so currently represents the best candidate for a true skylight (collapsed lava tube ceiling) on the Moon. Other rilles or pit crater chains have been found to be linear but discontinuous [16]. The space between such features likely represents uncollapsed tube. Obvious entrances to these structures have yet to be confirmed. While gaining access to this type of underground environment may be difficult, an inventory is appropriate for any comprehensive considerations of subsurface exploration/exploitation, and is in preparation.

Voids in impact melt: While lava tubes with collapsed ceilings (skylights) represent the most commonly visualized mechanism of lunar speleogenesis [e.g., 6,8], new evidence suggests that some lunar caves may result from internal adjustments during cooling within impact melt accumulations associated with large, complex craters [7]. More than 170 of these melt pond pits, of various shapes and sizes, were identified in NAC images associated with twenty-eight impact craters across the Moon [13]. Most of these pits appear to be the result of collapse into subsurface voids. For example, the bridge spanning the negative relief feature in Figure 2a would not be possible if the pits were caused by extension. Additional negative relief features occur as trench-like valleys and canyons ranging in length from less than 5 to 2,000 m (Figure 3). Their outlines may be sharply defined or subdued, with 1) irregular margins, 2) pinching terminations, 3) bridging across portions of their widths, and 4) suggestions of continuation (topographic lows in sinuous patterns) beneath adjacent surfaces.

Site selection for landed assets will rely on orbital data in the early stages of planning. Whenever feasible, preliminary considerations for any cave investigation should include 1) cross-sectional and lateral cave passage dimensions, 2) accessibility and trafficability estimates, 3) structural integrity determinations, 4) determining whether the floor surface is smooth or rocky; if rocky, size-frequency distribution and rock-arrangement determinations, and 5) whether there are one or multiple levels to the cave.

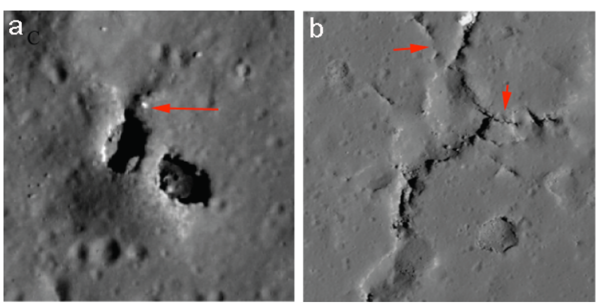

Figure 2. Examples of pit morphologies in impact melt deposits. 2a (175 m wide) and 2b (200 m wide) are in Al-Tusi pond, associated with King crater on the lunar farside. More than 170 such features have been found to date. North is up in all images. Note shadow to the west of the bridge on the pit floor in 2a. Red arrow indicates possible overhang or uncollapsed portion. 2b shows a region of collapse with several branching avenues, some of which may contain roofs or existing voids (red arrows).

Summary: Two types of lunar negative relief feature have different speleological implications — one that involves a cavernous void (collapse; found in both mare and impact melt), and another which may or may not be associated with a subsurface void space (extensional fracturing; found in impact melt). In the latter case, a subsurface system of networked voids can be visualized, but remains hypothetical. Separating the features involving possible extension from those resulting from melt withdrawal and collapse is being conducted by [13]. Continuing the assessment of known and future subsurface void discoveries will provide insights into the details of lunar speleogenesis, impact melt emplacement, mare deposit emplacement, and enhance applied exploration science. The practicability of using the lunar subsurface either for temporary or long-term habitation, or as resource caching facilities for surface exploration, is straightforward, and has been an anticipated chapter of lunar science for more than 130 years [5].

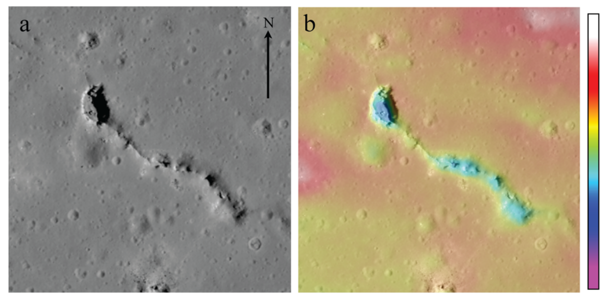

Figure 3. 3a presents a sinuous pit in the King crater Al-Tusi impact melt; NAC frame M136756054R. A number of bridged or "roofed-over" portions are apparent in this image. Figure 3b includes the complimentary NAC DEM data, the color scale for which ranges across 60 meters of topographic relief. Images are 0.5 km wide.

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FIRST SIMULATION OF AN EARTH-MOON L2/FARSIDE WAYPOINT MISSION AND TELEOPERATION OF A PLANETARY ROVER FROM THE ISS. J. O. Burns[1,3], L. Kruger[1]; T. Fong[2] and M. Bualat[2], [1]University of Colorado Boulder, [2]Intelligent Robotics Group, NASA/Ames, [3]NLSI Lunar University Network for Astrophysics Research (LUNAR), NASA/Ames.

Abstract: The NRC Astrophysics Decadal Survey identified *Cosmic Dawn* (i.e., first stars and galaxies in the early Universe, about 100 million years after the Big Bang) as one of the top three science priorities for this decade. The NLSI LUNAR team has shown that such observations are best conducted from the radio-quiet lunar farside using an array of low radio frequency telescopes, operating at frequencies <100 MHz, to measure highly redshifted 21-cm signals from neutral hydrogen that surround the first stars and galaxies. We have developed a concept for a deployable low-mass radio antenna array on the Moon using Kapton film as a backbone. Our team has proposed that such an array could be deployed with a modest rover on the lunar farside teleoperated by astronauts in the Orion crew vehicle stationed in orbit about the EM L-2 libration point. To demonstrate the feasibility for such a mission, we have recently conducted the first surface telerobotics engineering tests using the K-10 rover at the NASA Ames Roverscape under the command of an astronaut aboard the ISS. During three 3.5-hr ISS crew sessions in the summer of 2013, Kapton film strips were successfully unrolled from the back of the K-10 rover (Figure 1). These ISS crew sessions achieved a number of "firsts" including the first real-time teleoperation of a planetary rover from the ISS, the first astronaut to interactively control a high fidelity planetary rover in an outdoor analog testbest, and the first realistic simulation of a human-robot "Waypoint" mission concept.

Figure 1. Deployment of Kapton film by crew aboard the ISS using the teleoperated K10 rover at the NASA/Ames Roverscape.

NASA's Robotic Lunar Lander Development. D.G Chavers[1] and C. D. Author[2], [1]NASA Marshall Space Flight Center (greg.chavers@nasa.gov) , [2]J. B. Olansen, NASA Johnson Space Center (Jon.Olansen@nasa.gov), [3]C.L.B. Reed, John Hopkins University Applied Physics Laboratory (Cheryl.reed@jhuapl.edu), D.J.Eisenman, Jet Propulsion Laboratory (david.j.eisenman@jpl.nasa.gov)

Introduction: NASA's Resource Prospector (RP) Mission to the Moon brings together the lander development efforts under the Science Mission and Human Exploration Directorates. The RP Mission will be the first In-Situ Resource Utilization (ISRU) demonstration on the lunar surface. RESOLVE is a miniature drilling and chemistry plant packaged onto a medium-sized rover to collect and analyze soil for volatile components such as water and hydrogen that can be used for human exploration efforts.

Background: Over the past seven years, NASA has invested in development and risk-reduction for a new generation of small-medium planetary landers capable of carrying instruments and technology projects to the lunar surface. NASA Marshall Space Flight Center (MSFC) and the John Hopkins University Applied Physics Laboratory (APL) have jointly implemented the robotic lander development. The project has made significant investments in technology risk reduction in focused subsystems. In addition, many lander technologies and algorithms have been tested and demonstrated in an integrated systems environment using the Mighty Eagle free-flying vertical test bed. These design and testing investments have significantly reduced development risk for lander, thereby reducing overall risk and associated costs for future missions.

Since 2010, the NASA Johnson Space Center (JSC) has been developing a vertical test bed to demonstrate autonomous landing and hazard detection technology and demonstrate green propellant propulsion systems. Work on several systems began in 2006, when NASA's focus was to plan a human return to the Moon (known as the Constellation Program). Morpheus is a large lander, and is designed to deliver 500 kg or more of cargo to the lunar surface. Morpheus utilizes a quad configuration liquid oxygen and liquid methane propulsion system. This propellant combination is of great interest and extensible to human exploration. It is possible that the Moon's resources could be utilized to someday produce this propellant from the lunar surface. Since the first hot fire in 2011, the Morpheus test vehicle has progressed to free-flight testing at the Kennedy Space Center.

SMD Lander Risk Reduction Status: Many of the risk reduction activities started during the International Lunar Network lander development have been completed [1]. Three of the activities have not completed yet and these include: 1) real time battery testing for 72 lunar day/night cycles, 2) variable conductance heatpipe (VCHP) design and demonstration, and 3) fabrication and testing of 100 lbf thrusters that operate using MMH/MON25. This propellant combination is of interest since it has a freezing point of – 52 C (as opposed to -11 C for conventional oxidizer). The lower freezing and operational temperature allows reduced heater power requirements for long duration missions. Two of these In-Space Engines (ISE100) are currently being fabricated as development units.

Low Cost Robotic Lunar Lander Status:

The lander teams have merged to develop a low cost robotic lander concept for the Resource Prospector Mission. During 2013, MSFC, JSC, APL, and JPL have begun integrating activities to develop a low cost lunar lander for delivering up to 400 kg of payload to the lunar surface, specifically for the Resource Prospector Mission.

The RP lander architecture is cost driven (design to cost) and the lander has minimal functionality once landed. This RP lander concept combines efforts from the International Lunar Network risk reduction activities, including the Mighty Eagle vertical test bed, and the Morpheus vertical test bed.

The RP lander will deliver the payload following trans-lunar injection (TLI) to the lunar surface after a nominal 5 day transit followed by direct descent. A solid rocket motor provides the braking to remove most of the delta V during initial descent. The empty solid casing is ejected and the remaining delta V is removed by a liquid propulsion system using sixteen RS34's. These are grouped in a quad configuration of four thrusters. The thruster mounting bracket and propellant manifold have been designed. NASA is currently receiving the RS34's from the Air Force and will be hot-fire testing a single thruster at White Sands Test Facility in November, 2014. Flight Software and GN&C uses existing architectures from Morpheus and Mighty Eagle. This reduces cost and risk. The 100 meter radius precision landing is accomplished using Terrain Relative Navigation (TRN) via optical techniques. The primary structure is a riveted sheet metal construction and arrives to the lunar surface with the rover situated on top similar to a pallet. The rover egresses from the lander using small fixed ramps (non-deployable) on either side of the lander. A pathfinder primary structure has been designed and fabricated for initial integration and interface definition. The flight structure is currently being designed. The avionics system leverages the existing design from LADEE. Landing site hazard analysis has been performed in the south pole regions to determine probability of success landing without using active hazard avoidance.

Science-Driven CubeSat Missions to the Moon P.E. Clark[1], R. MacDowall[2], W. Farrell[2], N. Petro[2], R. Cox[3], E. Cardiff[2], D. Folta[2], D. Dichmann[2], J. Didion[2], D. Patel[2], J. Hudeck[4], S. Altunc[4], S. Schaire[4], T. Flatley[2], M. Bakhtiari-Nejad[2], [1]Catholic University of America@NASA/GSFC, Greenbelt, MD 20771, [2]NASA/GSFC, [3]Flexure Engineering Inc., [4]NASA /WFF (Correspondence email: Pamela.E.Clark@NASA.gov).

Purpose: We are in the process of evaluating application of the CubeSat Paradigm for deep space exploration, a frameword we refer to as LunarCube [1]. We are conducting systems definition and design activities, with focus on implementing enhanced thermal and radiation protection; attitude control, communication, navigation and tracking beyond earth orbit; power for science-driven applications; as well as propulsion requirements for cis-lunar space operation, as particular drivers for longer duration operation in lunar orbit or on the lunar surface. The end result will be cost-effective, generic design(s) for a cross-section of future high priority space or surface payloads for planetary, heliophysics, and astrophysics disciplines, the requirements for which are described in Table 1.

The CubeSat Paradigm: Over the last decade, CubeSat has evolved to support cutting edge multi-platform, multi-disciplinary science as well as key SmallSat hardware and software technology R&D, in Earth orbit, e.g., the scientifically useful monitoring of Earth's atmosphere and climate by several experiments (e.g., CINEMA, CubeSat for Ions, Neutrals, Electron, and Magnetic Fields) [2]. Recently CubeSat has been proposed as a model for a lunar swirl study mission [3]. Incorporating advances in the consumer electronics industry, the decade of development has seen the continuous reduction in size, mass, and power, and increase in processing capability of onboard avionics and power systems. CubeSat use of resources, including cost and development time, are kept low by using a standard "bus," standardized interfaces, and shared access by guest "instruments" to all subsystems using existing SmallSat protocols. This paradigm is similar to that commonly used by NASA in its first, and well into its second, decade, when launch rates were far higher and costs far lower [1]. Part of its appeal is that CubeSat model has afforded universities access for hands on student education subsidized by NSF, NASA, DOD, and other agencies.

Progress in Extending the CubeSat Paradigm: NASA Ames has already shown leadership in the use of SmallSats, such as LCross, for lunar mission design over the last decade, and is in the process of producing a report on current cubesat activities at NASA centers. Several organizations (e.g., Planetary Systems, Planetary Services) are developing 6U and 12U versions of the ubiquitous 3U 'PPOD' packaging and deployer. NASA WFF is developing a 54U cubesat 'carrier' that can be attached to an ESPA ring. Both ULA and SpaceX have proposed Earth escape launchers and cubesat carriers to provide transportation to targets beyond Earth orbit [4]. JPL and collaborators will be flying INSPIRE, the first cubesat mission to leave Earth orbit, in 2015. We are reporting here the results of an ongoing in-depth study at GSFC to design and develop a cubesat platform for a planetary target capable of meeting science requirement challenges of conventional missions as well as demonstrating technology [5,6]. The Astrophysics, Heliophysics, and Earth Applicaitons Divisons of the Science Mission Directorate have already implemented cubesat development options in their sensor and supporting technology development programs.

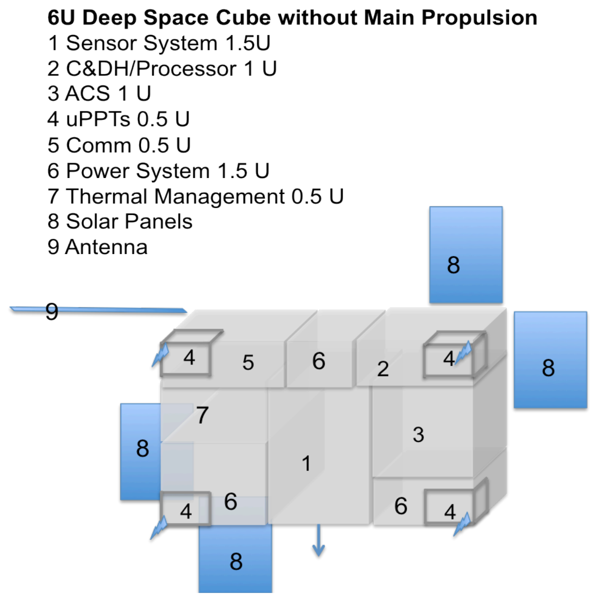

Figure 1: 6U Configuration L-WaDi Deep Space Cube from Fy13 IRAD work.

Development of LunarCube Concept: We are looking at a cross-section of progressively more challenging missions, incuding an orbiter, an impactor, and a pathfinder observatory, and considering designs using technology available now, in five years, and in ten year. The Moon is an ideal 'test' target because, as an atmosphereless, heavily bombarded body which experienced some degree of interior differentationa, it can act as an analogue for a broad cross-section of solar system enviornments and processes, as well as a testbed for technologies needed to operate in those environments. Our current mission focus is an orbiter with a single instrument (Lunar Water Distribution (LWaDi), a high spectral resolution near infrared spectrometer, using state of the art hardware and software. The mission goal is to characterize water and water

Representative Candidates for LunarCube Missions

Candidates	Lunar Water Distribution	Lunar Polar Impact Outflow	ROLLS Pathfinder
Concept	Nature of water components and their distribution	Measure ion, plasma, dust, volatile outflow after impact	Radio astronomy and imaging of solar radio bursts below terrestrial cutoff (10MHz) pathfinder
Type of Measurements, Instrument(s), Heritage	Near IR, 1 to 4 microns, .01 micron spectral resolution (240 8-bit channels), SNR 10dB, detection of features (wavelength, band center and width) associated with water type and component, imaging not required. Super compact NIR spectrometer with cryocooler.	1) Low E ion analyzer being developed for CubeSat (Mariner 2 ion spectrometer, AMPTE IRM, CATS MEMS 0-30 KeV electrostatic optics; 2) ULF electric field and plasma density DC to 20kHz (electric field .2 mV/M) plus optional Langmuir probes (Dynamic Ionosphere CubeSat Experiment); 3) UV spectrometer (LADEE UV spectrometer), 150-400nm, .5 nm spectral resolution	Radio receiver/riometer, 1 to 10 MHz (Lazio et al, Advances in Space Research 48, 1942-1957, 2011). supported by radio astronomy antenna(s) – wire of ~50 m total length or less, antenna deployer, preamp, CPU, data storage, downlink antenna and controller, thermal system, power system, solar arrays, housing. Subsequent versions of ROLSS are anticipated
Resources	2 kg, 2W, <2U, <10 mbits/day	1) <1 kg, <1W, <1U; 2) <1W, 1U stowed (2 10-m wire booms for plasma, 2 8-cm booms for Langmuir), 1kg; 3) 2kg, 3W, 4U.	4 kg, 5W, additional peak power for one-time antenna deployment, periodic data downlink. 1U, data volume could be reduced to <100 bits per sec. Desirable: higher datarate.
Operation Location, Modes, Duration	lunar orbit; minimum 9 (3 latitudes x 3 times of day) measurements/day for three lunar cycles, 6 month baseline.	Operating on limited (10% duty cycle in cis-lunar space, 100% duty cycle on 'last leg' capture by Moon's gravitation field until impact polar crater baseline. Desirable: fly small 'swarm' to generate greater detectable signal to be seen remotely. <hours for 'last leg'.	Lunar surface, nearside, near lunar equator. Survive at least one diurnal cycle (baseline), multiple cycles through several duty cycles desirable. Data collection and downlink modes.
Tall Poles, Special Needs	Optics, temperature monitored, nominal operation 150K via passive thermal. In-space propulsion. Protect windows from contamination. Comm drives pointing requirements.	Greater Volume required than 6U. Electromagnetic shielding. Nominal operation -50 to 50 degrees C with knowledge of temperature. Comm not science drives pointing requirements.	Thermal: surviving lunar night. Deployment of antenna. baseline single low mass wire. Desirable: tens of meters of polyimide antenna perhaps using 1D solar sail deployment mechanisms.

components for small areas representative of major lunar terrains and features as a function of latitude (upper, mid, equatorial), and time of day (dawn, mid-morning, noon, mid-afternoon, dusk). New flight dynamics software technology has turned out to be 'game-changing': We are developing the capability to create readily available families of low energy transfer routes to cislunar space which require far less fuel than conventional routes.

Current Activities: We have been focused on exploring the trade space (mass, power, volume, availability, mission duration) for the key subsystems, as well as for the sensor system. The result is a design for a deep space cubesat bus, with or without an onboard propulsion system (Figure 1).

Sensor: We have designed a 1.5U high resolution (10 nm) IR spectrometer operating from 1.3 to 3.7 microns. A compact cryocooler maintains the HCT detector at 150K, requiring an additional 5W+ of power.

Power: Deployable gimbaled cubesat solar panel arrays from several manufactor, including MMA Design and TUI, could provide required power.

Propulsion and Attitude Control: We can combine existing components either available or under development, including Reaction Wheel Assemblies, Star Trackers, and Busek micro-pulsed propulsion thrusters, in order to provide stationkeeping and momentum dumping capabilities without the use of magnetic torque bars used in Earth orbit (taking advantage of the Earth's magnetic field). Microthrust propuslions systems, particularly the Busek Xe ion thruster, could provide adequate delta V for lunar orbital insertion from GEO, making the vehicle substantially larger than 6U, but still within the cubesat formfactor. The propulsion system would require 70W during cruise, and thus a larger gimbaled solar panel array. Thus, we also consider the option of delivery to the Moon without an onboard propulsion system.

Thermal Design: The gimbaled solar panel assembly, fully deployed, is large enough to act as a sun shield for the small form factor spacecraft, mitigating thermal design challenges faced by larger orbiters.

Communication, Navigation and Tracking: The compact S-band/X-band transceiver under development combined with low stowed volume directional antenna would be adequate to support the required bandwidth for data downlink and radio navigation.

C&DH and Processing: The 'mini' version of the GSFC SpaceCube processor would provide the required control and processing functions. Low

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DEVELOPMENT OF MINI-LANDERS FOR VERY SMALL LUNAR SURFACE PAYLOADS. B. A. Cohen, NASA Marshall Space Flight Center, Huntsville AL 35812

Introduction: Over the last 5 years, NASA has invested in development and risk-reduction activities for a new generation of planetary landers capable of carrying instruments and technology demonstrations to the lunar surface and other airless bodies. The Robotic Lunar Lander Development Project (RLLDP) is jointly implemented by NASA Marshall Space Flight Center (MSFC) and the Johns Hopkins University Applied Physics Laboratory (APL). The RLLDP team has produced mission architecture designs for multiple airless body missions to meet both science and human precursor mission needs. The mission architecture concept studies encompass small, medium, and large landers, with payloads from a few kilograms to over 1000 kg, to the Moon and other airless bodies.

The payload and concept of operations for the U.S. contribution to the ILN was guided by an independent Science Definition Team, which required each node to operate for 6 years continuously, including through lunar eclipse periods, and to carry a seismometer, heat-flow probe, retroreflector, and electromagnetic sounding instrument. Some configuration trades using penetrators, hard landers, and soft landers are discussed in [1, 2]; the preferred concept became soft-landing propulsive landers discussed in [3]. The landers were sized primairly according to their power systems: an ASRG lander configuration is estimated at 155 kg dry mass, which includes a payload suite estimated at 23 kg including payload accommodation and deployment; a solar array-battery (SAB) lander configuration is somewhat larger at 265 kg of dry mass including a 19 kg payload suite with payload accommodation.

The ILN mission was the most demanding in terms of lifetime requirements on the lunar surface (6 years) and requirement to survive many 2-week eclipse periods. However, the team developed a mini-lander concept in an effort to design to cost for SMD's initial rquest for a two-lander mission for $200M. This lander concept accommodated the "floor mission" identified in the ILN SDT report. For the floor science mission, the RLLDT developed a concept that would put two landers on the lunar near side via separate launches on a Minotaur V vehicle from Wallops Flight Facility. This vehicles enables delivery of 413 kg to TLI on a direct trajectory. Non-direct trajectories were also investigated, but these longer cruise times would require solar arrays and additional structure/PSE/thermal to keep the vehicle warm during cruise; these lander additions offset propellant savings.

Because of the mission requirements, precision landing was not required and so was not included in the lander GN&C design. The landers would use direct-to-earth S-band communication and operate for 2-3 years in order to ensure two years of overlapping operations. The lander payload consisted only of the SEIS seismometer package, operating continuously through lunar day and night. The payload was 10 kg drawing 2.6W continuously and acquiring 130 Mbit of data per day (including 30% margin on all quantities, plus payload accommodation including blankets, heater, deployment mechanisms, booms, and associated electronics controllers allocated to the instrument). The mini-lander designs were enabled by potential availablility of the Derivative Advanced Sterling Radioiostope Generator (DASRG), essentially a half-powered ASRG concept weighing only 13 kg. Since this technology is no longer being pursued, a small RPS, solar array/battery system, or other power subsystem needs to be investigated.

The complete lander had a wet mass of 143 kg (including 20% margins); when combined with the Star stage for descent and launch vehicle adaptor, the total mass came to 412 kg (including 20% margin), just fitting within the Minotaur V capability. The mini-lander concept was costed for a Class D Mission, where each susbstem was single string and the mission accepted higher risk. The independently-confirmed cost estimates for a 2-lander mission of this scope fell within the $200M scope, in 2010 dollars.

The mini-lander concept developed for the ILN floor mission has exceptional promise for delivering small payloads to the lunar surface for a variety of lunar mission desires. Though the ILN concept is no longer moving forward as a directed mission, the project continues to make significant investments in technology risk reduction in focused subsystems, including the Mighty Eagle warm-gas prototype. These design and testing investments have significantly reduced development risk for airless body landers, thereby reducing overall risk and associated costs for future missions. More information on current maturation work using lander prototypes can be found in [4].

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Resource Prospector: A lunar volatiles prospecting and ISRU demonstration mission A. Colaprete[1], R. Elphic[1], Jerry Sanders[2], Jackie Quinn[3], Bill Larson[3], M. Picard[4], [1]NASA Ames Research Center, Moffett Field, CA, [2]NASA Johnson Space Center, Houston, TX, [3]NASA Kennedy Space Center, FL, [4]Candian Space Center, Québec, Canada.

Introduction: Over the last decade a wealth of new observations of the moon have demonstrated a lunar water system dramatically more complex and rich than was deduced following the Apollo era. Observation from the Lunar Prospector Neutron Spectrometer (LPNS) revealed enhancements of hydrogen near the lunar poles. This observation has since been confirmed by the Lunar Reconnaissance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) instrument. Observations from the Lunar Crater Observation and Sensing Satellite (LCROSS) mission, which impacted into Cabeus, a shadowed crater showing enhancements of hydrogen, showed that at least some of the hydrogen enhancement was in the form of water ice and molecular hydrogen (H2). Other volatiles were also observed in the LCROSS impact cloud, including CO2, CO, an H2S. These volatiles, and in particular water, have the potential to be a valuable or enabling resource for future exploration. In large part due to these new findings, the NASA Human Exploration and Operations Mission Directorate (HEOMD) has selected a lunar volatiles prospecting mission for a concept study and potential flight in CY2018. The mission includes the RESOLVE (Regolith and Environment Science and Oxygen & Lunar Volatile Extraction) payload, rover (provided by the Canadian Space Agency (CSA), and a lander (currently lead by MFSC and JSC). RESOLVE is a rover-borne payload that (1) can locate near subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials.

Real-time Prospecting and Combined Instrument Science: Temperature models and orbital data suggest near surface volatile concentrations may exist at briefly lit lunar polar locations outside persistently shadowed regions. A lunar rover could be remotely operated at some of these locations for the 4-7 days of expected sunlight at relatively low cost.

Given the relatively short time period this lunar mission is being designed to, prospecting for sites of interest needs to occur near real-time. The two instruments which are being used for prospecting are the neutron and NIR spectrometers (Fig. 1). A neutron spectrometer will be used to sense hydrogen down to concentrations as low as 0.5WT% to a depth of approximately 80 cm. This instrument is the principle instrument for identifying buried volatiles. A NIR spectrometer, which includes its own light source, will look at surface reflectance for signatures of bound H2O/OH and general mineralogy. Once an area of interest is identified by the neutron and/or NIR spectrometer (what was referred to as a "hot spot") the option to drill is considered. The drill can either auger or core. The auger drill can excavate samples to a depth of 50 cm and is monitored with a drill camera, the NIR spectrometer and thermal radiometer. If a particular location is considered of high-interest then the decision to core could be made. The coring drill (a push-tube) allows a 1-meter sample to be acquired and then processed by the OVEN/LAVA system.

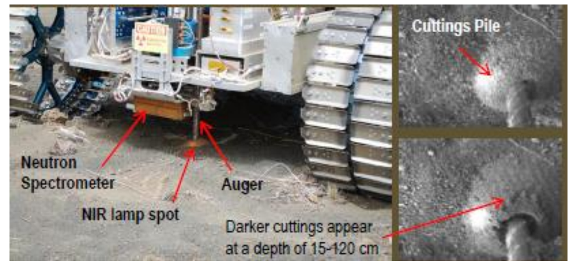

Figure 1. The RESOLVE Payload on the Artemis Jr. rover: Shown is an augering activity with the NIR lamp illuminating the drill spot the view from the Drill Camera.

RESOLVE Field Test: In July 2012 the RESOLVE project conducted a full-scale field demonstration. In particular, the ability to perform the real-time measurement analysis necessary to search for volatiles and the ability to combine the various measurement techniques to meet the mission measurement and science goals. With help from the Pacific International Space Center for Exploration Systems (PISCES), a lunar rover prototype (provided by the Canadian Space Agency) was equipped with a suite of prospecting instruments (neutron spectrometer and near-infrared spectrometer), subsurface access and sampling tools, including both an auger and coring drill (provided by CSA) and subsurface sample analysis instrumentation, including a sample oven system, the Oxygen and Volatile Extraction Node (OVEN), and Gas Chromatograph / Mass Spectrometer system, the Lunar Advanced Volatile Analysis (LAVA) system.

This presentation will describe the Resource Prospector mission, the payload and measurements, and concept of operations. The presentation will emphasize the lunar science that will be addressed by Resource Prospector.

The International Lunar Geophysical Year: 2017-2018, R. Cox[1], D. Dunlop[2], P.E. Clark[1&3], [1]Flexure Engineering Inc., [2]National Space Society, [3]Catholic University of America, (Correspondence email: Pamela.Clark@Flexureengineering.com).

The new phase of lunar surface scientific exploration has the potential to greatly enhance basic scientific understanding of solar system formation and current processes. Several fortuitous developments have combined to present unique opportunities to advance this agenda through the proposal for a declaration of an International Lunar Geophysical Year [1] (ILGY). Such a declaration could play a role analogous to the International Geophysical year of nearly 60 years ago, in greatly increasing awareness of the significance and importance of lunar exploration. International interest and momentum for lunar exploration is at its highest since the days of the cold war, and the US-Soviet race to the Moon. Several nations, including China, Russia, Japan, and possibly the U.S., have committed to sending lunar surface mission during this second decade of the century. We propose that the ILGY be proclaimed in 2017/2018 when several currently approved international lunar landers landings as well as one or more other low cost missions growing out of the Google Lunar X-Prize competition may occur.

Funded Mission Development: Several nations have committed to sending lunar surface mission during this second decade of the century. China with a Chang'e III mission scheduled for mid-summer 2013. Indian and Russia with a joint mission named Chandrayaan II and Lunar Resource in 2017, Russia with a mission called Lunar Grunt in 2015. Japan is also planning a Selene II mission in 2018. NASA has recently presented a mission concept of an Earth-Moon Lagrange 2 Gateway project which would provide a range of opportunities to develop technologies advancing access to the Moon, Mars, and asteroids. A new private initiative, The Golden Spike Company has announced its goal of providing lunar surface expeditions to potential nation state customers as well as to private industry using the capabilities of launchers from Space-X and United Launch Alliance [2].

Parallel Development in CubeSat Technologies: Parallel to this interest is the development of micro-engineering techniques and instrumentation which create the opportunities to create low cost, low mass, low volume, spacecraft with unique operating capabilities in the extreme environments on the Moon including ultra low temperature and low power electronics systems [3]. Several groups, including Planetary SYstems and Planetary Services, have 6U and 12U packaging/deployment systems under development, analogous to the 3U PPOD used by terrestrial CubeSats [4]. Advances in solar electric propulsion, including further miniaturization of main propulsion drive and micro-thrusters, as well as development of software to provide routine development of low energy trajectories to the Moon, can provide the basis for far more efficient transportation and control for cubesats as well as vehicles of any size, including larger dedicated 'buses' to provide transportation to the Moon. The United Launch Alliance has proposed, along with SpaceX, the development of Earth escape launch vehicles for CubeSats. ULA has also proposed a transportation system known as the 'mule' in collaboration with other partners [5].

Additional Opportunities at Low Price Points: Alternatively, Lunar Cube craft could rely on low cost secondary launch capabilities and opportunities to "hitchhike" on missions headed to Geostationary Earth Orbit, GEO, or other destinations which provide trans lunar injection trajectories [5], or to the Moon itself, as we describe below. Launch providers have expresses interest in this role and as such could facilitate 'matchmaking' opportunities for both government and commercial customers that are purchasing the primary payloads. The challenge is to put Lunar Cube 'hitchhikers' within the envelope of risk that is acceptable for primary customers.

Google Lunar-X-Prize: Advancing this exploration agenda is the Google Lunar X-Prize competition. This competition was announced in 2006 and open to teams from any where in the world that could land on the Moon, move 1500 meters, photograph its surroundings to prove its successful landing, and transmit these pictures to Earth for a first prize of $20 Milton dollars. A few have developed agreements for launch before the 2015 deadline. Some contenders, Astrobotics and Moon-X, have landers that can bring at least 100kg to the lunar surface. Astrobotics has a projected launch dates in October of 2015 while Moon-X has also indicated a 2015 launch [6]. This capability will bring the price point for instrument delivery to the lunar surface to approximately $1M per kilogram. Small payload of just a few kilograms could therefore cost in the single digit million dollar range. Second are small lunar orbital and or surface lander mission costing in the low tens of millions. Such missions are within the reach of smaller countries in collaboration and similarly with many institutional budgets.

Google Lunar X-Prize teams not good at raising money have no practical chance of winning the first or second GL X-Prizes. This does not mean that they do not have interesting and worthwhile technological ideas and approaches. After the gold and glory of winning the Google Lunar X-Prize are gone there is still the potential of many groups to advance their projects to the lunar surface if extended objectives can be developed and demonstrated. These GXLP "also-rans" present opportunities for national space agencies and commercial companies to invest in their capabilities and missions. Some teams which will not win the GLXP have advanced to a Phase A or "Phase B" stage of development. Such teams might perform useful science missions during a International Lunar Geophysical Year. They might also further the commercial paradigm of exploration that was both the intention of the Google Corporation, the X-Prize Foundation. NASA which has provided technical support in some cases like Moon-X and Astrobotics and Omega Envoy [6]. Team Space IL has also received approval to utilized data from the LOLA laser instrument now flying on the Lunar Reconnaissance Obiter. The Google Lunar x-Prize has characterized itself as Moon 2.0 in contrast to the Moon 1.0 of the Apollo era. The ILGY could mark the beginning of a new Moon 3.0 architecture paradigm with a commercial government partnerships in exploration.

A "Lunar Cube Hitchhiker" 50 Model: A flight program for the ILGY Lunar Cube Hitchhikers could be modeled on the QB50 Program of university developed Earth environmental monitoring satellites [7]. The NASA Lunar Science Institute has a network of international teams which might be enlisted in this scientific campaign [8]. This would allow NASA to both share the risks, costs, and rewards while still leaning forward in pursuit of its science, exploration, technology development, and education objectives. This challenge is not so much a matter of new expenditures as it is the coordination and optimizing of existing NASA efforts by the NLSI, Space Grant Consortiums, SMD, OCT, and HEOMD collaborating with DOD, commercial, and other international launch programs.

Lunar In Situ Technology Testing and Demonstration: NASA for example has many technology programs which are intended to advance the state of the art with regard to operating in the extreme cold environment of the Moon and Outer Planets and moons. The Moon is the closest and cheapest place to test and demonstrate these technologies. Their testing and qualification in cislunar space and on the Lunar surface is a matter of significant risk reduction for larger deep space missions by providing a flight heritage and record of reliability. The NASA 2013 budget and projected to outlying years from 2014 through 2017 contains a total of $3.2 billion for these technology development program [9]. These programs are in many cases in advanced development and both testing and demonstrations of their capabilities might occur in a well coordinated program of small lunar hitchhiker missions [9]. NASA could support an ILGY initiative within its Space Technology Mission Directorate budget by also engaging the next generation of scientists and engineers through a competed program involving its network of Space Grant funded Universities. Competitive Teams could propose such test missions working in partnership with existing NASA Centers and coordinating their efforts with both commercial and government secondary launch opportunities. This would continue NASA's role as a cutting edge provider of both science, technology and education by demonstrating a new low cost high capability exploration program. With its many international lunar science partners this proposal builds on the foundation of the International Space Station by pushing the frontier of international collaborative efforts out to the Moon.

Testing in LEO: NASA has made the decision to cancel its satellite launch program program [10], but SWORDs might be a low cost vehicle which could provide low cost LEO tests of some of these instrument [11] and the DARPA ALASA [12] program might also provide low cost LEO test opportunities in developing ILGY demonstration spacecraft and in demonstrating that such systems are of acceptable risk as secondary payloads on larger commercial or government launches. The constrained budget resources of an ILGY program Lunar Cube 50 project demands coordination of existing assets both domestic and with non-US partners. The matching of the talents of university teams with NASA Centers leadership can advance both science and commercial technology development goals that arise from the International Lunar Geophysical Year.

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The LunarCube Initiative. R.T.Cox[1], P.E. Clark[2], A. Vasant[1]
[1]Flexure Engineering (Russell.Cox@FlexureEngineering.com), [2]Catholic University of America.

Introduction: Cislunar space, from low Earth orbit to the Lunar far side halo orbit (LL2), is a uniquely accessible environment for planetary scientists and explorers. Cislunar space is a unique environment providing physical analogs for many extreme conditions from Mercury to Pluto. Cislunar space is the gravitational gateway for all destinations in the solar system.

Because of this, Cislunar space will be the staging and training ground for the human expansion into the solar system in the 21st century.

The LunarCubes Initiative is a collection of events and collaborative teams (initially sponsored by The Select Investor and Flexure Engineering) intended to vector interest, investment and activity to Cislunar space to enable and accelerate the exploration and settlement of the solar system in coming decades.

The Lunar Workshops: The Lunar Workshops are comprised of three annual workshops:

- International Workshop on LunarCubes (LCW) – LCW 3 will be held November 13-15, 2013 in Mountain View CA.
- International Workshop on Lunar Superconductor Applications (LSA) – LSA 4 will be held Spring 2014 in Cocoa Beach FL.
- International Workshop on Scientific Opportunities in Cislunar Space (SOCS) – SOCS 1 will be held March 16, 2014 in Houston TX.

The Lunar Challenges: Starting in 2014 each workshop will be augmented with a technical challenge competition. For each challenge the prize purse will be raised through crowd sourcing, such as KickStarter. The operations budget will be raised through sponsorships and the events will be coordinated with the annual workshop for each of the three challenges. Challenge goals will be defined by workshop participants. Smaller competitions will begin in 2014 with our target goals for 2016 as follows :

- LCW Challenge 2016 - $1 Million Prize
- LSA Challenge 2016 - $500,000 Prize
- SOCS Challenge 2016 - $250,000 Prize

Each challenge will have three parts :

- Technical Challenge : First or best wins
- Team Competition : Top three teams win
- Business Plan Completion : Team business plans will be reviewed, judged and possibly funded by a pool of qualified investors.

The LunarCubes Exploration Architectures: In the context of the workshops and challenges, The Select Investor and Flexure Engineering will spearhead the creation of study groups or collaborative teams to explore three LunarCubes Exploration Architectures:

- Astrobotic Lunar Lander
  - Orbital Deployed LunarCubes
  - Surface Deployed LunarCubes
  - Rover Mounted LunarCubes
- ULA - MULE LunarCubes Platform
  - Ion Drive (Moon, Mars, Venus)
  - ESPA Ring Spacecraft Bus
  - Swarm of 10's of LunarCubes
- Sierra Lobo CryoCubes
  - Passively Cooled to < 100K
  - LEO to Cislunar missions
  - Test bed for low temperature technologies : ULT\ULP\HTS

(The companies mentioned above are simply current leaders, these architectures will be implemented by many private and national organizations)

The Lunar Geophysical Year 2017 to 2018: From July 1957 to December 1958 : in order to better understand the Earth's environment from the surface to deep space, The International Geophysical Year (IGY) was carried out by the International Council of Scientific Unions. This event saw the discovery of the Van Allen Belts and the launch of Sputnik 1. To honor the 60th anniversary and to promote excitement in and understanding of space research we are proposing an International Lunar Geophysical Year from July 2017 to December 2018. The ILGY will promote additional missions to Cislunar space and provide a venue to explore and address the geopolitical and global economic issues around Cislunar exploration and exploitation. The ILGY will have three focus areas:

- Cislunar Missions (in Space 2017 to 2018)
- Cislunar Science (Lunar, Terrestrial and Planetary Analogs)
- Global Communities : Science, Political, and Public

NEXT GENERATION LUNAR LASER RETROREFLECTOR. **D. G. Currie**[1,2,3], currie@umd.edu, S. Dell'Agnello[2], G. O. Delle Monache[2] and B. Behr[1] [1]University of Maryland, College Park, Maryland, USA, (2) [2]INFN-Laboratori Nazionali di Frascati, Italy and [3]Lunar Science Institute, Ames Research Center, Mountain View,

Abstract: Lunar Laser Ranging to the Apollo Retroreflectors arrays has investigated the lunar interior leading to the discovery and evaluation of the size and shape of the liquid core a decade ago, as well as many other lunar properties. It has also produced some of the best tests of General Relativity (i.e., the Strong Equivalence Principal, the Inertial Properties of Gravitational Energy and the Constancy of the Gravitational Constant G) [1, 2]. However, while the measurement accuracy has improved by a factor of over 200, the magnitude of the return signal has decreased by 10 to 100 times. We will discuss the sources of this and the analysis to evaluate it. We will also address our next generation retroreflectors that will improve the accuracy by factors of ten to one hundred, depending upon the method of deployment.

Introduction: The Apollo Retroreflectors were developed by a national team centered at the University of Maryland, and were deployed on the surface of the moon during the Apollo 11, 14 and 15.[1], [2]. Ranging accuracy has improved by more than 200 so the interaction of the retroreflector design and the lunar librations means that the retroreflector arrays now limit the accuracy. The Univ. of Maryland now leads an effort to improve the range accuracy by one or two orders of magnitude, depending upon the method of deployment method. This will be accomplished with a single large solid Cube Corner Reflector.

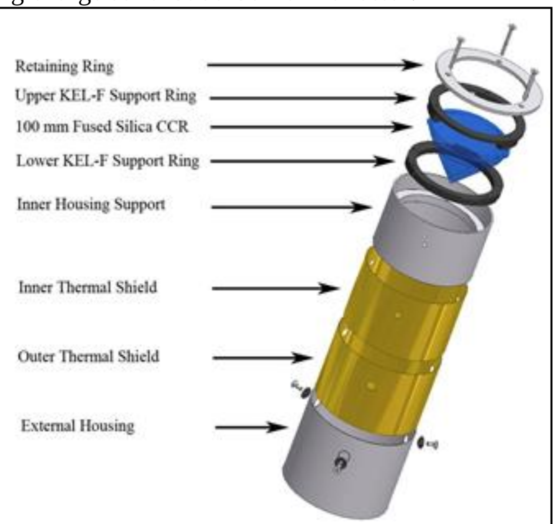

Figure 1 Current Design of LLRRA-21. The additional sunshade is illustrated in Figure 2.

Description of the LLRRA-21: In this section, we will describe the "**L**unar **L**aser **R**anging **R**etroreflector **A**rray for the **21**st Century" (LLRRA-21).

*Objectives of the LLRRA-21.*The LLRRA-21 will both improve the ranging accuracy and will allow participation by additional lunar observatories. The design will yield a signal level equal to that of Apollo 15. This should improve the science results by similar factors, to investigate the inner lunar solid core and some of the relativity theories addressing Dark Matter and Dark Energy.

Lunar Thermal Environment. To guarantee an acceptable signal, the CCR must provide a diffraction limited beam. A temperature gradient in the CCR will cause a gradient in the index of refraction which, will compromise the performance. An equatorial landing, the temperature range of the regolith will vary from ~70K to ~400K.

LLRRA-21 Design

The current design addresses each of the above challenges. In Figure 1, we see the nominal design.

Thermal Simulation: In order to address the overall design and the selection of the thermal coatings, a series of programs for the simulation of the solar input, the radiation exchange between the regolith and the external surfaces and the internal heat exchanges. This will be described.

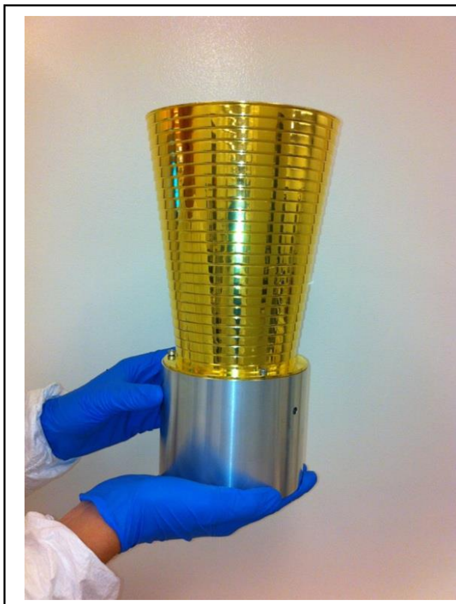

Figure 2 Prototype of LLRRA-21

Prototype of LLRRA-21: A prototype or brass board unit of the LLRRA-21 has been developed and fabricated. This is illustrated in Figure 2 and is essentially appropriate for lunar emplacement.

Thermal/Vacuum/Optical Tests: At the INFN-LNF in Frascati, Italy, a new facility, the SCF has been created, with two thermal vacuum chambers especially configured for testing of retroreflector packages in a large clean room.

Flight Opportunities: While there are a variety of flight possibilities, detailed discussions are being conducted with the most immediate possibility, Moon Express, located at the Ames Research Center, as illustrated in Figure 3.

Figure 3 A model the LLRRA-21 mounted on the instrument platform of the model of their Moon-Ex1. In the background are Joe Lazio, Deputy PI of LUNAR, Jack Burns, PI of LUNAR, Doug Currie, PI of LLRRA-21, Bob Richards, COO of Moon Express, Alan Stern, and Chief Scientist of Moon Express.

Summary and Conclusions: The LLRRA-21 is prepared for flight in the next several years and will greatly enhance the lunar science and tests of General Relativity.

Acknowledgements: We wish to acknowledge the support of the University of Maryland, via the NASA "Lunar Science Sortie Opportunities" (LSSO program (Contract NNX07AV62G) and the LUNAR Consortium (http://lunar.colorado.edu) headquartered at the University of Colorado which is funded by the NASA Lunar Science Institute (via cooperative Agreement NNA09DB30A). We also wish to acknowledge the support of the INFN-LNF and the Italian Space Agency (ISA).

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A Space Elevator for the Far Side of the Moon. T.M.. Eubanks[1], [1]Asteroid Initiatives LLC, 12644 Chapel Rd, Clifton, Virginia 20124.

Introduction: Space Elevators are not commonly considered in near-term plans for space exploration, primarily due to a lack of suitable materials for the construction of a Terrestrial space elevator. A Lunar Space Elevator (LSE) [1] could, however, be constructed with existing materials and technology; a functioning elevator could be placed into service with a single launch of an existing heavy launch vehicle[2]. An LSE at Earth-Moon Lagrange Point 2 (EML-2), above the Lunar Farside, offers several advantages over the previously considered LSE at EML-1, and could considerably advance the exploration and development of the Farside, providing a communications platform for missions in locations with no line-of-sight to the Earth and a means of early sample return from the Farside.

Lunar Space Elevators: Unlike the terrestrial space elevator, which would be kept aloft by the Earth's rotational acceleration, for an LSE the Lunar gravitational force is counterbalanced by the Earth's tidal acceleration. The low tidal gradient at a distance of 384,000 km means that Lunar space elevators are thus very long. Table 1 shows some details of the baseline LSE for EML1 presented at LEAG in 2011 [2], together with information about the analogous elevator for EML-2 (with the same fiber material, Zylon[3], mass, etc.). While the Moon gravity is roughly spherical, the Earth's tidal gradient is slightly weaker on the Farside of the Moon, and so an EML2 LSE will be about 7% longer with a 14% reduction in surface lift capacity compared to an EML1 LSE of the same mass.

The Landing Site and Sample Return from the Lunar Farside: To date, all Lunar sample returns have been from from 10 sites on the Lunar NearSide. The LSE in Table 1 assume "natural" elevator landing sites (i.e., directly beneath the Lagrange Point), as these seem most appropriate for a initial elevator deployment. An EML-2 LSE could thus provide an immediate sample return from a previously unsampled region (and, indeed, from a previously unsampled hemisphere). The EML-2 landing site (Figure 1) is near Lipskiy Crater, just North of Daedalus Crater in very rugged and heavily cratered terrain in the Lunar Highlands.

Farside Communications. Communications has always been a severe complication for the engineering of missions to the Lunar Farside, as there is no direct line-of-site between the Earth and any location deep in the Farside (librations bring occasional line-of-sight to locations at the Farside-Nearside boundary). A EML-2 LSE would provide a communications mast visible from almost any location on the Farside, and could thus serve as a relay for communications with the Earth. There is, as yet, no standard for Lunar relay communications as there is for Mars Orbiter Relay, and this would have to be developed to take full advantage of this capability. (The Mars Relays use UHF radio links at ~ 400 MHz which would not be appropriate for the long distances for Lunar elevator relays.)

Other Farside Science. An EML-2 LSE would enable a variety of other Farside science, including the monitoring of particles and fields in near interplanetary space at EML-2 and at the far end of the elevator, and also along the Earth magnetotail at Full Moon, and the monitoring of the Farside for meteor impacts, as is already being done for the near-side[3]. The monitoring of the time of Farside impacts will be especially important if a Lunar seismological network is established, as impacts on the Farside will provide seismic waves traversing the Lunar core to Nearside seismometers. A EML-2 LSE would also make it possible to extend the Lunar seismological network to the Farside itself, providing a truly global Lunar monitoring network.

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Lunar Elevator	LSE-EM1 NearSide	LSE-EML2 FarSide
String	Zylon PBO	Zylon PBO
Length	278544 km	297308 km
Total Mass	48,700 kg	48,700 kg
Surface Lift Capacity	128 kg	110 kg
Total Taper (in area)	2.49	2.49
Max Force	517 N	446 N
Landing Site	0° E 0°N	180° E 0°N

Table 1 : Lunar Elevators

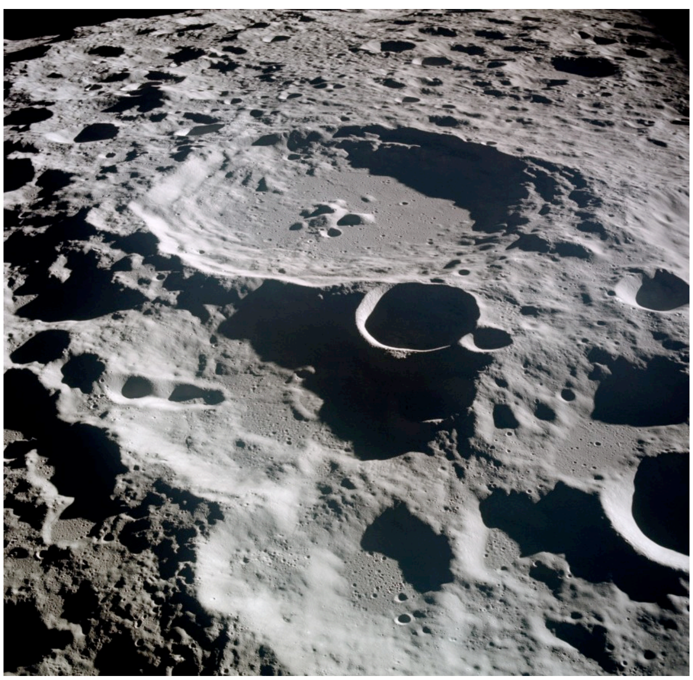
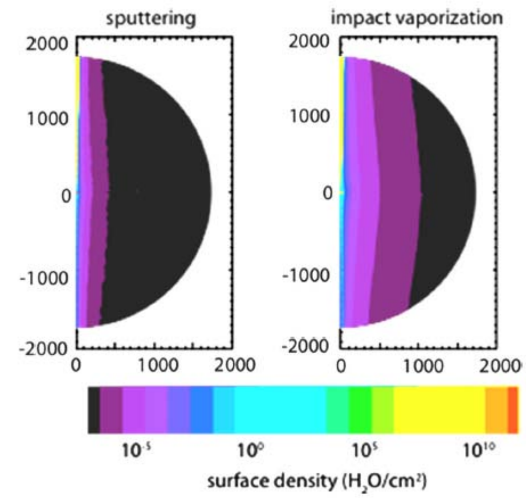


Figure 1 : Apollo 11 image of Daedalus Crater. The EML-2 LSE Landing site would be just below the bottom of this image; this view would be available ascending the elevator roughly an hour after leaving the surface.

Spillage of Polar Crater Resources onto Adjacent Terrains, W. M. Farrell[1,3], M. I. Zimmerman[2,3], & D. M. Hurley[2,3], 1. Solar System Exploration Division, NASA/Goddard SFC, Greenbelt MD; 2. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD; 3. NLSI/SSERVI, NASA/Ames RC, Moffett Field, CA. (William.M.Farrell@nasa.gov)

Abstract: We present an investigation of the release and transport of polar crater volatiles onto topside regions adjacent to the cold traps. The volatiles are liberated via surface energization processes associated with the harsh space environment, including solar wind plasma sputtering and impact vaporization. We demonstrate that such processes can transport cold-trapped volatiles to lower latitudes, possibly accounting for a portion of the mid-latitude water and OH veneer observed in the IR (the 3 micron absorption feature). We also demonstrate that some fraction of these volatiles can migrate from crater floors onto regions directly adjacent to the polar craters, and that the topside terrains should contain a sampling of the material originating within the crater itself. It is concluded that to derive volatile content in the crater, it may not be necessary to explore the cold, non-illuminated crater floors. Instead, the nature of the crater volatiles can be obtained by sampling the surface volatiles that have migrated or óspilled outô onto the adjacent terrain. This óspillageô effect could make human or robotic exploration of crater resources significantly easier, since an analysis may not require direct entry into the very harsh polar crater environment.



Model of polar crater water transport to mid-latitudes by sputtering and impact vaporization. Polar water emission source rate shown at 10^{19} H_2Oôs/s (From Farrell et al., 2013).

Raised Relief Maps of the Moon

I have been producing raised relief models of selected areas of the Lunar surface for several years. (http://finkh.wordpress.com/lunar-terrain-models/) They were made with a rapid prototyper using a sandstone material. 3D printing is a slow process, and expensive for models larger than 20cm. 3D models are usually unlabeled, or a single color.

I will be presenting at the conference raised relief maps that are fully three-dimensional, vacuum-formed with shaded relief and topographic detail. The initial series (30cm x 30cm and 30cm x 45cm) will include both poles and locations taken from the Constellation program areas of interest. My goal in subsequent production (2014): coverage of the entire moon at the 1:1,000,000 scale as seen at http://planetarynames.wr.usgs.gov/Page/Moon1to1MAtlas

Sandstone model of Apollo 15 landing site.

MEETING THE CHALLENGE OF AFFORDABLE LUNAR EXPLORATION – HERITAGE SYSTEMS, FLEXIBLE PARTNERSHIPS, NEW FLIGHT OPPORTUNITIES.

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Introduction: While lunar exploration has enjoyed turbulent times for almost a decade - politics and economics driving multiple resets to international mission plans - the lunar community remains doggedly optimistic and with somewhat good cause. Scientific evidence continues to build for the Moon's value-proposition within a sustainable exploration architecture while multiple assessments of alternate Flexible Path destinations conclude the Moon to be among the more affordable next steps. International support is increasing rather than receding for lunar science and prospecting, while increasingly viable candidates from the private sector are slowly emerging with newly-tuned business models that reflect the post-finanical crisis landscape. In contrast to the Constellation era the lunar community is now more acclimatized to the current economic conditions and there is widespread recognition that the scale, scope and ambition of near-term missions and technology development must be tailored accordingly.

At the same time the exploration frontier continues to push outwards and system performance envelopes continue to be pushed as future missions are tasked to go farther, into harsher environments all while being more efficient with limited spacecraft resources.

In this context it is well acknowledged that new approaches are required, and hence there exists an increased openness between international partners, an increased desire for public-private and terrestrial partnerships and an increased need to leverage developed capabilities alongside development of new in missions.

This presentation focuses on the near-term lunar prospecting context and considers three examples of industrial efforts at compelling, flexible and/or innovative approaches to help achieve more affordable lunar science and exploration missions.

Adaptation of Heritage Technology: MDA has provided robotics within international space exploration for over three decades across human and robotic spaceflight – from Shuttle and ISS assembly to Satellite Servicing Demo Missions, and more recently robotics and science instrumentation on each of the last 4 international Mars surface missions for both NASA and the CSA. MDA is currently building a CSA laser mapping sensor for NASA's OSIRIS-Rex asteroid mission and the Rover Mobility subsystem elements for ESA's ExoMars Rover in 2018. MDA recently conducted a 2013 study for CSA examing the flight concept of a candidate CSA contribution to NASA's Resource Prospecting Mission concept.

SSL, the Paolo-Alto based US commercial satellite manufacturer, has successfully flown over 150 spacecraft bus platforms and is a trusted provider of communications satellites worldwide. Most recently in space exploration SSL delivered elements of NASA's LADEE orbiter propulsion system based on a heritage design from its commercial spacecraft platform. This presentation will provide an update on several other emerging technologies that are being adapted from heritage systems for polar and far-side lunar surface science, prospecting and exploration:

- Lunar Resource Prospecting rover
- Autonomous navigation & teleoperation
- Lunar ISRU and sample return robotics
- Vision and lunar science instrumentation
- Lunar communications
- Lunar orbiter propulsion system

Flexible partnership models for lunar planning: International cooperation is an increasingly crucial element within space exploration. On the one hand it can provide dramatic leverage in terms of mission potential, while on the other hand it can introduce a number of sensitive programmatic considerations that must be handled carefully to maintain net positive benefit. Discussion is given to the topic of international cooperation from the perspective of industry with both a US and international presence and examples of the flexibility and risk reduction this currently provides for lunar exploration.

New Lunar Flight Opportunities: SSL is an established provider of hosted-payload opportunities aboard its commercial satellites. A short overview is provided of the hosted-payload potential aboard SSL satellites with multiple launches each year, and the potential for small lunar science and exploration payloads that either reside on the host spacecraft or are ejected for subsequent transit to the Moon.

SEARCH FOR A HIGH ALTITUDE DUST EXOSPHERE: OBSERVATIONAL STATUS PRIOR TO THE LADEE MISSION. D. A. Glenar[1], T. J. Stubbs[2], P. D. Feldman[3], K. D. Retherford[4], G. T. DeLory[5], A. Colaprete[6], R. Elphic[6], W. M. Ferrell[2], [1]Univ. of Maryland, Balt. Co. (dglenar@umbc.edu), [2]NASA Goddard Space Flight Center, [3]Johns Hopkins University, [4]Southwest Research Institute, [5]Univ. of California, Berkeley, [6]NASA Ames Research Center.

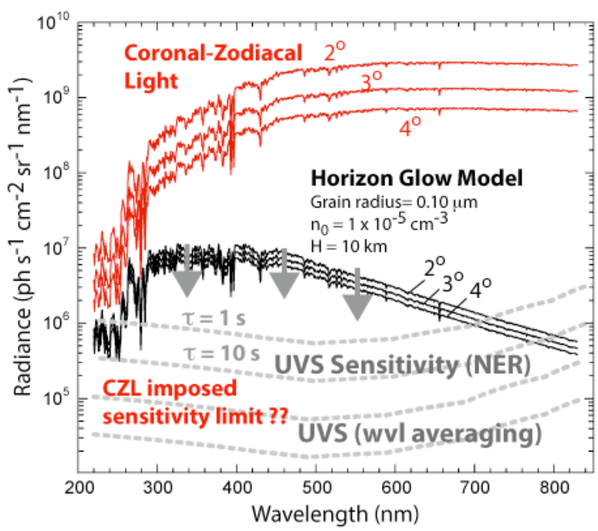
Introduction: Optical measurements during the Apollo missions produced evidence that the Moon has a significant, and perhaps sporadic, high altitude dust exosphere composed of "tenth micron" dust grains. The lines of evidence include Apollo 17 visual observations before orbital sunrise of rapidly brightening crepuscular rays [1] and extended horizon glow [2], neither of which could be explained by solar coronal-zodiacal light or coronal streamers. Further evidence came from excess brightness measurements in photometrically calibrated coronal photography during Apollo 15, leading to the McCoy dust "model 0" [3]. A reanalysis of those measurements in terms of small (~0.10 μm radius) grains [4] reaffirmed the McCoy dust estimates which predicts tangential LOS (line of sight) concentrations up to ~10^5 gr cm^{-2}. The McCoy results were also used to make some initial predictions for horizon glow as it migt be observed by the LADEE Ultraviolet Spectrometer (UVS) [6].

However, measurements since the Apollo missions contradict the notion of a substantial dust exosphere and raise new questions about the interpretation of those original measurements and the state of the exosphere at those times. An analysis of 1994 limb searches by the Clementine star trackers found no convincing evidence for a dust exosphere, down to a LOS detection limit of < 1000 r=0.1 μm grains cm^{-2}, after correcting for coronal-zodiacal light (CZL) [7].

Dust Upper-Limits from LRO LAMP: At present, LRO LAMP has completed a number of observations from within lunar shadow, to search for forward scattering of sunlight at the sunrise or sunset limb. Far-UV measurements are especially sensitive to scattering by small (0.1-0.2 μm radius) dust grains since the scattering cross section is near maximum. No definitive detection of dust has yet been made by LAMP, although weak excess brightness has been observed after correcting for grating scattered light. These results have been coarsely matched to 1D exponential upper-limit dust models with surface concentration n_0~10^{-5} cm^{-3} and H= 5-10 km [8]. This represents a far more tenuous exosphere than Apollo-era predictions, and lowers the expectations for bright horizon glow observable during the LADEE mission.

Implications for the LADEE UVS Dust Search: The figure shows the spectral brightness of horizon glow as it might be observed by UVS at 3 different solar depression angles (Sun just below the horizon). These simulations (black lines) were computed using an exponential dust model that is consistent with the LAMP-derived upper limits. Model radiances remain several times larger than the detection limit as measured for the UVS Engineering Test Unit, meaning that UVS should ultimately achieve better dust detection sensitivity than LAMP. Wavelength averaging will further improve the detection margin.

Coronal-zodiacal light (red lines) will likely be the dominant source of brightness at the small solar elongation angles observed by UVS. This will require careful subtraction using prior measurements of CZL spatial and spectral characteristics [9].



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DIVINER LUNAR RADIOMETER THERMOPHYSICAL AND COMPOSITIONAL RESULTS FROM THE EXTENDED SCIENCE MISSION. B. T. Greenhagen[1], D. A. Paige[2], and the Diviner Science Team; [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA; [2]Dept. of Earth and Space Sciences, University of California, Los Angeles, CA, USA. Email: Benjamin.T.Greenhagen@jpl.nasa.gov

Introduction: After over four years in operation, and well into its extended science mission, the Diviner Lunar Radiometer has revealed the extreme nature of the Moon's thermophysical properties and surface composition. This presentation will highlight contributions from members of the Diviner Science Team addressing a diverse range of scientific questions from the extended science mission.

Diviner Lunar Radiometer: The Diviner Lunar Radiometer is a nine-channel, pushbroom mapping radiometer that was launched onboard the Lunar Reconnaissance Orbiter in June 2009. Diviner measures broadband reflected solar radiation with two channels, and emitted thermal infrared radiation with seven infrared channels [1]. Generally, the three shortest wavelength, narrowband thermal infrared channels near 8 μm are used to constrain composition [2] and the four longer wavelength, broadband channels that span the mid- to far-infrared between 13 and 400 μm and are used to characterize the lunar thermal environment and thermophysical properties [3,4].

Diviner is the first multispectral thermal instrument to globally map the surface of the Moon. To date, Diviner has acquired observations over eight complete diurnal cycles and four partial seasonal cycles (the local time of day processes slowly relative to seasons such that Diviner is typically near a noon-midnight orbit around solstices). Diviner daytime and nighttime observations (12 hour time bins) have essentially global coverage, and more than 80% of the surface has been measured with at least 6 different local times. The spatial resolution during the mapping orbit was ~200 m and now ranges from 150 m to 1300 m in the current elliptical "frozen" orbit. Calibrated Diviner data and global maps of visible brightness temperature, bolometric temperature, rock abundance, nighttime soil temperature, and silicate mineralogy are available through the PDS Geosciences Node [5,6].

Diviner Foundation Dataset: A major effort during the extended science mission has been to create a "Foundation Dataset" (FDS) to improve the quality and usability of Diviner data available in PDS. To improve the radiometric accuracy, we reexamined Diviner's pre-flight ground calibration and revised the in-flight calibration methodology [7]. Diviner level 1b activity and quality flags have been modified based on critical reviews from Diviner data users. Finally, we used the new level 1 data to produce a wide range of level 2 and 3 gridded datasets that are more accurate, better organized, and include important geometric and observational backplanes [e.g. 8]. Delivery of the Diviner FDS to PDS is expected to begin in late 2013.

Thermophysical Properties: Diviner is directly sensitive to the thermophysical properties of the lunar surface including nighttime soil temperature, rock abundance, and surface roughness [3,4]. During the extended science mission we have produced higher fidelity maps of these properties and used them to investigate anomalous rock aboundances [9], "cold spots" with fluffier surface layers [10], regolith formationa and evolution [11], and surface roughness.

Compositional Properties: Diviner was designed to characterize the Christiansen Feature (CF) and constrain lunar silicate mineralogy [2]. Recent efforts in this area have focused on improving the quality of Diviner's mid-infrared "photometric" correction, groundtruthing Diviner observations to Apollo soils [12], using Diviner's longer wavelength channels to improve constraints on olivine [13,14], and combining Diviner with visible and near-infared datasets to enhance interpretations of pyroclastic deposits [e.g. 15], plagioclase-rich regions [16], high silica regions [e.g. 17], and space weathering [18].

New Observations: Diviner team members are also using Diviner's spacecraft-independed articulation to target and improve coverage of sites of interst, characterize the surface emission phase function, observe the Earth as an exoplanet, and investigate lunar horizon glow.

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LUNAR FLASHLIGHT: MAPPING LUNAR SURFACE VOLATILES USING A CUBESAT. P. O. Hayne[1], B. A. Cohen[2], R. G. Sellar[1], R. Staehle[1], N. Toomarian[1], and D. A. Paige[3] [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109, Paul.O.Hayne@jpl.nasa.gov), [2]Marshall Space Flight Center, [3]University of California, Los Angeles.

Introduction: The scientific and economic importance of lunar volatiles extends far beyond the question "is there water on the Moon?" Volatile materials including water come from sources central to NASA's strategic plans, including comets, asteroids, interplanetary dust particles, interstellar molecular clouds, solar wind, and lunar volcanic and radiogenic gases. The volatile inventory, distribution, and state (bound or free, evenly distributed or blocky, on the surface or at depth, etc.) are crucial for understanding how these molecules interact with the lunar surface, and for utilization potential.

The abundance and distribution of lunar water must be addressed before robots or humans can locate and extract it. Shadowed regions near the lunar poles maintain temperatures perennially below the sublimation point for water and many other volatiles of scientific and exploration interest [1]. The Moon Mineralogy Mapper (M3), EPOXI and Cassini instruments found both water (H_2O) and hydroxyl (OH) molecules on the lunar surface at high latitudes, indicating that trace amounts of adsorbed or bound water water are present [2-4]. Narrow-band reflectivity data from LRO also suggests volatiles may be present on the surface, yet surface roughness effects cannot be ruled out [5,6]. Regions of enhanced hydrogen abundance mapped by neutron spectrometers on board the Lunar Prospector and Lunar Reconnaissance Orbiter Spacecraft suggest the presence of subsurface ice in the polar regions, but the distribution is difficult to reconcile with thermal maps [7,8]. As we reach the limits of existing data, it is clear that a further investigation and mapping of water at the lunar surface to determine whether it can be considered an extractable resource, particularly in the lunar polar regions targeted for their subsurface ice reservoirs [e.g. 8-10]. Here, we describe an innovative, low-cost concept for such a mapping mission based on work done at the Jet Propulsion Laboratory, UCLA, and Marshall Space Flight Center, which was recently propsed to NASA's FY2014 Advanced Exporation Systems (AES) call.

Mission Overview: For this call, we focused on a non-optimized "Lunar Flashlight" concept on a 6U CubeSat bus. The spacecraft would be launched and delived as a secondary payload on the first test flight (EM1) of the Space Launch System (SLS) scheduled for 2017. The CubeSat then maneuvers to its lunar polar orbit and uses its solar sail as a mirror to steer sunlight into shaded polar regions while a spectrometer measures reflection diagnostic of surface compositional mix among rock/dust regolith, H_2O, CO_2, CH_4, and possibly NH_3.

Payload: IR spectroscopy has already proven useful in mapping lunar volatiles as demonstrated by M3 on Chandrayaan-1. As the light source for M3 was direct solar illumination, M3 was unable to investigate permanently shadowed areas. Lunar Flashlight, however, will utilize an 8-m solar sail to reflect ~50 kW of sunlight to the lunar surface, enabling IR spectroscopy of shadowed areas. The solar sail is flat to ~ 0.5 deg; when added to the 0.5 deg divergence angle of the sun, this provides a beam with ~ 1 deg divergence, illuminating a spot of ~400 m in diameter from an altitude of 20 km (perilune). Spectral modeling indicates that a point spectrometer with only four spectral bands can distinguish between dry regolith, H_2O, CH_4, and CO_2 ices, with a signal-to-noise ratio better than 100.

This instrument, consisting of a lens, dichroic beamsplitters and multiple single-element detectors, occupies 2U of the 6U CubeSat bus. The spectral bands are centered at wavelengths of 1.0, 1.4, 1.5, and 1.6 μm. For an orbital velocity of ~2 km/s (at perilune), an integration time of 0.2 s provides spatial sampling matched to the diameter of the illuminated spot on the surface (400 m). In the spectral band of width 0.2 μm centered at 1.5 μm (for example), the sail provides a source flux of ~2 x 1022 photons/s. For a lunar reflectance of 10%, a spectrometer at a range of 20 km with an aperture diameter of 2 cm, detector diameter of 1 mm, and system quantum efficiency of 0.5 will detect ~ 5 x 107 photons in this band per 0.2 s exposure. For an HgCdTe detector with diameter of 1 mm and cutoff wavelength of 1.7 μm, maintaining the dark current below the signal (< 5 x 107 e) requires cooling the detector to 210 K, and would provide an SNR ~ 3000 (accounting for both photon noise and dark noise).

Flight/Mission System: The Lunar Flashlight 6U spacecraft is derived from three predecessor systems--JPL's INSPIRE, Morehead State's Cosmic X-Ray Background NanoSatellite (CXBN), and JPL's experience with imaging spectrometers, including M3. The CubeSat bus will utilize mostly COTS elements such as the batteries, the CPU board, solar panels, star tracker and reaction wheels. A deployable solar sail/reflector is used from the small business Stellar

Exploration, based on their aluminized Kapton LightSail [11], scaled up to longer booms and 2U stowage volume. JPL will provide the INSPIRE-developed and tested Iris that provides timing, telecom and navigation at X-band.

Mission/Trajectory Concept: The Lunar Flashlight spacecraft would be ejected from SLS during its trans-lunar flight, and acquires the Sun for power using sun sensors and reaction wheels. The CubeSat would then be oriented in the appropriate direction for solar sail deployment from which to begin deflecting the trajectory toward a multiple lunar and earth swingby transfer and loose capture into a lunar polar orbit in 1-2 months. After lunar capture, the CubeSat would spiral down to the final elliptical polar orbit. From here, measurements begin, and apolune would be "staked" while perilune is lowered with care to 20 km, the primary data-taking altitude. The sail would be maneuvered to provide orbital changes, and to offset its own thrust produced while it is used to reflect sunlight into the target craters. A small steering mirror in front of the spectrometer aligns the field of view with the spot illuminating the lunar surface, moving at orbital speed, for 5-10 minutes of data taking per orbit. Preliminary geometric analysis of visibility indicates that all permanently shadowed locations are viewable using Lunar Flashlight at some times during a lunar month, and all locations within ~9 deg of the pole can be illuminated during any overflight. After sufficient coverage of all targeted craters, the orbit can be stepped down farther, e.g., to 10 km, to improve location determination of any discovered ice exposures. Alternatively, the perilune could be raised, and apolune lowered over the opposite pole, in order to obtain a similar dataset for each pole, over a period of months. The longer elliptical orbits could be planned to allow sufficient maneuvering time to maintain the orbit between successive polar passes, and to downlink the data.

Launch Integration and Deployment: The project works closely with MSFC to address launch environmental consitions, payload-to-launch vehicle integration and SLS Program coordination on required payload integration activities including interface documentation, models, schedules, and overall issue resolution to ensure successful integration of the project into the SLS mission. MSFC will also provide a 6U CubeSat deployer certified to SLS environments and meeting all safety requirements. Flight certification of the spacecraft and its components will be performed by JPL to SLS specs provided by MSFC.

Conclusions: In order to answer NASA's Human Exploration goals, caputured by lunar Strategic Knowledge Gap (SKG) I-D "Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps" [12], we propose a low-cost CubeSat-based method of locating, mapping, and identifying the composition of surfacial ice deposits in the Moon's polar shadowed regions. Development of the Lunar Flashlight CubeSat concept leverages JPL's Interplanetary Nano-Spacecraft Pathfinder In Relevant Environment (INSPIRE) mission, MSFC's intimate knowledge of the Space Launch System and EM-1 mission, Morehead State University's education-driven CubeSat program, small business development of solar sail and electric propulsion hardware, and JPL experience with specialized miniature sensors. Together, these components demonstrate a path where 6U CubeSats could, at dramatically lower cost than previously thought possible, explore, locate and estimate size and composition of ice deposits on the Moon. By addressing the polar volatiles SKG, Lunar Flashlight could enable a low-cost path to In-Situ Resource Utilization (ISRU) based on operationally useful deposits (if there are any), which is a game-changing capability for expanded human exploration.

A follow-on mission could then perform mini-LCROSS-style measurements, targeting a leader-follower nanosat pair, where the follower directly measures the plume of the leader's impact at the most promising locations revealed by Lunar Flashlight. Such confirmation could then ensure that targets for more expensive in-situ rover-borne measurements would include volatiles in sufficient quantity and near enough to the surface to likely be operationally useful.

Finally, Lunar Flashlight could provide an experience-based CubeSat mission architecture, hardware, and software, that can be applied to any NASA objective where delivering a 2U-class instrument within the inner Solar System can yield valuable results for human exploration, planetary science, heliophysics, and other applications.

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NEW APPROACHES TO LUNAR ICE DETECTION AND MAPPING: STUDY OVERVIEW AND RESULTS OF THE FIRST WORKSHOP. P. O. Hayne[1] , D. A. Paige[2], A. P. Ingersoll[3], M. A. Judd[4], O. Aharonson[5], L. Alkalai[1], S. Byrne[6], B. Cohen[7], A. Colaprete[8], J-Ph. Combe[9], C. Edwards[3], B.L. Ehlmann[1,3], W. Feldman[10], E. Foote[2], B. T. Greenhagen[1], B. Hermalyn[11,8], Y. Liu[1], P. Lucey[11], B. Malphrus[12], T. McClanahan[13], D. J. McCleese[1], T. B. McCord[9], C. Neish[14], M. Poston[15], G. Sanders[16], N. Schorghofer[11], R. G. Sellar[1], M. A. Siegler[1], and R. Staehle[1]. [1]NASA – Jet Propulsion Laboratory, California Institute of Technology (Paul.O.Hayne@jpl.nasa.gov), [2]UCLA, [3]California Institute of Technology, [4]Keck Institute for Space Studies, [5]Weizmann Institute of Science, [6]U. of Arizona, [7]NASA – Marshall Space Flight Center, [8]NASA – Ames Research Center, [9]Bear Fight Institute, [10]Planetary Science Institute, [11]U. of Hawaii, [12]Morehead State U., [13]NASA – Goddard Space Flight Ceneter, [14]Florida Institute of Technology, [15]Georgia Institute of Technology, [16]NASA – Johnson Space Center.

Introduction: The Keck Institute for Space Studies (KISS) is hosting a one-year study titled, “New Approaches to Lunar Ice Detection and Mapping”, as part of its ongoing mission of bringing together a broad spectrum of scientists and engineers for sustained interaction to develop new space mission concepts and technology. The primary objective of this study is to explore innovative, low-cost mission concepts for detecting and mapping “operationally useful” ice deposits on the Moon. In this presentation, we will provide an overview of the study and describe results of the July 22-25 workshop, which was the first of two such workshops to be held in 2013.

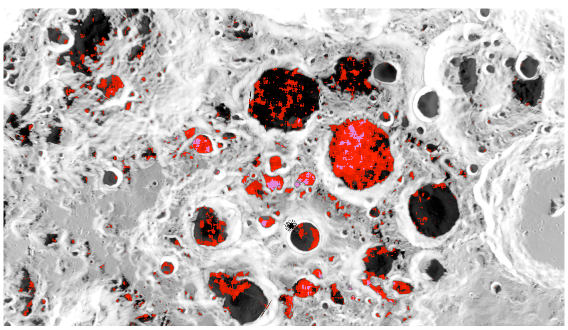

Figure 1. This south polar map of lunar annual maximum surface temperatures from Diviner [9] (grayscale) also shows the distribution of high apparent H_2O UV band depth from the LAMP instrument [13] constrained to regions with T_{max} < 110 K (reds and pinks). Although interesting patterns and contiguous features are revealed, their interpretation is ambiguous due to variable correspondence with other datasets.

Study Overview: As in previous KISS studies [1], the goal is to conduct in-depth discussions and develop new mission concepts with the potential for revolutionary scientific advancements or technological innovations. The question of whether volatile reservoirs exist on the Moon has a longstanding importance in planetary science [2,3] and space exploration [4]. Initial measurements from Earth and lunar orbit hinted at the presence of cold-trapped water ice in polar craters [5,6], but its abundance and distribution remained uncertain. New and complementary datasets from recent lunar missions, including the Lunar Reconnaissance Orbiter, LCROSS, and Chandrayaan-1, present further evidence for volatile enhancement in the polar regions [7,8,9]. However, agreement has not been achieved among the various datasets (e.g. temperature, neutron spectroscopy, radar, UV and near-IR albedo) in terms of the form, abundance, and distribution of volatiles on the Moon (Fig. 1) [10,11]. Furthermore, multiple competing theories regarding the origins, redistribution, and ultimate state of lunar volatiles have yet to be definitively tested [12]. We therefore initiated this study with the goals of: (1) assessing uncertainties in the nature of surface and subsurface ice deposits based on existing datsets and theory, (2) identifying the key measurement(s) needed to definitively detect lunar ice deposits, and (3) developing innovative, low-cost mission concepts to map these deposits at a spatial scale useful for sample extraction and in-situ resource utilization. Figure 2 shows an example of the type of flow

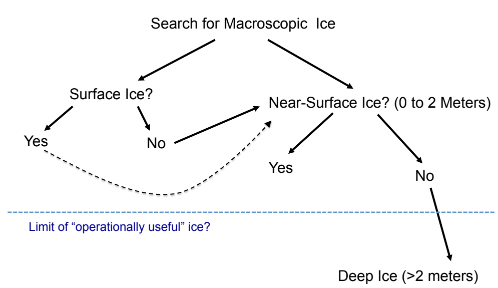

Figure 2. Example flow chart representing the search for “macroscopic” lunar ice deposits. The dashed arrow indicates a possible search for near-surface ice following detection of surface ice.

chart that could be followed to address the question of whether macroscopic ice deposits exist on the Moon.

Study Participants: The invitation-only workshop involves 30 core participants hailing from 16 separate institutions, including 5 NASA centers and 7 universities. Three study Co-leads (P. Hayne, D. Paige, and A. Ingersoll) direct the technical aspects of the study, along with the Distinguished Visiting Scientist (W. Feldman). Within this relatively small group, expertise spanning a range of disciplines including planetary science, lunar exploration, engineering and technology allows creative thinking, in-depth discussions, and analysis of a wide range of possible measurements and mission architectures.

Study Format: The study period consists of two workshops (July and November), a public one-day short course, and intensive collaboration among subgroups during the inter-workshop period. Presentations from the short course are promptly made publicly available on the KISS web site [1], as are many of the materials developed during the closed workshop. Following the second workshop in November, participants will produce a final report, which will also be posted on the KISS web site for reference and use by the lunar science and exploration community. After submission of the final report, a proposal for up to two years of follow-on technology development may be submitted to KISS, in competition with other studies.

Acknowledgements: This study is supported by the W. M. Keck Institute for Space Studies at the California Institute of Technology. Parts of the research were performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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GRIFFIN: INUDSTRY-LED DEVELOPMENT OF ROBOTIC LUNAR LANDERS. S. Huber[1], K.M. Peterson[1], J. Thornton[1], and W. L. Whittaker[1], [1]steven.huber@astrobotic.com, [2]kevin.peterson@astrobotic.com, [3]john.thornton@astrobotic.com, [4]red@cmu.edu;, Astrobotic Technology, Inc., 2515 Liberty Ave, Pittsburgh, PA 15222.

Introduction: This paper describes a financial and technical model for industry-led public/private partnerships in development of lunar landing capability. The paper discusses the public/private partnership, our model for payload services, and Griffin, a lunar lander that is core to the model.

Public/Private Partnership: Astrobotic envisions an industry-led partnership with NASA to co-develop a lunar lander. Each partner provides personnel effort, support services, equipment, expertise, information, and facilities to attain the best from a public/private partnership. The objectives of the proposed model are to:

- implement U.S. Space Exploration policy with investments to stimulate the commercial space industry,
- facilitate U.S. private industry development and demonstration of robotic lunar landers to deliver small (30-100kg) and medium (250-450kg) class payloads, and
- create a market environment in which commercial lunar payload delivery is available to Government and private sector customers.

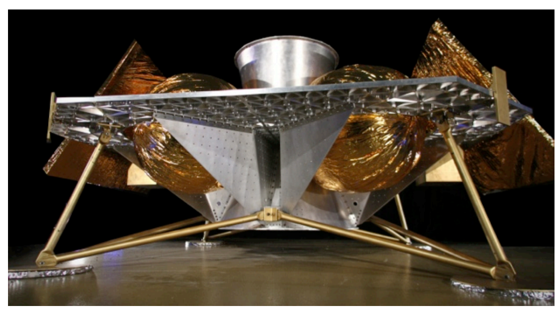
In this model the commercial partner is responsible for development and demonstration of lunar landing capabilities under commercial funding. NASA provides inputs in relevant data; systems engineering; process for build, integration, and test; technical expertise; collaborative design, development, and testing of lander systems; use of test facilities; and specific hardware and software elements. NASA contributions to the project target items that have significant risk or cost reduction potential and are needs that NASA is uniquely qualified to satisfy.

Payload Services Model: In the nominal mission revenue model, Astrobotic sells payload to one or multiple customers to fill a manifest, and generates revenue from sponsorships and other commercial activities, NASA could buy all or part of the available payload capacity.

The pricing strategy is to charge a nominal price per kilogram of $1.2M/kg for delivery to the Lunar surface. Payload can be deployed in cruise or orbit with alternative pricing structures. Further details about pricing can be found on www.astrobotic.com[1].

Services available: Standard prices cover basic power, data, and engineering support. Astrobotic offers options other than landed payload delivery, including commission of an Astrobotic rover for on-surface mobility and drop off in lunar cruise or in orbit (potentially for satellite delivery).

Griffin Lander: The Griffin lander precisely delivers small and medium class payloads to any destination on the Moon. Griffin's flexible payload mounts can accommodate a variety of rovers and other payloads to support robotic lunar missions like lunar polar volatile prospecting, sample return, geophysical network deployment, skylight exploration, regional prospecting, and mining. Details such as size of launch vehicle and solar arrays, orientation of high-gain antennas, and sizing of thermal radiators are customized for destination and purpose, while structure, propulsion, power, avionics, communications, and guidance, navigation, and control are invariant.



Griffin launches on a third-party launch vehicle. A SpaceX Falcon9 is currently under contract for launch in October-December of 2015. Medium-class payload capability in future missions is obtained with a larger launch vehicle, such as a Falcon Heavy or SLS. After achieving Low Earth Orbit, the launch vehicle second stage reignites for trans-lunar injection. Following a 4.5-day cruise, Astrobotic's lander establishes a 100km circular orbit, corrects its state estimation errors, and initiates deorbit by entering a 15km periapsis orbit. Deorbit is followed by a 20-minute powered descent

[1] http://astrobotic.com/wp-content/uploads/2011/09/AstroboticTechnologyPayloadUserGuide_v2.5.pdf

phase. During powered descent, Griffin autonomously aligns real-time data from cameras and LIDAR with existing satellite imagery to navigate to a precise landing location and maneuver past hazards to safely touchdown.

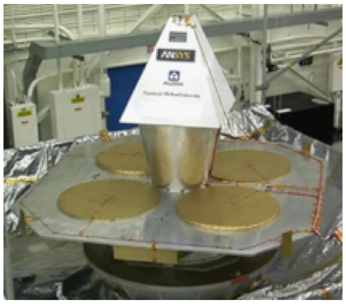


Figure 1: Griffin's primary structure vibration testing.

Structure: Griffin's aluminum frame is stout, stiff, and simple for ease of payload integration. The main isogrid deck accommodates flexible payload mounting on a regular bolt pattern. Thermal control is available through cruise and on the surface. Four legs absorb shock and stabilize Griffin on touchdown. Rover missions can use deck-mounted ramps for rover egress. Protoflight lander structure has been qualified for launch loads through vibration testing.

Guidance, Navigation, and Control: During orbit and landing, cameras register Griffin to lunar terrain for precise landing, while LIDAR constructs 3-D surface models of intended landing zone to detect slopes, rocks, and other hazards. This technology enables Griffin to safely land within 100m of any targeted landing site, even in complex and hazardous terrain.

Propulsion: Nine continuously-throttled Nitrous Oxide Fuel Blend (NOFBX) 100lbf engines perform primary braking and attitude maneuvering. This propellant and engine have been developed in cooperation with NASA for over a decade. The engines are arranged with five in a tight star pattern coincident with the central axis of the lander and four additional engines located around the perimeter of the lander clocked 90 degrees from each other, which enables single engine-out capability. Depending on the mission phase, it is possible to lose more than one engine and still succeed in landing. The engines are throttleable 100:1. For additional attitude maneuvering, Griffin incorporates cold gas thrusters for roll control and sources the fluid from the gas phase of its propellant.

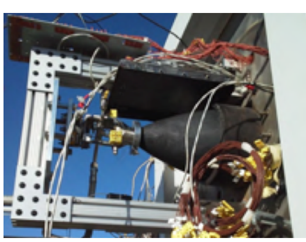


Figure 2: NOFBX thruster produced by FireStar

Avionics: Griffin's computing platform is a combination of Field Programmable Gate Arrays (FPGAs) and a general-purpose processor. Computationally expensive operations like feature detection and hazard analysis occur on FPGA-based computational accelerators. The processor marshals data and orders computational operations. This system enables high performance and the efficiency necessary for the real-time data processing during landing.

Night Survival: Unique battery, power system, avionics, and engineering enable Griffin to hibernate during the lunar night, then revive the following lunar day. Astrobotic's testing campaign has identified battery chemistry, power system, and electronic components that enable hibernation. Nominally, primary mission operations are completed in the first lunar day and additional days support reach goals, until night survival is verified on the 2015 mission.

Rover Deployment: A Griffin design option provides deployable ramps for rover egress. Once on the surface, deployable ramps enable egress of large rovers mounted to the top of the Frustum Ring. Ramps stow for launch and are spring-deployed upon release, accommodating both third-party rovers and Astrobotic surface rovers for payload delivery. Astrobotic rovers can support missions for any latitude – equatorial to polar. Griffin supports medium-class rovers up to 500kg.

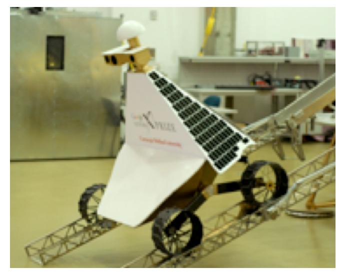


Figure 3: A Griffin design option provides deployable ramps for rover egress.

Payload Accommodations: Griffin supports payload operation with thermal control, power, and data transmission. Deck mounting locations are thermally regulated during all mission phases. Thermal regulation is by radiation dissipation from the topside of the deck and heaters. An average of 150W of power is available to payloads during cruise and on the surface. The lander downlink can support an average of 200kbps of payload data when on the surface. A Griffin design option provides wireless surface radio to act as a communication relay for mobile rovers.

HETEROGENEITY OF ICE IN LUNAR PERMANENTLY SHADOWED REGIONS. D. M. Hurley[1], R. C. Elphic[2], and B. Bussey[1], [1]Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Rd., Laurel, MD 20723; dana.hurley@jhuapl.edu), [2]NASA Ames Research Center (Moffett Field, CA 94035).

Introduction: Some future lunar missions will need detailed information about the distribution of volatiles in lunar permanently shadowed regions (PSRs) for either scientific or exploration purposes. However, it is unlikely that the distribution will be known *a priori* with enough spatial resolution to guarantee access to volatiles using a static lander. Some mechanism for mission mobility will be necessary to ensure access to volatiles. Thus, we examine the data regarding the spatial distribution of volatiles in lunar PSRs and couple those with models of smaller scale processes. We present findings regarding the heterogeneity of volatiles in PSRs. These results can be used in trade studies to determine the necessary range and duration of missions to lunar PSRs that can be anticipated in order to accomplish the mission objectives.

Impact Gardening Model: We use a Monte Carlo technique to simulate the stochastic process of impact gardening on a putative ice deposit [1-4]. By conducting multiple runs with the same initial conditions and a different seed to the random number generator, we are able to calculate the probability of situations occurring. This technique will never be able to reproduce the exact impact history of a particular area. However, by repeating the simulations with varied initial conditions, we calculate the dependence of the expectation values on the inputs.

The model uses the crater production function as a basis for generating impact craters over time [5-6]. The model explicitly follows a volume of regolith 20 m x 20 m x 5 m deep. However, impacts are generated over a larger area as some impacts centered outside of the box still contribute to the interior of the box. Thus the impact generation box is larger than the simulation box. The model implements impacts by calculating a bowl shape crater of the size and coordinates determined by the progam. The code alters the topography within the crater by replacing the existing topography with the new bowl at an altitude centered on the previous average altitude of the area. An ejecta blanket is deposited with a distance-dependent thickness overlying the pre-existing topography outside of the rim. The program modifies the volatile content and depth distribution resulting from the impact and then repeats the process for all of the impacts generated in the specified time window.

Data Sets: We compare data from PSRs that indicate the average surface distribution (FUV, laser) with data indicating distribution at depth (neutrons, radar, thermal).

Optical observations can only reveal the ice content of the extreme surface [7-10]. This population of ice can have two possible origins: 1) ice that is part of a continual delivery process that is ongoing on the Moon; or 2) ice that has recently been placed on the surface from an impact event that excavated ice that was buried below the surface. If the surface volatiles are part of an ongoing delivery, one would expect a rather uniform distribution throughout lunar PSRs. If the surface volatiles are from a recent exposure event, one would expect a more heterogeneous distribution. This can be calculated with the model.

Radar data suggest there are regions consistent with the presence of relatively pure ice, mainly in small PSRs distributed throughout the north polar region [11-13]. The model is applied to determine the fraction of filled small PSRs that would suffer a disruption event over time. This is compared to the fraction of PSRs with a significant radar CPR.

Neutron data provide additional insight into the depth distribution of hydrogen-bearing constituents of lunar PSRs [14-16]. We consider those data in conjunction with the model to understand the full, 3-D nature of the heterogeneity.

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ROVER WHEEL CHARGING NEAR AND WITHIN A LUNAR POLAR CRATER. T. L. Jackson[1,2] ,W. M. Farrell[1,2], M. I. Zimmerman[2,3], [1] *Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD, USA,* [2] *NASA Lunar Science Institute, NASA Ames Research Center, Moffett Field, California, USA,* [3]*Johns Hopkins Applied Physics Laboratory, Laurel, MD.*

Introduction: Any object moving along the lunar surface will experience tribo-charging due to the contact between the object and the regolith. As with the stepping astronaut charge model [1], a rover wheel will dissipate its collected charge through the most conductive path: through the surface or the ambient plasma. While roving in certain locations, such as about the lunar terminator and nightside regions, the dominant remediating path for dissipation will be the plasma. Roving within a lunar crater however, creates a situation where the rover is effectively cut off from the ambient plasma, causing dissipation times to increase significantly.

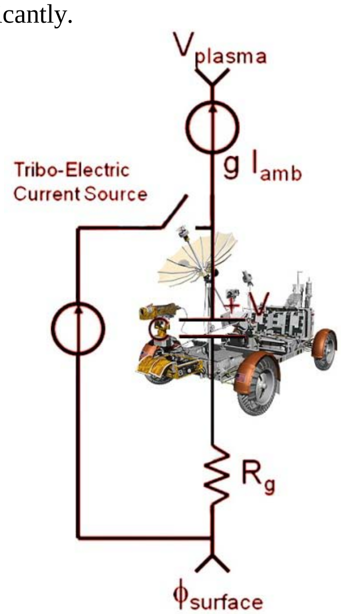

Figure 1: Equivalent circuit model for a rover on the lunar surface. The switch open signifies no movement, while the switch closed signifies roving, and hence, tribocharging.

The objective of this work is to present the results from the advancement of the wheel charging model derived from the astronaut charging model. The model is applied as an analog to determine the dissipation times for a continuously rolling rover wheel to bleed off its excess charge into the surrounding plasma at various locations on the lunar surface (i.e. dayside, near the lunar terminator, leeward of a crater wall, and at the far edge of a crater). A tribo-electric generator model is used as the charging source, and an expression that accounts for the adhesion of lunar dust (sticking factor) has also been included in order to determine how dust effects charge remediation. The effect on the charging/discharging behavior is observed while other parameters are varied, i.e. regolith grain size, wheel type, wheel speed and sticking factor.

We hope to gain a fundamental understanding of an object's electrical interaction with the charged surface and surrounding environmental plasma under varying conditions and identify electrostatically challenging regions like those within polar craters.

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SCIENCE PRIORITIES FOR LUNAR SAMPLE RETURN. B. L. Jolliff[1], S. J. Lawrence[2], M. S. Robinson[2], and J. D. Stopar, [1]Department of Earth and Planetary Sciences and The McDonnell Center for the Space Sciences, Washington University, St. Louis, MO, 63130, USA (blj@wustl.edu). [2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA.

Introduction. The Moon is a geologically complex world in its own right. Numerous exploration programs have investigated the Moon over the past 50 years [1,2], including orbiters, landers, human and robotic exploration, and sample returns. Additionally, lunar rocks are found on Earth, delivered by impacts on the Moon [e.g., 3,4]. The results from lunar missions, Earth observations, and samples have enabled scientists to construct a history of Earth's companion as a strongly differentiated object (with a core, mantle, and crust), a natural laboratory for the evolution of a rocky planetary body through internal thermal and magmatic evolution and volcanism, and a record of the impact process, especially for information regarding the flux of impactors at Earth and throughout the inner Solar System. Years of study of the lunar samples led to the hypothesis that the Moon's primary anorthositic crust and mafic mantle formed from an early magma ocean hundreds of kilometers deep [5]. The lunar samples also contain evidence of an origin by accretion of hot material following a colossal impact into proto-Earth ~4.5 billion years ago [6,7]. Indeed, lunar samples provided the first hints that all bodies in the inner Solar System experienced a cataclysmic bombardment by asteroids some 500 million years after accretion [8], possibly due to migration of the giant planets and subsequent destabilization of the early asteroid belt [9,10]. Most of these discoveries, which form a fundamental underpinning of modern planetary science, stem from the direct investigation of lunar samples in laboratories on Earth, including highly accurate and precise chemistry and isotopic analysis, mineralogy, spectroscopy, and geochronology. Moreover, having samples from known localities on the Moon enabled the coupling of sample knowledge with remote sensing and geophysical data to extend our understanding of the distribution of materials globally around the Moon and throughout the Moon's depths [11].

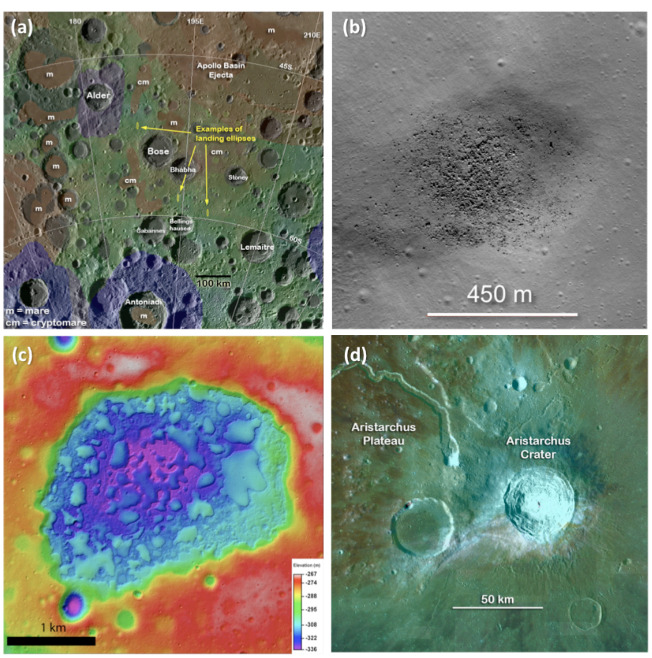

Figure 1: (a) Interior of SPA basin, showing geologic formations and example landing sites, LRO WAC base image; (b) Boulders on a small dome at the Compton-Belkovich silicic volcanic complex, LRO NAC; (c) Ina-D caldera topography, NAC digital topographic model; (d) Aristarchus region, Clementine mineral ratio map on LRO WAC 100 m base image.

New samples needed! Despite the early period of surface exploration and sample return (US and Soviet) much remains unknown about the Moon. Its polar regions, one of the truly unique environments in the Solar System, have been probed from orbit and with the LCROSS impact, and found to contain frozen volatile elements, trapped in extremely cold regions that receive little or no sunlight [12,13]. The farside contains a record of Moon's early primary anorthositic crust and one of the largest impact structures in the Solar System, South Pole-Aitken (SPA) basin (Fig. 1a). This mega-basin is our key to understanding the materials and conditions of the lunar interior and unlocking the timing of heavy impact bombardment (on the Moon and the inner Solar System as a whole). The Moon's many thousands of large, well-preserved impact craters record the history of impact bombardment in the Solar System and await future sample collection and analysis to decipher that history. The Moon's volcanic rock formations hold a record of internal thermal and chemical evolution, and timing of these events that have only begun to be unraveled with existing samples. Simply put, the Moon offers tremendous potential for addressing key questions of planetary history and evolution, and for untangling the impact record of the Solar System. These issues have fundamental implications for all of the planets and for the development and sustainability of habitable environments on Earth, Mars, and elsewhere.

Volcanism: Oldest, youngest, extents of chemical variations, petrogenetic relationships. Extensive basaltic volcanism occurred on the Moon 3.9-3.2 Ga, and continued, at a much lower rate, to as recently as ~1 Ga [14]. The mare basalts formed by melting in the Moon's mantle, thus they provide direct evidence of mantle compositions and conditions, from which the thermal history of the Moon has been inferred. Far less abundant are the petrologically and chemically "evolved" silicic volcanic materials. The silicic volcanics provide evidence of the extremes of internal chemical differentiation in the Moon's shallow interior and thus also provide key constraints on thermal and magmatic evolution. Basalts spanning the age range ~3.9-3.2 Ga were sampled by Apollo and Luna; however, areas of old buried basalts and the youngest basalts have not been visited; these need to be sampled and their ages and compositions determined. None of the silicic volcanics such as Gruithuisen and Mairan Domes, and Compton-Belkovich [15] (Fig. 1b) have been directly sampled, and only small pieces of silicic rocks are found in the lunar samples [16]. Enigmatic volcanic features such as the Ina-D caldera (Fig. 1c) and similar sites are not understood at all; samples are needed to determine their age and whether they represent sites of potentially recent outgassing [17].

Impact cratering flux and the question of a cataclysm. In addition to evidence from samples, recent remote sensing and numerical models suggest various hypotheses about the early large-impactor flux [10,18]. The issue of cataclysmic bombardment at ~4 Ga, when life on Earth was first establishing a foothold, has garnered public interest [19]. It is time for a new suite of targeted samples to be collected from the Moon to determine in detail the early flux, beginning with SPA basin and other key basins such as Nectaris [20], as well as the timing of large and stratigraphically important craters that occurred later in Solar System history, including the intermediate aged craters (Eratosthenian) and younger craters (Copernican). Such craters can be dated directly by sampling their impact melt sheets. Moreover, direct ages of the volcanic rocks that formed throughout the Moon's full active volcanic period will cement the lunar cratering stratigraphy, which is still the primary evidence for timing of crustal modifications on the terrestrial planets. Samples are needed for the required very high-precision chemical and isotopic analyses.

Volcanic pyroclastic deposits: Samples of the deep lunar interior. Among the most scientifically significant of the lunar samples were the green and orange volcanic glasses, collected at the Apollo 15 and Apollo 17 sites, respectively [1]. These glasses are important because they erupted from hundreds of kilometers deep in the mantle with little or no modification enroute to the surface. Their ages, compositions, isotopic characteristics, and volatile-element contents are keys to the origin and evolution of the Moon and to our understanding of early Earth and how it originated and evolved. Many pyroclastic deposits occur on the Moon that could be targeted for simple sample returns, but the most interesting one is the Aristarchus Plateau deposit because of its proximity to Aristarchus crater (Fig. 1d), which excavated a suite of diverse and uncommon lunar rock types.

Polar volatile deposits. Thanks to low obliquity, the Moon's poles are hosts to deposits of volatile elements, sequestered in polar cold traps that reach as low as several tens of Kelvins. The origin, extents, and detailed makeup of these deposits are unknown. Much could be learned in-situ, with both scientific and resource potentials. However, the ultimate scientific goal is the return of a cryogenic sample for detailed chemical and isotopic analysis to determine the origins and ages of the volatile element deposits.

Sample return: How? The best way to explore and collect samples with full contextual information is with boots on the ground and mobility, with well-trained astronauts using all of their senses and with rapid assessment and decision-making capabilities, as demonstrated by the Apollo experience. Sampling with very specific objectives, however, can be done robotically [21], with potential advantages by having astronaut presence in orbit or at Earth-Moon Lagrange point L2 [22], especially in terms of return mass and conducting farside mission operations.

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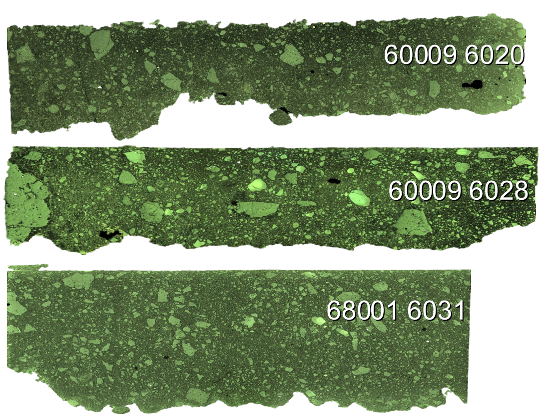
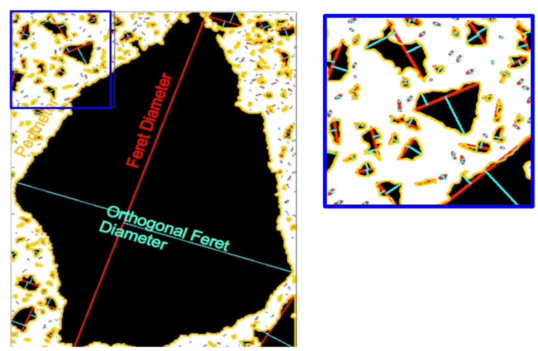
Lunar Regolith Particle Shape Analysis From Thin Sections. Kiekhaefer, R.[1], Hardy, S.[2], Rickman, D.[3] Clemson University[1], University of Texas at El Paso[2], Marshall Space Flight Center[3]

Introduction: Future engineering of structures and equipment on the lunar surface requires significant understanding of particle characteristics of the lunar regolith. Nearly all sediment characteristics are influenced by particle shape; therefore a method of quantifying particle shape is useful both in lunar and terrestrial applications. We have created a method to quantify particle shape, specifically for lunar regolith, using image processing. Photomicrographs of thin sections of lunar core material were obtained under reflected light. Three photomicrographs were analyzed using ImageJ and MATLAB. From the image analysis measurements for area, perimeter, Feret diameter, orthogonal Feret diameter, Heywood factor, aspect ratio, sieve diameter, and sieve number were recorded. Probability distribution functions were created from the measurements of Heywood factor and aspect ratio.

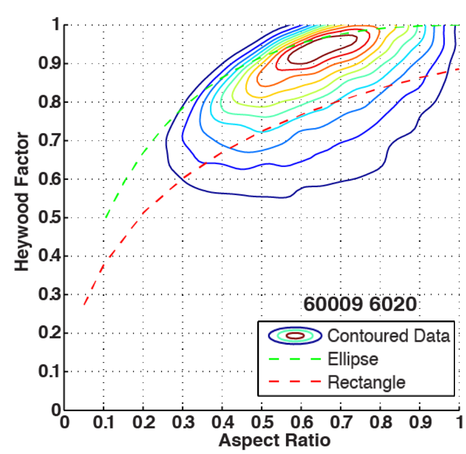
Methods: Shape can be characterized by aspect ratio and Heywood factor. Aspect ratio is a function of Feret diameter and orthogonal Feret diameter; which are the longest distance between two edges and the longest distance between two edges which is perpendicular to the Feret diameter. Heywood factor is a function of perimeter and area. Historically, these measurements have been done by hand or with an apparatus that measures one particular measurement. An example is a sieve. Sediment is passed through a set of screens that decrease in mesh size from top to bottom in order to determine the grain size.U sing ImageJ and MATLAB software, we have created a method to produce these measurements for over 50,000 particles within the three lunar thin sections below.



ImageJ requires the image to be analyzed first be imported. The image should be an RGB image in TIFF format. The RGB image is split into three 8-bit grayscale images in red, green and blue channels. For quality purposes, the green channel is used for processing. In order to minimize noise within the image, a median filter is applied via the Hybrid 2D Median Filter plugin. A Hysteresis threshold is then applied. This threshold converts the greyscale image into a binary image so individual particles can be measured.The area, perimeter, Feret diameter, orthogonal Feret diameter, and theoretical sieve diameter are measured for each particle as seen in the image below.



Analysis: Particles with areas greater than 100 pixels were measured in ImageJ, yielding a total of 52,286 measured particles between the three thin sections. 2D frequency distributions of the measured Heywood factor and aspect ratios were generated in MATLAB for each of the three thin sections, based on the obtained data. The results for thin section 60009 6020 are shown below.



Conclusions: We created an automated method capable of measuring lunar regolith particle shape from thin sections. This method measured approximately 52, 000 particles. The distributions show that all three thin sections have similar shape frequencies, which is likely due to the close proximity from which the samples were taken and the process which created the regolith. These data will allow us to quantify the similarity of the sample's shapes. Future analyses that can be built off of this method include determining relationships between particle shape, composition, size, orientation, and spacing. For future applications of this technology, better adjustment of the illumination is recommended; and a technique to mend cracked particles should be developed

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THE SPACE LAUNCH SYSTEM AND LUNAR MISSIONS. K. Klaus, The Boeing Company (13100 Space Center Blvd, Houston TX 77059, kurt.k.klaus@boeing.com).

Introduction: The Space Launch System (SLS) is the most powerful rocket ever built and provides a critical heavy-lift launch capability enabling diverse deep space missions. The exploration class vehicle launches larger payloads farther in our solar system. The vehicle's 5 m to 10 m fairing allows utilization of existing systems which reduces development risks, size limitations and costs. SLS lift capacity and superior performance will shorten mission travel time. Enhanced capabilities enable a myriad of missions including human exploration, planetary science, astrophysics, heliophysics, planetary defense and commercial space exploration endeavors. This paper will focus on mission concepts to the lunar vicinity and surface.

Asteroid Redirect & Return Mission (ARRM): Bill Gerstenmaier at the NASA Lunar Science Institute (NLSI) meeting in July 2013 refered to the ARRM in part as a mission to the lunar vicinity. Our mission concept for ARRM advocates for a dual manifest launch on the SLS for the Asteroid Retreival spacecraft and a habitable volume with an airlock to help reduce the requirements on the Orion by providing storage, habitable volume, abort destination, and opportunity for International Partner contributions.

Boeing has developed an Asteroid Redirection Vehicle (ARV) concept that leverages the benefits of our commercial spacecraft portfolio, extensive Solar Electric Propulsion design, integration, and operations heritage, and successful autonomous rendezvous and capture expertise from Orbital Express. These key attributes provide an affordable flight system with the required capabilities to execute the Asteroid Redirect Mission (ARM). The ARM mission requirements result in system design based on a modified version of our 702 commercial spacecraft product line. The Boeing 702 spacecraft is a sturdy platform that can accommodate large (> 10,000 kg) propellant loads with minimal structural modifications. The expansive payload deck can accommodate a large capture/redirect system with established interfaces for power, telemetry, and other payload services. Including a NASA Docking System (NDS) on the ARV allows for easier crewed exploration mission integration and execution. Key to our concept is that the ARV also enables potential reuse as a cargo tug or power/propulsion system for any translunar assets in the vicinity after the ARM is complete.

Boeing has a broad experience base with complex mechanisms for spacecraft. On the International Space Station alone, Boeing successfully led the integration of 27 complex mechanisms in a wide variety of applications. Our design studies of the capture systems envision a stand-alone capture pallet mated to the capture vehicle. Left attached to the asteroid and fitted with a docking or grapple interface, it would allow for future potential commercial exploitation of the asteroid once the NASA mission is complete. Boeing recognizes that all the capture methods will require close-loop control dynamic simulations that model the interaction between the capture system and the GN&C system of the capture vehicle. Lessons learned from the assembly of the ISS are extensive in this area, and are directly applicable to an asteroid capture mission. Boeing also brings experience as the integrating contractor for the NASA Docking System (NDS) which is an excellent candidate for consideration on the ARM

Asteroid Exploration Module: Crew operations at a redirected asteroid could be significantly enhanced by providing additional systems and EVA capabilities beyond those available from Orion only missions. An Asteroid Exploration Module (AEM) located with the asteroid would improve the science and technical return of the asteroid mission while also increasing Orion capability through resource provision and providing an abort location and safe haven for vehicle contingencies. Additional volume and EVA capable elements could significantly increase the effectiveness of asteroid exploration by increasing mission duration and providing more utilization options and tools for the ARRM. Orion mission capability will be stretched to the limit by asteroid missions and could be augmented by an AEM that provides resources such as power and atmosphere revitalization to extend mission duration and a storage location that saves launch mass for the Orion by storing needed items. The AEM would also provide an abort location for an Orion mission and sustain the vehicle and crew while problems are identified and resolved. At the end of the asteroid mission, the AEM would remain a viable and extensible element that could provide translunar capabilities and services and could be reused to enhance future missions or as a building block in a new architecture. We envision the AEM as the first component of a Lagrange point exploration platform. An AEM could be created using existing hardware from a number of sources. International partner space systems are well developed and ideal for these new uses, such as adapting current Russian Science Power Module (SPM) and node designs for translunar use. Study and work already done on new ISS node development could be continued. Hardware from the Space Shuttle and International Space Station (ISS) programs, such as the Orbiter Docking System

(ODS) and the ISS node test article, could be combined with existing satellite hardware with a long operational history in the GEO environment.

Cislunar Exploration Platform: The AEM could be repurposed as a cislunar exploration platform that advances scientific research, enables lunar surface exploration and provides a deep space vehicle assembly and servicing site. We have been studying an architecture for Cislunar Development that includes early deployment of an Exploration Platform at one of the Earth – Moon Lagrange points. The Exploration Platform provides a flexible basis for future exploration, since it reduces cost through reuse of expensive vehicles and reduces the number of launches needed to accomplish missions. International Space Station (ISS) industry partners have been working for the past two years on concepts for using ISS development methods and residual assets to support a broad range of exploration missions. These concepts have matured along with planning details for NASA's Space Launch System (SLS) and Multi-Purpose Crew Vehicle (MPCV) to allow serious consideration for a platform located in the Earth-Moon Libration (EML) system. [1]

Lunar Surface: The mission objectives are to provide lunar surface access for crew and cargo and to provide as much system reuse as possible. The reusable lander is a single stage, bi-propellant system which is sized to transport crew from a 100Km circular low lunar orbit to the surface and back. The lander is used in conjunction with another vehicle which we call a Lunar Transfer Vehicle (LTV) whose job is to shuttle the lander between high lunar orbit (HLO) and low lunar orbit (LLO). A polar orbit provides the ability to land at any site on the lunar surface. The platform is relocated to HLO in order to reduce the overall propellant requirements for the landing system.

The first surface expedition crew departs the AEM in the lander and performs a rendezvous and docking with the LTV. The LTV propulsion system is used to perform the transfer from HLO down to LLO. The crew next performs the necessary maneuvers to descend and land under pilot control. Subsequent missions to the surface can reuse the same lander and LTV. [2]

Secondary Payloads: We continue to examine using the mass margin available on the 2017 un-crewed ORION/SLS EM-1 to launch secondary payloads that advance science and exploration objectives. As an example, there is sufficient volume and mass margin for a number of small sats that could be used for science and technology demonstration payloads that could be included in EM-1 and subsequent missions. This capability could be made available with every SLS launch.

International Partnerships: On a global scale, space exploration provides a visible and unifying challenge to humanity and offers opportunities for broad international engagement and participation. It can contribute to global societal security through sharing of knowledge, international cooperation and economic development. All of the major space-faring nations have shown interest in long-term Solar System exploration.

Although most countries' space programs contain nationalistic perspectives, most also recognize the benefits of cooperation. Budgetary pressures of conquering new frontiers in space will make it difficult for any nation to go it alone. Given the fact that the International Space Station has now merged the human space flight programs of several space-faring nations, it seems a natural consideration that future exploration planning be inclusive of an international approach.

Stakeholder consultation and engagement activities have always been an important element in the planning process for space exploration activities. There is an accepted acknowledgement that industry perspective is important and complimentary to the planning currently underway within the major space-faring nations working to define future exploration initiatives. While our team cannot speak for our respective national agencies, we offer an international industry perspective on international partnerships for deep space exploration.

Summary: The SLS offers a great deal of flexibility with regard to missions to the lunar vicinity, lunar surface and beyond. We have shown how these missions open the door for international participation and can reduce cost through reuse of assets. Every SLS launch has capacity for secondary science and technology payloads. We advocate cislunar development as the next logical step to extend our reach beyond low earth orbit (LEO).

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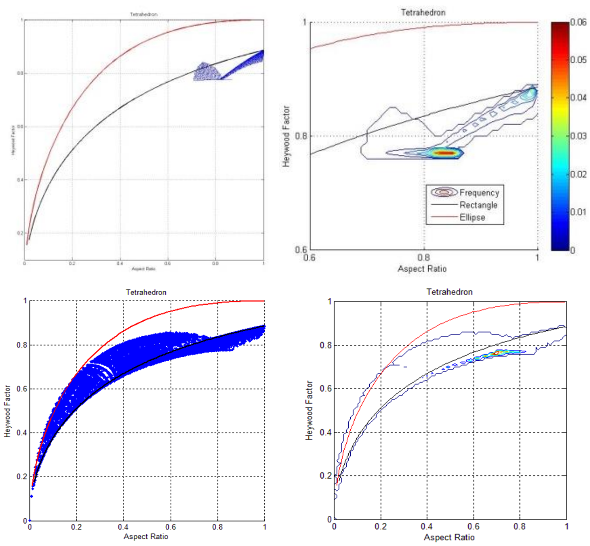
Particle Shapes of 3D Populations from 2D Numerical Modeling. Joshua Knicely[1] and Blake Lohn-Wiley[2] and Dr. Douglas Rickman[3], [1]Texas A&M University, [2]Tarleton State University, [3]Marshall Space Flight Center

Introduction: Particle shape affects many things, such as the bioavailability of drugs, the electrical properties of metals used in batteries, and the macroscopic behavior of lunar regolith. Most methods of particle shape analysis involve either a plane of section or a plane of projection. Both methods acquire 2D information from a 3D object. With either method, a specific 3D particle can produce a variety of 2D shapes, and the 2D shapes cannot be uniquely inverted to a specific 3D object. However, we can compute all possible 2D shapes that a convex 3D object creates. Therefore, the probability density function (PDF) for selected measures of shape can be evaluated for possible 3D objects. We have developed these PDFs for several 3D convex shapes. Now generated, 2D measurements compared to these PDFs will determine the likely 3D particle shapes, allowing for a more accurate characterization of the particles.

Background: Our selected measures are Heywood factor (a measure of circularity) and aspect ratio (a measure of elongation). Plane of section creates a polygon by taking a slice of a shape, and plane of projection creates a polygon by mapping the silhouette of the 3D object onto a plane.

Methodology: We create several convex 3D objects. We define 'n' equidistant points on a sphere centered at the origin. Each point on the sphere and the origin define a normal to a plane. For plane of section, we translate the plane along the normal from the origin at a fixed step size and determine the points of intersection. For plane of projection, we project the points of the object onto a plane defined by a point on the sphere and the normal and create a convex polygon from the projected points. This gives us the polygon from which we calculate aspect ratio and Heywood factor. We bin this data, and then create a contour from the number of occurrences in each bin.

Results: We have obtained the datasets and PDFs for several 3D shapes. In the next column is an example of this information for a tetrahedron. Clockwise from the top left, there is the data for plane of projection, the PDF for plane of projection, the PDF for plane of section, and the data for plane of section.



Conclusions: We have produced datasets and the corresponding PDFs for the plane of projection and plane of section. Plots of the PDFs show the combinations of aspect ratio and Heywood factor are limited to specific regions. The comparison of real data to the PDFs will determine the likely 3D shapes responsible for these 2D measurements. This new particle characterization will advance pharmaceuticals, metallurgy, geology, and more.

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Striking analogies between tectonic features of Moon and Earth: SPA Basin – Indian Ocean, Mare Orientale – Congo craton

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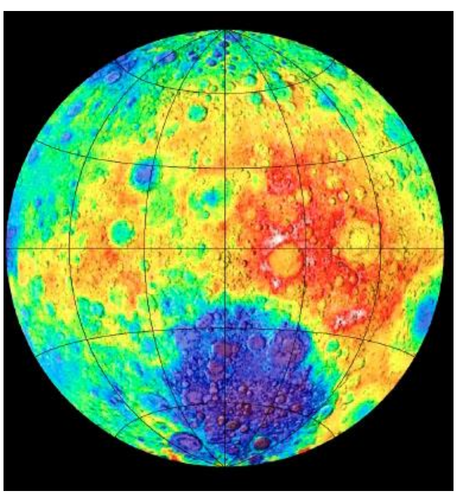
Earth and its satellite both are well studied topographically and gravimetrically. It turned out that at both bodies there are solitary unique planetary scale objects origins of which puzzles scientists. Geophysicists know about existence of a unique depression in the geoid form on the Indian Ocean aquatory deep –112 m but its origin is mysterious. According to prevailing since some time the plate tectonics the basin of the Indian Ocean was formed as a result of moving apart core blocks around a triple junction of the middle-ocean ridges. Such interpretation of the present tectonics contradicts to a real disposition of different ages planetary geologic blocks around the Indian minimum [1] and does not explain its profound nature. The minimum occurs at the axe “b” of three main Earth’s moments of inertia and thus is a fundamental part of its rotation figure [2].

Lunar Basins and Marea, as it is known, are traditionally considered as traces of impacts of giant cosmic bodies during an earlier bombardment (3 to 4 b. y. ago). Even their regular symmetric disposition on the surface is neglected [3]. However, serious difficulties recently arise in concordance of their supposed ages with ages of “impact” breccias and relations between them. But the supporters of impacts stand firm on their opinion and do not accept alternatives. The South Polar-Aitken basin is considered as the largest impact basin in the Solar system; its depth is about 8 km with the total lunar relief range about 20 km.

The comparative wave planetology [3-4 & others] could help in solution of the question. It turns out that both considered planetary structures occupy analogous positions in a wave structure of their bodies (Fig. 1, 2). They are deeply subsided sectors (πR-structures) on their respective uplifted continental highland segments-hemispheres (2πR-structures) [5]. Similarity of the lunar and Earth’s deepest geoid minima (the SPA Basin and the Indian Ocean basin) is proven by their even relative sizes, similar tectonic settings and dense mantles (Fig. 1, 2) [5-7]. Such regular their arrangement on two globes makes dubious their interpretation according to the hypotheses of plate tectonics and impacts [5, 6].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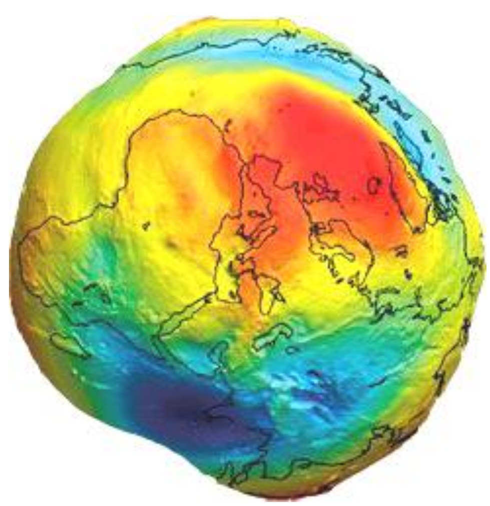
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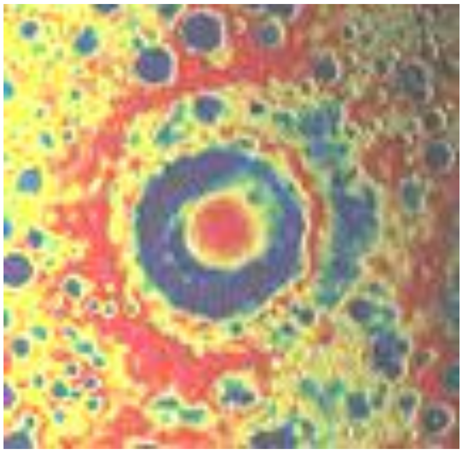
Fig. 1. Lunar geoid. Center-down (dark blue) – SPA basin (moontopogeoidusgs_farside.jpg).
Fig. 2. Earth’s geoid. Center-down (dark blue) – Indian minimum (832e4f812d1e_.jpg).
Fig. 3. Lunar concentric gravity in Mare Orientale area. Red-high, blue-low (Science, 2013, v. 339, # 6120, book-jacket).
Fig. 4. Congolese superstructure: 1. Benoue trough, 2. Afar depression, 3. Rifts in the craton frame, 4. Archean greenshist belts, 5. Radial weakness zones, 6. Tangential weakness zones, 7. Walvis ridge



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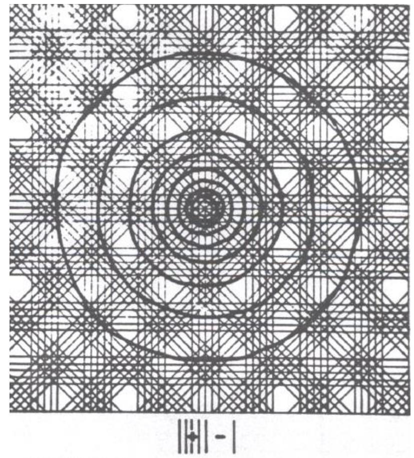

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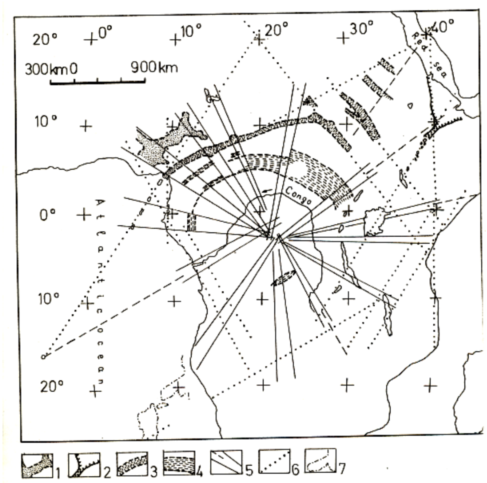

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Fig. 5. Graphic representation of crossing waves (+ up, - down) producing chains and grids of round forms (craters) and multi-ring structure (better seen from some distance).

Resemblance between the Mare Orientale and the Congo craton superstructure (Fig. 3, 4) is in their relative sizes (both have πR/4 dimensions) and nearly perfect concentric structures. The concenters are well expressed in topography, gravity field (the lunar case, Fig. 3 [8]), in geological construction (the terrestrial case, Fig. 4). Spacing between concentric zones in both cases increases outward with the factor √2 (a model in Fig. 5) [9]. Mare Orientale has enigmatic collars of the crater-beads. They not only surround the Basin but are revealed also inside of this large concentric structure. This multi-ring construction consists of intercalating mountainous and plain belts revealed by topography. But the more profound GRAIL gravity shows that many of the belts are composed of uniform crater-beads (they are better seen on the positive gravity "red" areas and somewhat worse on the negative "blue" areas, Fig.3). This fine structure is better explained by the wave interference, a graphic model of which is in Fig. 5. The considered striking similarities between fundamental tectonic features of both cosmic bodies require thorough examination for unveiling true tectonic histories and origin of this "double planet".

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Landing Site Selection and Surface Traverse Planning using the Lunar Mapping & Modeling Portal E. Law[1], G. Chang[1], B. Bui[1], R. kim[1], K. Dodge[1], S. Sadaqathullah[1], and S. Malhotra[1], [1]Jet Propoulsion Laboratory, Califronia Institute of Technology.

Introduction: The Lunar Mapping and Modeling Portal **(LMMP)**[1], is a web-based Portal and a suite of interactive visualization and analysis tools for users to access mapped lunar data products (including image mosaics, digital elevation models, etc.) from past and current lunar missions (e.g., Lunar Reconnaissance Orbiter, Apollo, etc.), and to perform in-depth analyses to support lunar surface mission planning and system design for future lunar exploration and science missions. It has been widely used by many scientists mission planners, as well as educators and public outreach (e.g., Google Lunar XPRICE teams, RESOLVE project, museums etc.)

This year, LMMP was used by the Lunar and Planetary Institute (LPI)'s Lunar Exploration internship program to perform lighting analysis and local hazard assessments, such as, slope, surface roughness and crater/boulder distribution to research landing sites and surface pathfinding and traversal. Our talk will include an overview of LMMP, a demonstration of the tools as well as a summary of the LPI Lunar Exploration summer interns' experience in using those tools.

References:

[1] http://www.lmmp.nasa.gov

SAMPLING THE YOUNGEST LUNAR BASALTS. S. J. Lawrence[1], M. S. Robinson[1], B. L. Jolliff[2], B. R. Hawke[3], G. J. Taylor[3], J. J. Hagerty[4], and B. W. Denevi[5] [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (samuel.lawrence@asu.edu) [2]Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO, USA [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA. [4]Astrogeology Science Center, United States Geological Survey, Flagstaff, AZ, USA [5]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

Introduction: Determining the timing and compositional range of basalts on the lunar surface is key information for interpreting the origin and geologic evolution of the Moon, with implications for comparative terrestrial planetology. Here, we advocate an automated sample return mission to key basaltic sites, addressing fundamental questions about the composition of the lunar crust and the time-stratigraphy of lunar volcanic processes, with implications for all of the terrestrial planets. Sampling these basaltic materials complements currently proposed missions [e.g., 1] and helps prepare for future human exploration.

Background: The Moon preserves a record of time that were erased on other terrestrial planets, such Earth and Venus [2]. The Moon is the only extraterrestrial body from which we have contextualized samples, yet unanswered questions remain: we lack important details of the Moon's early igneous history, the full compositional and age ranges of its crust, or the bulk composition of the crust, mantle, and whole Moon.

Lunar mare basalts form through partial melting of the mantle and are the most direct window into the composition of the interior. Mare basalts cover ~17% of the lunar surface, primarily contained within topographic lows on the nearside [3]. Analysis of remote sensing data sets shows that the full range of mare basalt compositions and ages has not yet been sampled [4,5]. Knowledge of the duration of mare volcanism comes from (a) radiometric dating of Apollo and Luna samples and lunar meteorites and (b) crater counting of mare surfaces from remote sensing data (an imprecise method). Mare volcanism reached its maximum volumetric output between 3.8 and 3.2 Ga [6], but began as early as 4.3 Ga [7-9] and may have persisted until as recently as 1.2 Ga [5,10]. This uncertainty needs to be addressed.

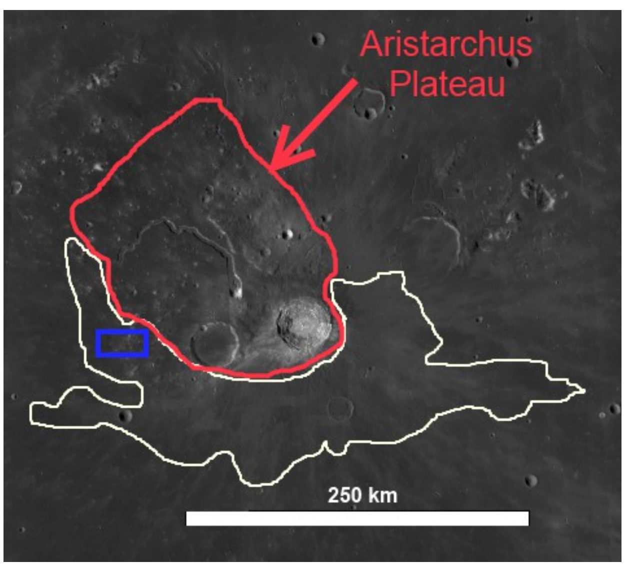

Figure 1: LROC WAC base map highlighting the P60 area of Hiesinger et al., 2003 (white line), along with the crater counting region used to derive the model basalt age (in blue). The Aristarchus Plateau is highlighted in red for reference.

Some of the basalt flows on the Moon are significantly younger than the youngest Apollo basalts [10]. Hiesenger et al. [5] mapped 60 spectrally homogenous basalt units in Oceanus Procellarum. Crater counting methods determined that 5 of these units have model ages ranging from ~1.5-2.0 Ga. Unit P60 (Fig. 1) directly south of the Aristarchus Plateau has the youngest model age (1.2 Ga; uncertainty +0.32/-0.35 b. y.).

The analysis of returned samples from the P60 region would increase knowledge about isotopic and trace-element variations in lunar basalts, help to distinguish differences in basalt source regions/reservoirs and eruption rates over time, and significantly improve knowledge of the Moon's absolute chronology. The nearside location of the sampling location makes this an ideal site for an automated sample return. In addition, the proximity of the proposed sampling station to the Aristarchus Plateau (a high-priority target for future human exploration and development) also makes this an attractive site as a precursor mission for human lunar return.

Mission Strategy: An automated sample return mission functionally similar to the Soviet Luna 24 mission and the recently proposed MoonRise mission [1] can meet the return requirements. The advanced scouting capabilities provided by the NASA Lunar Reconnaissance Orbiter enable precisely targeted landings. The required spacecraft consists of a single landed element with sampling capabilities, an ascent vehicle, and a sample return system. After landing, a robotic arm collects and stores a scoop of bulk regolith, then collects a kilogram of 3-10 cm rocklets by raking or sieving. Following collection, the samples are returned to Earth. The mission duration is less than a lunar day;

no-long-duration survival for the landed element is required.

Traceability: Sampling the youngest lunar basalt unit is directly responsive to science goals outlined in [11], especially Goal 5b: Determine the age of the youngest and oldest mare basalts. Sampling the youngest lunar basalts is also responsive to other goals outlined in that report, including establishing a precise absolute chronology for the Moon, characterizing the thermal state of the interior and elucidating the workings of the planetary heat engine, quantifying the local and regional complexity of the current lunar crust, determining the origin and variability of lunar basalts, and investigating the flux of lunar volcanism and its evolution over time.

Implications:: Collecting samples of the basalts thought to be the youngest on the lunar surface offers a low-risk, high-reward pathway to address fundamental questions in planetary science, including: understanding the lunar interior, the flux of mare volcanism, and improving the absolute chronology for the inner Solar System.

Understanding the lunar interior: The Apollo samples and lunar meteorites only sample a limited range of lunar basalt compositions and ages, which limits our understanding of the lunar interior and the full extent in space, time, and composition of lunar basaltic volcanism. Returning samples from the youngest lunar basalts will increase our knowledge about isotopic and trace element variations in lunar basalts, and in principle will distinguish prospective differences in basalt source regions and reservoirs over time.

Understanding the flux of mare volcanism: An important measure of the thermal history of a planetary body is the changes in the rate of lava eruption with time. Age determinations of samples from the maria indicate that most mare volcanism took place between 3.7 and 3.1 Ga [12]. If sample return from the youngest mare basalts shows that volcanism did, in fact, continue to as recent as 1.2 Ga, then that information would help to unravel how mare eruption rates varied with time.

Improve the absolute chronology for the Inner Solar System: The fieldwork and samples from the Apollo and Luna missions yield an absolute chronology that extends to the rest of the Solar System [12-16]. Collecting samples from the youngest mare basalts will therefore have important ramifications for planetary science [11,17]. Current cratering flux calibration curves from the Moon are anchored by dates from mare surfaces near Apollo landing sites (3.8-3.2 Ga), and very few young dates establish the more recent (<2 Ga) cratering flux [13].

If the Procellarum basalt samples have older or younger absolute ages than expected, than we will have significantly improved our knowledge of the surface ages on the Moon, and by extension, the other terrestrial planets. No matter what the age date of the Procellarum samples is determined to be, the result will still provide new knowledge for Solar System history and exploration.

Sample Return is Required: The Apollo experience demonstrates the importance of returning planetary samples to Earth [18]. To achieve the objectives discussed here, detailed analysis of compositions, mineralogy, rock textures, and physical properties in addition to laboratory-determined radiometric ages are required. Important measurements could be made using in-situ instrumentation, but terrestrial laboratories offer more capability for the foreseeable future, and to date, the only method with sufficient precision to adequately answer the question of the age of the youngest lunar basalts. Samples become resources, so new measurements can be made as analytical techniques improve. For sample return missions to be successful, the scientific community must maintain key capabilities, including lunar sample curation, lunar remote sensing data analysis, and laboratories staffed with experienced planetary scientists. Sample return missions will also play an important complementary role towards human lunar return by giving the next generation of lunar scientists experience analyzing new lunar samples prior to the seventh human lunar landing.

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OPERATIONAL AND SCIENTIFIC ASSESSMENT OF LUNAR EXPLORATION SITES.

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Introduction: New observations from Kaguya, Chandrayaan-1, and the NASA Lunar Reconnaissance Orbiter (LRO) are advancing our understanding of the lithologies present in the lunar crust [e.g., 1-4], the distribution and timing of lunar volcanic features [e.g., 5-10], the surficial nature of lunar swirls [e.g., 11], and the nature of lunar tectonism [12-14].

While the LRO mission continues to produce important advances in lunar science, the original goal of LRO was to collect observations required to facilitate planning and operations of future human lunar and robotic exploration missions. Relatively few analysis efforts have leveraged LRO data for exploration planning [15-19], and these have in general focused on the Constellation lunar surface exploration architecture [20]. The Constellation Regions of Interest encompass a diverse range of exploration sites, but recent discoveries have identified additional sites of high exploration and science value that should also be studied in an exploration context...

To address this issue, we are complementing other lunar exploration site studies by systematically assessing (from both scientific and operational perspectives) fifteen places on the Moon considered to be likely locations for near-term robotic precursor missions (Table 1). In order to maximize the near-term utility of the proposed research, our goals are directly traceable to three generalized examples of robotic missions (short-duration rover, long-duration rover, and automated sample return) that have been recommended as desirable precursor missions [21]. However, the results of this study will also be applicable to future human lunar exploration.

Objectives: This study has three main goals:

Define optimal landing sites for future robotic precursor lunar missions: Using morphology, topography, temperatures, illumination, roughness, slopes, and rock abundances we are identifying landing sites optimized for scientific exploration of the lunar surface and/or the achievement of specific exploration objectives (i.e., In-Situ Resource Utilization [ISRU] demonstrations).

Identify meter-scale traverses and focused investigation stations: Using LRO NAC images and NAC-derived digital terrain models (DTM), we are identifying outcrops, specific boulders, craters, and other lunar geologic features and evaluating how these locations as traverse stations will satisfy scientific or engineering objectives. We are deriving slope and roughness parameters to automatically determine the navigability of a proposed traverse. Planning at this level was not generally enjoyed by the Apollo missions; however, by beginning the process now, the results of this and similar studies can inform and enable future exploration destinations and enhance science return.

Develop Concept of Operations for Teleoperated Spacecraft to Inform Future Hardware Decisions: Assessments for each study region will produce results directly addressing critical questions about rover, lander, and/or human exploration concepts of operation, including: distances required to reach scientifically interesting locations from landing sites, accessibility of specific locations, ability of wheeled mobility systems to fulfill mission objectives, and measurement objectives needed to fulfill investigation goals.

Reference Missions: In order to frame decisions about how to assess the scientific targets within a given study area, we define three use cases that are designed to be responsive to lunar surface activities recommended in the Lunar Exploration Roadmap [21] and that can be executed within the next decade as either competed Discovery/New Frontiers missions or human exploration precursor missions.

Automated Sample Return: The first use case is an automated sample return similar to the recent proposed MoonRise mission [16]. Automated sample returns have been suggested as a mechanism to answer key science questions about the timing and nature of lunar volcanism and lunar resource potential [16, 22-23].

Limited Duration Rover: This use case envisions a teleoperated, solar-powered rover with capabilities comparable to the Mars Exploration Rovers [24] designed to address specific objectives during a single lunar day. Under this use case, a single rover would travel several kilometers at a single site, visiting preselected science targets to answer specific science questions.

Long-Duration Mobile Prospector: This use case has mobility capabilities analogous to the Mars Science Laboratory, designed to travel a minimum of 5-20 km and powered by a radioisotope generator. This would be a long-duration roving mission to prospect for lunar resources and provide ground truth for orbital observations. This mission requires the ability to travel 10s-100s of km with a mission duration of at least six months to assay resources at several sites and determine the lateral and vertical distribution of prospective lunar resources while accomplishing key science objectives [25].

Study Area Selection: The study areas involved in this project (Table 1) were selected to address lunar science and exploration goals defined by community reports [21,23,26-28], particularly the need to determine the extent and compositional variations in lunar volcanism and to assess lunar resource potential. In order to maximize the near-term utility for exploration missions, nearly all of the proposed sites are located on the lunar nearside, where a communications relay will not be necessary.

Methods: We are coregistering LROC (NAC, WAC, and DTMs), Diviner, and LOLA datasets with Moon Mineralogy Mapper (Chandrayaan-1), Kaguya Terrain Mapping Camera, Clementine, and Apollo Metric Camera frames. The integrated datasets are being used to determine important lithologies and geologic units, identify productive exploration locations and resources such as pyroclastic deposits, and then identify candidate landing sites. NAC DTMs are being used to assess the accessibility of each site in terms of the Terrain Ruggedness Index [29] and slopes. Finally, we have developed a preliminary path planning algorithm [30] based on a generalized least-energy model for planetary rovers, altered for the lunar use case [31]. This algorithm identifies least energy traverse paths and allows us to determine capabilities (rolling resistance, turning capability, maximum slopes) that are required to reach specific targets.

Conclusions: This project will further science and exploration objectives by identifying locations for future robotic precursor exploration, specific traverses designed to achieve science objectives, sampling stations, and resources to define hardware requirements for feasible lunar precursor missions.

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Table 1. Study Area Locations

Site Name	Center Lat	Center Lon	Rationale	Use Case
Mairan Domes	41.7	312	Silicic Volcanism	Rover/Sample Return
Ina D	18.5	5.2	Unique Volcanism	Rover
Marius Hills	13.7	304.1	Non-Silicic Volcanism	Rover
Isis/Osiris	18.8	27.6	Non-Silicic Volcanism	Rover
Rima Parry V	-7.1	343.2	Non-Silicic Volcanism	Rover
Compton-Belkovich	60	99.6	Farside Silicic Volcanism	Rover/Sample Return
Dewar	-2.1	166.7	Farside Volcanism	Rover/Sample Return
Procellarum Basalts	18.9	308.3	Young Volcanism	Sample Return
Marius Hills Pit	14.1	303.2	Volcanic Terrain and Subterranean Voids	Rover
Aristarchus-1	24.4	311.5	Complex Geology and ISRU Prospecting	Rover/Sample Return
Sulpicius Gallus	19.7	10.2	Pyroclastics	Rover/Sample Return
Sinus Aestuum	5.6	344.8	Spinel Composition	Rover/Sample Return
Reiner Gamma	7.3	300.9	Lunar Swirl	Rover
North Polar PSR	89.3	130.9	Polar Volatiles	Rover
South Polar PSR	-89.7	201.2	Polar Volatiles	Rover

Line-of-sight Communication on the Moon - Analysis for Landing Spot Selection. P. Mahanti[1] , M. S. Robinson[1], A. Boyd[1] and S. Lawrence[1], [1]Lunar Reconnaissance Orbiter Science Operations Center, Arizona State University, Tempe, Arizona, pmahanti.lroc@gmail.com

Introduction: Sustainable communication between assets on the lunar surface is a primary requirement for any lunar science and exploration mission. There is a long history of line-of-sight communication planning for lunar exploration, evident from the requirements from the Apollo era [1]. Laser communications, to be experimentally tested in the imminent LADEE mission [2], depends also on line-of-sight availability.

High resolution lunar elevation data and the development of methods and data products well suited to this requirement will advance NASA's preparedness for conducting science and exploration on and from the Moon. Further, in context of science and exploration research directions in terms of a lunar geophysical network or for a rover assisted sample return [3] mission (robotic or human) from scientifically significant sites (e.g. the South Pole Aitken basin) – the planning of line-of-sight communication at these sites needs to be addressed to optimize site selection from several requirements. In this work an example analysis is discussed for landing spot selection.

Methods: High resolution (2 meter sampling) Lunar Reconnaissance Orbiter Camera (LROC) [4] topographic data derived from stereo observations controlled to laser ranging is now available for key sights enabling accurate line-of-sight analysis. These digital elevation models (DEMs) of scientifically prioritized sites were generated from LROC Narrow Angle Camera (NAC) stereo observations [5] tied to Lunar Orbiter Laser Altimeter (LOLA) profiles. These products provide the means to identify and characterize high priority science and exploration targets [6] at a scale relevant to surface landers and vehicles. In this work we develop and analyze viewshed maps to down-select a landing spot at the lunar South Pole Aitken basin from the communications point-of-view.

The experimental method for landing spot selection from line-of-sight analysis is as follows: Multiple exploration routes are first selected for an exploration site based on scientific target priorities and basic safety concerns. Next a viewshed analysis cross-checks the existence of continuous line-of-sight from possible landing spots (touchdown-point or start-of-mission) along the exploration routes or important waypoints. In the example shown in Fig.1, the DEM used is a priority target site located on the rim of the South Pole-Aitken basin. The three possible landing locations are indicated as A, B and C, and viewsheds were generated at each of these locations. Location A is a better choice from the communication perspective since it has about 50% of the exploration path connected by line-of-sight.

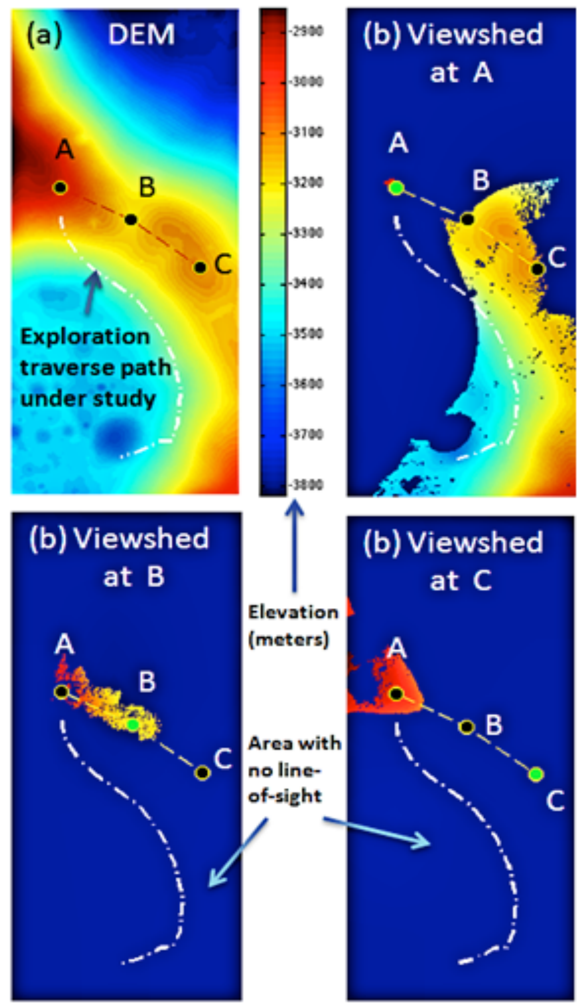

Figure 1 : Viewshed computation and line-of-sight coverage for different landing locations. [DEM source- NAC images M136226953 & M136226953; DEM center: 51.06° S, 170.84° E]

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ETHICAL CONDUCT TO LUNAR COMMERCIALIZATION. G. Zhou[1] and A. A. Mardon[2], [1]University of California, Los Angeles (School of Engineering and Applied Science, Los Angeles, California, USA, gordzhou@ucla.edu) [2]Antarctic Institute of Canada (Suite 103, 11919-82 Street NW, Edmonton, Alberta, Canada, aamardon@yahoo.ca).

Introduction: Ever since the launch of the Sputnik, countries from across the world have continually strive to exploring and one day colonizing of space. [1] With the growing demand on natural resources to fuel intercontinentant technological advances, and with reducing terrestrial sources, government and industries are investing in space exploration missions. It is important to develop moral and ethical models for space commercialization, specifically, as it relates to lunar settlements. [2]

Existing "Moon Treaty": The agreement Governing the Activities of States on the Moon and Other Celestial Bodies have been proposed to United Nation members by several member states, however, has not been widely accepted due to its controversial language. Specifically, the provisions requiring spacefaring nations to share the benefits for the "common heritage of mankind" and that no nation should be military bases on the lunar surface creates a conflict between third world countries that argue benefits derived from outerspace commerce be equally distributed to all countries and that of free market private sector ideologies. The ethical issues arise when one has to balance between the necessary business profits and the demand for distribution between all nations.

Code of Ethics: The classical environmental concern has always been the question the right to disrupt, and change the character of the lunar surface. The impact of construction, traffic, mining and other human activities related to lunar settlement needs to be analyzed. A balanced approach between the classical environmental concern and corporate and commercial will prove to be a long-term evolutionary process. [3] ' It is especially difficult to define moral and ethical standards in relation to lunar commercialization as it is based on subjective values that differ between various cultures and societies. One solution is to create a business code of conduct based on objectivity. Through the lens of stewardship, social scientists have proposed three guidelines to ethical conduct to lunar development that resembles a standard business code of conduct: [4]

1. Space Preservation – value space for its own sake regardless of potential benefits that can be derived from it
2. Space conservation – protect and care for the universe's resources for the sake of all
3. Space stewardship – holding ourselves accountable for managing space resources.

Future Research: A legal framework should be further researched so that governments can begin to think about establishing controls on space businesses. The centerpiece of this system must include moral and ethical codes of behaviour for those living and working on celestial bodies in the future. A possible model that exists on earth is the US Federal Lease Royalty Model whereby a certain percentage of royalty to the federal government or Native American tribal government in exchange for rights to continue rights to its operations. The royalty payment will be used by the organization in charge to advance interests for the betterment of all of humanity and to fund initiatives that given equal opportunities to all nations.

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LUNAR EXPLORATION FACTORS FOR CONSIDERATION G. Zhou[1] and A. A. Mardon[2], [1]University of California, Los Angeles (School of Engineering and Applied Science, Los Angeles, California, USA, gordzhou@ucla.edu) [2]Antarctic Institute of Canada (Suite 103, 11919-82 Street NW, Edmonton, Alberta, Canada, aamardon@yahoo.ca).

Introduction: Terrestrial Construction Techniques face numerous challenges posed by the different lunar geography and can not be used. One daunting problem is the production of suitable construction materials. Materials must offer similar strength, durability and other engineering properties to support human habitation as on earth. It is not feasible to transport large amount of construction material from earth to the moon due to large transport costs. Like many space exploration missions, cost is a determining factor. Transportation alone imposes a cost of $10,000 per kilogram for the entire mission making it simply not profitable or attractive to potential investors. [1] A potential near-instantaneous solution would be to develop an asteroid mining economy developing of a human-commercial market. It is suggested that this scenario will create the economical and technological opportunities not available today. The National Aeronautics and Space Administration (NASA)'s Space Exploration Initiative (SEI) promoted industrial involvement in the research and exploitation of lunar resources in the early 1900's. Although this initiative failed in the end, it prompted NASA to consider engaging industry for financial investments. Future lunar missions must prioritize private investments in this sector in order to meet preliminary program cost. Therefore due to the lack of funding, one feasible solution to reducing mission costs is to use native material such as lunar regolith to produce useful construction material.

It is proposed that a process to devise and extract volatiles from lunar regolith can be used to create construction material on the moon. Currently, space travelling require missions to carry life necessities such as air, food, water and habitable volume and shielding needed to sustain crew trips from Earth to interplanetary destinations. [2] In theory, the focus from any lunar mineral mission will focus on regolith excavation and transportation, water and oxygen production and fuel/energy production. All of these necessities along with construction and site preparation will be taken from the lunar regolith. [3] In-Situ Resource Utilization (ISRU) offers long term sustainability for large human colonization.

The majority of the mineral found on the moon is composed of silicates. Composition of lunar basalts is approximately 50% pyroxenes, 25% plagioclase and 10% olivine by volume. [4] With the chemical composition in mind, the designer must take into account the loads for structure. In basis structural mechanics, a designer must take into account the dead load which is primarily from the weight of the construction material caused by gravity. Internal pressurization and the amount of shielding must also be taken into account as this may increase the dead load. Live loads caused by moving or vibrating objects such as ventilation machinery must be also included in the calculation of overall design. A Factor of Safety (like for terrestrial designs) must be included for accidental impact loads from potential micrometeorites, possible seismic activity, extreme solar maximums and the like. This value needs to be estimated through experimentation. As we can not test the experiments on the moon, scientists and engineers can only conduct these tests under similar environment which will have a larger factor of error.

Conclusion: Robotic surveys of the lunar surface would be the precursor to the development of in situ resources. Advanced technology directed towards space mineral exploitation, excavation and effective transportation is necessary.

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SPACE MINING AND IN-SITU MINERAL RESOURCE UTILIZATION. G. Zhou[1] and A. A. Mardon[2], [1]University of California, Los Angeles (School of Engineering and Applied Science, Los Angeles, California, USA, gordzhou@ucla.edu) [2]Antarctic Institute of Canada (Suite 103, 11919-82 Street NW, Edmonton, Alberta, Canada, aamardon@yahoo.ca).

Introduction: Like many space exploration missions, cost is a determining factor. Transportation alone imposes a cost of $10,000 per kilogram for the entire mission making it simply not profitable or attractive to potential investors. A potential near-instantaneous solution would be to develop an asteroid mining economy developing of a human-commercial market. It is suggested that this scenario will create the economical and technological opportunities not available today. Future manned missions would require the use of native material and energy on celestial objects to support future human and robotic explorations. The process of collecting and processing usable native material is known as In-situ resource utilization (ISRU). Currently, space travelling require missions to carry life necessities such as air, food, water and habitable volume and shielding needed to sustain crew trips from Earth to interplanetary destinations. [1] The possibility of a mission depends on the deduced market value from commercial sale of the product. Engineering choices are identified; a matrix of mineralogy, product and process choices can be developed. [2] One major consideration in the process of obtaining energy and life supporting materials from the lunar surface is the identification and excavation of raw material. [3] Lunar soil is produced primarily by meteorite impacts on the surface. This process caused for mineral fragmentation with composition consisting of miscellaneous glasses, agglutinates and basaltic and brecciated lithic fragments. The natural specific gravity of lunar soil is said to be between the values of 2.90 and 3.24. [4]

Professor Xiangwu Zeng and his team at the NASA Glenn Research Center have developed a design calculation model to determine the excavation force based on basic principles of soil mechanics. Simulants with the properties of Apollo Regolith were used: the JSC1a fines, JSC1a very fines and the JSC1a. A hydrometer test was used to determine particle size. This test is based on Stoke's Equation.

Unlike traditional models, the Zeng model takes into account the ability to handle acceleration of the tool blade while other models assume constant velocity. It is also able to calculate passive earth pressure. [6] The model is based on the principles of basic soil mechanics and the parameters can be determined by soil tests. These include horizontal and vertical acceleration, soil blade friction angel and external friction angel. A relationship between the total excavation force, the passive earth pressure components and the side friction and the above variables are drawn.

Conclusion: The results find the Zeng model have high dependence on soil cohesion and therefore forms a linear relationship with the amount of excavation force needed for ISRU. The results will deviate from the actual lunar specimen as simulants were used for the experiments. The use of real samples may give a more accurate understanding of soil properties and experimental results.

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USING LUNAR ORBITER LASER ALTIMETER DATA TO INVESTIGATE THE LUNAR POLES.
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Introduction: The lunar poles have been the focus of recent scientific missions such as the Lunar Reconnaissance Orbiter, and several efforts are being planned to land and investigate in situ their unique properties. Because the Moon's spin axis is nearly perpendicular to the ecliptic plane, the Sun is always low on the horizon in the polar regions, and topographic relief such as impact craters can be sufficient to provide permanent shadow. As such, the lunar polar regions have the potential to trap volatiles in permanently shadowed regions (PSRs). This was recognized before good topographic knowledge of the polar regions existed **[1]**. We and others have modeled the location and distribution of such areas, in both lunar polar regions **[2,3,4,5,6]**.

Data: The data collected by the Lunar Orbiter Laser Altimeter (LOLA) instrument **[7]** onboard the Lunar Reconnaissance Orbiter (LRO) **[8]** since July 2009 have proven the most useful to conduct modeling simulations of the solar illumination on the Moon. We use more than 6 billion LOLA altimetric measurements to construct accurate high-resolution map of the surface elevation. The polar orbit of the LRO spacecraft, provides excellent coverage of the poles. We use a recent GRAIL gravity model **[9]** to improve the LRO orbit reconstruction and geodetic accuracy.

Method: We use the horizon method, as described in detail in **[6]**, with several computational improvements. In particular, we use a multi-resolution approach, where topographic grids of varying resolution and extent from the pole are used to model both near-field topographic effects and all possible far-field obstacles that affect the illumination on a more regional scale (e.g. large elevated regions). This enables us to conduct long-term (decade-long) simulations at high resolution (100m/pixel).

Results: We present the results of simulations with the LOLA topography, documenting the extent and distribution of permanently shadowed regions, as well as the illumination statistics on the proposed targets for future missions (ESA Lunar Lander, IKI LunaGlob). We also present maps of the sky visibility from the surface (Figure 1), which are important in calibrating and interpreting some instrument data. For instance, to calibrate the UV incident flux in the PSRs and yield UV surface albedo, maps such as shown in Figure 1 were used for the LAMP instrument. Visible sky angle is also important to predict or assess relative effects of the various proposed space weathering processes.

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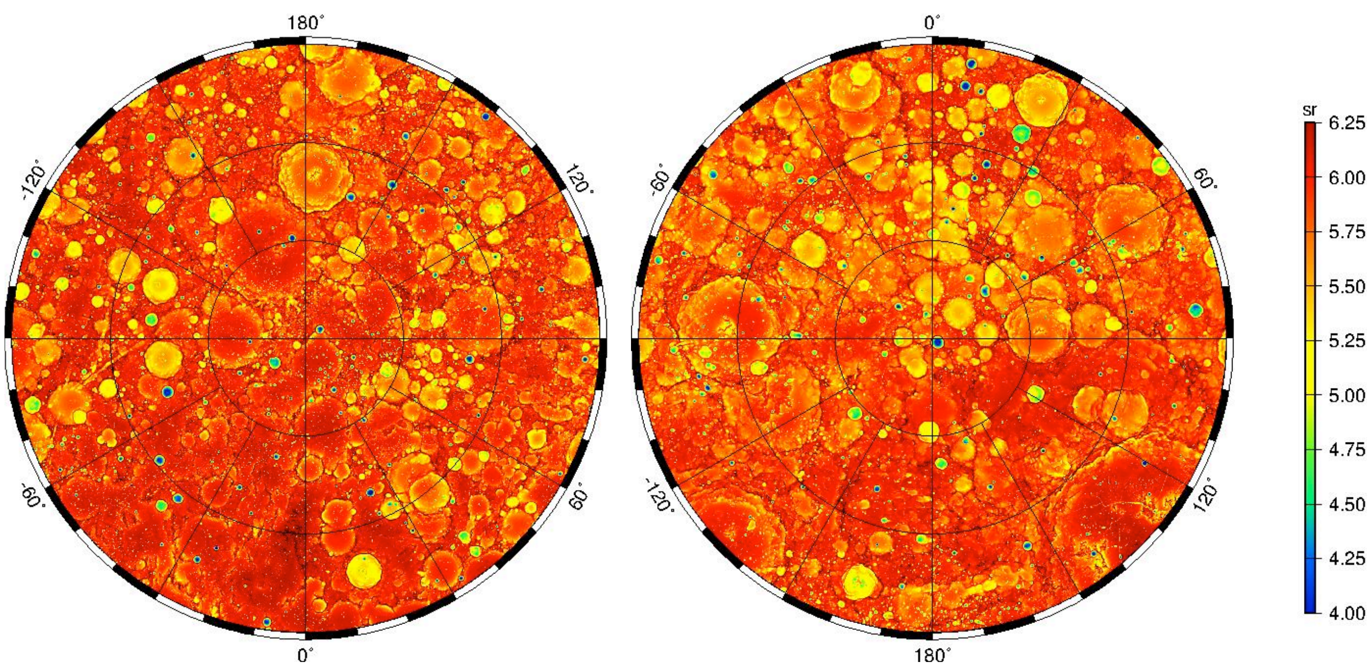

Figure 1. Maps of visible sky solid angle (in steradians) for the northern (left) and southern (right) polar regions. The latitude circles are every 5 degrees, down to 75° latitude. The floors of deep craters such as Shackleton see only a fraction of the sky compared to the typical 2π value of a flat surface.

The Low Latitude Extent of Lunar Slope Hydration Derived from the Lunar Orbiting Neutron Spectrometers and LOLA Topography. T. P McClanahan[1], I. G. Mitrofanov[2], G. Chin[1], W. V. Boynton[4], L. G. Evans[5], M. Litvak[2], T. A. Livengood[3], R. Z. Sagdeev[6], A. B. Sanin[2], R. D. Starr[7], and J. J. Su[6], G.M. Milikh[6] [1]NASA/GSFC, Greenbelt, MD (timothy.p.mcclanahan@nasa.gov), [2]Institute for Space Research, Moscow, Russia, [3]CRESST/UMD/GSFC, Greenbelt, MD, [4]Lunar and Planetary Laboratory, Tucson, AZ, [5]Computer Science Corporation, Lanham-Seabrook, MD, [6]University of Maryland, College Park, MD, [7]Catholic University of America, Washington, DC.

Introduction: Epithermal neutron count-rate maps from the two lunar orbiting neutron spectrometers: including the Lunar Exploration Neutron Detector (LEND) onboard the Lunar Reconnaissance Orbiter (LRO), and the Lunar Prospector Neutron Spectrometer (LPNS) were correlated with topographic slope and illumination factors derived from the Lunar Orbiting Laser Altimeter (LOLA) [1-4]. In that approach we decomposed the polar region epithermal neutron count-rate maps in latitudes above ±75° as a function of a common slope geomorphology using a two-parameter insolation model [5]. All six of the derived maps for both poles and the three epithermal detector systems we considered, indicated the poleward-facing slopes in polar latitudes above 75° have a consistent suppression of epithermal count-rates consistent with enhancements in hydrogen. Results from LEND's high-resolution Collimated Sensor for Epithermal Neutrons (CSETN) indicates the poleward facing slopes, may be enhanced by at least ~20 to 25 ppm H relative to equivalent equator-facing slopes. These consistent observations indicate polar hydrogen distributions are biased by the topography towards trapping in regions at the lower end of the insolation continuum. Spatial distributions of these effects appear to be ~uniform in high-latitudes suggesting a solar wind source or an active hydrogen transport process. However, the local spatial scale of slopes and cratering appears to have an influence on the results due to instrumental blurring.

In this research, we will shift the focus of the investigation towards the mid-latitudes to quantify the low-latitude extent of the slope hydration effects. We consider both the LEND and LPNS detector results, and use a topographic masking technique developed in [5] that isolate slopes of increasing spatial scale, showing improvements in the signal-to-noise ratio. Evidence from this experiment shows the low latitude extent of slope hydration effects. Results also suggest small craters and slopes, perhaps at ~meter or less scales, may also act as cold-traps for hydrogen in polar latitudes. These small traps may collectively reflect a systematic trapping of hydrogen as a function of local insolation conditions. Evidence suggests these small cold-traps are effectively blurred by these detector systems broader instrument response and may provide an explanation for the Extended Polar Suppression of Epithermal Neutrons (ESPEN) that indicates poleward increases in hydrogen beginning near ±70° latitude [6,7].

References: [1] Chin et al. (2010) *Sp. Sci Rev*. 150(1-4) Mitrofanov et al.(2010) *Science*, 330-6003, 483-486 [2] Feldman et al.,(2001) *JGR*, 106-E10, 23231-23251 [3] Smith et al.(2010) *Sp. Sci. Rev., 150(1-4)* [4] Mazarico et al., (2011) *Icarus*, (211) 1066-1081 [5] McClanahan et al., 2013, LPSC #2374 [6] Mitrofanov et al.(2012) *JGR-Planets,* 17-E7 1-14 [7] Boynton et al., ((2012) *JGR-Planets*, 17-E7 1-16

RUSSIN PLANS FOR THE FIRST STAGE OF LUNAR ROBOTIC EXPLORATION. I. G. Mitrofanov[1] , A. A. Petrukovich[1] and L. M. Zelenyi[1], [1]Institute for Space Research of Russian Academy of Science, Profsojuznaja 84/32, 117997 Moscow, Russia (*imitrofa@space.ru*).

The current plans will be reported for the first stage of the future Russion robotic missions to the South pole of the Moon.

The major goal of the sequence of the missions at the first stage is the sample return of polar regolith. It is commonly accepted that polar regolith has a lot of trapped volatiles, so the detaied studies of these samples on the Earth will allow to understand the history of the Moon, to determine the physical environment at lunar poles, and also to get the basic knowledge for future utilization of lunar polar resources.

The first mission of the sequence, historically named *Luna Glob* for 2015, should land to the most secure spot at south polar area and to study the polar regolith and exosphere. The next mission for 2016 is the polar orbiter of *Luna Resurs* project, which should investigate the polar regions of the Moon from the 100 km polar orbit. The third mission for 2017 is the lander of *Luna Resurs* project, which should land at the most interesting site at the south polar area for detailed analysis of regolith from the shallow subsurface.

When these three missions will be accomplished, with the tested technology and with the obtained necessary science and engineering knowladge, the forth mission *LPSR* (from *Lunar Polar Sample Return*) should be performed, which launch is preliminary scheduled at 2020.

COMPACT, MODULAR HEAT FLOW PROBES FOR LUNAR LANDERS. S. Nagihara[1], K. Zacny[2], M. Hedlund[2], and P. T. Taylor[3], [1]Department of Geosciences, Texas Tech University, Lubbock, TX 79409 (seiichi.nagihara@ttu.edu), [2]Honeybee Robotics, Pasadena, CA 91103, [3]Goddard Space Flight Center, Greenbelt, MD 20711.

Introduction: Measurement of heat released from the lunar intertior is important in understanding the Moon's structure, composition, and origin [1, 2]. Heat flow is obtained as a product of the thermal conductivity and the vertical temperature gradient in the regolith. Apollo 15 and 17 recorded heat flow measurements [2]. More measurements in the future would reveal geographic variation of heat flow across the lunar surface, and they will complement the findings from NASA's recent GRAIL and LRO /DIVINER missions.

We are currently developing a compact, modular heat-flow system that can be accommodated into various forms of robotic and human lunar-landing missions (Fig. 1). For example, JAXA's Selene II, and Russian Luna 27 and 29 scheduled for 2017 and 2020, respectively, could accommodate our heat flow system. Other flight opportunities may be materialized by the privately funded Google Lunar X-Prize and Golden Spike.

The New Modular Heat Flow System: The new heat flow system is compact and light-weight (~ 2 kg in total), and it can be attached to any stable, landed platform (Fig. 1). In addition, it uses a pneumatic excavation mechanism and requires little electrical power [3]. The modular, compact, low-mass and low-power nature of the system makes it easily adaptable to a variety of missions.

The new system is designed to reach 3-m depth into lunar regolith (Fig. 2). This depth has been considered necessary for future lunar heat flow measurements in order to avoid the effects of long-term temporal changes in lunar surface thermal environment [4]. Such changes may be due to the 18.6-year-cylcle lunar precession [5, 6], or may be initiated by presence of the lander itself [7]. Reaching the 3-m depth with a low-power, low-mass system is a technological challenge. For example, driving a 3-m long probe into the ground by a rotary or percussive drill would make a system several times heavier and require more power than our system. In contract, an internal hammering mechanism such as moles [8] would be as light-weight as our instrument, but may lack the excavation capability necessary for reaching the target depth. Our pneumatic approach may be one of the very limited options for achieving all the technical requirements.

The pneumatic excavation system utilizes a glass fiber composite stem which winds out of a reel and pushes its conical tip into the regolith (Fig. 3). Simultaneously, Helium gas jets, emitted from the cone tip, remove the regolith. The material for the stem is chosen for its mechanical strength and low thermal conductivity.

Attached to the tip of the penetrating cone is a probe for *in-situ* thermal conductivity measurement (Fig. 4). During a deployment, when the penetrating cone reaches one of the depths targeted for a thermal conductivity measurement, it stops operating, and the stem pushes the short probe into the yet-to-be excavated, undisturbed bottom-hole regolith. When the measurement is complete, the system resumes excavation.

The *in-situ* thermal conductivity probe consists of a short (~1 cm) metal tube containing a resistance temperature detector (RTD) wrapped in a coil of heater wire. In its current design, the probe has a diameter of 2-mm in order to insure good thermal contact with powdery regolith materials in lunar vacuum, and for mechanical strength. The penetrating cone is made of a low-conductivity plastic in order to thermally insulate the probe from the rest of the instrument.

We use a variant of the 'needle probe' method [9] for thermal conductivity measurement. The probe emits heat (Q) with a constant rate and its temperature (T) increases linearly with the natural logarithm of the total heating time (t):

$$T = C \ln t + T_0 \qquad (1),$$

where the coefficient C is proportional to Q and inversely proportional to the thermal conductivity. This constant can be constrained by lab calibration experiments [10].

In monitoring the stability of regolith temperature up and down the hole, which is necessary in obtaining the thermal gradient, we embed a series of RTDs along the stem with an equal spacing of ~30 cm. Once the probe is fully deployed to the target depth, the regolith around the hole, overtime, reestablishes thermal equilibrium at the depths unaffected by the insolation.

Acknowledgments: This work is supported by NASA under 10-PIDDP10-0028.

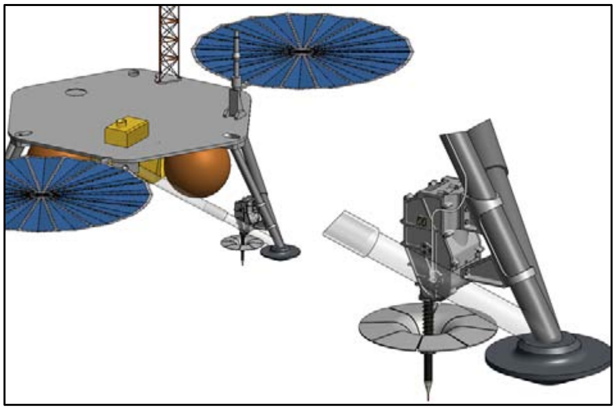

Figure 1: A conceptual drawing of the proposed heat flow system attached to a leg of a lunar lander.

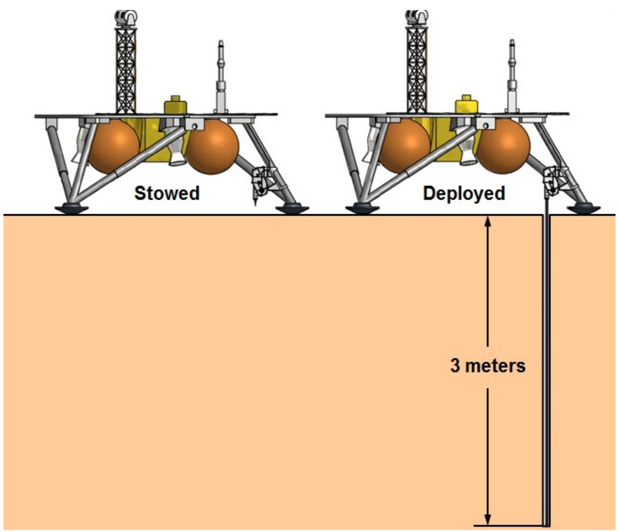

Figure 2: The heat flow probe in stowed (left) and deployed (right) configurations.

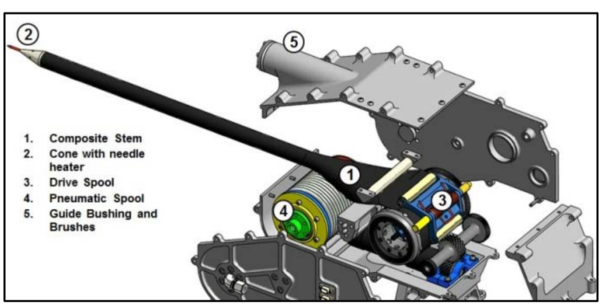

Figure 3: More detailed schematics of the major components of the heat flow system.

Figure 4: A photograph of the prototype of the cone tip and thermal conductivity.

References: [1] National Research Council (2011) pub# 13117. [2] Langseth. M. G. et al. (1976) *LPS VII*, 3143-3171. [3] Zacny, K. et al. (2011) *LEAG* 2028. . [5] Cohen, B. A. et al. (2009) *ILN Final Report*. [5] Wieczorek, M. A. and Huang, S. (2006), *LPSC XXXVII*, 1682. [6] Saito, Y. et al. (2006), *Bull. Japanese Soc. Planet. Sc. 16*, 158-164. [7] Kiefer, W. S. (2011) *Planet. Space Sc., 60*, 155-165. [8] Spohn, T. et al. (2012) *LPSC XXXXIII* 1445. [9] Von Herzen, R.P. and A.E. Maxwell (1959) *J. Geophys. Res., 64*, 1557-1563. [10] Nagihara, S. et al. (2012) *International Workshop on Instrumentation for Planetary Missions*, 1014.

Future Missions to the Moon: Building a Strategy for Lunar Science and Exploration. C. R. Neal[1] [1]Dept. of Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notree Dame, IN 46556, USA. (neal.1@nd.edu)

Introduction: The proximity and the fact that humans have visited the lunar surface, have been interpreted as negatives for the US to continue science and exploration of the Moon [1]. However, thanks to a reinvigorated and vibrant Lunar Community, the Moon features heavily in the current NASA Planetary Sciences Division Decadal Survey [2]. A number of other countries have recently focused their space exploration efforts on exploring the Moon: SMART-1 (ESA); SELENE/Kaguya (Japan); Chandrayaan-1 (India); Chang'e-1 and -2 (China). In addition, the US missions GRAIL, LRO, and LADEE continue to add to our knowledge of the Moon and the inner Solar System. Finally, the ISECG has produced a Global Exploration Roadmap [3] that develops a "Moon-first" approach to Solar System exploration.

The Decadal Survey [2] specifies 2 New Frontiers class (cost cap $1billion) lunar missions are highlighted: Sample return from the South Pole-Aitken Basin; a long-lived Lunar Geophysical Network. The decadal also highlights important lunar science issues that should be addressed by future missions:

- Determining the nature of polar volatiles;
- Understanding the significance of recent lunar activity at potential surface vent site;
- Reconstructing the thermal-tectonic and magmatic evolution of the Moon;
- Determining the impact history of the inner Solar System through the exploration of better characterized and newly revealed lunar terranes.

Interestingly, the decadal goes on to say that such missions may include orbiters, landers and sample return.

LEAG has developed, through community input, the Lunar Exploration Roadmap (LER) [4] that is updated annually. This large document is a comprehensive view of how to explore the Moon to further lunar science, develop capabilities to visit othe places in the Solar System, and develop commercial on-ramps with a view to making lunar exploration sustainable and permanent. In 2011, LEAG submitted to NASA 3-phase outline plan for enabling the LER [5]. Pivotal to this was the development of lunar ISRU and a technical demonstration that would extract, refine, and store resources on the lunar surface.

Phase 1: *Lunar Resource Prospecting*. Robotic prospectors on the lunar surface will quantify the the extent of resources identified from orbital data;

Phase 2: *Lunar Resource Mining*. Based on the results of Phase 1, an end-to-end resource miner feasibility demonstration would be deployed to 2-3 areas with the most abundant and extractable resources;

Phase 3: *Lunar Resource Production*. Based on the results of Phase 2, a larger-scale continuous processing capability would be deployed to the most appropriate site. Greater quantities of resources will be produced and be used to undertake more extensive demonstrations such as life support, mobility technologies, and fuel for a robotic sample return.

It is exciting to hear that "Resource Prospector" is a NASA HEOMD Class D mission in pre-Phase A [6]. This carries the Resolve payload [7,8] to the lunar surface and is tentatively scheduled to launch in 2018. In fact, there are several robotic missions planned to go to the Moon over the next decade (Table 1).

Table 1: Future Lunar Missions

COUNTRY	NAME	TYPE	YEAR
China	Chang'e 3	Lander	2013
USA	LADEE	Orbiter	2013
Private	GLXP	Landers	2014
India	Chandrayaan-2	Lander	2015
Russia	Lunar 25 (Glob)	Lander	2015
Russia	Lunar 26	Orbiter	2016
Russia/India	Lunar Resource 1	Lander/Rover	2017
China	Chang'e 5 (sample return)	Lander	2017
USA	Resource Prospector	Lander/Rover	2018
Japan	SELENE-2	Lander	2018?
Russia	Lunar 27 (Resource2)	Cryo SR	2019
Russia	Lunokhod 3	Rover	2020?

The Future. The Lunar Community needs to organize so strong Discovery proposals are submitted that cover many (if not all) of the lunar mission call-outs in [2]. In addition, with the number of international and even private missions planned (Table 1), we should lobby for regular SALMON calls so US scientists can be involved. We also need to support Resource Prospector, as well as MoonRise (SPA sample return resubmission). We have to be proactive in advancing our science and exploration the Moon.

References: **[1]** Obama B. (2010) *http://www.nasa.gov/news/media/trans/obama_ksc_trans.html* **[2]** NRC (2011) Vision & Voyages *http://www.nap.edu/catalog/13117.html* **[3]** ISECG (2011) Global Exploration Roadmap *http://www.globalspaceexploration.org* **[4]** LEAG (2013) *http://www.lpi.usra.edu/leag* **[5]** LEAG (2011) *http://www.lpi.usra.edu/leag/reports.shtml* **[6]** Colaprete A. (2013) *http://lunarscience.nasa.gov/lsf2013/agenda* **[7]** Captain J. et al. (2010) *SRR XI http://www.isruinfo.com/index.php?page=srr_11_ptmss* **[8]** Sanders G.B & Larson W.E. (2010) SRR XI *http://www.isruinfo.com/index.php?page =srr_11_ptmss*

Future Missions to the Moon on a Discovery (or Less) Budget. C. R. Neal[1] [1]Dept. of Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notree Dame, IN 46556, USA. (neal.1@nd.edu)

Introduction: The Moon features heavily in the current NASA Planetary Sciewnces Division Decadal Survey [1]. The decadal specifies 2 New Frontiers class (cost cap $1billion) lunar missions are highlighted: Sample return from the South Pole-Aitken Basin; a long-lived Lunar Geophysical Network. The decadal also highlights important lunar science issues that should be addressed by future missions (orbital, landed, and sample return):

- Determining the nature of polar volatiles;
- Understanding the significance of recent lunar activity at potential surface vent site;
- Reconstructing the thermal-tectonic and magmatic evolution of the Moon;
- Determining the impact history of the inner Solar System through the exploration of better characterized and newly revealed lunar terranes.

Therefore, we need to be thinking of credible missions to the Moon that will address the science highlighted above, but at a Discovery budget (cost-cap $500 million) or less for those issues not named as New Frontiers missions. Given the plethora of recent orbital missions, future missions will likely need to get to the surface and have some mobility to explore at least the local area. This is not to say that there should not be orbital missions proposed that could, for example, determine the nature of polar volatiles or characterize the global surface mineralogy at higher resolution than M^3. Assuming an upper budget limit of $500 million, landed missions will be limited to the nearside, unless a Com Sat is independently available. I assume here that it won't be and discuss potential landing sites and mission types that will address important lunar science and exploration questions.

Landed missions on the lunar nearside would answer a number of important science questions. I list some examples below in no order of preference:

- A landed mission in the youngest mare terrane (see [2-4] and Fig. 1) would allow a sample return not unlike those of the Soviet Luna 16, 20 and 24 missions (i.e., regolith samples). In addition, such a mission could deploy a heat flow probe as this site is well within the Procellarum KREEP terrane [5] and this would potentially give us an unambiguous idea of lunar heat flow in a KREEP-rich area.
- A rover mission (remotely controlled from Earth) to, for example, the Ina Structure [6] would allow a detailed examination of potential recent lunar activity. A sample return mission to this area would also yield significant scientific advances and potentially the age of the structure/activity.
- A rover mission to a carefully chosen PSR could allow a landing in sunlight in the bottom of a crater and roving into the PSR for relatively brief periods to examine the volatile content, geotechnical properties, and composition of the regolith.
- Sample return from impact craters that sample impact melts would clearly define the age of these craters (e.g., Copernicus, Nectaris).
- Sample/return or rover mission to a high-Th region of the Moon (e.g., Hansteen Alpha [7]) would give vital information about the age and geological setting of potentially evolved igneous constructs.

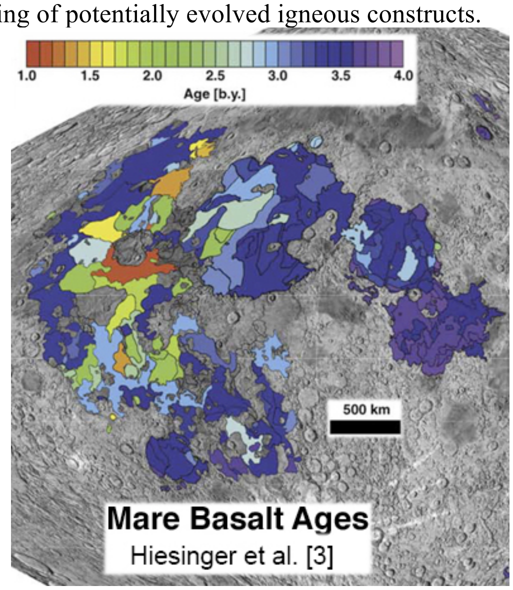

Figure 1: Ages of different mare terranes [3].

There are other mission concepts that I will discuss at the LEAG meeting, but the examples given above address the bulleted list of lunar science objectives that can be addressed by missions. Also, we should not forgot the exploration aspect of these missions, such as ISRU. With the potential for HEOMD to launch Resolve Prospector in 2018 [8], we need to be thinking of not only giving this mission our full support, but what follow on missions could be developed.

References: **[1]** NRC (2011) Vision & Voyages http://www.nap.edu/catalog/13117.html **[2]** Hiesinger H. et al. (2000) *JGR 105*, 29239-29275. **[3]** Hiesinger H. et al. (2000) *JGR 108*, doi:10.1029/2002JE001985 **[4]** Hiesinger H. et al. (2010) *JGR 115*, doi: 10.1029/2009JE003380. **[5]** Jolliff B.L. et al. (2000) *JGR 105*, 4197-4216. **[6]** Schultz P. et al. (2006) Nature 444, 184-186. **[7]** Lawrence D.H. et al. (2005) GRL 32, doi:10.1029/2004GL022022. **[8]** Colaprete A. (2013) http://lunarscience.nasa.gov/lsf2013/agenda

Albedo-Temperature Correlations in Lunar Polar Craters

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Introduction: MESSENGER observations of the polar regions of Mercury have revealed strong correlations between normal surface albedo and temperature [1-2] that have been interpreted as strong evidence for the presence of thermally stable surface and subsurface water ice. The LOLA instrument on LRO [3] has obtained an analogous set of normal albedo measurements on the Moon at a wavelength of 1.064 μm [4] that can be interpreted with the aid of surface temperature measurements obtained by the LRO Diviner Lunar Radiometer instrument [5].

Approach: Polar stereographic maps of all calibrated LOLA normal reflectance observations and Diviner annual maximum Channel 8 brightness temperatures obtained poleward of 70° latitude were binned at a resolution of 0.5 km and cross correlated. To reduce the potential effects of "geological" albedo variations, the cross correlations were limited to the interiors of ~400 quasi-circular impact craters with diameters ranging from 10 to 100 km. LOLA normal reflectances within each crater were binned in increments of 10K and then normalized to a value of 1.0 at a bin centered at 255K. The resulting relative variations in normal reflectance as a function of temperature were then averaged for all craters.

Results: Figure 1 shows the average temperature-correlated reflectance variation within all north polar and south polar craters. A strong and consistent trend of increasing albedo with decreasing temperature is evident. Relative albedoes increase by ~8% as temperatures decrease from 350K to 75K in both polar regions. Large error bars are observed at temperatures lower than 75K because the coldest regions occupy a small fraction of the available area, particularly in the north.

Interpretation: The observed ~8% increase in albedo with decreasing temperature must be the result of phenomena that are presently active on the lunar surface. Candidate processes include:

1. *Space Weathering* - Exposed regolith surfaces on the moon darken over time due the formation of nanophase iron and agglutinates [6]. The rates of both darkening processes may be diminished in low temperature regions as colder surfaces receive less sun exposure, and are less prone to melting.
2. *Opposition Effect* - Lunar soil reflectance increases markedly at zero phase angle due to the combined effects of shadow hiding and coherent backscatter [7]. Colder temperatures may affect soil packing geometry or density of soils to alter their backscatter characteristics to produce the observed albedo trends.
3. *Volatiles* - The presence of increasing concentrations of bright surface water ice or other volatiles with decreasing temperatures has been observed on Mercury, and may also be occurring on the moon. The ice may be preferentially concentrated in small regions at textural scales below the spatial resolution of the present study.

We expect to narrow our interpretations through further analysis and consideration of additional data.

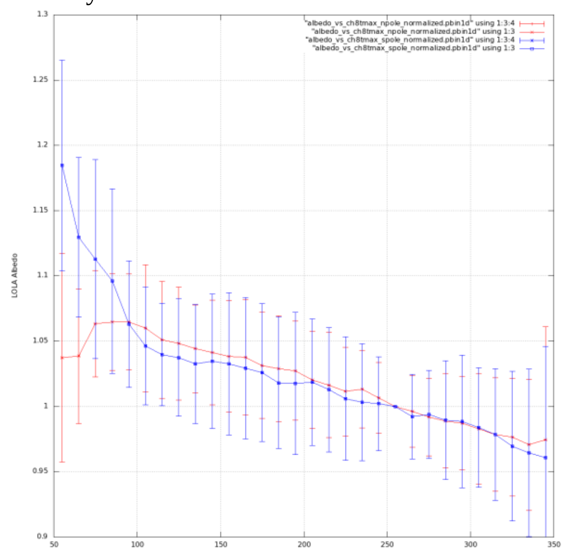

Figure 1. Correlation of relative LOLA albedo with Diviner Channel 8 annual maximum temperatures within ~400 impact craters in the lunar north (red) and south (blue) polar regions.

References: [1] Neumann et al., Science 339, 296-300, 2013. [2] Paige et. al., Science 339, 300-303, 2013; [3] Smith et al., Space Sci. Rev. 150, 209-241, 2010; [4] Lucey et al., JGR *in preparation*, 2013; [5] Sefton-Nash et al, NLSI Volatiles Workshop, 2013; [6] Hapke JGR 106, 10,039-10,073, 2001; [7] Hapke, Theory of Reflectance and Emittance Spectroscopy, Cambridge Univ. Press, 1993.

BISTATIC RADAR OBSERVATIONS OF THE MOON USING MINI-RF ON LRO AND THE ARECIBO OBSERVATORY. G.W. Patterson, D.B.J. Bussey, and the Mini-RF Team. Johns Hopkins University Applied Physics Laboratory, Laurel, MD (Wes.Patterson@jhuapl.edu).

Introduction: The Mini-RF team is acquiring bistatic radar measurements of the lunar surface to understand the scattering properties of materials as a function of phase angle. These observations have produced the first lunar bistatic radar images ever collected with non-zero phase angles. The goal of these observations is to differentiate between scattering indicative of surfaces that are rough versus surfaces that harbor water ice in quantities detectible by a radar system operating at a wavelength of 12.6 cm.

Bistatic Operations: Radar observations of planetary surfaces provide unique information on the structure (i.e., roughness) and dielectric properties of surface and buried materials [e.g., 1-4]. These data can be acquired using a monostatic architecture, where a single antenna serves as the signal transmitter and receiver, or they can be acquired using a bistatic architecture, where a signal is transmitted from one location and received at another. The former provides information on the scattering properties of a target surface at zero phase. The latter provides the same information over a variety of phase angles. NASA's Mini-RF instrument on the Lunar Reconnaissance Orbiter and the Arecibo Observatory in Puerto Rico are currently operating in a bistatic architecture (the Arecibo Observatory serves as the transmitter and Mini-RF serves as the receiver). This architecture maintains the hybrid dual-polarimetric nature of the Mini-RF instrument [5] and, therefore, allows for the calculation of the Stokes parameters (S_1, S_2, S_3, S_4) that characterize the backscattered signal (and the products derived from those parameters).

Observations: A common product derived from the Stokes parameters is the Circular Polarization Ratio (CPR),

$$\mu_C = \frac{(S_1 - S_4)}{(S_1 + S_4)} \qquad (1).$$

High CPR values can serve as an indicator of rough surfaces [4,5] or as an indicator of the presence of water ice [6]. Recent work using monostatic radar data and inferences from surface geology suggests that anomalously high CPR values associated with some polar lunar craters are indicative of the presence of water ice [7,8]. However, a unique determination of water ice is hindered by the surface roughness characteristics of craters [4]. Bistatic radar data can take advantage of differences in the CPR characteristics of rough surfaces and water ice as a function of phase angle to differentiate between these possibilities [9-11]. To do so, Mini-RF is currently acquiring bistatic radar data of lunar polar and non-polar crater materials.

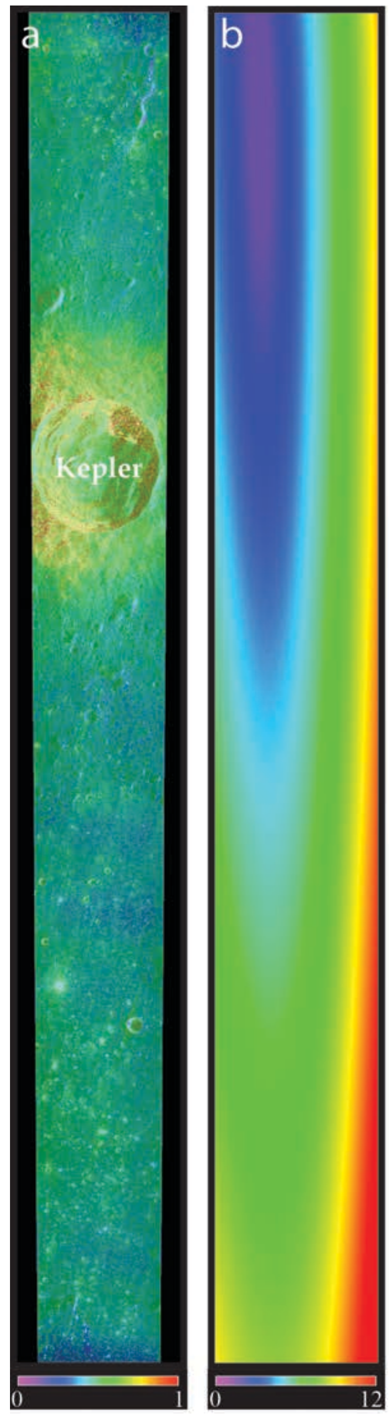

Fig. 1. Bistatic (a) CPR and (b) phase angle information for Kepler crater (8.1°N, 38.0°W, dia. 32 km).

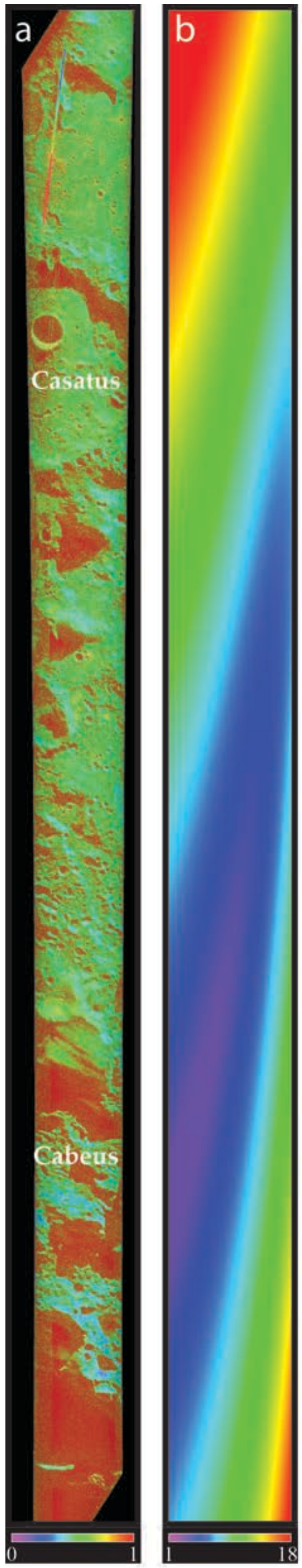

Fig. 2. Bistatic (a) CPR and (b) phase angle information for Casatus (72.6°S, 30.5°W, dia. 111 km) and Cabeus craters (84.9°S, 35.5°W, dia. 98 km).

To characterize the CPR of solely rough surfaces as a function of phase angle, we are acquiring bistatic radar data of a number of relatively fresh non-polar craters that have high monostatic CPR values (e.g., Fig. 1). This information can then be compared directly to data acquired of polar targets that include anomalous craters identified by [7,8] (e.g., Fig. 2).

Results: Initial analysis shows that the CPR of mare materials are only weakly sensitive to variations in phase angle and that the CPR of crater ejecta increases steadily for phase angles < 5°. This is markedly different from the expected behavior of water ice [9]. Bistatic data for polar craters clearly indicate the presence of crater material associated with small fresh impacts (yellow – Fig. 2). Analysis of the phase angle characteristics of these materials and polar crater floors is ongoing.

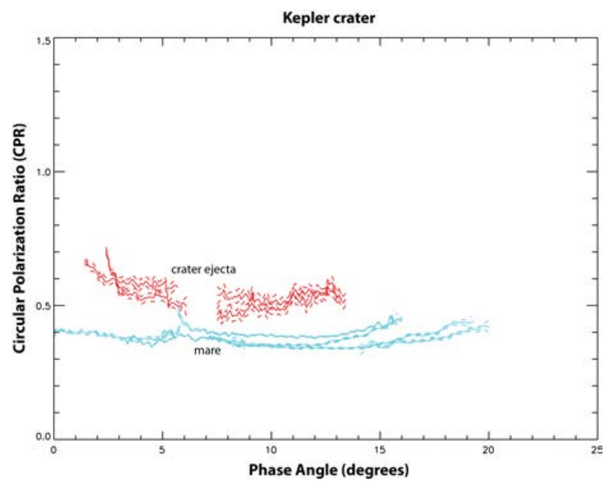

Fig. 3. Plot of CPR vs. phase angle for crater ejecta and mare materials associated with Kepler crater (Fig. 2).

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LUNAR RECONNAISSANCE ORBITER (LRO): DATA AND RESOURCES FOR FUTURE LUNAR MISSIONS. N.E. Petro[1] and J.W. Keller[1], [1]NASA Goddard Space Flight Center, Greenbelt, MD (Noah.E.Petro@nasa.gov).

Introduction: The Lunar Reconnaissance Orbiter has been orbiting the Moon for over four years, transmitting a wealth of data that has significantly altered our view of the Moon and its environment [1, 2]. All data from LRO is delivered to the Planetary Data System (PDS) in an accessible format every three months. As of July 2013, over 420 Tb of data is available, from level 0 raw data to higher-level data products (mosaics, maps, derived products, etc.). Data from LRO, as well as GRAIL, LCROSS, eventually LADEE, and the number of recent international missions all provide an excellent basis for the identification of science targets and safe landing sites.

Here we describe the available data from LRO that are useful for future mission planning as well as prospects of LRO support of future landed assets.

LRO Data: LRO data is regularly delivered to the PDS nodes (Geosciences, Imaging, PPI, NAIF) with many higher-level data products regularly being created and added to the archive. A number of tools produced by the teams are available in order to interact or obtain/analyze data (Table 1). Additionally, each team has prepared a set of Reduced Data Records (RDR's) that typically include mosaics and derived products (Table 1). These higher-level products greatly enhance the usability of the datasets by the community. Example of such products include LRO NAC derived stereo Digital Terrain Models of select locations [3] (Figure 1a), global slope and roughness maps derived from LOLA topography [4] (Figure 1b), and global rock abundance [5] (Figure 1c) Should any users experience difficulty in using LRO data, each team has contacts than should be reached and a data users forum is planned for the LPSC in 2014.

Future Prospects for LRO: As of the 2013 LEAG meeting LRO will be roughly halfway through its two-year extended mission. Preparations are underway to propose a second extended mission, and we are excited for the opportunity for many more years of operations. It is important to note that the pairing of both the quasi-stable polar orbit (30 x 200 km, Figure 2) and the remaining fuel suggest that LRO can remain in orbit for at least 8 years beyond the current extended mission. During that time, there may be landed assets that would benefit from both the LRO data and the capabilities that LRO may offer.

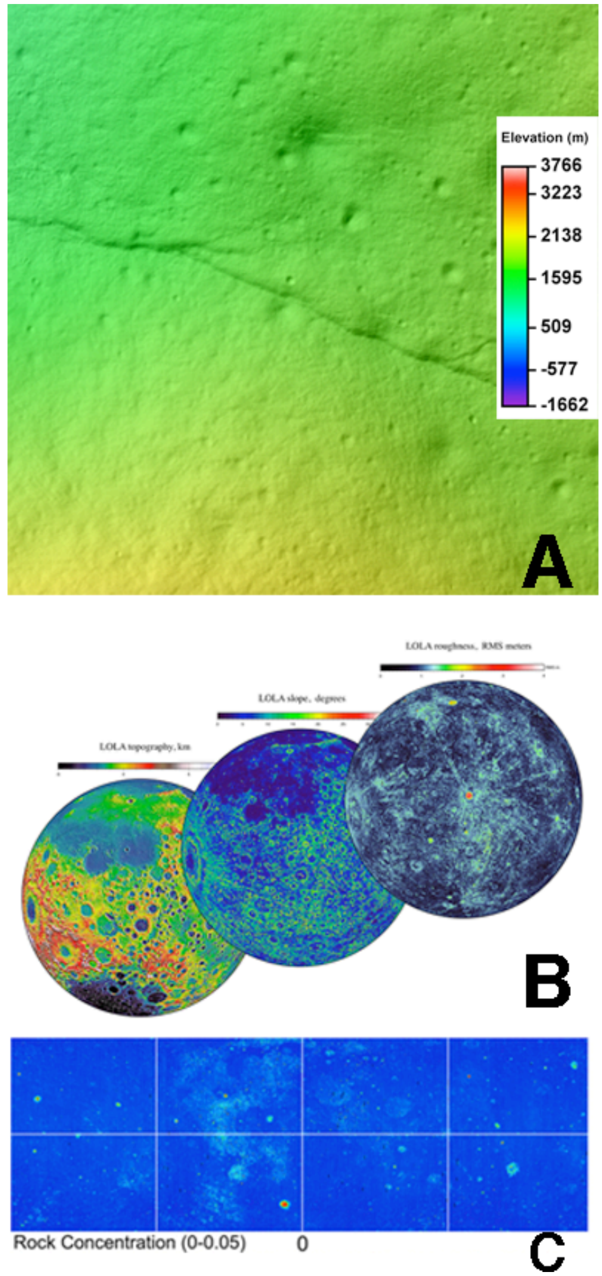

Figure 1. Example derived data products produced by LRO instrument teams. A) 1 km wide LRO NAC derived DTM at 2 m/pixel of a Lobate Scarp in Slipher Crater. B) Global topography, slope, and roughness derived by LOLA [4] C) Diviner derived surface rock concentration between 60ºN and 60ºS [5].

Table 1. Example LRO data resources and data product sources.

Tool	URL
LRO PDS Home	http://geo.pds.nasa.gov/missions/lro/default.htm
JMARS for Moon	http://jmars.asu.edu/download-jmoon
LROC Quickmap	http://target.lroc.asu.edu/q3/
Lunar Mapping and Modeling Portal (LMMP)	http://pub.lmmp.nasa.gov/LMMPUI/LMMP_CLIENT/LMMP.html
LROC RDR Products	http://wms.lroc.asu.edu/lroc/rdr_product_select
LOLA Gridded Data Products	http://imbrium.mit.edu/DATA/LOLA_GDR/
LOLA Illumination Data Maps	http://imbrium.mit.edu/EXTRAS/ILLUMINATION/
Mini-RF Polar Mosaics	http://pds-geosciences.wustl.edu/missions/lro/mrf.htm

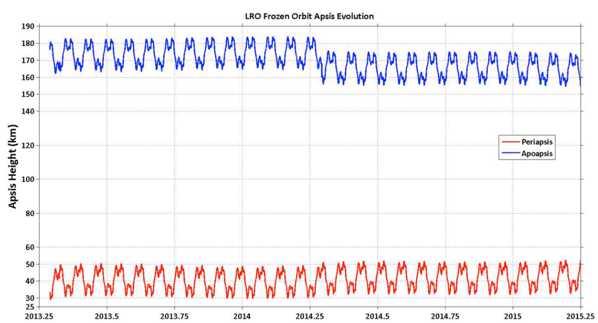

Figure 2. Evolution of LRO's periapsis and apoapsis during the two years of the current extended mission. The quasi-stable orbit is maintained by a yearly maneuver.

Unique Observations and Collaborations:

LRO's current primary science investigations revolve around four themes; 1) determining the nature of volatiles deposited in the Moon's polar region, 2) terrestrial planet differentiation and early evolution, 3) the lunar impact record and its relation to solar system history, and 4) the Moon's interactions with its external environment. These science themes drive many of the observations LRO makes during nominal operations. However, LRO has made several observations in support of other missions or to take advantage of unique opportunities (e.g., Comet ISON observations, atmospheric observations during meteor showers, lunar eclipse measurements). These unique measurements highlight the robustness of both the LRO spacecraft and the LRO and instrument planning.

LRO has demonstrated numerous times its capability to respond to opportunities for unique science observations, from the impact of the LCROSS and GRAIL spacecraft, to planned coordinated observations with the LADEE mission. While each of these opportunities demands attention from the instrument teams and the LRO project, they have been not only successful collaborations but also have provided excellent and unique science results.

LRO as a Relay Satellite: While not designed as a relay satellite, LRO could be configured to use its dual onboard Omni-directional antennas to communicate with surface assets. At this point only one-way communication between surface assets and LRO has been investigated; further analysis needs to be performed to determine if LRO can transmit to surface assets. While the data-rate of the Omni's is low (4 kbps), LRO's polar orbit enables multiple communication links on consecutive orbits, implying that data can be uploaded to LRO and then transmitted to Earth via our standard data downlink.

Public Engagement with LRO: As LRO data continues to yield science results, communicating those results to the public remains an important aspect of LRO operations. With each opportunity to engage the public, interest in the Moon remains high. For example, the LAMP press release featuring the GRAIL impact observations resulted in more hits to the Southwest Research Institute (LAMP's home institution) web site in 2013 than any other news release. The LRO experience suggests that the public is still interested in the Moon and the science that missions produce, and engaging that audience should remain a priority for any lunar mission.

Conclusions: LRO continues to operate nearly flawlessly, returning a substantial volume of data and reshaping our scientific view of the Moon. The spacecraft itself contains enough fuel to operate for an addition 8 years following the current extended mission, and the LRO project is planning for the next extended mission proposal. Future missions to the Moon will benefit from the high-resolution data to identify safe landing sites and, should the need arise, LRO would be able to act as a relay satellite to a landed asset.

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MOON MINERALOGY MAPPER PERSPECTIVE ON THE COMPOSITION OF THE SCULPTURED HILLS: IMPLICATIONS FOR THE ORIGIN OF THE APOLLO 17 STATION 8 BOULDER AND GUIDANCE FOR FUTURE LUNAR ROVERS. N. E. Petro[1] and R. L. Klima[2], [1]NASA Goddard Space Flight Center (Noah.E.Petro@nasa.gov), [2]Johns Hopkins University Applied Physics Laboratory.

M^3 Observations of the Sculptured Hills: The Moon Mineralogy Mapper (M^3) was a high spatial and spectral resolution imaging spectrometer that flew on the Chandryaan-1 Mission to the Moon [1-3]. Results from M^3 have shown the value of imaging spectroscopy at the Moon, enabling an improved assessment of the mineralogy of the Moon [3, 4]. One of many strengths of M^3 was the detailed detection of the variations in pyroxene composition [5] and in the distribution of olivines [6, 7]. While M^3 has shown that the Moon is rich with diversity across the entire lunar surface, it also provides the opportunity to revisit the Apollo landing sites and examine the diversity of materials in and around those exploration sites. Of particular interest are the materials in the massifs of the Tarus-Littrow Valley, reflected in the samples from Apollo 17. Recent data from the LRO Camera raises the question of the origin of the Sculptured Hills and suggests that they may be derived from the Imbrium Basin [8]. The Sculptured Hills were identified as being spectrally distinct in Clementine data [9, 10]; here we revisit the diversity of materials in the Sculptured Hills and their possible connection to the boulder sampled at Station 8 of Apollo 17 [11].

Over the life of the Chandrayaan-1 mission, several observations of the Apollo 17 landing site were made by M^3. A handful of observations were made while the spacecraft was in its lower 100km orbit [1] resulting in a spatial resolution of ~140m/pixel (Figure 1). A strength of the M^3 dataset is the capability to create overviews of the mineralogical diversity of a region through the use of parameters [5, 6]. One such parameter set captures the strengths of the 1.0 µm and 2.0 µm ferrous absorption bands and the albedo around ~1.5 µm. Shown in Figure 2 is the Apollo 17 landing site with these three parameters displayed in the red, green and blue channels respectively. The diversity of materials in the Sculptured Hills is apparent, with plagioclase bearing rock appearing in blue/purple, pyroxenes appearing green and yellow, and olivine appearing red. Clementine data illustrated that the Sculptured Hills were diverse [10] but such data could not differentiate the specific mafic mineralogies. The Sculptured Hills show a greater diversity of materials than what is exposed in the North Massif (for example), generally supporting the hypothesis that they formed in a different manner possibly tied to the formation of the Imbrium Basin [8].

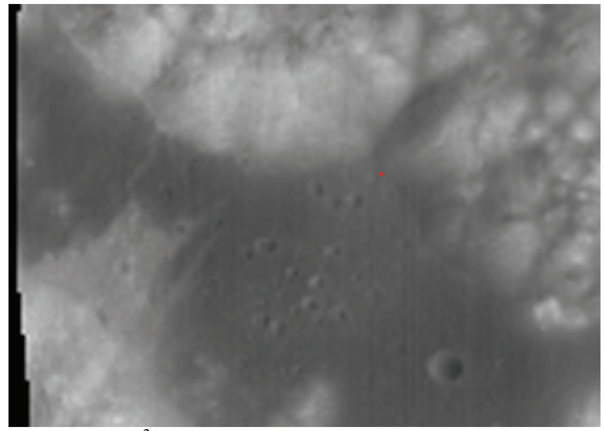

Figure 1. M^3 view of the Apollo 17 landing site at 750 nm (file ID m3g20090203t080104). The location of Station 8 is identified by a small red point.

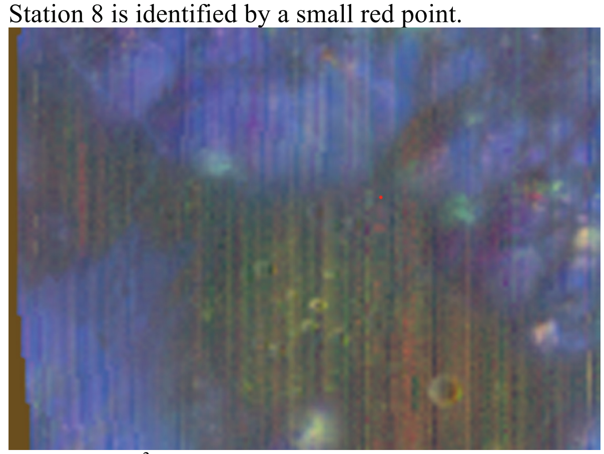

Figure 2. M^3 color composite of the Apollo 17 landing site illustrating the mineralogic diversity of the site. The Sculptured Hills, the eastern portion of the Taurus-Littrow valley, shows a previously unidentified diversity of materials. Small red dot identifies the location of Station 8 (file ID m3g20090203t080104).

Apollo 17 - Station 8 Boulder: Station 8 was located about 20 meters above the Tarus-Littrow valley at the western base of the Sculptured Hills. The boulder was selected as a sample target as it was easily accessible, yet contained no boulder tracks leading to an outcrop of origin [e.g., 12]. Samples of the boulder (Figure 3) are noritic in origin and range in ages from 4.11 to 4.426 Ga. Jackson et al. [13] describe a possible history of the boulder including relevant events leading to its delivery to what would be Station 8. These are "At rest at an unknown location for about 0.75

m.y. with its bottom up, receiving micrometeorite craters on its glass coating. Movement to its discovery site at Station 8, where it rested, with top side up, for an amount of time approximately equal to that at its former site [13].”

Between the remote sensing data and sample composition, it is enticing to suggest that the Station 8 boulder is derived from one of the noritic (green in Figure 2) outcrops in the Sculptured Hills. Additional study of the composition of the Sculptured Hills and the Station 8 boulder samples will aid in determining what, if any, link exists.

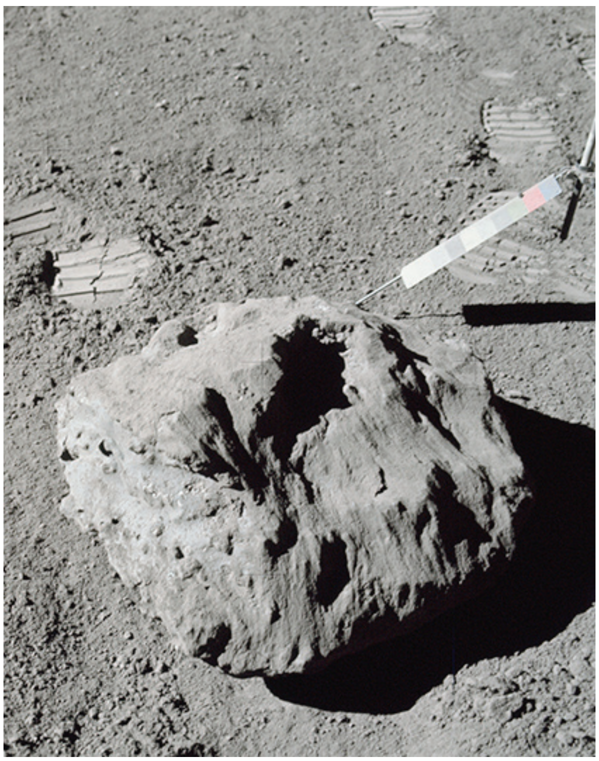

Figure 3. Context image of the Station 8 boulder (AS17-146-22370) after it had been rolled over. Left face of the boulder is the source of samples 78235-6, and 8 [12].

Implications for Future Robotic Exploration of the Moon: If the Station 8 boulder is indeed derived from the Sculptured Hills there are implications for how a robotic explorer on the Moon could sample unique compositions and what instruments would be useful in identifying such samples.

Crater central peaks and walls have long been known to contain a rich diversity of materials [e.g., 3, 4, 14] and boulders from such outcrops are readily identified in high-resolution LROC images. However, the resolution of M^3 data limits the detection of smaller scale outcrops. A rover investigating the base of a peak or crater slope could encounter a number of boulders, if such a rover contained a high-resolution imaging spectrometer it could differentiate unique samples derived from upslope or, in the case of Station 8, nearby.

Conclusions: The combination of remote sensing data (from M^3) and sample composition and location information (from Apollo and LROC) suggest that even for samples that lack details that point to their origin such as a boulder track absent from the Station 8 boulder [12], their origin might be inferred. While additional work is necessary to more confidently identify the origin of the boulder (including detailed spectral measurements of samples of the boulder and compositions inferred from M^3 data), it is clear that any future mission will benefit from the wealth of data from multiple instruments.

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Determining the Magnitude of Neutron and Galactic Cosmic Ray (GCR) Fluxes at the Moon using the Lunar Exploration Neutron Detector (LEND) during the Historic Space-Age Era of High GCR Flux

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Historic Space-Age Era of High Galactic Cosmic Ray Flux: The Lunar Reconnaissance Orbiter (LRO) was launched June 18, 2009 during an historic space-age era of minimum solar activity [1]. The lack of solar sunspot activity signaled a complex set of heliospheric phenomena [2,3,4] that also gave rise to a period of unprecedentedly high Galactic Cosmic Ray (GCR) flux [5]. These events coincided with the primary mission of the Lunar Exploration Neutron Detector (LEND, [6]), onboard LRO in a nominal 50-km circular orbit of the Moon [7].

LEND measures the leakage flux of thermal, epithermal, and fast neutrons [6] that escape from the lunar surface. Neutrons are produced within the top 1-2 meters of the regolith by spallation from the GCR flux. The energy spectrum and flux of the emergent neutron population is highly dependent on the incident flux of the GCR due to its influence on the depth of neutron production and total number of neutron-producing events.

Methods to calculate the emergent neutron albedo population using Monte Carlo techniques [8] rely on an estimate of the GCR flux and spectra calibrated at differing periods of solar activity [9,10,11]. Estimating the actual GCR flux at the Moon during the LEND's initial period of operation requires a correction using a model-dependent heliospheric transport modulation parameter [12] to adjust the GCR flux appropriate to this unique solar cycle. These corrections have inherent uncertainties depending on model details [13]. Precisely determining the absolute neutron and GCR fluxes is especially important in understanding the emergent lunar neutrons measured by LEND and subsequently in estimating the hydrogen/water content in the lunar regolith [6].

Simultaneous measurements of the LEND detectors determine the absolute GCR and neutron flux levels: LEND is constructed with a set of neutron detectors to meet differing purposes [6]. Specifically there are two sets of detector systems that measure the flux of epithermal neutrons: a) the uncollimated Sensor for Epi-Thermal Neutrons (SETN) and b) the Collimated Sensor for Epi-Thermal Neutrons (CSETN).

LEND SETN and CSETN observations form a complementary set of simultaneous measurements that determine the absolute scale of emergent lunar neutron flux in an unambiguous fashion and without the need for correcting to differing solar-cycle conditions. LEND measurements are combined with a detailed understanding of the sources of instrumental background, and the performance of CSETN and SETN. This comparison allows us to calculate a constant scale factor that determines the absolute flux of neutrons at the Moon and then subsequently to deduce the proper scale of the GCR flux model without correction by use of the heliospheric modulation potential for this unique solar cycle minimum.

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Overview of Results from the Lunar Reconnaissance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) Instrument. R. Z. Sagdeev[1], W. V. Boynton[2], G. Chin[3], M. Litvak[4], T. A. Livengood[5], T. P. McClanahan[3], I. G. Mitrofanov[4], and A. B. Sanin[4]. [1]University of Maryland, College Park, MD, [2]Lunar and Planetary Laboratory, Tucson, AZ, [3]NASA/GSFC, Greenbelt, MD, [4]Institute for Space Research, Moscow, Russia, [5]CRESST/UMD/GSFC, Greenbelt, MD.

The Lunar Exploration Neutron Detector (LEND) on the Lunar Reconnaissance Orbiter (LRO) is tasked with evaluating the quantity of hydrogen-bearing species within the uppermost meter of the lunar regolith; investigating the presence and distribution of possible water-ice deposits at the bottom of permanently shadowed regions (PSRs) near the poles; and determining the neutron contribution to total radiation dose at an altitude of 50 km above the Moon [1]. To fulfill these goals, LEND has been mapping the distribution of thermal and epithermal neutron leakage flux since LRO entered the polar mapping orbit at 50 km altitude in September 2009 [2]. In December 2011, LRO moved to an elliptical orbit with 30 km periselene over the south pole to map it in greater detail, with aposelene above the north pole. During the commissioning phase of the mission, July–September 2009, LEND obtained preliminary mapping of hydrogen/water deposits near the lunar south pole which contributed to selecting the site for the successful LCROSS impactor mission [3].

Global maps of neutron leakage flux measured with LEND show regional variations in thermal (energy range < 0.015 eV) and fast neutrons (>0.5 MeV), and yield a global map of epithermal neutron flux [2]. Spatial resolution of the collimated detector has been shown consistent with the design value of 5 km radius for half the detected lunar neutrons, with the remainder spatially diffuse [4]. Statistically significant neutron-suppressed regions (NSRs) are not closely related to PSRs [5]. Outside of the NSRs, hydrogen content increases directly with latitude at both poles. Thermal volatilization of water deposits may be responsible for increasing H concentrations nearer the poles because it is minimized at the low surface temperature of the poles. Significant neutron suppression regions (NSRs) relative to neighboring regions have been found in three large PSRs, Shoemaker and Cabeus in the south and Rozhdestvensky U in the north [6]. Some small PSRs display excess neutron emission in comparison to the sunlit vicinity. On average, PSRs other than these three do not contain significantly more hydrogen than sunlit areas around them at the same latitude.

Correlation between neutron suppression measured by LEND and illumination models for the Moon's polar regions suggests that insolation at the Moon's poles is an important factor in locally modulating hydrogen concentrations [7]. The highest concentrations of hydrogen appear to be found on poleward-facing vs. equivalent equatorward slopes, although some localized high-latitude variations in hydrogen concentration exist that are not explained via insolation.

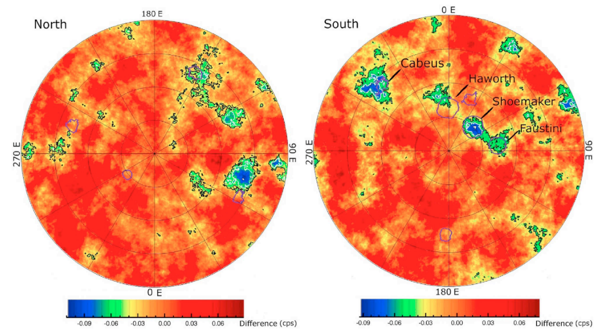

Fig. 1: Count rate differences relative to smoothed region near north and south poles to latitude 82°. The maps are made by subtracting the background and taking differences from the local count rates at the same latitude. Neutron-suppression regions (NSRs) appear in green and blue. Larger PSRs are outlined. Some NSRs are associated with PSRs (Shoemaker and Cabeus), but many are not.

The long duration of the LRO mission and steady nadir-pointing geometry enable investigations of low-amplitude regional-scale neutron suppressions in new investigations. Epithermal neutron flux is slightly suppressed near the dawn terminator at near-equatorial latitude, with least suppression in local lunar mid-afternoon, implying a mobile population of hydrogen-bearing volatiles near the terminator that resides transiently in the regolith [8]. The observed pattern supports hypothesized mineral hydration at the terminator in the form of H_2O/OH.

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LUNAR POLAR IN SITU RESOURCE UTILIZATION (ISRU) AS A STEPPING STONE FOR HUMAN EXPLORATION. Gerald B. Sanders, NASA-Johnson Space Center, 2101 NASA Parkway, Houston, TX,

Introduction: A major emphasis of NASA is to extend and expand human exploration across the solar system. While specific destinations are still being discussed as to what comes first, it is imperative that NASA create new technologies and approaches that make space exploration affordable and sustainable. Critical to achieving affordable and sustainable exploration beyond low Earth orbit (LEO) are the development of technologies and approaches for advanced robotics, power, propulsion, habitats, life support, and especially, space resource utilization systems. Space resources and how to use them, often called In-Situ Resource Utilization (ISRU), can have a tremendous beneficial impact on robotic and human exploration of the Moon, Mars, Phobos, and Near Earth Objects (NEOs), while at the same time helping to solve terrestrial challenges and enabling commercial space activities. The search for lunar resources, demonstration of extraterrestrial mining, and the utilization of resource derived products, especially from polar volatiles, can be a stepping stone for subsequent human exploration missions to other destinations of interest due to the nearness of the Moon, complimentary environments and resources, and the demonstration of critical technologies, processes, and operations.

ISRU and the Moon: There are four main areas of development interest with respect to finding, obtaining, extracting, and using space resources: Prospecting for resources, Production of mission critical consumables like propellants and life support gases, Civil engineering and construction, and Energy production, storage, and transfer. The search for potential resources and the production of mission critical consumables are the primary focus of current NASA technology and system development activities since they provide the greatest initial reduction in mission mass, cost, and risk. Because of the location of the Moon, understanding lunar resources and developing, demonstrating, and implementing lunar ISRU provides a near and early opportunity to perform the following that are applicable to other human exploration mission destinations:

- Identify and characterize resources, how they are distributed, and the material, location and environment in which they are found;
- Demonstrate concepts, technologies, and hardware that can reduce the cost and risk of human exploration beyond Earth orbit;
- Use the Moon for operation experience and mission validation for much longer missions farther from Earth
- Develop and evolve ISRU to support sustained, economical human presence beyond Earth's orbit, including promoting space commercialization

As Table 1 depicts, the Moon provides environments and resources applicable to Mars and NEOs. Two lunar ISRU resource and product pathways that have significant synergism with NEO, Phobos/Demos, and Mars ISRU are oxygen/metal extraction from regolith, and water/volatile extraction from lunar polar materials. To minimize the risk of developing and incorporating ISRU into human missions, a phased implementation plan is recommended that starts with prospecting and demonstrating critical technologies on robotic and human missions, then performing pilot scale operations (in non-mission critical roles) to enhance exploration mission capabilities, leading to full utilization of space resources in mission critical roles. Which lunar ISRU pathway is followed will depend on the results of early resource prospecting/proof-of-concept mission(s), and long-term human exploration plans.

Table 1. Human Destination Characteristics

	Moon	Mars	NEOs
Gravity	1/6 g	3/8 g	Micro-g
Temperature (Max) (Min.) (Min. Shade)	110 °C/230 °F -170 °C/-274 °F -233 °C/-387.4 °F	20 °C/68 °F -140 °C/-220 °F	110 °C/230 °F -170 °C/-274 °F -233 °C/-387.4 °F
Solar Flux	1352 W/m^2	590 W/m^2	Varied based on distance from Sun
Day/Night Cycle	28+ Days - Equator Near Continuous Light or Dark - Poles	24.66 hrs	Varied - hrs
Surface Pressure	1x10^{-12} torr	7.5 torr	1x10^{-12} torr
Atmosphere	No	Yes CO_2, N_2, Ar, O_2	No
Soil	Granular	Granular & clay; low hydration to ice	Varied based on NEO type
Resources	 Regolith (metals, O_2) H_2O/Volatile Icy Soils	Atmosphere (CO_2) Hydrated Soils	 Regolith (metals, O_2) Hydrated Soils H_2O/Volatile Icy Soils

Why the Lunar Poles and Resources?: The poles of the Moon provides an optimal location for sustained surface operations with areas of near permanent sunlight for power and habitats, and permanent shadow for power, science instruments, and resources. The shadowed areas at the lunar poles may contain significant quantities of hydrogen and water as well as other volatiles that may be extremely helpful such as carbon monoxide, ammonia, and light hydrocarbons. With these resources, a wide range of consumables can be produced for propulsion, life support, and power. As with other locations on the Moon, oxygen and metals can also be extracted from the lunar regolith. From these resources, sustained and reusable transportation is possible for lunar surface-to-surface exploration, surface-to-orbit, and even cis-lunar space, as well as increased crew safety for life support and radiation shielding. Ultimately, ISRU propellants, consumables, and metals can enable the commercialization of cis-lunar space.

Determining Whether Operationally Useful Resources Exist at the Poles: While the Lunar Crater Observation and Sensing Satellite showed that hydrogen, water, and other volatiles exist in at least one shadowed crater at the lunar poles, and the Lunar Reconnaissance Orbiter and other scientific spacecraft show that these volatile resources may exist elsewhere, it is still necessary to determine whether the volatile resources at the poles are 'operationally useful'. Whether a resource is operationally useful is a function of its location and how economical it is to extract and use.

With respect to the location, the resource must be assessable, it must be within a reasonable distance of the mining infrastructure (including power, logistics, processing, etc.), and it must be within reasonable distance of transportation capabilities to ensure the product can reach the necessary 'markets'. For lunar polar volatiles, there are five main site selection criteria: 1) presence of surface/subsurface volatiles (neutron spectrometer, radar, optical), 2) traversable terrain, 3) limited solar illumination/subsurface temperature <100 K, traversable terrain, 4) direct to Earth communication, and 5) hospitable environment nearby for outposts and infrastructure.

For the resource extraction and processing to be economical, the concentration and distribution of the resource and associated processing technique must allow for a return on investment (ROI) for mass, cost, time, and/or mission and crew safety. This is highly dependent on what product is needed, how much is needed, how often it is needed, and what is required to extract the resource. During NASA's Constellation Program, a production need of 1000 kg of oxygen per year was desired to eliminate life support consumable delivery needs from Earth for a crew of 4 to 6. Performing simple first-order rocket equation propellant needs for a reusable lunar lander from the lunar surface to an Earth-Moon L_1/L_2 Lagrange point, somewhere between 3000 kg of oxygen to 30,000 kg of oxygen and hydrogen are required per mission depending on whether a depot at L_1/L_2 containing propellants from Earth are used for some of the mission phases. Laboratory tests to date have shown that infrastructure for oxygen extraction from regolith can provide mass and cost ROI for these production needs in less than 3 years.

To determine whether polar volatile resources are operationally useful, a three phase approach of Exploratory Assessment, Focused Assessment, and Mining Feasibility is recommended. The Exploratory Assessment is potentially a short duration mission to evaluate the physical and mineral characteristics of polar regolith, determine the distribution of polar volatiles down to 1 to 2 meters and spatial distribution to 1 to 3 km, validate site selection methods, and validate the design and operation of the hardware. NASA's Resource Prospector Mission (RPM) and Russia's Luna 27 mission which are both tentatively scheduled for 2017/2018 will perform this type of resource assessment. If the site looks promising, a Focused Assessment, possibly nuclear powered to allow for sustained operations in the shadowed region, should be pursued to fully assess the distribution of polar resources as well as determine the economics of extracting them. Finally, a mining feasibility mission (either demonstration or pilot scale) should be flown to validate mining and resource extraction and collection techniques for a sustained period of time.

Lunar Polar ISRU as a Stepping Stone for Human Exploration: Using NASA's Resource Prospector and Asteroid Retrieval concept missions as potential starting points, a notional evolutionary mission sequence can be constructed to guide in the selection and development of common technologies and systems that will minimize the cost and risk for development and utilization of space resources for multiple human exploration destinations. The International Space Station can also be utilized to begin the examination of micro-gravity effects on regolith collection, transport, and processing. Should NASA and other space agencies proceed from the initial lunar polar volatile Exploratory Assessment phase with RPM and Luna 27 to more Focused Assessments and Mining Feasibility, the ISRU and mission capabilities evolved and developed for these missions can serve as the basis for enabling other missions to NEA's, Phobos, and Mars.

Acknowledgement: Understanding of terrestrial prospecting and mining approaches were obtained from several presentations by Dale Boucher (NORCAT) and John Chapman. Definition of operationally useful resources has benefitted from discussions at the Keck Institute of Space Studies (KISS) study on New Approaches to Lunar Ice Detection and Mapping.

DOSE SPECTRA FROM ENERGETIC PARTICLES AND NEUTRONS (DoSEN).

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Abstract. DoSEN is an early-stage space technology research project that combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. Linear energy transfer (or LET) is the mean energy absorbed locally, per unit path length, when a charged particle traverses material. An LET spectrometer measures the amount of energy deposited in a detector of some known thickness and material property as a high-energy particle passes through it, usually without stopping. For LET measurements, DoSEN contains stacks of thin-thick Si detectors similar in design to those used for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). CRaTER is the first instrument of its kind to provide the needed ground truth measurements of LET spectra that provide the direct and critically-needed link between biological effectiveness to the radiation environment. With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically-based quality factors provide not only doses and dose-rates, but also dose-equivalents, associated rates and even organ doses. DoSEN also measures neutrons from 10-100 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce. The penetrating nature of the neutrons is offset by their intensity and sufficiently long exposure times, thus the constraining envelope dimension is the range of the recoil particles—typically protons in hydrogenous material. Because it is prohibitive to make a detector large enough to absorb the full energy of each neutron, the response of the instrument is broad, but still the task of measuring the spectrum and intensity in the featureless neutron spectrum is straightforward. Such technology has been in use for decades, but adapting it to the smallest, most efficient and lowest mass envelope is challenging. DoSEN develops the new concept of combining these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. Thus, we introduce the instrument concept and present first lab measurments from DoSEN, a promising low mass device that detects the full spectrum of energetic particles, heavy ions and neutrons to determine biological impact of radiation in space.

DoSEN is an Innovation for LET and Neutron Coincidence (Fig. 1) to provide complete characterization of radiation biological effectiveness in a small and light-weight device. Such a device must be capable of measurement of LET spectra and neutrons. We de-

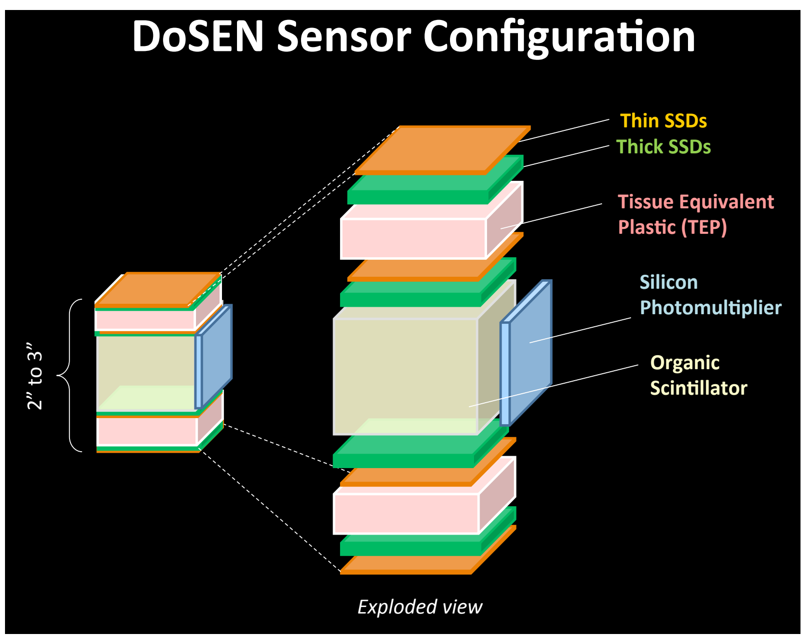

Figure 1. *The DoSEN sensor configuration includes a combination of Solid State Detectors (SSDs), organic scintillator with PSD and Si photomulitipliers (SiPMs) allowing coincident detection of energetic particle LET and neutrons. The unique coincidence offered by LET & neutron detection promises a significant advance for a new generation of dosimetry measurements.*

scribe here a new concept of ***combining*** these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. The use of coincidence techniques has a long history in space physics. Often, the use of such techniques results in transformational shifts in research. For example, the use of triple coincidence in spectrometry led to measurements of ion composition within plasmas [e.g., 1] and on the Interstellar Boundary Explorer Mission [2] triple coincidence techniques are used to pick out a very weak signal of neutral atoms from many competing backgrounds [e.g., 3]. Without such coincidence measurements many of the *in situ* discoveries over the last two decades in space science would not have been possible. The CRaTER instrument itself combines a stack of six solid-state detectors (SSDs) with three sets of thin and thick SSDs separated by Tissue Equivalent Plastic [TEP; 4]. Coincidence provides not only suppression of backgrounds, but also separation between energetic particle sources from beyond the Moon and albedo sources from the Moon itself [5].

A similar transformational advance is provided by the DoSEN concept in which coincidence is achieved by combining a CRaTER-like LET measurements via a stack of four SSDs with neutron measurements using an organic scintillator with pulse-shape discrimination (PSD) coupled to Si Photomultipliers (SiPMs). The SiPM (also known as the solid-state photo-multiplier or the multi-pixel photon counter) operates like a Photomultiplier Tube (PMT); however with at least an order of magnitude less mass and volume. The SiPM is compact and low mass, and will eventually allow the SSDs to go on all six sides of the detector for full 3-D detection of sources. A SiPM is a novel photo-detector originally developed in Russia for high-energy physics applications [6-8]. It consists of a two-dimensional array of small cells, typically ~50 μm is size, each of which acts as an independent avalanche photo-diode. These cells are reversed-biased slightly above their breakdown voltage so that they operate in "limited Geiger mode:" when a photon is absorbed, an avalanche is quickly generated which produces a large signal independent of the number of photons that was absorbed. A resistor in series with the cell quenches the avalanche after several tens of ns. The outputs of all the cells are summed together into an analog sum so that the intensity of the incident light is proportional to the number of cells that absorb photons.

The advantages of the SiPM include high gain ($\sim 10^6$) at low operating voltages (typically 20-70 V), compactness, insensitivity to magnetic fields, fast timing response (rise times less than 1 ns), and the potential for low cost through mass production runs. SiPMs have by now been shown by many groups to perform well as readout devices for scintillators [e.g., 9-12].

In addition to introducing the DoSEN instrument, we show recent results from laboratory measurments including sensor calibration and gamma-ray coincidence measurements.

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RELATIVE CONTRIBUTIONS OF GALACTIC COSMIC RAYS AND LUNAR PARTICLE ALBEDO TO RADIATION DOSE AND DOSE RATES NEAR THE MOON. H. E. Spence[1], C. Joyce[1], M. D. Looper[2], N. A. Schwadron[1], S. S. Smith[1], L. W. Townsend[3], and J. K. Wilson[1], [1]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824, USA., [2] The Aerospace Corporation, El Segundo, CA 90009, USA., [3] Department of Nuclear Engineering, University of Tennessee, Knoxville, TN 37996, USA.

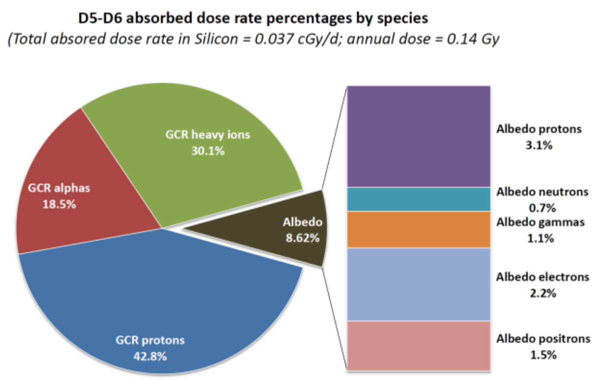
Introduction: The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) [1] has been immersed in the ionizing radiation environment near the Moon since its launch on NASA's Lunar Reconnaissance Orbiter (LRO) [2] and insertion into lunar orbit in June 2009. CRaTER measurements yield robust estimates of the linear energy transfer (LET) [3] of extremely energetic particles traversing the instrument, a quantity that describes the rate at which particles lose kinetic energy as they pass through and interact with matter. The resultant ionizing radiation of these interactions poses a radiation risk for human and robotic space explorers subjected to deep space energetic particles [4].

Methodology: CRaTER employs strategically placed solid-state detectors and tissue equivalent plastic (TEP), a synthetic analog for human tissue, to quantify radiation and shielding effects [5] pertinent to astronaut safety. Though designed to measure galactic cosmic rays (GCR) and solar energetic protons [6] coming from zenith and deep space, CRaTER observations have been used also to discover an energetic proton "albedo", caused by a process known as nuclear evaporation coming from the lunar surface [7]. We use validated radiation transport models of the CRaTER instrument and its response to both primary GCR and secondary radiation [8], including lunar protons released through nuclear evaporation, to estimate [9] their relative contributions to total dose rate in silicon (0.037 cGy/day) and equivalent dose rate in water (0.071 cSv/day).

Results: In the figure to the right, taken from [9], we show that near the Moon the GCR accounts for ~91.4% of the total absorbed dose, with GCR protons accounting for ~42.8%, GCR alpha particles ~18.5%, and GCR heavy ions ~30.1%. The remaining ~8.6% of the dose at LRO altitudes (~50 km) arises from secondary lunar species, primarily "albedo" protons (3.1%) and electrons (2.2%). Other lunar nuclear evaporation species contributing to the dose rate are positrons (1.5%), gammas (1.1%), and neutrons (0.7%).

Relative contributions of these same species to the total effective dose rate in water, a quantity of more direct biological relevance, favor those with comparatively high weighting factors, including neutrons. Consequently, the primary GCR components are collectively higher (~96.5% of the total) with the GCR heavy ions alone contributing 62%, and the albedo neutrons jumping to over 3%. In recognition of the biological importance of the neutron dose, not just in lunar orbit but even more so at the lunar surface, a new exploration-motivated instrument, Dose Spectra from Energetic particles and Neutrons (DoSEN) is presently under development. DoSEN leverages the considerable flight heritage of the CRaTER design but with a novel, compact neutron detection capability [10].

Finally, we note that when considering the lunar radiation environment, although the Moon blocks approximately half the sky, thus essentially halving the dose rate near the Moon relative to deep space, the secondary radiation created by the presence of the Moon adds back a small, but measurable amount (~4-8%) that can and should now be accounted for quantitatively in radiation risk assessments at the Moon and other exploration targets.



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INTREPID: LUNAR ROVING PROSPECTOR PROVIDING KEY GROUND TRUTH MEASUREMENTS AND ENABLING FUTURE EXPLORATION. E. J. Speyerer[1], M. S. Robinson[1], S. J. Lawrence[1], J. D. Stopar[1], School of Earth and Space Exploration, Arizona State University, Tempe, AZ (espeyerer@asu.edu).

Introduction: As described in the Decadal Survey and the Lunar Exploration Roadmap [1,2], the science and exploration communities require critical ground truth measurements to tie orbital remote sensing datasets to physical characteristics on the lunar surface. Given the breadth and diversity of lunar geology, such measurements can best be made from moving platforms (i.e., rovers). We propose a Lunar Roving Prospector, *Intrepid*, to collect essential measurements to address key scientific questions, obtain exploration-enabling datasets for future human activities, and demonstrate technology required for future exploration of the Moon and other terrestrial bodies.

Mission Concept: The *Intrepid* rover concept is devised to be highly mobile, with a baseline traverse of 1000 km over a two-year nominal mission. This long-range rover enables measurement collection and provides ground truth for remotely sensed data products over a wide range of geologic terrains (i.e., mare and highlands). To enable the long traverses, the onboard instrument suite will acquire a majority of the measurements while in motion or during short pauses. This concept is in stark comparison to the rovers studying Mars, which stop frequently for long periods to gather measurements. While this architecture limits time intensive studies of a particular site, the coverage gained by a highly mobile platform will increase the scientific return over wide diversity of geologic materials. An advanced sliding autonomous navigation system will enable the rover to traverse with little interaction from human drivers thus reducing cost of operations, while increasing efficiency. However, humans monitoring the progress of the rover will be able to intervene when sites of opportunity appear in the live feed.

Objectives: The *Intrepid* prospector is capable of investigating twenty major, and hundreds of minor sites over its 1000 km traverse. This mobility enables *Intrepid* to collect key scientific measurements and essential data for future human missions, including the ability to:

- Provide ground truth for major terrain types measured by orbital datasets
- Inventory rock type diversity, characterize the impact process, improve the understanding of lunar volcanism, determine volatile abundance and distribution
- Detect, assay, and map potential resources (identifying and quantifying ISRU potential)
- Investigate the nature of regolith structure, including mechanical properties
- Quantify the nature of dust, its environments, and its interactions with systems/humans, and demonstrate dust mitigation strategies and technologies
- Measure radiation (primary and secondary) hazards to future human explorers
- Demonstrate precision landing, autonomous navigation, teleoperations, dust mitigation, sampling, and long-duration operations
- Sample cache

Traverse Options: The architecture of the *Intrepid* prospector enables it to be flexible and handle many lunar traverse plans. One example traverse (**Fig 1**) initiates in southern Oceanus Procellarum and characterizes several high priority exploration targets identified by [3,4], including four Constellation (Cx) Regions of Interest (Reiner Gamma, Marius Hills, Aristarchus 1 and 2). At the landing site, *Intrepid* will characterize the mineralogy and the chemistry of the mare basalt units in southern Oceanus Procellarum as well as the depth and structure of the regolith. *Intrepid* will then travel northward to the Reiner Gamma albedo anomaly where it will investigate the magnetic anomaly, geochemistry and surface properties (soil maturity). The traverse continues through the Marius Hills volcanic vent complex where it then investigates the diversity of volcanic emplacement and characterizes compositional variations and resource potential. Continuing along the northward traverse, *Intrepid* travels through, and scouts out young mare basalt samples south of Aristarchus. The *Intrepid* traverse concludes with an in-depth exploration of the varied Aristarchus plateau where it will assay resources, determine the composition and nature of the dark mantle, and investigate the composition of Aristarchus crater materials. This traverse includes diverse lithologies, albedo, color, magnetic anomalies, as well as a full range of lunar volcanic types and ages thus providing critical data for further scientific study.

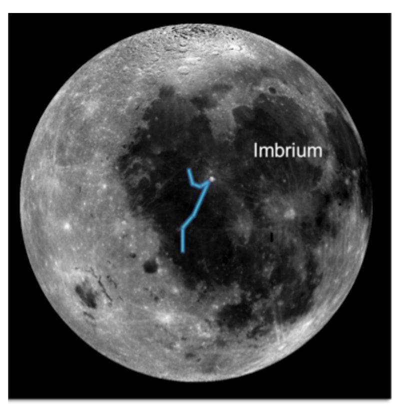

Fig 1-Proposed Oceanus Procellarum traverse includes a variety of geologic materials and four Cx sites.

Notional Instrument Suite: The proposed emphasis on mobility of the *Intrepid* prospector makes short integration time stand-off measurements a critical concept for operations. To maximize the effectiveness of the mission, *Intrepid* will use a high-resolution telephoto reconnaissance imaging system called FARCAM [5]. FARCAM (**Fig 2)** is an adaptation of the 100 mm focal length MSL Mastcam (M-100) instrument modified to meet lunar requirements. The design of FARCAM enables the acquisition of images with a pixel scale of 5 cm from 1 km or 1 m at 20 km. The M-100 on MSL can capture 7.4 cm pixels from 1 km. The increased spatial resolution on FARCAM is achieved by reducing the pixel pitch (5.5 µm vs. Mastcam's 7.4 µm) and slightly increasing the focal length (110 mm vs. Mastcam's 100 mm). The benefits of such a capability on *Intrepid* are threefold:

- En-route reconnaissance of sampling stations
- Rapid remote analysis of distant materials (widening *Intrepid's* footprint along its traverse)
- En-route navigation enabling hazard analysis and determination

In addition to FARCAM, the baseline instrument suite consists of a multispectral stereo imaging system, a Raman spectrometer, an APXS for major element chemistry determinations, a magnetometer, and a radiation environment sensor.

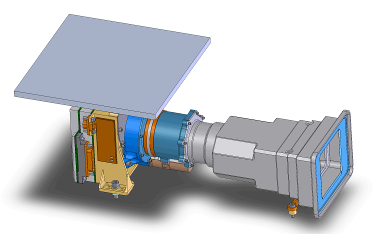

Fig 2-A schematic of the proposed FARCAM with radiator configuration.

Leveraging Existing Remote Datasets: In the past two decades, orbital satellites have collected datasets essential for planning future missions to the Moon. One of the main objectives of Lunar Reconnaissance Orbiter (LRO) is to provide datasets to enable future ground-based exploration activities. Research is currently underway to define optimal landing sites, identify traverses, and synthesize a concept of operations for teleoperated spacecraft [6-8]. This study leverages high-resolution and synoptic images provided by Lunar Reconnaissance Orbiter Camera (LROC) as well as datasets provided by other instruments onboard LRO and other satellites (Clementine, Lunar Prospector, Chandrayaan, etc.). Additionally, viewshed analyses for high priority landing sites have been used to determine the best places for broad scale line of site coverage [9]. Such analysis will enhance the use of FARCAM and other long range standoff instruments.

Filling Strategic Knowledge Gaps (SKGs): To implement safe, effective, and efficient human missions to the Moon, gaps in our knowledge of the Moon's surface properties must be addressed. LRO and other recent missions such as Kaguya, Chang'e, Chandrayaan, LCROSS, and GRAIL have answered many key concerns such as characterizing the lighting environment near the lunar poles [10-12]. However, many of the SKGs that remain can only be addressed with assets on the lunar surface. The mobile platform that *Intrepid* provides will enable this single mission to answer a broad range of SKGs, including:

- Quality, quantity, distribution, and form of H species and other volatiles in mare/highlands regolith
- Composition, volume, distribution, and form of pyroclastic/dark mantle deposits and characteristics of associated volatiles
- Resource identification and characterization procedures and technologies to improve ISRU production efficiency
- Monitor the radiation environment at lunar surface
- Improve lunar geodetic control with laser ranging
- Collect high resolution topographic data
- Acquire in-situ measurements to determine lunar surface trafficability
- Test performance of lunar dust mitigation procedures and provide real-time environmental information relevant to daily lunar operations
- Determining near-surface electrical environment and plasma characteristics in multiple localities
- Test micrometeorite protection technologies

Conclusions: Rovers offer many operational advantages over static landers, which lack the capability to perform investigations beyond a limited distance from the original landing site. *Intrepid* offers the flexibility and the capability to perform wide-scale investigations that characterize the composition and properties of the lunar regolith over hundreds of square kilometers to address key science and exploration objectives. Such a broad scale collection of critical ground truth measurements will aid the interpretation of orbital remote sensing datasets, thus strengthening our knowledge of the Moon's past and present state.

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Moon Express: Lander Capabilities and Initial Payload and Mission. P.D. Spudis, Lunar and Planetary Institute, Houston TX 77058 (spudis@lpi.usra.edu), R. Richards, Moon Express Inc., Moffett Field CA, J.A. Burns, Univ. Colorado, Boulder CO

Moon Express Inc. is developing a common lander design to support the commercial delivery of a wide variety of possible payloads to the lunar surface. Although one of the Google X-Prize contestants, the company is committed to developing a commercial market for delivery of payloads to the lunar surface. Significant recent progress has been made on lander design and configuration. In addition, we have developed a straw man mission concept designed to return significant new scientific and resource utilization data from the first mission. Here we describe the lander concept and a scenario for a low-mass payload and mission scenario.

Spacecraft. The ME lander is derived from designs tested at NASA Ames Research Center over the past decade. It is designed to deliver payload to the lunar surface, with no global restrictions on landing site. The lander can carry an upper stage designed for missions that require Earth-return, such as sample retrieval. The upper stage utilizes a unique toroidal design and can return surface samples back to Earth. The ME lander is powered by a specially designed engine capable of being operated in either monoprop or biprop mode.

First Mission. We have recently examined an initial mission designed to use the ascent stage of the ME lander design as a separate spacecraft to land a limited payload on the Moon. This small payload would be optimized to answer some specific and carefully posed scientific and operational questions. Flying this mission would validate the ascent stage design while at the same time, obtain useful science data relevant to future exploration. As currently envisioned, this mission would also satisfy the requirements of the Google X-Prize competition.

Landing Site Rationale. The mission concept involves a visit to a regional pyroclastic deposit on the lunar near side [1,2]. We know from study of the Apollo samples that solar wind hydrogen is implanted onto the dust grains of the lunar regolith. Moreover, the concentration of this solar wind hydrogen appears to be dependent upon both grain size (smaller grain size fractions being more enriched) and titanium content (higher Ti regolith showing higher H concentrations). Mature, high-Ti regional dark mantle deposits in theory should show the highest concentrations of implanted solar wind hydrogen as they are uniformly small grains (mean size of the glass spheres ~ 50 microns or less) and the black, devitrified glasses have microscopic blades of crystallized ilmenite (the presumed carrier of implanted hydrogen) at their surfaces [1]. Thus, based on current understanding, regional dark mantle deposits should have enhanced amounts of solar wind hydrogen, in some cases approaching several hundred parts per million (typical H abundance in returned regolith is on the order of 20-50 ppm). Mature, regional dark mantle has never been sampled, so these relations are postulated and not certain. A mission to measure the hydrogen concentration of these deposits will help to resolve this issue.

Several possible landing sites for the ME lander are found on the near side of the Moon. We have focused on the Rima Bode dark mantle deposits (east of crater Copernicus, around 13° N, 4° W). These deposits are mature [2], having been exposed to solar wind implantation for at least 3 billion years and have high Ti content; smooth areas near the vent suggest that the ash beds are several tens of meters thick. The dark mantle extends over several hundred square kilometers, requiring low precision for landing point designation. The fine-grained nature of the deposit (which also shows very low diffuse radar backscatter; [2]) indicates that the surface is poor in decimeter-scale rocks and obstacles, thus ensuring a relatively safe landing area over a wide region.

Payloads for Lunar Geoscience and Conops. Our projected payload includes three instruments. An imaging system will document the geological setting of the landing area. Two instruments for compositional analysis are under consideration. An APX instrument (heritage: Mars landers [3]) will provide major element composition of the regolith; we are particularly interested in the surface Ti content, to help calibrate and better understand the remote sensing data from which we infer Ti composition. In addition, we plan to fly a neutron spectrometer [4] (heritage: the RESOLVE lunar prospecting package [5]) to measure the bulk hydrogen composition of the regolith at the landing site. These two parameters are critical to our understanding of solar wind abundance in the lunar regolith and selection of the Rima Bode site assures that we will have documented its occurrence in the end member regolith assumed to retain the most hydrogen of known mid- and low latitude sites.

Measurements of the surface composition would commence immediately upon landing. APX chemical analysis and neutron measurements would be completed with an hour or so. If any propellant remains after landing and a "hop" to another site could be undertaken, we can repeat these analyses at the second site, adding to our confidence that we have obtained representative measurements. Thus, the scientific goals of the first ME mission are satisfied early and easily in the mission profile.

This mission scenario provides significant scientific accomplishment for very little investment in payload or operational time. Although minimally configured, the payload has been chosen to provide the most critical parameters for mapping hydrogen across the entire lunar surface. As hydrogen is a key element to the development of the Moon, understanding its occurrences in both non-polar and polar environments is critical. This mission takes the first step towards lunar presence and permanence.

Lunar Laser Retroreflector. An additional instrument under consideration for the first or second flights of ME is a next generation lunar laser retroreflector. The new design includes a single corner cube, a sunshade, and dust protector to increase efficiency and reduce effects produced by solar heating of dust which settles on the retroreflector. An added retroreflector(s) will markedly improve measurements of lunar librations and, therefore, improve constraints on both the liquid and potential solid inner cores. Also, additional retroreflectors will be helpful in constraining models of gravitational including deviations from General Relativity.

References [1] Heiken G. et al. (1991) *The Lunar Sourcebook*, Cambridge Univ. Press, 971 pp. [2] Gaddis L. et al. (1985) *Icarus* **61**, 461. [3] Campbell et al. (2009) *JGR* **114**, E04006. [4] Elphic R. et al. (2010) *Earth and Space 2010*, 1119. [5] Sanders G. and Larsen W. (2010) *COSPAR* 2010, http://tinyurl.com/kykyrr8

ASSESSMENT OF FUNDAMENTALLY DIFFERENT LUNAR TERRAINS FOR FUTURE LONG-DURATION SURFACE EXPLORATION. J. D. Stopar[1], S. J. Lawrence[1], M. S. Robinson[1], E. J. Speyerer[1], and B. L. Jolliff[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287. [2]Department of Earth and Planetary Sciences, Washington University in St. Louis, MO, 63130.

Introduction: Data from the Lunar Reconnaissance Orbiter (LRO) mission have unquestionably contributed to recent scientific advancements; however, the application of LRO data is, as of yet, underutilized in support of the mission's original primary purpose: enabling future exploration and site assessment activities. Therefore, as part of a larger effort, Lawrence et al. [this vol] identified 15 high-priority sites for characterization to address key lunar science and exploration goals that primarily focus on volcanic and polar processes and complement similar recent analyses [1-4]. The goals of the Lawrence et al. study are to define optimal landing sites for future robotic missions, provide meter-scale traverses and site assessments for future exploration planning, and synthesize concepts of operations to inform future hardware decisions.

While there are many potential surface exploration scenarios ranging from static landers, limited-duration rovers, and long-duration rovers, Robinson et al. [5] proposed that a long-duration lunar prospecting rover might provide a wide-ranging mission that could investigate high priority nearside targets, for example. This mission scenario would exceed past and current missions (Lunokhod; MERs; Curiosity) in design for distance and rate of travel. Such a mission, however, will encounter a variety of terrains and be tasked with numerous science objectives. In order to define notional hardware requirements for such a mission, parameters including wheel traction, power, component lifetimes, and temperature survivability must be rigorously defined. Therefore, we have characterized the topography and illumination conditions of several key representative landforms including impact craters, volcanic constructs, and plains units in order to determine how mission objective will affect the design of the surface explorer platform (i.e., rover). Key questions include: Can the most engaging locations in a particular terrain be easily accessed? How far apart are crucial study areas? Are surfaces navigable and what are the meter-scale hazards? What are the illumination considerations over time?

Methods and Results: LROC NAC map-projected and mosaicked images allow evaluation of meter-scale hazards [6]. Where available, NAC images of each location collected under a variety of illumination geometries allow characterization of surface materials and illumination considerations (including persistence of shadows) [e.g., 3]. PDS-archived NAC-derived Digital Terrain Models (DTMs) allow determination of local slopes and surface roughness over a range of scales from meter to decameter as well as potentially impassable topographic obstacles. Roughness was defined for the purposes of this study as the average standard deviation in slope (°) over a 30-m length scale. Identification of key science waypoints in each terrain type was carried out using a variety of geologic datasets (Clementine UVVIS, LRO Diviner, LRO LROC), and each point was geospatially tagged using ArcMap in order to compute first-order distances between each waypoint (**Fig.1**). Calculated slopes (mean and maximum) likely encountered, maximum 30-m length scale roughness, potential hazards, and travel distances between key waypoints are presented in **Table 1** for 14 sites that represent plains units, impact craters, and volcanic terrains.

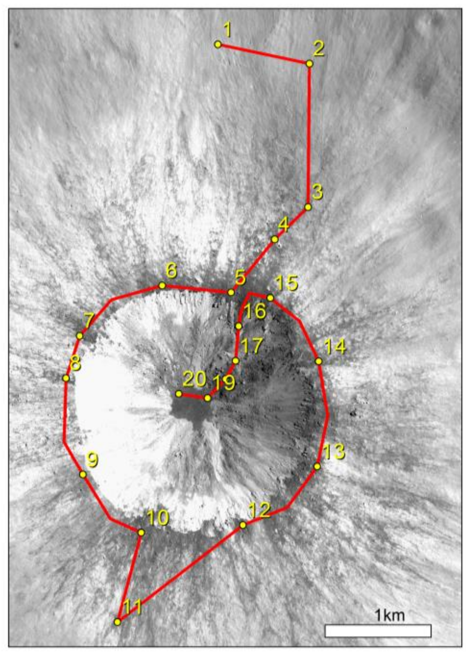

Figure 1. Example of waypoints selected for a 2.5-km Copernican crater to assess the composition and diversity of impact melt. Descent into crater requires traverse of 30° slopes.

Discussion and Summary: The results presented here represent an initial phase of site assessment and path planning and evaluation processes. Results will continue to be improved and refined through integration with trafficability metrics including a least-energy algorithm that will include the topographic parameters investigated here (slope, roughness, hazards, and illumination) [7]. Topography and objective definition play prominent roles in mission design. For example, minimum travel distances, minimum mission duration, wheel slip tolerance, and maximum approach and departure angles are fundamental for defining hardware as well as instrument-suite selection.

In general, exploration of impact craters, particularly fresh ones, may best be accomplished from a rover platform by sampling ejected materials scattered near the crater; however, this strategy would preclude exploration of any subsurface voids in impact melt on the crater floor [e.g., 8]. The interiors of fresh craters can also have extensive shadows during significant periods of time. While older craters generally have easier egress paths and reduced shadow effects, the identification of geologic units and materials can be difficult owing to extensive degradation.

Typical lunar mare domes (e.g., Hortensius) have flank slopes of a few degrees with few meter-scale hazards. However, in-situ outcrops are more common in association with more irregular domes (e.g., Marius Hills), but navigation of steep slopes and irregular topography may require more aggressive rover hardware at these sites when “rolled boulders” do not provide adequate samples from higher topographic units.

Plains units such as regional pyroclastic deposits, mare plains, and other smooth plains units have gentle slopes and few topographic obstacles; however, due to large (apparently) homogeneous areas, travel distances between waypoints may be greater. Excavated blocks can potentially provide subsurface samples from the panoply of geologic materials located beneath a relatively thin plains unit; these blocks are generally derived from small recent impact craters, including secondaries from relatively recent cratering events [e.g., 9-10].

Owing to the various hazards, slopes, and surface materials likely faced by a long-lived roving exploration platform crossing different terrain types, including volcanic edifices and fresh impact craters, prior delineation of mission objectives is critical for definition of minimum hardware requirements.

Acknowledgements: The authors gratefully acknowledge the efforts of the LRO and LROC teams.

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TABLE 1. PRELIMINARY RESULTS OF ACCESSIBILITY, NAVIGATABILITY AND HAZARD ANALYSIS FOR DIFFERENT TERRAINS

SITE	DEM RES (MPP)	NOMINAL SCIENCE GOAL	PRIMARY TARGET/FEATURE	AVG SLOPE (°)	MAX SLOPE (°)	MAX 30-m "ROUGHNESS" (°)	POTENTIAL HAZARDS	TRAVEL DISTANCES (KM) BTWN KEY WAYPOINTS
Plains								
Bhabha Plain	2	Composition and Origin of Non-mare Smooth Plain	Small crater ejecta	4	11	4	Minimal	5-15
Sulpicius Gallus FM	2	Composition and Origin of Pyroclastics	Pyroclastic deposits, vent structure	6	11	4	Descent into "vent" includes slopes >20°	1-10
Reiner Gamma	2	Composition and Origin of Albedo Anomaly (Swirl)	Regolith, small crater ejecta	4	6	2	Minimal	1-5
Imbrium Flows	5	Structure and Composition of Mare Flow Fronts	Flow surfaces	2	9	2	Minimal	2-10
Craters								
Fresh 2.5-km Impact Crater Near Denning	2	Composition and Distribution of Impact Melt	Impact Melt Deposits	6	13 (rim); 30 (wall)	4 (rim); 13 (wall)	Large dm-scale blocks near rim; 30° slope descending into crater; steep slopes near rim	0.5
Linne	2	Impact Mechanisms and Ejecta Distribution	Ejecta, Boulders	4 (ejecta); 14 (rim)	10 (ejecta); 35 (wall)	4 (ejecta); 7 (rim)	Some large dm-scale blocks near rim; >30° slopes descending into crater	0.1-1
Giordano Bruno	2	Age and Composition of Extremely Young Impact Crater	Ejecta, Impact Melt Deposits	4 (melt); 9 (rim)	20 (rim); 35 (wall)	6 (rim); 13 (boulder fields)	Areas along rim with dense boulder populations	0.1-3
"North Crater"	6	High Latitude Crater Materials	Crater Walls and Floor	27 (wall)	30 (wall)	5 (wall)	Polar illumination; slopes ~30° inside crater	0.5-1
Volcanic Constructs								
Hortensius	2	Composition of Lunar "Mare" Dome	Volcanic Domes and Vents	5 (flank)	9 (flank); 30 (vent)	3 (flank)	Up to 30° slopes descending into "vents"	0.5-10
Isis and Osiris	5	Composition of Lunar Cones	Volcanic Cones	5	23	4	>20° slopes ascending cones	0.1-5
Marius Hills	2	Composition and Structure of Complex Lunar Volcanism	Volcanic Domes, Cones, and Vents (Including Rilles)	5	20	3	Minimal	0.1-5
Sosigenes Rille	2	Composition and Age of "Ina-Style" Volcanism	Volcanic Deposits and Rille Structure	4	13	3	Ascent from rille floor includes slopes up to 30°	0.1-0.5
Gruithuisen Domes	2	Composition and Age of Silicic Volcanism	Volcanic Domes	9	20	5	Minimal	1-10
Mairan T	2	Composition and Age of Silicic Volcanism	Volcanic Dome (rolled blocks)	5 (base); 30 (flank)	3 (base); 40 (flank)	6 (flank)	>30° slopes ascending dome	0.5

Characterization of emergent leakage neutrons from multiple layers of hydrogen/water in the lunar regolith by Monte Carlo simulation

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Introduction: The leakage lunar neutrons produced by precipitation of galactic cosmic ray (GCR) particles in the upper layer of lunar regolith and measured by Lunar Exploration Neutron Detector (LEND is investigated by Monte Carlo simulations. Previous Monte Carlo (MC) simulations have been used to investigate neutron production and leakage from lunar surface in order to assess the elemental composition of lunar soil [1-6] and their effect on the leakage neutron flux.

In this investigation, we use Geant4[7] to calculate neutron production by spallation process of GCR particles [8,9] in the top lunar soil. Multiple layers of differing hydrogen/water at different depths in the lunar regolith model are introduced to examine enhancement or suppression of leakage neutron flux. We find that the majority of leakage thermal and epithermal neutrons are produced in 25 cm to 75 cm deep from the lunar surface. Neutrons produced in top shallow layer escape from lunar surface mostly as fast neutron. This provides a diagnostic tool in interpreting leakage neutron flux enhancement or suppression due to hydrogen concentration distribution in lunar regolith. We also find that the emitting angular distribution of thermal and epithermal leakage neutrons can be described by $\cos^{3/2}(\theta)$ where the fast neutrons emitting angular distribution is $\cos(\theta)$.

Reference: [1] [1] W. C. Feldman, et al., Science 4 September 1998: Vol. 281 no. 5382 pp. 1496-1500. [2] Gasnault, O., et al., (2000) J. Geophys. Res., 105(E2), 4263–4271. [3] Little, R. C., et al. (2003), J. Geophys. Res., 108(E5), 5046. [4] McKinney et al., (2006), J. Geophys. Res., 111, E06004. [5] Lawrence et al., (2006), J. Geophys. Res., 111, E08001. [6] Looper et al, (2013), Space Weather, VOL. 11, 142–152. [7] J. Allison, et al, (2006) IEEE TRANS. ON NUCL SCI, VOL. 53, NO. 1. [8] J. Masarik and R. Reedy (1996), J. Geophys. Res., 101, 18,891–18,912. [9] P. O'Neil (2010) IEEE Trans. Nucl. Sci., 57(6), 3148-3153.

DETECTING LOW-CONTRAST FEATURES IN THE COSMIC RAY ALBEDO PROTON YIELD MAP OF THE MOON. J. K. Wilson[1], H. E. Spence[1], N. Schwadron[1], M. J. Golightly[1], A. W. Case[2,7], J. B. Blake[3], J. Kasper[2,7], M. D. Looper[3], J. E. Mazur[3], L. W. Townsend[4], C. Zeitlin[5], T. J. Stubbs[6], [1]Space Science Center, University of New Hampshire, Durham, NH, (jody.wilson@unh.edu), [2]High Energy Astrophysics Division, Harvard CFA, Cambridge, MA, [3]The Aerospace Corporation, Los Angeles, CA, [4]Department of Nuclear Engineering, University of Tennessee, Knoxville, TN, [5]Southwest Research Institute, Boulder, CO, [6]NASA Goddard Space Flight Center, Greenbelt, MD, [7]NASA Lunar Science Institute.

Introduction: High energy cosmic rays constantly bombard the lunar regolith, producing secondary "albedo" or "splash" particles like protons and neutrons via nuclear evaporation[1], some of which escape back to space. Two lunar missions, Lunar Prospector and the Lunar Reconnaissance Orbiter (LRO), have shown that the energy distribution of albedo neutrons is modulated by the elemental composition of the lunar regolith[2-5], with reduced neutron fluxes near the lunar poles being the result of collisions with hydrogen nuclei in ice deposits[6] in permanently shadowed craters. Here we investigate an analogous phenomenon with high energy (~100 MeV) lunar albedo *protons*.

CRaTER Instrument: LRO has been observing the surface and environment of the Moon since June of 2009. The CRaTER instrument (Cosmic Ray Telescope for the Effects of Radiation) on LRO is designed to characterize the lunar radiation environment and its effects on simulated human tissue. CRaTER's multiple solid-state detectors can discriminate the different elements in the galactic cosmic ray (GCR) population above ~10 MeV/nucleon, and can also distinguish between primary GCR protons arriving from deep space and albedo particles propagating up from the lunar surface.

Results so far: We use albedo protons with energies between 60 MeV and 150 MeV to construct a cosmic ray albedo proton map of the Moon. The yield of albedo protons is proportional to the rate of lunar proton detections divided by the rate of incoming GCR proton detections. The map accounts for time variation in the albedo particles driven by time variations in the primary GCR population, thus revealing any true spatial variation of the albedo proton yield.

Our current map is a significant improvement over the proof-of-concept map of Wilson et al.[7]. In addition to using more numerous minimum ionizing GCR protons for normalization, we filter out all solar particle enhancement periods, correct for certain subtle observational biases, and make use of all six of CRaTER's detectors to reduce contamination from spurious non-proton events in the data stream.

In general, the yield of albedo protons from the maria is 0.8% ± 0.4% higher than the yield from the highlands. In addition there appear to be localized peaks in the albedo proton yield that are co-located with peaks in trace elemental abundances as measured by the Lunar Prospector Gamma Ray Spectrometer.

Next Steps: More data may reveal subtler proton yield variations correlated with latitude, time of day, or the locations of permanently shadowed craters, due to the presence of water frost. Given that the most obvious features in the map have a proton yield only 2σ above average, the search for more subtle regions of enhancement or reduction in proton yield will require precise corrections for small but systematic effects of time and spacecraft altitude on the apparent proton yield. We will show the effects of these trends as well as the latest version of the albedo proton map.

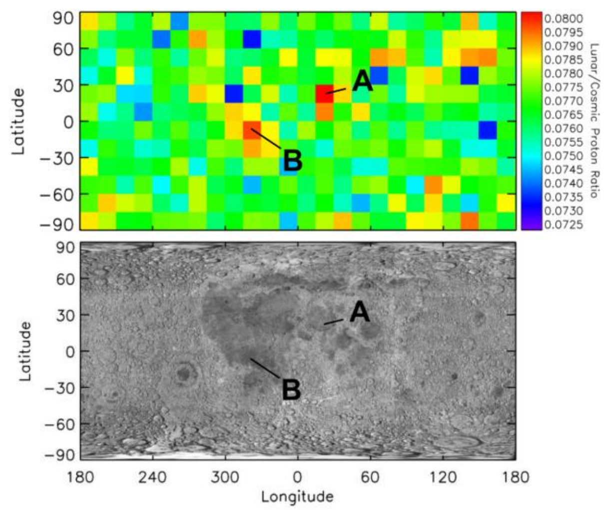

Figure 1. *Top*: Color-coded lunar albedo proton map, with two high-yielding mare regions labeled "A" and "B". *Bottom*: Clementine white-light mosaic of lunar surface.

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PAST, PRESENT, AND FUTURE LUNAR DRILLING TECHNOLOGIES

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Introduction: On 22 August 1976, 170 grams of lunar samples were returned to Earth by the Soviet Luna 24 mission. This marked an end to lunar exploration for almost two decades and it was also the last landed lunar mission to date.

The 1990s saw three orbiter missions, of which Lunar Prospector was the most significant. The Neutron Spectrometer data revealed large, potentially water ice deposits in the polar craters. This renewed interest in lunar exploration with eight missions launched between 2003 and 2010. The 2009 LCROSS mission provided direct evidence of ground ice. This water reservoir could be an enabling resource to support human presence on the Moon and human exploration of other Solar System.

Drilling Technologies: Since 1990s, Honeybee Robotics has been developing numerous drilling and sample acquisition technologies [1, 2]. These could be either fully autonomous or astronaut-deployable. The latest systems are at TRL of 5/6 and include a 1 meter rotary percussive and fully autonomous drilling system weighing 10 kg, a numerous surface core drills at TRL 4-5 weighing from 1 kg to 3 kg. The excavation systems include pneumatic and vibratory/percussive which make sampling much faster and easier to do.

In addition, we have developed planetary several geotechnical systems that enable measurement of soil strength from near surface to 1 m depth.

Other systems include fully autonomous Heat Flow Probe weighing just 1.5 kg and anchoring system with a Corner Cube reflector.

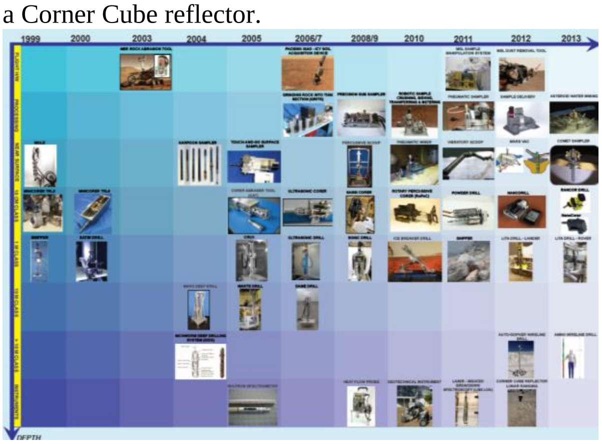

Figure 1. Honeybee Robotics range of drilling, sampling, geotechnical systems, and instruments developed for planetary applications. These could be either deployed robotically or by astronauts on the Moon.

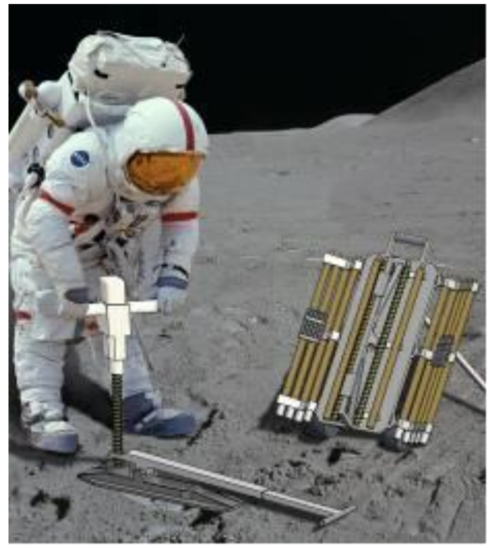

Figure 2. Astronaut deployable deep drill.

Since the early 2000s, we have been extensively testing our hardware across various planetary analog field sites.

Table 1. Analog sites for testing Honeybee drills

Analog Site	Drill Name	Year
Rio Tinto, Spain	MARTE	2005
Devon Island, Arctic	Dame	2004-07
Devon Island, Arctic	CRUX	2007-09
Devon Island, Arctic	Icebreaker	2010-13
Antarctica	Icebreaker	2010-13
Mauna Kea, Hawaii	Lunar Anchor, Lunar Heat Flow, Lunar 5 m drill	2010
Mojave	SASSI	2011
Greenland	Sniffer	2012-13
Atacama, Chile	LITA	2012-13
Borrego Springs	AutoGopher	2012

During the presentation, we will discuss past, present, and future technology developments as well as as challenges of drilling, regolith and rock acquisitions on the Moon.

References: [1] Zacny et al. “Drilling and excavation for construction and in situ resource utilization”, in Moon: Prospective Energy and Material Resources, Badescu (ed), Springer, 2010. [2] Bar-Cohen and Zacny, Drilling in Extreme Environments - Penetration and Sampling on Earth and Other Planets, Wiley, (2009).

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