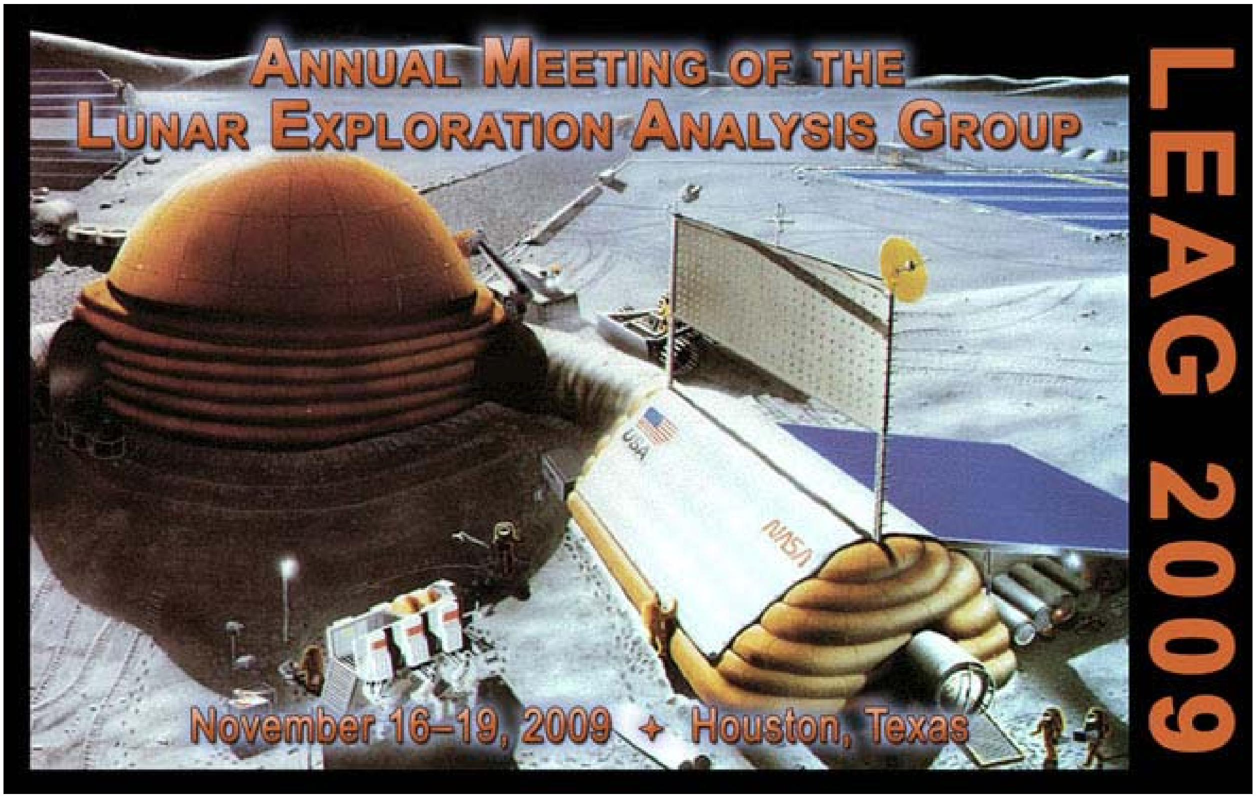

Program and Abstract Volume

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ANNUAL MEETING OF THE LUNAR EXPLORATION ANALYSIS GROUP

November 16–19, 2009 • Houston, Texas

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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, November 16–19, 2009, Houston, Texas.

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

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Tuesday, November 17, 2009

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Wednesday, November 18, 2009
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Moderator: Robert S. Wegeng

Sessions on Wednesday, November 18, have been organized and are sponsored by the Space Resource Roundtable (SRR). A nonprofit organization, the SRR seeks to bring together interested parties to discuss issues related to the In Situ Resource Utilization of lunar, asteroidal, and martian resources.

Premise: Lunar resources can be used to make space exploration beyond LEO more affordable and to bring direct benefits back to Earth. Discussions will include "on-ramps" for inserting lunar resources into the lunar architecture, resource prospecting, technologies and technology demonstrations, and lunar resource products and applications.

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Taylor L. A. *(University of Tennessee, Knoxville)*
Jolliff B. L. *(Washington University, St. Louis)*
Taylor G. J. *(University of Hawai'i, Manoa)*

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Wednesday, November 18, 2009
LUNAR IN SITU RESOURCE UTILIZATION (continued)
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Moderator: Robert S. Wegeng

1:15 p.m. Panel: Robotic Lunar Rover Prospectors

Boucher D. S. *(Northern Centre for Advanced Technology Inc.)*
Deans M. C. *(NASA Ames Research Center)*
Whitaker W. *(Carnegie Mellon Institute)*

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Moderators: Lars Borg
Clive Neal

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Microgravity and Partial Gravity Research

Hosted by: Space Resources Roundtable

Thursday, November 19, 2009
SYNTHESIS SESSION: INPUT AND REFINEMENTS
TO THE SUSTAINABILITY THEME OF THE LUNAR EXPLORATION ROADMAP
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Moderator: Paul Eckert

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What is Required to Make Lunar Exploration Sustainable?

8:55 a.m. Taylor G. J. *
How does a Sustainable Lunar Exploration Program Benefit Lunar Science and Solar System Exploration?

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Results from LRO/LCROSS – Part 1

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Results from LRO/LCROSS – Part 2

9:25 a.m. Wengeng R. S. *
Lunar In Situ Resource Utilization

9:45 a.m. Neal C. R. *
The Need for Lunar Samples and Simulants

9:55 a.m. DISCUSSION AND FINDINGS

12:00 p.m. ADJOURN

THE POSITION OF THE MOON, SUN, STARS AND SPACE SCIENCES IN AFRICA: OPPORTUNITIES AND POTENTIALS

Mr. B. Abubakar
Alhaji Budar Kuya House, Fezzan,Maiduguri,Borno state, Nigeria (babaganabubakar2002@yahoo.com)

Abstract

The Moon, the Stars and the Sun in some extent even the Clouds in the Sky are regarded as sacred or gods by some African traditional religions which are at present in control of approximately 25% of the entire African population of approximately 900 million as at 2009. In this respect the followers of these traditional religions are therefor restricted from studying the Moon, Sun, Stars or any other object above the atmosphere or the astronomy. However the religion of Islam and Christianity which are collectively in control of 70% of the African population have not restricted their followers from studying the Moon, Sun, Stars or the Astronomy, but however due to the presence of elements of astrology in the space sciences generally, which is a branch of studies many Africans use locally through studying the movements of Stars in the prediction of future events or in fortune telling businesses made the Space Sciences generally to be less attractive to both the Muslims and the Christians in Africa, hence this situation is making many young promising potential future astronomers, aerospace engineers, climatologist, metrologies or the astrologists in their early education (primary or secondary/highschools) end up studying nonspace sciences related courses in their University levels. Hence this situation has lead to the underdevelopment of the space sciences generally in Africa and which also has the potential of under developing the future of space sciences at the global level too over time.

In view of the above and in order to expand the development of space sciences as a whole the under listed suggestions/recommendations were proffered which if adopted and implemented it will enhance the development of the space sciences at all levels;

1. Major stake holders in the space sciences like the United Nations Organization of the Outer Space Affairs (UNOOSA), National Aeronautic Space Agency (NASA), European Space Agency (ESA) and many others should be helping in sponsoring and organizing Public enlightenment conferences, workshops, seminars or capacity building programs in Africa with the aim of developing the space sciences on the continent. 2. Religious scholarse specially the Muslim, Christian and the African traditional religious scholars should be included in the capacity development programs towards developing the space sciences in Africa. 3. The international Space Organizations, especially those organizations that have excel or at the peak of the modern space sciences like the NASA, ESA and others should open their offices and possibly training institutes in Africa. 4. The international space organizations like the NASA, ESA and even the UNOOSA should be given scholarships to identified future space scientists in Africa that may not likely get the financial support to study the space sciences at the University level. 5. Papers and Abstracts coming from Africa should be given priority by organizers of conferences, workshops or seminars on the ground that many papers coming from Africa are towards developing the space sciences instead of being highly technical papers in this field of science, because the space sciences itself is not yet developed or recognized on the continent.

In conclusion the author thinks that religious believes will continue to underdevelop or even restrict the studies of space sciences in Africa or even globally over time, unless if the above listed suggestions/recommendations are adopted and implemented otherwise the rate at which the space sciences will continue to under develop will ever be on the increase.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: 10/9/09

Presenter's Name: Carlton Allen
Presenter's Title: Astromaterials Curator / Member, Diviner Science Team
Presenter's Organization/Company: NASA Johnson Space Center

Presentation Title

Infrared (DIVINER) – rock abundance/composition

Key Ideas

Rock abundances can be calculated from nighttime temperature data. Diviner rock abundance calculations will be compared to published rock counts based on orbital and surface imagery.

Mineral composition can be calculated from the position of the "Christiansen feature", a portion of the thermal infrared. Three of Diviner's spectral channels were specifically chosen to provide estimates of this feature position. Calculations will be compared to other orbital data and ground truth from the Apollo sites.

Supporting Information

Published paper:

D.A. Paige · M.C. Foote · B.T. Greenhagen · J.T. Schofield · S. Calcutt · A.R. Vasavada · D.J. Preston · F.W. Taylor · C.C. Allen · K.J. Snook · B.M. Jakosky · B.C. Murray · L.A. Soderblom · B. Jau · S. Loring · J. Bulharowski · N.E. Bowles · I.R. Thomas · M.T. Sullivan · C. Avis · E.M. De Jong ·W. Hartford · D.J. McCleese (2009) **The Lunar Reconnaissance Orbiter Diviner Lunar Radiometer Experiment**, *Space Science Reviews*, DOI 10.1007/s11214-009-9529-2 online at: http://www.springerlink.com/content/y2633v4619834462/fulltext.pdf

Diviner Lunar Radiometer Experiment website: http://www.diviner.ucla.edu/

HIGH-GRADING LUNAR SAMPLES FOR POTENTIAL RETURN TO EARTH.

Carlton Allen[1], Glenn Sellar[2], Jorge Nunez[3], Daniel Winterhalter[2], and Jack Farmer[3]

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Introduction: Astronauts on long-duration lunar missions need the capability to “high-grade” their samples – to select the highest value samples for potential transport to Earth – and to leave others on the Moon. We are supporting studies to define the “necessary and sufficient” measurements and techniques for high-grading samples at a lunar outpost.

A glovebox, dedicated to testing instruments and techniques for high-grading samples, is in operation at the JSC Lunar Experiment Laboratory. A reference suite of lunar rocks and soils, spanning the full compositional range found in the Apollo collection, is available for testing in this laboratory. Thin sections of these samples are available for direct comparison. The Lunar Sample Compendium, on-line at http://www-curator.jsc.nasa.gov/lunar/compendium.cfm, summarizes previous analyses of these samples. The laboratory, sample suite, and Compendium are available to the lunar research and exploration community.

In the first test of possible instruments for lunar sample high-grading, we imaged 18 lunar rocks and four soils from the reference suite using the Multispectral Microscopic Imager (MMI) developed by Arizona State University and the Jet Propulsion Laboratory [1,2]. The MMI is a fixed-focus digital imaging system with a resolution of 62.5 microns/pixel, a field size of 40 x 32 mm, and a depth-of-field of approximately 5 mm. Samples are illuminated sequentially by 21 light emitting diodes (LEDs) in discrete wavelengths spanning the visible to shortwave infrared (450 to 1750 nm). Measurements of reflectance standards and background allow calibration to absolute reflectance. ENVI-based software is used to produce spectra for specific minerals as well as multi-spectral images of rock textures.

The suite of lunar samples included basalts and breccias with a wide range of textures. Figure 1 is a pseudo-color image of Apolo 14 crystalline breccia 14321, created from images using the red, green, and blue diodes. Figure 2 is a false color image of the same sample created to aid in mineral and clast identification. The spectra from every point in the scene, each consisting of reflectance in the 21 LED wavelengths, were grouped into eight characteristic spectra, which were correlated with specific minerals and clast types.

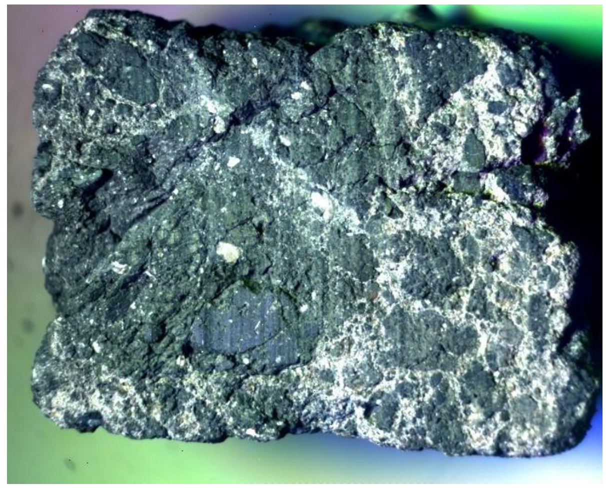
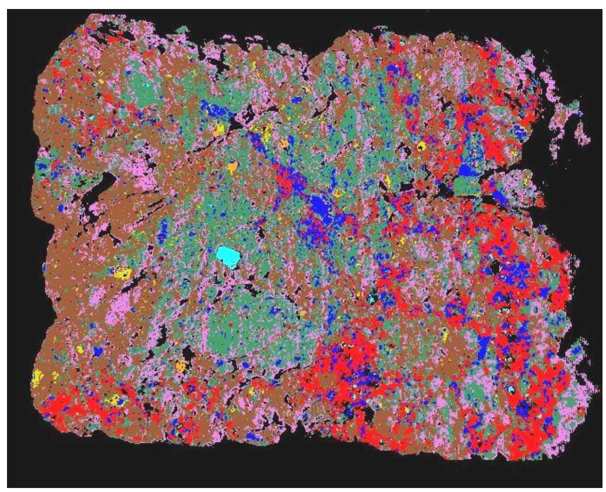


Figure 1. MMI RGB image of crystalline breccia 14321; frame width 40 mm



Figire 2. MMI false-color image of crystalline breccia 14321 illustrating mineral and clast identification; frame width 40 mm

References: [1] Nunez J. et al. (2009) *NASA Lunar Science Forum*. [2] Allen C. C. et al. (2009) *NASA Lunar Science Forum*.

Quantitative Approaches to Lunar Economic Modeling

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Abstract
Decision analysis tools have long been used in the extractive industries to discern the expected value of short and long-term investment in mineral properties and infrastructure. These tools may also have utility in quantifying costs and benefits related to future investments in human space exploration and technology, and more specifically to aid in down selection when a number of viable alternatives exist. This paper will describe various quantitative lunar economic modeling efforts conducted at the Colorado School of Mines (CSM) during 2002-2005 time frame.

A series of In-Situ Resource Utilization (ISRU)-based human exploration architectures were developed at the CSM Center for Commercial Applications of Combustion in Space (now the CSM Center for Space Resources). Architectural development, production and operations costs were modeled using the NASA and Air Force Cost Model (NAFCOM). Revenues related to ISRU product sales to various modeled future markets for in-space propellant and commodities formed the foundation for an economic cost/benefit model of the value of the use of space resources. The modeling approach included infrastructure and capability growth as a function of time. These architectures are generally consistent with the development of a self-sufficient outpost on the Moon during the period 2020-2030, and rely on systems and technological assumptions similar to the current NASA lunar architecture. Critical assumptions include deploying a set of precursor robotic missions were assumed to emplace ISRU capabilities as well as infrastructure in preparation for human missions. Model results included economic and performance (mass ratio) benefits and relative costs of ISRU compared to baseline expendable lunar scenarios. Sensitivity analysis of various technology options enabled the identification of priorities for future research and modeling. Economic conclusions included expected product unit costs and rate of return analysis as a function of resource concentration, market size as well as capital and operations costs.

LUNAR POLAR ILLUMINATION CONDITIONS DERIVED USING KAGUYA LASER DATA. D. B. J. Bussey[1] , J. A. McGovern[1], P. D. Spudis[2], C. D. Neish[1], and S-A. Sörensen[3], [1]The Johns Hopkins Applied Physics Laboratory, Laurel MD, USA (ben.bussey@jhuapl.edu), [2]Lunar and Planetary Institute, Houston TX, USA, [3]University College London, United Kingdom.

Introduction: The lunar Polar Regions experience unusual illumination conditions that make them attractive candidates for future exploration and possible use. The small angle between the Moon's spin axis and the ecliptic plane result in locations that are permanently shadowed as well as some that are nearly continuously illuminated. We have used the Kaguya laser-altimeter derived topography to comprehensively characterize the illumination conditions at both poles of the Moon.

The Data: This detailed illumination study became possible with the partial release of the Kaguya laser-derived topography data set. Kaguya was a JAXA lunar orbiter, launched in 2007, which mapped the Moon from a 100 km polar orbit for 2 years. Kaguya (known as SELENE before launch) carried an extensive suite of instruments that conducted a comprehensive study of the lunar surface [1]. The primary data set used in this study is the polar Digital Elevation Model (DEM) derived from the laser altimeter experiment. The laser altimeter on Kaguya used a 1064 nm laser firing at 1 Hz (with a corresponding along track spacing of ~1.6 km). Spot size on the lunar surface was 40 m and the vertical accuracy was 5 m. These data were used to produce a 500 m/pixel spatial resolution DEM covering from 85° S to 90° [2].

Technique: We are able to simulate where is illuminated on the lunar surface for a chosen value for Sun position. We have used a Kaguya-derived DEM to generate simulations of a diverse range of lunar polar illumination conditions.

Results: Specifically we have addressed four topics: 1. Clementine Comparison, 2. Permanent-shadow, 3. Seasonal variations, & 4. Illumination profiles for key sites.

Clementine Comparison: We ran multiple simulations using solar positions that correspond to a Clementine UVIS image. An example is shown in Figure 1. We find that the Kaguya DEM can be used to predict illumination conditions with a high degree of confidence. In fact we think that this is the first data set of sufficient quality to be used for conditions where this is not an image to provide ground truth.

Permanent Shadow: We used the Kaguya DEM to calculate areas of permanent shadow and also those areas, which are also Earth shadowed.

Seasonal Variations: We have used the data to investigate seasonal variations in the illumination conditions. Even though the Sun only varies a total of 3° in elevation during a year there are significant variations between summer and winter. Initially we produced a quantitative illumination map over the course of an entire year. Next quantitative illumination maps were made for seven lunar days. Day 1 had mid-summer for the southern hemisphere at the middle of the day, whilst day 7 has mid-winter at the middle of the day. The maps for days 1 & 7 for the South Polar Region are shown in Figure 2.

Illumination Profiles: We used the seasonal-variation maps to identify regions that receive the most illumination near both poles. For several of these regions we then determined the detailed illumination profiles. These show the amount and duration of the eclipse periods. Additionally they show the maximum single amount of time that they receive continuous illumination. We have found places near the south pole that are illuminated continuously for more than four months around mid-summer.

Conclusions: The Kaguya DEM has proved to be a major asset in trying to understand the illumination conditions at the lunar poles. We have used this topography product to comprehensively characterize the lunar polar illumination conditions. New data now being obtained by LRO will increase our understanding of polar lighting conditions.

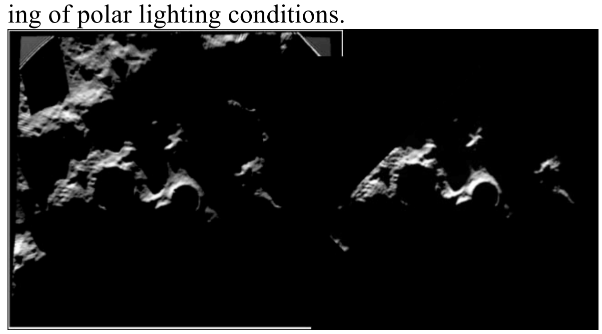

Figure 1. Comparison between a Kaguya-derived simulation and an actual Clementine image.

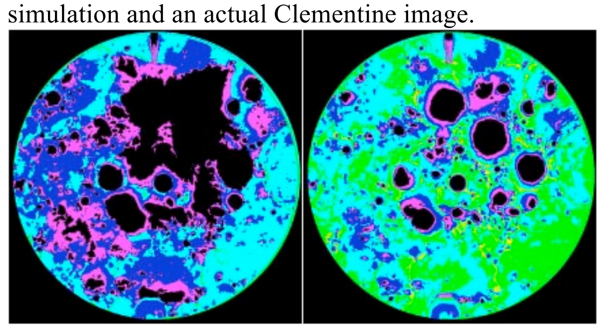

Figure 2. Quantitative south-pole illumination maps for winter (left) and summer (right).

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SOME MENTAL HEALTH PROBLEMS AND LONG TERM MANNED SPACE MISSIONS. R. Chahal[1] & A. A. Mardon[2], [1]University of Alberta (Edmonton, Alberta, Canada, ravichahal@gmail.com), [2]Antarctic Institute of Canada (Post Office Box 1223, Station Main, Edmonton, Alberta, Canada T5B 2W4, aamardon@yahoo.ca).

Introduction: With the establishment of the Interna-tion Space Station (ISS) and establishment of an interna-tion selection program for austronauts from different countries and cultural backgrounds to man and peform scientific studies, the psychological health of the inhabi-tants becomes an intriguing area of reserch. With the ultimate goal of, once again, manned missions to the Moon and a lunar base as a launch pad for further mis-sions to perhaps Mars, the mental health of the austro-nauts has never been of higher concern.

With the tragic destruction of the space shuttle Dis-covery, upon re-entry, and the state of NASA fleet of Shuttle's being grounded, manned missions of any sort by NASA will be limited at best, as the spots for the person-nel will have to be bought from the Russian Federal Space Agency (RFSA). Therefore the amount of time required for the autronauts to be in isolation will increase along with the subsequent danger to their mental health. The longest mission on the ISS thus far ended on the March of 2008 with the Endevour of 14 days docked with 5 space walks. With the eventual goal of a Manned Lunar Missions, how would the austronauts cope with the pro-longued isolation, from all the comforts of home and un-der tremendous pressure.

All factors from lighting conditions, to social net-working must be considered and implemented. An exam-ple of the effect of lighting conditions can be observed in the prevalence of Seasonal Affective Disorder (SAD). SAD is most prevalent in the winter time and around the Artic regions[1]. The main cause of the syndrome is thought to be the availability of light, and a common treatment is one in which the sufferer is exposed to a light source with a full spectrum of light.. Though the physio-logical pathway of the disorder is not completely known, theories have been put forth regarding the amount of seri-tonin, or the melatonin which is produced in the pineal gland in dim light, suggesting the perhaps a connection pathway between the pineal gland and the rods or cones plresent in the eye. Though the obvious solution to this problrm is artifical or suppliments, the long term effects include nightmares, drowzyness, reduced flow among others which could compound over the period of months, requiring additional intervention to deal with the side effects.

The advent of the internet and more specifically social networking sites, offers an ideal mode by which austro-nauts in prolongue isolation can keep in touch with friends, family (if they choose) without any real adverse effect on their efficiency. Studies conducted regarding prolonged isolation have indicated reduced efficiency and overall wellbeing of the isolated individuals. Allowing for continual networking between the austonauts and their kin on Earth allows the individual an outlet to talk from and maintain productivity, and efficiency.

Continual interaction with broad community has been known to increase the resistance to diseases and, in gen-eral has shown to increase feelings of well being [2]. Though sending entire families into space would be, im-practical with the advent of social networking sites, and the prevalence of their use on our culture has offer an intruging solution.

Websites such as Facebook, and Myspace and instant messaging software's allow users to essentially talk across the globe, and potentially work in space. With increasing stress being placed on resources, the key to, efficiency in prolongued isolation is resourcefulness, and not essentially resources. Instead of video conferencing between the austonauts and their social network, requir-ing immense load on equiptment, technical support and other rsources, instant messaging, which requires far less bandwidth, equiptment, could serve as the medium through which communication can flourish on long term missions and could be utilize on a computer with limited power.

Conclusion: Space travel, the final frontier, poses many great opportunities for exploration of our universe, and ourselves. Though the steps are small, the leaps in our understanding will come with continual exploration and lunar missions. How will this effect humans is still yet to be determined, however in orer to make any disco-veries the, progress on our understanding of our selves, and our limits must coincide with technological discove-ries.

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Research Support: This research was supported by the Antarctic Institute of Canada.

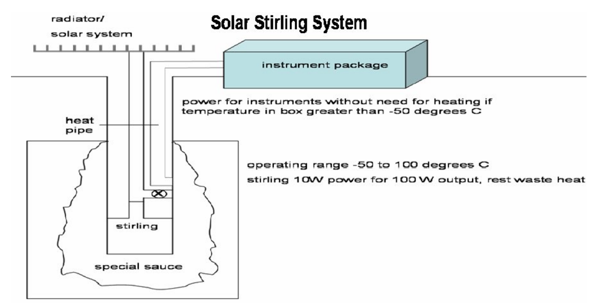
GEOTHERMAL SYSTEM DESIGNS FOR LUNAR SURFACE ENVIRONMENT SCIENCE ACTIVITIES.
P. E. Clark[1], R. Boyle[2], J. Ku[2], B. Beaman[2], R. D. Rogers[3], M. Smiglak[3], S. Nagihara[4], G. Knowles[5], M. Bradley[5], M. B. Milam[1]. [1]Catholic University of America@NASA/GSFC, Greenbelt, MD 20771 (Pamela.E.Clark@nasa.gov); [2]NASA/GSFC, Greenbelt, MD 20711; [3]The University of Alabama, Tuscaloosa, AL 35487; [4]Texas Technical University, Lubbock, TX 79409; [5]Qortek, Inc., Williamsport, PA 17701

Introduction: We have been analyzing and modeling two promising innovative geothermally-based designs for science package power and/or thermal support systems which meet the operational challenges and harness the extreme thermal conditions on the lunar surface, the most typical surface environment in the solar system. Both 1) the combined solar thermal/stirling geothermal power system and 2) the heat-pipe based thermal protection system, involve preliminary deployment using innovative drilling and fluid injection technology with newly available designer fluids to transform the regolith into a viable heat reservoir. The goal is, in the face of great uncertainty in the availability of radioisotope-based power systems, to radically minimize the mass required for science payloads to meet small deliverable mass constraints, while maximizing performance under conditions even more demanding than those routinely experienced by spacecraft in deep space.

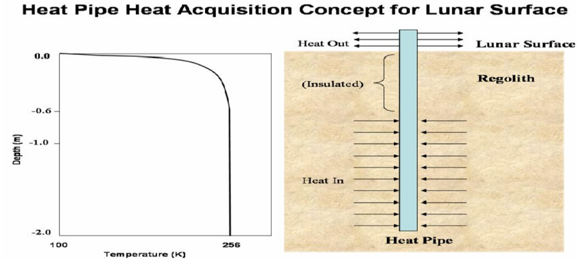
Thermal System: We investigated the feasibility of using heat pipes to bring heat from the constant (latitude-dependent) temperature regolith that exists 0.5 meters below the lunar surface. Heat pipes could be imbedded in the instrument mounting plate to maintain instruments temperature levels. For unmodified regolith, the volume required to provide a constant power of 10W for the entire night time is about 0.62 m^3. The heat transport requirement (10W) is well within the current heat pipe capability, but the extremely low thermal conductivity and heat capacity of the regolith severely limits the rate at which heat can be removed. More than 10 heat pipes with diameters of 0.625″ and flanges of 1″ width deployed to 2 meters depth would be required to increase the rate of heat transfer with major implications for mass and EVA time. Thus, at least one order of magnitude increase in thermal conductivity is required to make this concept feasible.

Power System: We developed a preliminary concept for a solar thermal/geothermal power system for instrument packages. A solar thermal system provides power while trapping excess heat in the 'heat sink' regolith during the day, and then harnesses that 'heat reservoir' to drive a sterling engine mechanism at night. Currently the free piston Stirling engine has been used for cryocoolers and as part of the ASRG to generate power reliably over long periods. We utilize this heat engine to generate electrical power from the temperature differential between the relatively warm regolith acting as a thermal storage reservoir during lunar night. Again, 1 to 2 orders of magnitude increase in thermal conductivity is required to make this concept feasible.

Geothermalizing the Regolith: We investigated approaches to 'geothermalizing' the regolith (increasing the low thermal conductivity and heat capacity normally resulting from limited heat transfer between grains in a vacuum) via subsurface deployment of 'geothermalizing' fluids to maintain contact between grains, facilitating heat transfer, without evaporating significantly over time. Such materials are in fact available within a suitable range of thermal (2 orders of magnitude or more greater thermal conductivity than lunar regolith) and physical (low volatility and melting point) properties These liquids would be injected with a Qortek-designed innovative low power, readily portable and deployable, muti-functional, high torque drill assembly enabling multiple drilling in a trilaterally stable configuration. This assembly would emplace the heat pipe or stirling into the regolith and transform the subsurface into a serviceable heat reservoir for geothermal use. Two fluid candidates are 1) AOS thermal grease 52030, a perfluorinated non-silicone zinc oxide compound with a very low melting point (-100°C) combined with high thermal conductivity and heat capacity, extremely low vapor pressure and high viscosity; 2) Ionic liquids (organic salts) with low melting point (down to -80°C) and negligible vapor pressure. We are in the process of screening liquid and regolith mixtures for appropriate thermal and physical properties.



Heat Pipe Heat Acquisition Concept for Lunar Surface



TECHNOLOGICALLY OPTIMIZED INSTRUMENT PACKAGES FOR LUNAR SURFACE SCIENCE.
P.E. Clark[1], P.S. Millar[2], P.S. Yeh[2], L. Cooper[2], B. Beaman[2], S. Feng[2], J. Ku[2], E. Young[2], M.A. Johnson[2]. [1]Catholic University of America@Goddard Space Flight Center, Greenbelt, MD 20711 (Pamela.E.Clark@nasa.gov), [2]Goddard Space Flight Center, Greenbelt, MD 20771

Introduction: Development of selectable, competitive science payloads requires optimization of instrument and subsystem design, packaging and integration for planetary surface environments to support solar system exploration fully. This process must be supported by incorporation of components and design strategies which radically minimize power, mass, and cost while maximizing the performance under extreme surface conditions that are in many cases more demanding than those routinely experienced by spacecraft in deep space.

Phase 1: Previously, we launched a multi-year effort to develop strategies and design concepts for ALSEP-like stand-alone lunar surface instrument packages with minimized mass/power requirements and without dependence on radioisotope-based batteries [1,2,3,4]. An initial conventional attempt to design an environmental monitoring package with a solar/battery based power system led to a package with a unacceptably large mass (500 kg) of which over half was battery mass. Our Phase 1 work led to considerable reduction (5x to 100 kg) in the initial mass of such a concept deployable near the poles (up to a few days of darkness once a year) by incorporating a) radiation hard, cold temperature electronics readily available but not routinely considered for deep space missions and b) innovative thermal balance strategies through use of multilayer thin materials and gravity-assisted heat pipes.

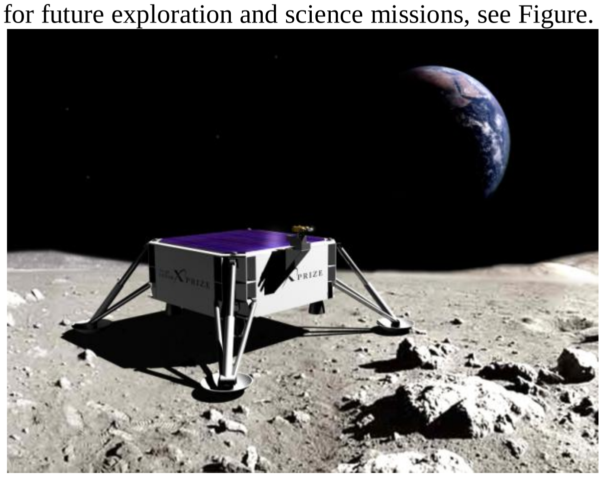
Phase 2: We are investigating strategies and leveraging ongoing work in the universal incorporation of Ultra Low Temperature/Ultra Low Power (ULT/ULP) digital and analog electronics, lower voltage power supplies, and distributed or non-conventionally packaged power systems. These strategies will be required to meet the more challenging thermal requirements of operating through a normal 28 day diurnal cycle while maintaining a mass of under 150 kg. ULT/ULP radiation hard digital components, developed at GSFC and through partnerships with the U. Idaho and the DOD National Reconnaissance Office, have successfully been demonstrated to offer orders of magnitude savings in power consumption and thermal tolerance. CULPRiT (CMOS Ultralow Power Radiation Tolerant) technology has successfully flown on NASA's ST5 90 day mission. Similar high end channel coder and compression chips have been requested for use in MMS, and GOES-R missions. Design and testing of the first custom designed radiation hard, low power analog components for ASICS in for extreme environments is also being harnessed. The ultimate goal is the development of ULT/ULP analog and digital logic chips for use in system on a chip which includes CPU as well as other components. Similarly, we leveraging existing conceptual studies of microbatteries for use as distributed power supplies or converters.

Application and Future: Having already facilitated incorporation of Phase 1 findings into ongoing instrument integration efforts, we plan to incorporate the full range of technologies into science instrument package and payload accommodation concepts currently under study and considered near-term contenders for implementation and to provide guidelines for applying these approaches generically to the widest range of lunar surface instrument packages, leveraging existing and projected unique capabilities to create and implement these technologies that are critically in-demand to serve needs for exploration of the Moon and other solar system bodies.

References: [1] Clark, P.E., P.S. Millar, P.S. Yeh, J. Lorenz, S. Feng, W. Powell, B. Beaman, K. Brown, and L. Leshin (2009) 'Enabling Technology for Lunar Surface Science", in proceedings of *Space, Propulsion & Energy Sciences International Forum (SPESIF-09)*, edited by Glen A. Robertson, AIP Conference Proceedings, Melville, New York (2009); [2] Clark, P.E., Millar, P.S., Beaman, B., Yeh, P.S.., Cooper, L., Feng, S., Young, E., 'Ultra Low Temperature Ultra Low Power Instrument Packages for Planetary Surfaces,' in proceedings of *Space, Propulsion & Energy Sciences International Forum (SPESIF-10)*, edited by Glen A. Robertson, AIP Conference Proceedings, Melville, New York, (2010).

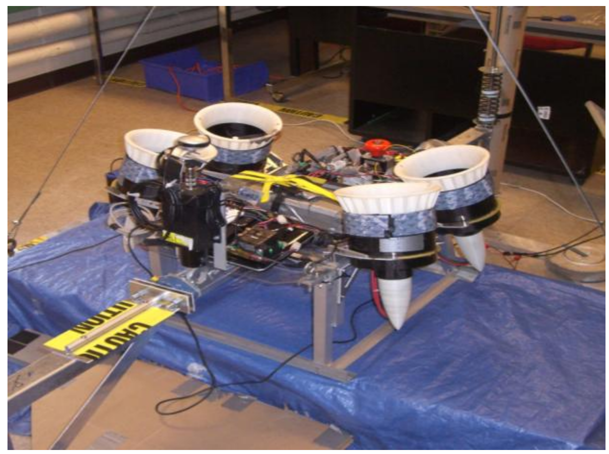
TAKING THE NEXT GIANT LEAP. B. Cohanim[1], M. Joyce[2], T. Mosher[3], S. Tuohy[1], and P. Cunio[4]. [1]The Charles Stark Draper Laboratory (555 Technology Square, Cambridge MA 02139), [2]Next Giant Leap, [3]Sierra Nevada Corporation, [4]Massachussetts Institue of Technology

Abstract: As part of the Google Lunar X-Prize, the Next Giant Leap team is developing a lander/hopper architecture that will not only compete in the prize, but will also demonstrate a new method of surface mobility for future planetary science missions. Current government funded efforts to explore space are costly, one of a kind missions. The Next Giant Leap team is not only creating an affordable architecture to win the Google Lunar X-Prize, but also developing a platform for future exploration and science missions, see Figure.



This paper will describe the Next Giant Leap team's architecture, the challenges associated with developing this architecture, the options for mitigating them, and the solutions the Next Giant Leap team has chosen. There are significant challenges, both in the development and operation for such a venture, especially by a privately funded company as part of the Google Lunar X-Prize. Mass and performance are key. Mass is a significant driver of launch vehicle cost. New technologies can not only reduce the mass of the system, but also enable this type of small lander/hopper mission to achieve the goals for exploration, science, and future endeavors on the moon and other planetary bodies.

It is also important to develop a testbed to prove our concepts before launch. As part of the development and promotion of the next giant leap team, a lunar robotic hopper testbed is being developed to mature operations, algorithms, and experience. Named the Terrestial Autonomous Lunar Reduced gravIty System (TALARIS), the testbed is designed to mimic the lunar environment by providing a 1/6th gravity mode. This paper will describe the current status of this testbed, future work, and opportunities for others to use this testbed and development of other technologies for lunar science and exploration.eplace these instructions with the text of your abstract.



GEOHAZARDS ON THE MOON AND THE IMPORTANCE OF THE INTERNATIONAL LUNAR NETWORK (ILN). B. A. Cohen[1] and the MSFC/APL ILN Team. [1]NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov).

Introduction: Seven of the 28 shallow seismic events recorded by the Apollo passive seismic experiment (PSE) network released energy equivalent to earthquakes with magnitudes of 5 or greater. On Earth, such quakes can cause extensive damage to structures near the epicenter. Unexpected structural damage to a lunar habitat could have devastating results and thus, lunar seismicity may present a significant geohazard to long-term human habitation.

Seismic Hazard? Lunar seismicity is 3-5 orders of magnitude lower than Earth. However, the propagation of quake energy is strikingly different on the Moon than on the Earth. The Moon is largely anhydrous and its crust is extensively fractured; the resulting high lunar Q values mean that moonquake attenuation is low. The maximum signal from a shallow moonquake can last up to 10 minutes with a slow tailing off that can continue for hours in total duration, and moonquakes tend to produce seismic waves of higher frequency than earthquakes. Ground motion is the most important factor in causing structural damage, and on the Moon, the observed ground motion of the PSE instruments during moonquakes were typically less than 1 nanometer and artificial seismic signals dampened out within ~ 10 km. However, the Apollo PSEs never recorded a strong shallow moonquake directly below the seismic network.

One mechanism for generation of shallow moonquakes may be lithospheric stress at terrain boundaries such as basaltic mare or large impact basins. If this mechanism is valid, siting a lunar base on the edge of the largest, deepest lunar basin (SPA) could put it at increased seismic risk. We do not yet have enough data on strong, shallow moonquakes to understand their cause, depth, or lateral distribution. Predicting where shallow moonquakes may occur is important for the next phase of lunar exploration.

To evaluate a potential lunar seismic risk, two approaches are needed. First, further research to understand and effectively model lunar ground motion and acceleration by applying advanced terrestrial models and numerical techniques to the lunar environment is crucial. Second, a long-lived, global lunar seismic network needs to be established to globally characterize lunar seismicity and establish the origin, frequency, and propagation of strong moonquakes.

The ILN Mission: NASA's Science Mission Directorate's (SMD) International Lunar Network Anchor Nodes Mission continues its concept development. The mission will establish two-four nodes of the International Lunar Network (ILN), a network of lunar geophysical stations envisioned to be emplaced by the many nations collaborating on this joint endeavor. The US stations of the ILN, called the Anchor Nodes, are being planned by NASA Marshall Space Flight Center (MSFC) and the Johns Hopkins University Applied Physics Laboratory (APL), with contributions from JPL, ARC, GRC, DOD, and industry.

The Anchor Nodes project has progressed through pre-Phase A design activities and is currently conducting an extended risk reduction program. Risk reduction activities include propulsion thruster testing; thermal control testing and demonstration; low power avionics development; composite coupon testing and evaluation; landing leg stability and vibration; and demonstration of landing algorithms in the MSFC Lunar Lander Robotic Exploration Testbed, which was established in support of risk reduction testing to demonstrate ILN capabilities. An MSFC test vehicle using an Anchor Nodes-like design and a compressed air propulsion system is in use for demonstration of control software. A second version of the MSFC vehicle is planned that will utilize an alternate propulsion system for longer duration flight and descent testing. The upgraded test vehicle will also integrate flight-like components for risk reduction testing, such as landing sensors (cameras, altimeters), instruments, and structural features (landing legs, deployment mechanisms).

International Participation: Representatives from space agencies in Canada, France, Germany, India, Italy, Japan, the Republic of Korea, the United Kingdom, and the United States agreed on a statement of intent for near and long-term evolution and implementation of the ILN. Working groups are addressing potential landing sites, interoperable spectrum and communications standards, and a set of scientifically equivalent core instrumentation to carry out specific measurements.

Summary: The concept of an International Lunar Network provides an organizing theme for US and International landed science missions in the next decade by involving each landed station as a node in a geophysical network. Creation of such a network will dramatically enhance our knowledge regarding the internal structure and composition of the moon, as well as yield important knowledge for the safe and efficient construction and maintenance of a permanent lunar outpost.

An Overview of the Lunar Crater Observation and Sensing Satellite (LCROSS) Mission Results from Swing-by and Impact. A. Colaprete[1], G. Briggs[1], K. Ennico[1], D. Wooden[1], J. Heldmann[1], L. Sollitt[2], E. Asphaug[3], D. Korycansky[3], P. Schultz[4], A. Christensen[2], K. Galal[1], G. D. Bart[5] and the LCROSS Team, [1]NASA Ames Research Center, Moffett Field, CA, Anthony.Colaprete-1@nasa.gov, [2] Northrop Grumman Corporation, Redondo Beach, CA, [3]University of California Santa Cruz, [4]Brown University, [5]University of Idaho.

Introduction: Interest in the possible presence of water ice on the Moon has both scientific and operational foundations. It is thought that water has been delivered to the Moon over its history from multiple impacts of comets, meteorites and other objects. The water molecules migrate in the Moon's exospheric type atmosphere though ballistic trajectories and can be caught in permanently shadowed polar cold traps that are cold enough to hold the water for billions of years. Verification of its actual existence would help science constrain models of the impact history of the lunar surface and the effects of meteorite gardening, photo-dissociation, and solar wind sputtering. Measurements of the ice distribution and concentrations would provide a quantitative basis for studies of the Moon's history and a test of current theories on the form and distribution of lunar hydrogen.

The LCROSS Mission: The primary objective of the Lunar Crater Observation and Sensing Satellite (LCROSS) is to confirm the presence or absence of water ice at the Moon's South Pole. This mission uses a 2300 kg kinetic impactor with more than 200 times the energy of the Lunar Prospector (LP) impact to excavate more than 250 metric tons of lunar regolith. The resulting ejecta cloud will be observed from a number of Lunar-orbital and Earth-based assets. The impact is achieved by steering the launch vehicle's spent Centaur upper stage into a permanently shadowed polar region. The Centaur is guided to its target by a Shepherding Spacecraft (S-S/C), which after release of the Centaur, flies toward the impact plume, sending real-time data and characterizing the morphology, evolution and composition of the plume with a suite of cameras and spectrometers (Figure 1). The S-S/C then becomes a 700 kg impactor itself, to provide a second opportunity to study the nature of the Lunar Regolith.

Impact Target: The specific impact site for LCROSS depends on the exact launch date for LRO. The launch date of June 18, 2009 resulted in a 4 month cruise and an impact in at the south pole on October 9. The impact site is selected based on a number of requirements including solar illumination of ejecta, visibility to earth (specifically observatories in Hawaii), and target properties (e.g., slopes and roughness). The targeting capability of the LCROSS S-S/C, ~1 km (3σ), allows for a fairly precise selection of impact point. Inter-crater impact targeting could be adjusted up until Trajectory Correction Maneuver #7 which occurred on September 25. Intra-crater targeting refinement occurred up until October 6 allowing for the maximum use of LRO observations in LCROSS target selection.

LCROSS provides a critical ground-truth for Lunar Prospector and LRO neutron and radar maps, making it possible to assess the total lunar water inventory, as well as provide significant insight into the processes that delivered the hydrogen to the lunar poles in the first place. Also, during swing-by, LCROS made measurements of the farside northern hemisphere, including unique near ultraviolet observations. This talk will summarize the results from LCROSS lunar swing-by and impact, including observations from the S-SC, ground and earth orbiting observations.

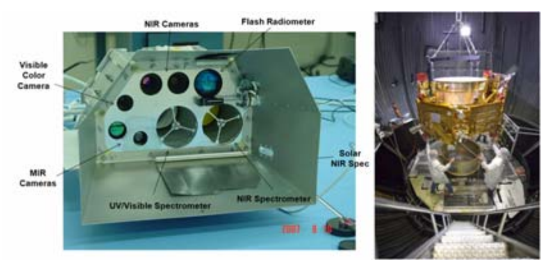


Figure 1. Left: The LCROSS Payload Observation Deck and its eight nadir viewing instruments (an additional solar occultation spectrometer is to the side). Right: The LCROSS spacecraft entering thermal vacuum testing at Northrop Grumman.

ENABLING GROWING CIS-LUNAR AND LUNAR ENTERPRISES

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Abstract:

The Intergovernmental Panel on Climate Change (2009) now clearly challenges world policy makers to enable a new sustainable and clean carbon-free global power system within the early part of this century. Otherwise, Earth’s biosphere and the world economy face irreversible deleterious changes (Ref. 1). A Lunar Solar Power (LSP) System, built on the Moon from the common lunar materials, can provide the needed clean, affordable, and sustainable power (Ref. 2). The United States can return to the Moon, implement the LSP System, and enable a sustainably prosperous Earth. Within 5 to 8 years microwave power beams can be sent from stations on Earth to recycling ion-drive tugs that carry cargo between low-orbit about Earth to low-orbit about the Moon (Ref. 3, 4). High-tonnage cis-lunar transport cost can be reduced to the order of 10s $/kg. Low-cost commercial-scale power can also be beamed to lunar bases and immediately enable the industrial-scale operations appropriate to the rapid growth of the LSP System. Japan and Western Europe now consume 1 terawatt-y of electric power (1 TWe) to output 42 T$ of gross domestic product. The LSP System can increase global electric power to 20 TWe by mid-century and enable gross world product to increase from ~45 T$ of non-sustainable product to over 840 T$ of sustainable net new product. Clean LSP electric energy can be used to extract within this century all industrial carbon dioxide from Earth’s atmosphere. The gross lunar product could exceed $10 trillion within this century.

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Scaling Relations for Repose Angles of Lunar Mare Simulants

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Repose angles for lunar *mare* simulants were measured in rotating drum experiments during parabolic flight maneuvers. A range of flow behaviors from cascading through rolling was obtained under both vacuum and standard atmospheric pressures. Flow phenomenology is correlated with a Froude Number, and we obtain critical Froude Numbers demarcating the different flow regimes in analogy to studies performed on model granular materials in 1-g. Finally, a scaling relationship for repose angles of the form $\theta \propto \sqrt{\omega^2/g_{eff}}$ is obtained from experimental data over variations in effective gravity level g_{eff}, and drum rotation rate ω.

Introduction Measurements of repose angles in granular materials are notoriously sensitive to experimental methodology. In particular, the drained and poured angles of pile-based measurements are dependent on experimental design and technique. A reasonably well-controlled proxy measurement for these angles is the *dynamic* angle of repose obtained in rotating drum experiments. The drum containing simulant media rotates horizontally around its principal symmetry axis at a rotation rate ω. By varying the rotation rate, the range of stable repose angles can be explored.

Scaling Hypothesis When the ratio of average particle size d to drum radius R satisfies $d/R << 1$, results of drum experiments are not sensitive to particle size or drum geometry. Flow behavior for a given material satisfying $d/R << 1$ is determined primarily by the Froude Number, $Fr = \omega^2 R/g_{eff}$.

A scaling hypothesis for dynamic repose angles in drum experiments was first proposed in the work of Klein and White[1]. Repose angles measured under variable gravity were shown to scale with $\theta \propto g_{eff}^{-1/2}$ at constant rotation rate. Subsequent work under hyper-gravity conditions have suggested that the appropriate scaling parameter is $Fr^{1/2}$ [2].

Much of the prior work directed at investigating scaling forms for repose angles has been carried out using model granular materials with mono-disperse particle sizes. The experiments reported here make use of well-characterized lunar regolith simulants JSC-1A and GRC-3, and so may provide more relevant engineering constraints on repose behavior of lunar regolith materials.

Results In Fig. 1, measured surface angles for JSC-1A and GRC-3 are plotted against the scaling parameter $Fr^{1/2}$.

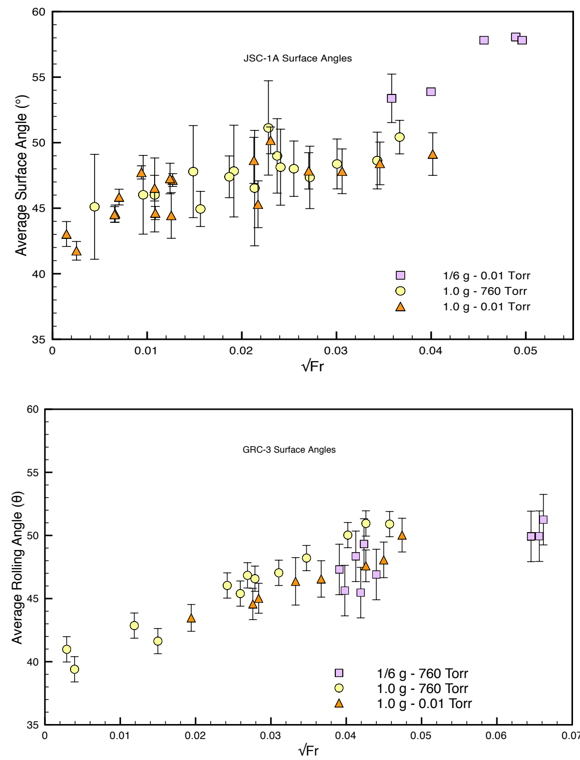

Figure 1: Measured surface angles for JSC-1A and GRC-3. Error bars indicate variance in the measurement sets. Uncertainty for some lunar $(1/6 - g)$ data is not available because each data point represents only one or two angle measurements.

Discussion We have examined the repose behavior of two bulk lunar *mare* simulants under both standard atmospheric and vacuum conditions at 1/6, 1.0, and 2.0 g. We find that surface flow is characterized by the Froude Number $Fr = \omega^2 R/g_{eff}$. Three flow regimes, avalanching, cascading, and centrifuging were observed with transitions between regimes occurring at fixed values of Fr that are material dependent. Surface angle measurements were made in the avalanching and cascading regimes. We find no detectable difference in surface angle behavior with ambient gas pressure in the range $10^{-2} - 10^3$ Torr.

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LUNAR OUTGASSING INTERACTIONS WITH THE REGOLITH. A. P. S. Crotts[1] and C. Hummels[1], [1]Columbia University, Department of Astronomy, 550 West 120th Street, New York, NY 10027 (arlin, chummels@astro.columbia.edu).

Introduction: Several developments in the past few years inspire us to question how volatiles might leak from the lunar interior and how this might manifest itself in existing or future data. Among these developments are 1) the discovery that picritic glass spherules from the deep lunar interior, liberated in fire fountains, are relatively rich in water and sulfur [1,2]; 2) the finding that some eroded areas on the lunar surface inconsistent with impact craters were modified relatively recently, probably in the past several million years, in a manner consistent with a massive outgassing event [3], and 3) the locations of episodes of ^{222}Rn outgassing, as observed on *Apollo 15* and *Lunar Prospector*, are geographically coincident with sites that have consistently produced over history reports by observers of optical transient lunar phenomena (TLPs), as are the residuals of recent ^{222}Rn outgassing as traced by ^{210}Po [4,5].

In particular we ask if TLPs might be generated by outgassing. Until 20 to 30 years ago, optical transients on the lunar surface (Transient Lunar Phenomena: TLP or LTP) were seen as an important, outstanding lunar mystery in need of study [6,7,8]. Since then, we have gained little understanding of TLPs, excepting for developments listed above. The debate on even the reality of TLPs as a coherent physical effect (as opposed to observer error) has been limited to the popular literature, both pro and con [9,10]. We find the results of our model interesting in the context of this debate.

Models of Explosive Outgassing: In a recent paper, we explore in the interaction of gas penetrating the regolith via seepage, fluidization and explosive disruption [11]. The latter is calculated for a source of gas rising from the interior and meeting the base of the regolith as a point source. For a 15 m regolith depth, a gas flow of greater than about 3 g s^{-1} is sufficient to eventually build up a sufficient overdensity (amounting to about 1 tonne for 20 AMU gas) such that the gas punctures the regolith and is explosively liberated into the vacuum. After this heavy regolith particles (larger than about 0.1 mm) quickly fall into the crater blown by this explosion, but lighter particles expand into a partially ballistic/partially gas-supported cloud that expands over several km radius and for several minutes before disappearing. The area affected and timescale of this model event turns out to be similar to the observed quantities typical of TLPs. The lightest dust particles can be accelerated up to about 50 km altitude. A layer of fresh regolith is generated which can likely be detected to about 1 km radius for of order 1000 y before being lost to gardening effects, and much longer in the central crater (~ 30 m diameter). We also discuss how during the outburst event pressures inside the cloud linger near the Paschen minimum condition and speculate that charge separation within the cloud might cause coronal discharge effects. We discuss in detail how these hypotheses based on this straightforward model might be tested via remote sensing.

Seepage through the Regolith: We also calculate the conditions in the past under which water vapor leaking from the interior might have undergone a phase change in order to produce water ice at significant depths in the regolith (of order 10 m or more), and for large regions near the poles find that ice might accumulate into significant masses (depending on the outgassing rate). These might be expected to survive over geological time scales. We discuss at length how these might be detected via remote sensing, as well.

Finally, given the possible long-term presence of water ice interacting with the regolith, we speculate that one eventual outcome of this interaction might be the filling of regolith particle interstices by motile material in a manner similar to cement, as might be further aided by the presence of sulfates as seen in lunar volcanic glasses. This requires further investigation, but would possibly result in a concrete-like layer formed over the ice, which would tend to thicken as the ice migrates downward due to the thermal evolution of the regolith.

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LUNAR AND MARTIAN LAVA TUBE EXPLORATION AS PART OF AN OVERALL SCIENTIFIC SURVEY

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Introduction: Lava tubes exist on the Moon and almost certainly on Mars. If we can locate, characterize, and gain entry to one of these caverns, very considerable advantages may be found for both scientific exploration and surface systems architecture. Due to the extreme cost of bringing technology to the Moon, it is quite probable that a great savings in landed mass can be accomplished by using a lava tube as a shelter for a habitat and science lab. Such a habitat would be completely protected from radiation, extreme temperature variations, and regolith dust.[1]

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Implications for Science: The implications for logistical and mission planners are that a substantially larger fraction of the payload mass landed on a planetary surface can be dedicated to life support and science mission support. This could enable longer duration missions without risk of radiation overdosing, better reliability and a more diverse set of scientific technology, and a larger habitat area in which to work.

Importantly, the effort required to discover and qualify a candidate uncollapsed lava tube has a high degree of synergy with other compatible science missions, and it may be possible to multi-task the same equipment for this purpose. While gaining entry to a tube may be difficult, it is within our capability.

The confirmation of Martian lava tubes [2,3] would present the scientific community with a compelling opportunity as well as a quandary. Tubes and caves represent a prime location to focus the search for life and liquid water, and they would provide numerous opportunities for geological studies that could reveal much about the history of Mars[4,5]. They could also provide a means of reducing the landed payload mass for manned Mars missions by providing shelter from UV radiation, wind storms, and large temperature fluctuations. However, preinvestigation of the tubes would be necessary to assure that the environment is sterile, and precautions would need to be taken to prevent the transplantation of terrestrial microorganisms.

The difficult environmental conditions that exist on the surfaces of the Moon and Mars are equally concerning to planetary scientists and habitat and surface systems designers. The existence of natural caverns on both bodies represents an opportunity to enable more ambitious planetary science investigations and the search for these features should be approached collaboratively by scientists, engineers and mission planners. There is great opportunity for multi-purposing technologies that can be used to discover these tubes and to exploit them. Lava tubes and caves should be given high priority in the planning of future exploration missions.

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AN INVESTIGATION INTO USING ADDITIVE MANUFACTURING TECHNIQUES FOR CONSTRUCTING STRUCTURES USING INDIGINOUS LUNAR MATERIALS. M. Drever[1] T. Shelfer PhD, R. Gaza PhD, K. Deighton, and J. Posey[2], [1]Lockheed Martin (mike.drever@lmco) [2]Affiliation for second author (full mailing address and e-mail address).

In-situ resource utilization increases the sustainability of a lunar facility by minimizing the amount of material transported from Earth.

The very fine materials in lunar regolith can be used to construct structures that can be outfitted and used as part of a lunar facility including pressure vessels, retaining walls and other structures. [1][2][3]

Structures of different shapes can be constructed using a combination of well established fabrication methods using just lunar materials. Additive manufacturing creates functional parts from a variety of powdered materials, including plastics, ceramics and metals. These part can be inspected during and after manufacture using non-destructive evaluation methods.

Fine lunar materials can be manipulated using electrostatic adhesion to allow thin layers on fine materials to bond to a thin form. [2] Materials that have been loosely bonded to the form with electrostatic adhesion can then be flash melted and bonded to each other using a variety of methods. [3] This process can be repeated until the final thickness has been obtained. This approach of gradually increasing the thickness allows for a structure tuned to its requirements. For enclosed volumes such as pressure vessels the form provides a gas barrier and for unenclosed volumes the form can be reused.

The structure can be tested and evaluated using non-destructive evaluation methods as the thickness increases. Known flaws can be logged and material added as needed until the flaws has been repaired or mitigated. The process is terminated when sufficient material has been applied to pass the inspection criteria and other design requirements are met. [4]

This method provides a means to create the primary structure of lunar habitats using indigenous materials in a wide variety of shapes, including flat plates, cylinders and other shapes. [1][2][3] Inspecting structures as they are built provides confidence in the structural integrity of the structure prior to being placed into service. [4]

Methods such as these allow fabrication of primary facility structures on the moon with only select components being flown from Earth for some structures. Volumes constructed using this method can provide load bearing structure, radiation shielding, micrometeoroid protection, retaining walls, aerial masts, etc.

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SOUTH POLE HYDROGEN DISTRIBUTIONS FOR PRESENT LUNAR CONDITIONS. R. C. Elphic[1], D. A. Paige[2], M. A. Siegler[2], V. R. Eke[3], L. F. A. Teodoro[4], and D. J. Lawrence[5], [1]Planetary Systems Branch, NASA Ames Research Center, MS 245-3, Moffett Field, CA, 94035-1000, [2]Earth and Space Sciences Dept, University of California, Los Angeles, CA 90024, [3]Institute for Computational Cosmology, Physics Department, Durham University, Science Laboratories, South Road, Durham DH1 3LE, UK, [4]ELORET Corp., Planetary Systems Branch, Space Sciences and Astrobiology Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035-1000, [5]Johns Hopkins University Applied Physics Laboratory, MP3-E104, 11100 Johns Hopkins Road, Laurel, MD 20723.

Introduction: The poles of the Moon evidently harbor enhanced concentrations of hydrogen [1,2]. The hydrogen could be in several chemical and physical forms. In addition to solar wind implanted hydrogen, seen in returned samples, there may be stably cold-trapped ice in locations of sufficiently low subsurface temperatures. The lack of polar topography data prevented the accurate estimation of lighting conditions and hence annualized near-surface regolith temperatures. Nevertheless, using imagery from Clementine it was possible to roughly estimate permanently-shadowed regions (PSRs), and to perform image reconstructions of the Lunar Prospector epithermal neutron flux maps [3,4].

A key assumption in the image reconstruction analyses was that any location that was *not* a PSR could only have solar wind hydrogen abundances (<200 ppm), whereas PSRs themselves could have any amount of hydrogen that the fit required, from 100% to zero. Preliminary Kaguya/LALT topography data provided greatly improved estimates of PSR locations [5], and additional reconstructions were performed under the same assumptions. Several PSRs were identified as containing > 1 wt% water-equivalent hydrogen (WEH). These reconstructions are excellent, statistically consistent fits to the model. In fact, reconstructions that did not treat the PSRs at all were statistically inferior to those that decoupled PSRs from non-PSRs. Nevertheless, models are only as good as their assumptions.

New Measurements: New results from Chandrayaan and NASA's Lunar Reconnaissance Orbiter are revising our picture of conditions at the lunar poles. Data from the Diviner Lunar Radiometer Experiment indicate extensive areas of very low temperatures (<100K) in the south polar region, and these areas are not limited to locations of permanent shadow [6]. Such cold terrain has subsurface temperatures low enough to keep shallow buried ice stable for 1 Ga or longer [7]. Moreover, Earth-based telescopic spectral reflectance observations [8] have suggested the possible presence of phyllosilicates in the near-polar regions. Both of these results indicate that the confinement of potentially high hydrogen concentrations to permanent shadow is overly restrictive. The Lunar Prospector epithermal data can now be used to fit a model that includes these three possible hydrogen repositories.

Modeling: Permanently-shadowed regions comprise a subset of the more areally extensive terrains that have annualized subsurface temperatures low enough to permit stable water ice. For that reason, reconstructions are likely to have lower average hydrogen abundance than in the PSR-only reconstructions. In effect, the same amount of hydrogen is placed into a larger area, resulting in lower average abundances.

We will present the results of performing pixon reconstructions using new spatial constraints, such as regions of near-subsurface ice stability, and compare these with our previous results. Also under investigation are topographic effects on neutron leakage flux and the expected signatures of present-day relict ice resulting from the emplacement of abundant polar ice following a cometary impact in the distant past.

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PREPARATIONS FOR ESA'S FIRST LUNAR LANDER. S. Espinasse*,, J.D. Carpenter, R. Fisackerly, B. Gardini,, B. Houdou, S. Di Pippo, A. Pradier, ESA-ESTEC, HSF-E, Keplerlaan 1, 2201 AZ, Noordwijk (*e-mail: Sylvie.Espinasse@esa.int)

Introduction: Recent years have seen a researgence of interest in lunar exploration and the emergance of countries like China and India as space fairing nations. In 2004 the US announced a new Vision for Space Exploration [1], whose objectives were focused on human missions to the Moon and Mars. Recent international missions have included the Japanese Kaguya orbiter in 2007. the Chinese Chang'e mission, India's Chandrayaan (2008) and the US LRO/LCROSS mission (2009). All these orbital missions are advancing our understanding of the Moon and preparing for future surface and manned missions.

At its 2008 ministerial council meeting the European Space Agency (ESA) proposed to engage Europe in lunar human exploration [2]. This proposal was made in the context of the considerable potential for international cooperation, extensively formulated in "The Global Exploration Strategy" [3] and with the goal to guarantee a possibility for a European astronaut to walk on the Moon in the early stages of the return of humans to the Moon.

As a first step current lunar exploration activities at ESA are focussed on the development of European technologies and capabilities, to enable significant European participation in future international human exploration of the Moon. A major element in this contribution has been identified as a large lunar cargo lander, which would fulfill an ATV-like function, providing logistical support to human activities on the Moon, extending the duration and the capabilities of sorties and extended stays of human explorers and accelerating the establishment of a lunar outpost.

To meet this ultimate goal, ESA is currently considering various possible development approaches, involving lunar landers of different sizes.

Lunar Lander Mission Options: A high capacity cargo lander able to deliver consumables, equipment and small infrastructure, in both sortie and outpost mission scenarios, would use a full Ariane 5 launch and is foreseen in the 2020-2025 timeframe.

To achieve this objective, ESA is considering an intermediate, smaller-scale precursor mission, to mature the necessary landing technologies, to demonstrate human-related capabilities in preparation of human presence on the Moon and to gain experience in landing and operating on the lunar surface.

Within this frame, ESA has recently concluded several feasibility studies of a small lunar lander mission, also called "MoonNEXT", which assumed a launch from Kourou with a Soyuz in the 2016-2018 timeframe. This mission would be a first step towards mastering the automated precision landing with hazard avoidance required for the future cargo lander and essential for landing at the South Pole Aitken basin (SPA), the provisional MoonNEXT landing site. For the purpose of the studies, a preliminary strawman payload with several technology demonstration and testing packages to investigate advanced fuel cell and life support technologies was considered.

To complete these first studies, additional investigations based on a medium-size lander to be launched in a shared Ariane 5 configuration are soon to begin. Such a configuration is expected to provide a significantly increased payload mass to the surface.

The candidate mission options will be traded off to find the best balance of cost, mission timeframe, development effort and representability. The reference intermediate lunar lander mission will be established so as to proceed with industrial Phase B1 activities early in 2010.

Mission Objectives and Payload:

In the meantime, a Lander Exploration Definition Team has been established to identify the objectives and requirements for the mission considering the following priorities:

1. demonstrate capabilities and perform technology enabling research for future human exploration;
2. characterisation of the lunar environment and potential resources in advance of human exploration;
3. Perform fundamental research of, on and from the Moon.

Based on the responses received to a Request For Information issued early this year to the broad Euorpean community, this Team will identify the mission objectives and requirements from which the model payload considered for the phase B1 study will be derived.

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GEOLAB 2010: DESERT RATS FIELD DEMONSTRATION. C.A. Evans[1], M.J. Calaway[2], and M.S. Bell[2], [1]Astromaterials Acquisition and Curation Division, NASA Johnson Space Center , Mail Code KT, 2101 NASA Parkway, Houston, TX 77058, cindy.evans-1@nasa.gov; [2]Jacobs Technology (ESCG) at NASA JSC

Introduction: In 2010, Desert Research and Technology Studies (Desert RATS), NASA's annual field exercise designed to test spacesuit and rover technologies, will include a first generation lunar habitat facility, the Habitat Demonstration Unit (HDU). The habitat will participate in joint operations in northern Arizona with the Lunar Electric Rover (LER) and will be used as a multi-use laboratory and working space. A Geology Laboratory or GeoLab is included in the HDU design.

Historically, science participation in Desert RATS exercises has supported the technology demonstrations with geological traverse activities that are consistent with preliminary concepts for lunar surface science Extravehicular Activities (EVAs). Next year's HDU demonstration is a starting point to guide the development of requirements for the Lunar Surface Systems Program and test initial operational concepts for an early lunar excursion habitat that would follow geological traverses along with the LER. For the GeoLab, these objectives are specifically applied to support future geological surface science activities. The goal of our GeoLab is to enhance geological science returns with the infrastructure that supports preliminary examination, early analytical characterization of key samples, and high-grading lunar samples for return to Earth [1, 2].

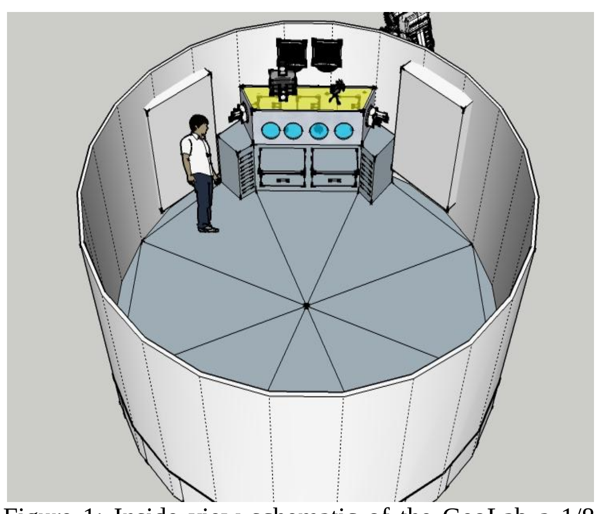

Figure 1: Inside view schematic of the GeoLab a 1/8 section of the HDU, including a glovebox for handling and examining geological samples. Other outfitting facilities are not depicted in this figure.

GeoLab Description: The centerpiece of the GeoLab is a glovebox, allowing for samples to be brought into the habitat in a protected environment for preliminary examination (see Fig. 1). The glovebox will be attached to the habitat bulkhead and contain three sample pass-through antechambers that would allow direct transfer of samples from outside the HDU to inside the glovebox. We will evaluate the need for redundant chambers, and other uses for the glovebox antechambers, such as a staging area for additional tools or samples. The sides of the glovebox are designed with instrument ports and additional smaller ports for cable pass-through, imagery feeds and environmental monitoring. This first glovebox version will be equipped with basic tools for manipulating, viewing, and early analysis of samples. The GeoLab was also designed for testing additional analytical instruments in a field setting.

Operational Evaluation: The GeoLab will be evaluated based on how well it interfaces with the rover and EVA operations, as well as the potential science value a shirt-sleeve laboratory will bring to a lunar mission. We will design tests to evaluate the laboratory facility in general, the glovebox design and operations, and the instruments used with the glovebox. We will use these field tests to develop and assess preliminary crew and science support "back-room" procedures, and to test sample handling protocols for key samples in order to best support informed decisions about planned traverses, sample priorities and sample return [1, 2].

Anticipated outcomes: GeoLab will enable the development of advanced laboratory concepts (both lab & field tools) and the sample handling protocols required for efficient field campaigns and initial curation efforts that control contamination and preserve pristine samples collected during exploration missions. Assessment of the laboratory operations will drive the definition of requirements and the advancement of new technologies for handling and examining extraterrestrial samples, and transporting them back to Earth.

GeoLab capabilities and the derived operational concepts will also provide a venue for participation by the science team in surface mission planning for future exploration missions. Through GeoLab deployment and operations, we will gain a practical understanding of the field operations and performance of a specific habitat laboratory facility so that we can confidently work with mission planners to optimize astronaut activities on the lunar surface.

References: [1] Treiman, A.H. (1993) Curation of Geological Materials at a Lunar Outpost, JSC-26194 and Office of the Curator Publication #187. [2] Shearer, C. et al. (2009) Review of Sample Acquisition and Curation During Lunar Surface Activities, LEAG and CAPTEM White paper, in press.

Lunar Construction Material Production Using Regolith Simulant in a Geothermite Reaction. E. J. Faierson[1] and K. V. Logan[1], [1]National Institute of Aerospace – Virginia Tech, 100 Exploration Way, Hampton, VA, 23666 USA, Corresponding author E-mail: faierson@vt.edu

Establishing a permanent human presence on the Moon will necessitate the use of in-situ resources to both reduce launch costs and conserve space within the launch vehicle. Experiments have shown that a chemical reaction can be initiated by applying heat to a mixture of lunar regolith simulant and aluminum powder. The reaction between regolith simulant and aluminum powder exhibited characteristics of a thermite-type reaction and is shown in Figure 1. Thermite-type reactions between minerals and a reducing agent are referred to as geothermite reactions by the authors.

Figure 1. Propagation of a geothermite reaction through a cylinder sample

The product of the geothermite reaction examined in this study was a ceramic-composite material with a near-net shape. Experiments have primarily been conducted in a standard Earth atmosphere; some experiments have been conducted in a vacuum (~0.6 Torr) environment.

X-Ray Diffraction (XRD) analyses indicated that silicon, grossite ($CaAl_4O_7$), corundum (Al_2O_3), and spinel ($MgAl_2O_4$) were common chemical species present within the reaction product, both in standard and vacuum environments.

Scanning Electron Microscopy (SEM) analyses have indicated growth of nano-scale whiskers in the standard atmosphere reaction products as shown in Figure 2. Energy Dispersive Spectroscopy (EDS) indicated that the nano-scale whiskers were primarily composed of aluminum nitrides, indicating interaction with atmospheric gases.

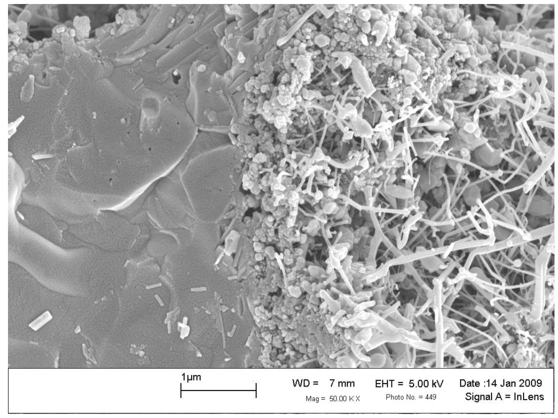

Figure 2. Growth of aluminum nitride nano-whiskers on the surface of a particle

Mechanical testing has indicated that reactant proportions and simulant particle size can affect the compressive strength of the reaction product formed in a standard atmosphere. Mean compressive strengths up to 18 ± 3.7 MPa were measured. Whiskers of aluminum nitride likely increased the strength of the reaction products.

The product of the geothermite reaction has potential for use in landing pads, blast berms, roadways, radiation shielding, and micro-meteoroid shielding on the lunar surface. Using the reaction product in some of the above applications could also mitigate lunar dust issues.

Future work will involve further experiments in vacuum and utilization of a solar furnace to initiate the geothermite reaction. Use of a solar furnace would be an efficient way to implement the geothermite reaction on the Moon due to availability of sunlight.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared:	10-19-2009
Presenter's Name:	Robert J. Ferl
Presenter's Title:	Professor and Director of Biotechnology
Presenter's Organization/Company:	University of Florida

Presentation Title

Lunar sample requirements for biology; plant responses to lunar regolith in support of human missions and as a measure of lunar biological responses.

Key Ideas

Science on the moon - extraterrestrial biology
In situ resource utilization – lunar regolith as a plant growth substrate
What do we need to know before we go?

Supporting Information

Recent plans for human return to the Moon have significantly elevated scientific interest in the lunar environment with emphases on the science to be done in preparation for the return and the science to be done while on the lunar surface. Since the return to the Moon is envisioned as a dedicated and potentially longer term commitment to lunar exploration, questions of the lunar environment and particularly its impact on biology and biological systems have become a significant part of the lunar science discussion.

Plants are integral to the discussion of biology on the Moon. Plants are envisioned as important components of advanced habitats and fundamental components of advanced life support systems. Moreover, plants are sophisticated multicellular eukaryotic life forms with highly orchestrated developmental processes, well characterized signal transduction pathways and exceedingly fine tuned responses to their environments. Therefore plants represent key test organisms for understanding the biological impact of the lunar environment on terrestrial life forms. Indeed, plants were among the initial and primary organisms that were exposed to returned lunar regolith from the Apollo lunar missions, as represented by a large body of literature by Charles Walkinshaw and colleagues in the early 1970's. In these studies plants were *exposed* to a variety of lunar materials while growing in terrestrial substrates, a setup designed to maximize information on biotoxicity but a setup that does not address biological reactions to lunar regolith. Contemporary tools can significantly expand on the amount of information that can be collected on the biological impact of lunar materials on terrestrial biology. The sophisticated genomics, proteomics and metabolomics tools of the modern molecular era that were not available during the initial biological experiments of the Apollo era can now be applied to a robust characterization of plant responses to lunar regolith, which would inform the approaches we take for in situ resource utilization for lunar sortie and outpost missions. Further, the development of small model systems, such as the plant *Arabidopsis thaliana*, enables the use of undiluted materials that would better mimic true in situ utilization parameters.

ANALYTIC SHIELDING OPTIMIZATION TO REDUCE CREW EXPOSURE TO IONIZING RADIATION INSIDE SPACE VEHICLES. Razvan Gaza[1], Tim P. Cooper[1], Arthur Hanzo[1], Hesham Hussein[1], Kandy S. Jarvis[1], Ryan Kimble[1], Kerry T. Lee[2], Chirag Patel[1], Brandon D. Reddell[1], Nicholas Stoffle[2], E. Neal Zapp[2], and Tad D. Shelfer[1]

[1]Lockheed Martin, 2625 Bay Area Blvd, Houston, TX 77058
[2]NASA, Johnson Space Center, MC SF21, Houston, TX 77058

A sustainable lunar architecture provides capabilities for leveraging out-of-service components for alternate uses. Discarded architecture elements may be used to provide ionizing radiation shielding to crew habitats in case of a Solar Particle Event. The specific location relative to the vehicle where the additional shielding mass is placed, as corroborated with particularities of the vehicle design, has a large influence on protection gain. This effect is caused by the exponential-like decrease of radiation exposure with shielding mass thickness. Consequently, the most benefit from a given amount of shielding mass is obtained by preferentially supplementing thinly shielded regions of the vehicle exposed to the radiation environment.

A novel analytic technique to derive an optimal shielding configuration was developed by Lockheed Martin during Design Analysis Cycle 3 (DAC-3) of the Orion Crew Exploration Vehicle (CEV). [1] Based on a detailed Computer Aided Design (CAD) model of the vehicle including a specific crew positioning scenario, a set of under-shielded vehicle regions can be identified as candidates for shielding augmentation. Analytic tools are available to allow visualization of an idealized supplemental shielding distribution in the CAD environment, which in turn is used as a reference for deriving a realistic shielding configuration from available vehicle components.

While the analysis referenced in this communication applies particularly to the Orion vehicle, the general method can be applied to a large range of space exploration vehicles, including but not limited to lunar and Mars architecture components. In addition, the method can be immediately applied for optimization of radiation shielding provided to sensitive electronic components.

References:

[1] Lockheed Martin, DRD CEV-T-045001 "Project Orion: CEV Space Radiation Analysis and Certification Report", NASA Deliverable (2009)

LUNAR BEAGLE: THE SCIENTIFIC PACKAGE FOR ANSWERING IMPORTANT QUESTIONS ABOUT LUNAR WATER AND POLAR VOLATILES. E.K. Gibson[1], C.T. Pillinger[2], L. Waugh[3], I.P. Wright[2], M.R. Sims[4], D.S. McKay[1], and L. Richter[5]. [1]KR, ARES, NASA Johnson Space Center, Houston, TX 77058, [2]Planetary and Space Sciences Research Institute, The Open University, Milton Keynes MK7 6AA, UK, [3]EADS Astrium, Stevenage, UK, [4]Dept. of Space Sciences, Leciester University, Leicester, UK and [5]Deutsches Zentrum fur Luft- und Raumfarht, DLR Cologne, Germany. [everett.k.gibson@nasa.gov].

The Lunar Beagle package is the ideal payload to use on the lunar surface for determining the nature of hydrogen, water and lunar volatiles found in the polar regions of the Moon.

The Lunar Beagle payload can operate with minimal human interaction or completely autonomously on the lunar surface. This system is analogous to the ALSEP instruments used on the Apollo missions. The adaptation of scientific payloads developed for other planetary missions, such as those of Beagle 2, has the major advantage of having already established resource requirements, including mass, power and data transmission capabilities and cost.

The Beagle 2 payload was designed to operate on the Martian surface in an autonomous manner. It can be easily adapted to operate autonomously on the lunar surface and is suitable for both a robotic lander or a human mission. In a human mission, once deployed on the surface, Lunar Beagle would require minimal crew interaction and could send data directly back to Earth without further crew attention. Its size allows for inclusion with a lunar rover mission. Key instruments include a magnetic sector mass spectrometer to analyze volatile species [H, D/H, water abundances and other potential carbon containing molecules (i.e., hydrocarbons?)] trapped in cold regions of the moon, instruments for assessing elemental composition of the lunar soils and rocks, and a range of spectrometers capable of fully determining rock and soil mineralogy.

The Gas Analysis Package (GAP) instrument suite was the most sophisticated mass spectrometer ever sent to Mars, and the first with a real chance of documenting isotopic biosignatures in the soil and rock record. Application of the Beagle technology to answer the lunar hydrogen and H_2O question seems obvious. Measurement of the isotopic composition of polar volatiles will distinguish whether the water and associated volatiles are derived from cometary volatiles, the solar wind, a magmatic source and/or meteoritic. The presence of a lunar vacuum will significantly reduce the mass and power requirements for the GAP and simplify its design and operation, compared to the baseline Martian design that includes a vacuum pump.

Best of all, the Beagle instrument package has already been designed, built, extensively tested in the laboratory, and flight qualified for the mission to Mars. Extensively testing already done on Earth can be used for evaluation of the Beagle concept applied to the Moon.

The instrumentation onboard the Lunar Beagle with its Gas Analysis package (GAP) and Position Adjustable Workstation (PAW) sampling arm can provide science answers (i.e. *in situ* noble gas ages) and document potential lunar resources. The primary Beagle sampling device (MOLE) can obtain subsurface samples and would be ideal for seeking out subsurface ices. The GAP can provide information on hydrogen abundances in the lunar polar regions, possible ice concentrations beneath the surface, and provide direct abundances and isotopic measurements of any trapped meteoroid or cometary volatiles in the permanently shadowed regions. Hydrogen isotopic compositions will assist in the identification of its origin (i.e. solar wind or cometary). These measurements will provide keystone data points which can be utilized in answering the lunar availability question and assist in planning for "living off the land concepts".

A Combined Chemical-Electric Propulsion Architecture for Lunar and Planetary Exploration. T. W. Glover, A. V. Ilin[1], R. Wilks[2], R. Vondra[3] [1]Ad Astra Rocket Company, 141 W. Bay Area Blvd., Webster, TX 77598 tim.glover@adastrarocket.com, andrew.ilin@adastrarocket.com [2] rodney.wilks@atk.com , [3] P. O. Box 596, Wrightwood, CA 92397 bob.vondra@gmail.com

Abstract: ATK and Ad Astra Rocket Company have examined the use of an advanced space propulsion system for use in lunar and planetary exploration missions. Ad Astra's Variable Specific Impulse Magnetoplasma Rocket (VASIMR®) plasma rocket technology, currently under development, when integrated into an Orbital Transfer Vehicle (OTV), offers the ability to transfer large payloads using much less propellant than chemical rockets and significantly reduced transit times for high Δv missions. The combined system results in a highly flexible architecture that can be scaled easily to meet a range of payload and program needs.

Low-power (less than 10 kW) electric propulsion has been successfully used to enhance chemical propulsion for lunar (SMART-1) and planetary (DAWN) exploration missions. Ad Astra Rocket Company is developing a 200 kW thruster that could provide significantly more performance than previous electric propulsion systems. This new capability could play a significant role in enhancing near-term lunar exploration capabilities and longer term planetary missions. The VASIMR® engine differs from ion engines and Hall thrusters in that it uses abundant (and hence inexpensive) argon as its propellant, and places no solid components in contact with energized plasma, thereby mitigating most erosion mechanisms. Under a NASA Space Act Agreement, Ad Astra is planning a space test of the VASIMR® engine on the International Space Station in 2013, to verify the engine's performance in the space environment.

Anticipating a wide range of lunar and planetary exploration programs undertaken by both NASA and international agencies, Ad Astra and ATK have examined the utility of a reusable OTV that can enable lower cost missions. By using argon, Ad Astra's VASIMR® engine reduces propellant costs for its electric propulsion by a factor of 100 relative to xenon-based thrusters. With continuous thrust from the VASIMR® engine during a cis-lunar or planetary transit, a continuous trade between payload mass and transit time is available to mission designers. The high specific impulse (greater than 500 seconds) employed on such trajectories dramatically reduces the vehicle mass fraction required for propellant. Not only will this enable larger payloads but, for sample return, this can significantly raise the return payload mass as well.

A YOUNG PROFESSIONAL'S PERSPECTIVE ON THE HUMAN WORKFORCE GAP IN THE SPACE INDUSTRY.

M. Gordon[1], L. Phonharath[2], G. J. Slavin[3], and J. K. Tramaglini[4].
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Introduction: As Neil Armstrong transcended on the surface of the moon and took his first steps, he uttered the infamous line, "That's one small step for man, one giant leap for mankind." July 20, 1969 proved to be one of America's greatest achievements and revolutionized the journey through the frontiers of space. This feat indicated the commencement of an era for great ambition in the future of human space exploration. It should be acknowledged that our last human embarkment on the lunar surface occurred 37 years ago! With the magnitude of success exhibited within space exploration, we are now confronted with a new and more frightening challenge: a gap in the aerospace workforce. According to current NASA Science and Engineering population statistics in Figure 1, nearly 87% of its workforce is of the age 35 and older. Of that 87%, 45% of those individuals will be eligible for retirement within the next five years [1]. Now is the time for NASA and its strategic partners to collaborate on the best possible solutions for investing in the education of the future workforce to ensure sustainability of the Lunar Exploration Roadmap. In order to continue our success in space exploration, it is crucial to raise awareness through open forms of communication, educational outreach, and leveraging media outlets.

Measures:

(1) Communication: NASA and its global network need to engage and communicate with the community on the importance and relevance their space-age technologies facilitate in the advancement of this nation. Time should be allotted for those willing to volunteer for community outreach programs that will inspire and inform teachers, students, and the community regarding scientific and technological developments and opportunities.

(2) Education: The global community needs to educate teachers and students in the classroom on the growing need for science and engineering professionals in the coming era and inspire students to believe that a career in the space industry is attainable.

(3) Media: Leveraging the proper media outlets will exponentially increase the amount of support that exists for the space industry. Community websites such as Facebook, Twitter, and YouTube can be utilized to keep open communications with those individuals not closely tied to the scientific community. NIKE, Bridgestone and Energizer have all capitalized on NASA's innovation, technology and successes from the space program. Their products and advertisements provide evidence of these endeavors. Through the use of media outlets, the success and interactive products made possible through the exploration of space can be used to increase awareness and support for future space exploration initiatives.

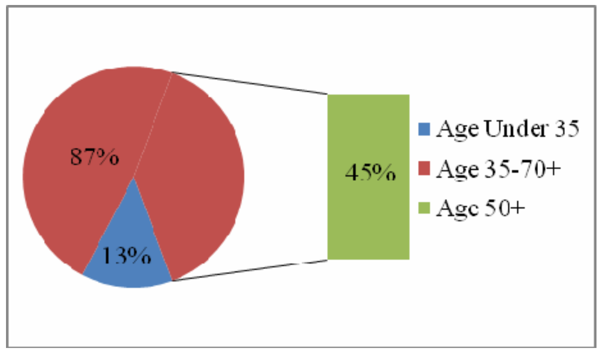

Figure 1: Workforce profile on the number of employees based on age classification in the Science and Engineering occupation across all NASA Centers.

Results and Discussions: A solid and robust plan to invest in education is critical to the sustainability and continuation of lunar and space exploration. Investing in education and community outreach programs invests in the innovation of the future workforce. The space-age technologies developed by NASA and its global network fuels the economy through alternative applications or spinoffs which gives the competitive edge America needs to sustain in its economic growth among international partners. By investing in the aforementioned activities, it ensures that America continues its leadership role amongst international partners in the areas of space and lunar exploration.

References:

[1] M. McCann. (2009). *NASA Workforce Profile*. Retrieved September 12, 2009, from NASAPeople Office of Human Capital Management http://nasapeople.nasa.gov/workforce/default.htm.

LUNAR CRATER OBSERVATION AND SENSING SATELLITE (LCROSS) MISSION: PRELIMINARY REPORT ON THE LCROSS OBSERVATION CAMPAIGN RESULTS. J.L. Heldmann[1], T. Colaprete[1], D. Wooden[1], and the LCROSS Astronomer Team, [1]NASA Ames Research Center, Moffett Field, CA, 94035

Introduction: The primary objective of the LCROSS (Lunar Crater Observation and Sensing Satellite) mission is to confirm the presence or absence of water ice on the Moon. The LCROSS mission, which launched with the Lunar Reconnaissance Orbiter in June 2009, will use the Atlas V Centaur Earth departure upper stage of the launch vehicle as a kinetic impactor. The impact creates an ejecta plume whose properties, including water ice and vapor content, will be observed by the LCROSS shepherding spacecraft (S-S/C) plus Earth- and space-based telescopes. Following a similar trajectory of the Centaur, the S-S/C will fly through the Centaur impact plume and then the S-S/C will also impact the Moon. The S-S/C impact will likely also be observable to ground-based and space-based telescopes.

Impact Observing Information: The LCROSS impacts are scheduled for ~11:30 UTC on October 9, 2009. We estimate that the Centaur impact debris plume should be in view several seconds after Centaur impact and will peak in brightness at 30 to 100 seconds after impact. If water is lofted above the lunar surface then the photodissociation process could also result in the presence of an OH atmosphere which could persist for several hours to days.

The LCROSS mission is currently targeting the Cabeus A crater. The selection of Cabeus A was based on a set of conditions that include proper debris plume illumination for visibility from Earth, a high concentration of hydrogen, and mature crater features such as a flat floor, gentle slopes and the absence of large boulders. All of these characteristics will help ensure a plume that can be observed from the variety of assets participating in the LCROSS Observation Campaign. In addition, Cabeus A is on the nearside of the Moon and thus this region is visible to telescopes on the ground to enable Earth-based observations. The LCROSS Team may retarget a different location on the Moon in the event of additional data and/or information suggesting a more optimal impact location.

Observational Support: This paper presents a preliminary report from the LCROSS Observation Campaign. Numerous ground and space-based observing assets plan to observe these impacts through a coordinated observation campaign effort. Professional astronomer teams have been integrated into the LCROSS Science Team in order to facilitate observation planning (e.g. time and location of impact, science expertise regarding mission objectives, identification of scientific synergies amongst observations, etc). The Observation Campaign members have worked together on pre-planning activities (including pointing methodology, generation of image mosaics and lighting models, etc.) as well as planning for the analysis of observations post-impact. The synthesis of observations from multiple observing platforms and a variety of wavelength regimes and instruments provides a unique perspective from which to maximize the amount of information learned from this unique lunar impactor mission.

ELECTROSTATIC AND ELECTROMAGNETIC CLEANING OF LUNAR DUST ADHERED TO SPACESUITS. H. Kawamoto, Dept. of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan, kawa@waseda.jp

Introduction: Cleaning of lunar dust adhered to astronaut spacesuits is of critical importance for long-term lunar exploration. We are developing three kinds of cleaning devices that involve the use of electrostatic and magnetic forces.

Electrostatic Flicker: This system employs an alternating electrostatic field that forms a barrier on the surface of fabrics. Two-phase rectangular voltage is applied to parallel wires stitched into the insulating fabric, as shown in Fig. 1. Since a traveling wave is not generated by application of two-phase voltage, particles are not transported in one direction but are flicked outwards from the fabric. A lunar dust simulant was placed on the fabric and the fabric was mounted perpendicularly. Two-phase voltage was applied to parallel wires that were stitched into the fabric. Particles flicked and removed onto the floor were weighed and the cleaning rate, i.e., the ratio of flicked particles to initial particles, was determined. It was observed that the cleaning rate was less than 30%. It was difficult to flick out the dust trapped between fibers of the fabric. Thus, there is a need for further improvement in the system performance.

Electrostatic Cleaner: This system employs a combination of electrostatic separation and electrostatic transport, as shown in Fig. 2. The spacesuit fabric is placed between the lower plate electrode and the upper electrode, which contains holes. A high voltage is applied between the upper and lower electrodes. A Mylar sheet positioned under the surface fabric acted as the lower electrode. Because of the electrostatic force dust adhered to the fabric is captured by the holes of the plate electrode. The captured dust is transported by the traveling wave[1] and transferred to the collecting bag. The observed cleaning rate was less than 60%. As in the case of the electrostatic flicker, removing dust trapped between fabric fibers was difficult.

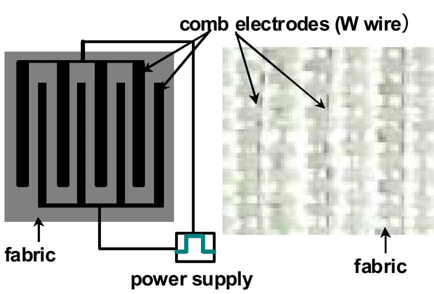

Figure 1: Electro-static flicker of dust.

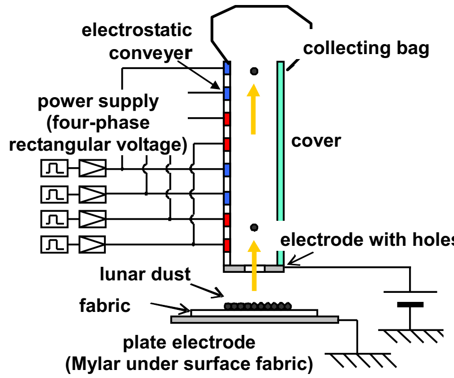

Figure 2: Electrostatic cleaner.

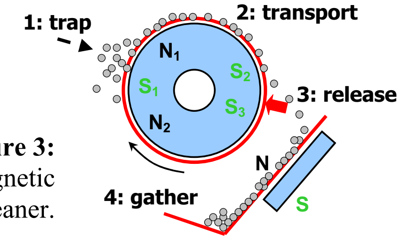

Figure 3: Electromagnetic cleaner.

Magnetic Cleaner: The operation of this device is based on the fact that lunar dust is magnetic. The device consists of a shaft, stationary multi-pole magnetic roller, rotating sleeve, plate magnet, and collection bag as shown in Fig. 3.[2] Magnetic lunar dust is attracted to the stationary magnetic roller and transported via the rotating sleeve by means of magnetic and frictional forces. The magnetic roller is designed such that a repulsive force acts on the particles at a certain position (indicated by the arrow shown in Fig. 3). When the dust is transported to this position, particles are separated from the sleeve, and are attracted to the plate magnet facing the release position. The dust particles then gather in the collecting bag that covers the plate magnet. The advantages of the system are that it is very simple, and that it works without power consumption. The observed separation rate was almost 100%, but capture rate was 40%. Therefore, the total cleaning rate was 40%. We are now developing a magnetic roller made of rare-earth magnets, to increase the magnetic force for the capturing process.

Samples of the fabric were provided by ILC Dover and Oceaneering Space Systems.

References: [1] Kawamoto H, Seki K and Kuromiya N. (2006) J. Phys. D: Appl. Phys., 39, 1249-1256. [2] Kawamoto H., Inoue H. and Abe Y. (2008) LEAG-ICEUM-SRR, 71.

MITIGATION OF LUNAR DUST ADHERED TO MECHANICAL PARTS OF EQUIPMENTS USED FOR LUNAR EXPLORATION. H. Kawamoto[1] and T. Miwa[1], [1]Dept. of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan, kawa@waseda.jp

Introduction: The lunar surface is covered by a regolith (soil) layer; approximately 20% of this material by volume consists of particles less than 20 μm in diameter. Because of its small size and the low gravity, lunar dust is easily lofted when any disturbance occurs. The airborne dust might adhere to mechanical parts of equipment and get into bearings and seals; such a situation could lead to catastrophic damage. To overcome this problem, we have developed a barrier system that employs an electrostatic field to flick out and remove the lunar dust from the surface of mechanical parts.

System Configuration: A two-phase rectangular voltage is applied to the parallel electrodes printed on a plastic substrate in order to flick out the lunar dust on the flicker plate. The setup is shown in Fig. 1. Because a traveling wave is not generated by the application of two-phase voltage, particles are not displaced in one direction but are flicked out from the plate. An alternating electrostatic field acts as a barrier against the dust. Particles less than 60 μm in diameter were sieved from lunar dust stimulant FJS-1 for these experiments.

Results and Discussion: While several conventional techniques are available for the removal of large particles, removal of small particles is difficult. The flicker plate was inclined at an angle of 40 degree, and small dust particles were placed on it. Two-phase rectangular voltage was applied to the parallel electrodes printed on the flicker substrate, and the particles flicked onto the floor were weighed in order to determine the separation rate.

The determined separation rate, i.e., the ratio of removed dust to initial dust amounts, with respect to applied voltage and frequency is shown in Figs. 1 and 2, respectively. Dust on the flicker plate was removed at a threshold voltage of 0.4 kV. The separation rate increased with an increase in applied voltage up to 1.2 kV, but remained constant at voltages above 1.2 kV. On the other hand, the separation rate was almost independent of the frequency up to 100 Hz.

The observed separation rate was less than 70%. However, an investigation of electrostatic transport by means of the traveling wave revealed that system performance can be improved by applying ultrasonic vibration.[1] Numerical calculations using a 3D distinct element method[2] estimated that performance would further improve in the low gravity and vacuum environment on the Moon.

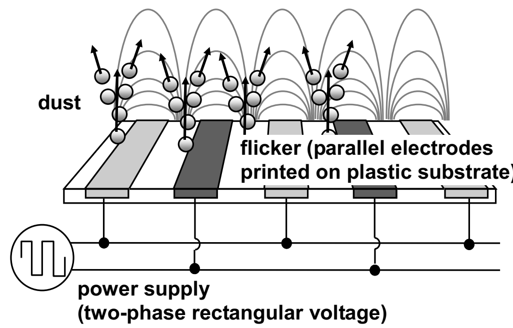

Figure 1: Electrostatic lunar dust flicker.

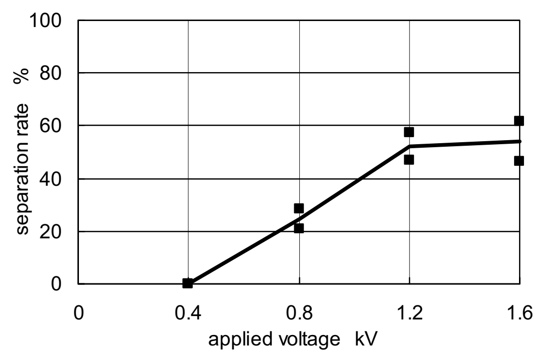

Figure 2: Separation rate with respect to applied voltage.

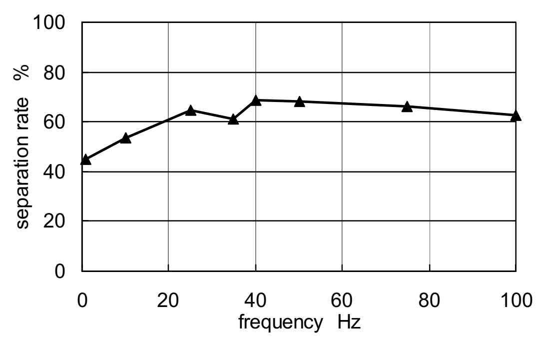

Figure 3: **S**eparation rate with respect to frequency.

References: [1] Kawamoto H, Uchiyama M, Cooper L and McKay D S (submitted) J. Aerospace Eng., [2] Kawamoto H, Seki K and Kuromiya N. (2006) J. Phys. D: Appl. Phys., 39, 1249-1256.

MITIGATION OF LUNAR DUST ON SOLAR PANELS AND OPTICAL ELEMENTS FOR LUNAR EXPLORATION UTILIZING ELECTROSTATIC TRAVELING-WAVE. H. Kawamoto[1], M. Uchiyama[1], B. L. Cooper[2] and D. S. McKay[3], [1]Dept. of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan, kawa@waseda.jp; [2]Oceaneering Space Systems, 16665 Space Center Blvd., Houston, TX 77058-2268; [3]Johnson Space Center, NASA, 2101 NASA Parkway, Houston, TX 77058.

Introduction: The lunar surface is covered by a layer of regolith (soil), and approximately 20% by volume of this material consists of particles less than 20 μm in diameter. Because of its small size and the low gravity, lunar dust is easily lofted when any disturbance occurs. The dust then covers solar panels and optical elements such as lenses and mirrors, causing degradation of their optical performance. To overcome this problem, we have developed a cleaning system that employs electrostatic traveling-waves for removing lunar dust. [1], [2]

System Configuration: The developed cleaner system is shown in Fig. 1. The conveyer consists of transparent ITO electrodes printed on a glass substrate. Traveling-wave propagation is achieved utilizing a set of positive and negative amplifiers controlled by a microcomputer. Four-phase rectangular voltage is applied to the electrodes because it is most efficient compared to sine or triangular waves. The power system is designed to be simple, small, and lightweight for space applications.

Results and Discussion: The following features have been clearly demonstrated:

(1) A simple power supply was developed for the cleaning system. Power consumption was as low as 0.06 Wh for cleaning an area of 1 m^2.

(2) More than 98% of the dust could be removed in vacuum as shown in Fig. 2. The transmission rate of light was reduced only a few percent when ultrasonic vibrations were used in conjunction with the traveling-waves. The amount of residual dust increased slightly over repeated tests; reducing a saturation level which did not seriously affect light transmission, as shown in Fig. 3.

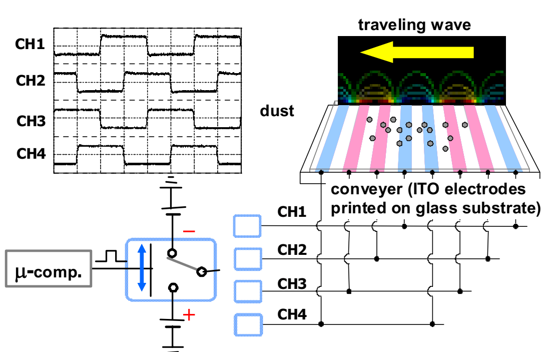

Figure 1: Electrostatic cleaning system.

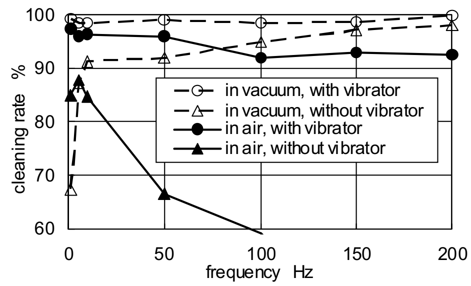

Figure 2: Performance of electrostatic cleaner.

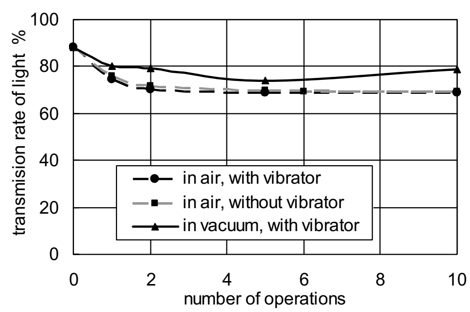

Figure 3: Decrease in averaged transmission rate of light due to increase in residual dust on conveyer.

(3) Both positively and negatively charged dust particles (as well as electrically neutral particles) could be cleaned without changing the system configuration.

(4) From the results of a numerical investigation based on a 3D distinct element method, it is predicted that the performance of the system will improve in the low-gravity environment on the Moon.

(5) On the basis of these investigations, we have successfully demonstrated the removal of actual lunar dust returned by the Apollo 11 lunar surface mission. It was easier to remove actual lunar dust than the widely used simulant JSC-1A. Cleaning performance of the system is expected to further improve in the low-gravity environment of the Moon. Evaluation with simulants on the Earth is a conservative approach.

A part of this study was supported by a Grant-in-Aid for Scientific Research (B) from the Japan Society for the Promotion of Science.

References: [1] Kawamoto H, Seki K and Kuromiya N. (2006) J. Phys. D: Appl. Phys., 39, 1249-1256. [2] Kawamoto H and Uchiyama M. (2008) LEAG-ICEUM-SRR, 72.

NASA Orphan Equipment List for Lunar Science

NASA/JSC – Rob Kelso

NASA/Ames – Bruce Pittman

The Commercial Lunar Services Office at NASA JSC recently initiated a study to qualify and quality science instruments that may be available to fly on commercial lunar missions connected to the Google Lunar X Prize. The first of these missions could occur as soon as 2012. This survey is focused on identifying flight spares, prototype units, or other developmental units that could be used as early demand for lunar lander flights. This list is being compiled from the NASA field centers, various research institutes and some universities. The list will be cross-linked to the LEAG Lunar Roadmap in assessing potential high value science at low cost.

Commercial ISRU Flight Demonstrator – MINER

NASA/JSC – Rob Kelso

NASA/JSC – Jerry Sanders

NASA/GRC - Kurt Sacksteder

NASA/Ames – Bruce Pittman

NASA has performed several recent assessments relative to a possible oxygen extraction demonstration at the lunar surface. The project is entitled: Mini-ISRU Nodal Evaluation of Regolith (MINER). The concept is to leverage commercial capabilities and partner with NASA to demonstrate ISRU O2 production within a lunar flight experiment. A costing analysis was performed to quantify the financial value of producing oxygen at the lunar surface (ISRU) for a lunar outpost versus the cost of transporting the oxygen from earth-to-moon. A second assessment will be performed to provide sufficient design and analysis to develop system definition, potential project team, and project schedule and budget, and to determine mass, power, and volume estimates. A brief summary of the costing assessment and Pre-Phase A study will be presented.

Low-Cost Commercial ISRU Flight Demonstrator – MINER

Rob Kelso & Jerry Sanders, NASA/JSC

Kurt Sacksteder, NASA/GRC

Bruce Pittman, NASA/ARC

While the production of oxygen, water, and propellants on the Moon from in-situ resources holds great promise for reducing the cost and risk of robotic and human exploration, NASA mission architects and planners are hesitant to rely on this ability for mission success until it has been adequately proven to be cost effective and technically achievable. One way to gain confidence in this new approach to exploration, known as In-Situ Resource Utilization (ISRU), is to perform subscale demonstrations on robotic precursor missions to verify critical processes and steps involved in in-situ processing, as well as verify critical engineering design factors to allow confidence in finalizing the full scale system design (ex. forces exerted in excavation, time and energy required to extract resource, etc.). NASA has performed several recent preliminary assessments relative to a possible oxygen extraction from regolith demonstration on the lunar surface. The project, entitled: Mini-ISRU Nodal Evaluation of Regolith (MINER), is aimed at leveraging past and current Mars robotic science exploration hardware with on-going lunar ISRU volatile and oxygen extract from regolith development to create a low mass and low power ISRU demonstration package. The concept is to leverage commercial capabilities and international partnerships with NASA in an effort to lower the cost of the demonstration(s) and potentially led to commercialization of oxygen production on the Moon. A costing analysis was performed to quantify the financial value of producing oxygen at the lunar surface (ISRU) for a lunar Outpost versus the cost of transporting the oxygen from Earth-to Moon for both life support and early propulsion needs. A second assessment was to performed to determine initial mass, power, and volume estimates for an subscale ISRU demonstration that heavily leverages past and current hardware designs. A brief summary of the costing assessment and demonstration sizing study will be presented.

THE LUNAR RADIO ARRAY. J. Lazio[1], C. Carilli[2], J. Hewitt[3], S. Furlanetto[4], and J. Burns[5] for the LUNAR Consortium[6] [1]Naval Research Laboratory, Lazio@nrl.navy.mil, [2]National Radio Astronomy Observatory, [3]Kavli Institute for Astrophysics & Space Research, MIT, [4]UCLA, [5]U. Colorado, Boulder, [6]NASA Lunar Science Institute.

Cosmology and Astrophysics with the Highly-Redshifted 21-cm Line: Hydrogen is the dominant component of the intergalactic medium, and neutral hydrogen (H I) displays a hyperfine spin-flip transition at a rest wavelength of 21 cm (1420 MHz frequency). The feasibility of observing this redshifted H I line has excited interest because it offers the chance to extend current cosmological data sets by orders of magnitude[1,2]. Through detailed mapping of the H I line brightness temperature, it may be possible to determine the distribution of hydrogen from the present day to a redshift $z \sim 100$. This unprecedented data set would constrain the properties of the inflation era, detect signatures of any exotic heating before the first star formation (e.g., dark matter decay), and constrain properties of "dark energy" by tracking the evolution of the angular scale of the baryon acoustic oscillations. It would also provide a wealth of astrophysical data on the first galaxies, including the properties of the first stars and black holes.

The Moon as an Astronomical & Cosmological Platform: The lunar *farside* is the only site in the inner solar system for observing the highly-redshifted 21-cm line:

No Human-generated Interference. Civil and military transmitters make heavy use of the relevant spectrum (e.g., FM radio), and ionospheric refraction causes interference in the HF band used for international communication to be independent of location on Earth. Terrestrial transmitters can be much stronger ($\sim 10^{12}$) stronger than the H I signals. The Moon reduces such interference to a negligible level.[3]

No (Permanent) Ionosphere. The Earth's ionosphere produces phase errors that limit radio observations (in addition to reflecting interference from distant transmitters). The Moon's ionized layer disappears during lunar night.

Shielding from Solar Radio Emission. When the Sun bursts, it is the strongest celestial source at these wavelengths. The only mitigation for solar radio emissions is physical shielding, such as observing on the farside during lunar night.

Mission Description: The LRA concept draws on the experience from ground-based radio interferometers. The LRA will be located on the lunar farside, e.g., Tsiolkovsky crater, with components delivered using a heavy-lift vehicle (e.g., Ares V) and lander (e.g., Altair cargo). Unpacking and antenna deployment will be handled by rovers. A central processing unit on the lander will serve as a control and communications center.

Technology Development. We have identified technologies that need to mature over the next decade in order to enable the LRA: (1) Long-wavelength, low-mass science antennas; (2) Ultra-low power, radiation tolerant electronics; (3) Autonomous, low power generation; (4) Low-mass, high-capability, autonomous rovers; and (5) High data rate, lunar surface data transport. Many of these technologies are broadly relevant, beyond just the LRA.

Roadmap. Many ground-based radio arrays have been preceded by scientifically productive prototypes, and ground-based arrays will provide important scientific pathfinding for the LRA. An illustration of the staged deployment of lunar radio telescopes is

I. One dipole deployed on an orbiter or on the near side, such as the Lunar Array Precursor Station (LAPS), a concept developed under the Lunar Sortie Science Opportunities (LSSO) program. Key science would be searching for the H I signature from the Epoch of the First Stars or probing the lunar ionosphere.
II. A small, near-side interferometer, such as the Radio Observatory for Lunar Sortie Science (ROLSS), a concept developed under the LSSO program. Key science would be particle acceleration in the inner heliosphere. Deployment could be done either robotically or with astronaut assistance in a sortie scenario.
III. A modest-sized interferometer. Key science would include extending ground-based observations of the 21-cm line and potentially detecting magnetospheric emissions from extrasolar planets. Deployment would be largely robotic.
IV. The fully capable LRA on the far side.

The Lunar University Network for Astrophysics Research (LUNAR): Science and technology development for the LRA are being conducted in LUNAR, one of the inaugural 7 teams in the NASA Lunar Science Institute (NLSI). A LUNAR key project is Low Frequency Astrophysics & Cosmology, involving (1) Refinement of theoretical tools for predicting highly-redshifted H I signals; (2) Array concept and algorithm development; and (3) Science antenna technology development.

Acknowledgements: The LUNAR consortium is funded by the NLSI (NNA09DB30A).

References: [1] Loeb, A., and Zaldarriaga, M. (2004) *Phys. Rev. Lett.*, *92*, 211301. [2] Furlanetto, S. R., Oh, S. P., and Briggs, F. H. (2006) *Phys. Reports*, *433*, 181. [3] Alexander, J. K., and Kaiser, M. L. (1976) *JGR*, *81*, 5948.

NEUTRON RADIATION ENVIRONMENT AROUND THE MOON FROM LUNAR EXPLORATION NEUTRON DETECTOR ONBOARD LRO

M.L Litvak[1] , I.G. Mitrofanov[1] , A.B. Sanin[1], V.I. Tretyakov[1], A.S. Kozyrev[1], A.V. Malakhov[1], M.I. Mokrousov[1], A.A Vostrukhin[1], D. V. Golovin[1], A.B. Varenikov[1], V. N. Shvecov[2], W.V. Boynton.[3], K Harshman[3], R.Z. Sagdeev[4], G. Milikh[4], G. Chin[5], J. Trombka[5], T. Mcclanahan[5], R. Starr[6], L. Evans[7], V. Shevchenko[8], [1]Space Research Institute, RAS, Moscow, 117997, Russia, litvak@mx.iki.rssi.ru , [2]Joint Institute for Nuclear Research, Dubna, Russia, [3]University of Arizona, Tucson, AZ, USA, [4]University of Maryland, College Park, MD, USA, [5]Goddard Space Flight Center, Greenbelt, MD, USA., [6]Catholic University, Washington, DC, USA, [7]Computer Sciences Corporation, Glenn Dale, MD, USA. [8]Sternberg Astronomical Institute of Moscow State University, Moscow, Russia.

Introduction: The Lunar Exploration Neutron Detector is designed to perform orbital mapping of Moon neutron flux in wide energy range starting from thermal neutron up to high energy neutrons above 10 MeV [1]. It consists of 8 gas filled proportional counters of neutrons and one organic scintillator (Stylbene crystal), see figure 1. The primary goal of this experiment is a search of enhanced content of hydrogen inside polar Moon shadow regions which are suspected to be a signature of comet relict water ice. LEND is installed onboard Lunar Reconnaissance Orbiter (LRO) which has been successfully launched in June 2009 and now has completed three months commissioning phase and started primary mapping observations [2].

In parallel, data from LEND detectors may be used to deconvolve neutron spectra on the orbit (30-50 km) as well as on the surface of Moon. This information may be used to monitor neutron component of radiation environment starting from low energies up to 10 MeV. Here we have tried to concentrated on the discussing this subject estimation neutron radiation dose around Moon and comparing it with measurements of near Earth and near Mars radiation environment

Data Analysis: The model dependent deconvolution of the accumulated LEND data has been used to deconvolve neutron spectra and estimate radiation dose related to the neutron component of Moon radiation background. We have used numerical simulation of orbital observations based on MCNPX code and known response functions for each LEND detector. The results of numerical simulations have been compared with real observational data to find best fit parameters of the neutron spectra shape. Multiplying with known radiation dose coefficients and integrating by energy we have estimated neutron radiation dose around Moon at different energy bands. These results have been compared with other components of Moon radiation background measured both by the previous Lunar missions and data gathered onboard LRO (CRATER experiment onboard LRO). We also made comparison with measurement of the neutron component of near Earth and near Mars radiation background using measurements from HEND instrument onboard Mars Odyssey mission (start of operation in February 2002) [3] and BTN instrument onboard International Space Station (start of operation in February 2007) [4].

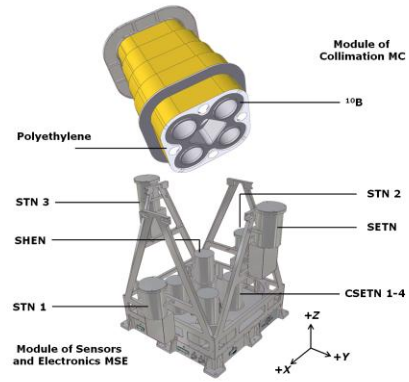

Figure.1. LEND instrument.

References:

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[2] Chin G (2007) Lunar Reconnaissance Orbiter Overview: The Instrument Suite and Mission, Space Science Reviews, Volume 129, Issue 4, pp.391-419

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[4] V.I. Tretyakov et al. Start of the first stage of space experiment BTN-Neutron onboard Russian segment of International Space Station, accepted for publication in Cosmic Research (Kosmicheskie Issledovaniya), on Russain.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared:

Presenter's Name: Gary Lofgren
Presenter's Title: Lunar Curator
Presenter's Organization/Company: NASA Johnson Space Center, Astromaterials Acquisitions and Curation Office

Presentation Title

Overview and Status of the Apollo Lunar Collection

Key Ideas

I will describe the current state of the Lunar Collection. How much sample has been used for analysis and how much remains for future study. I will review the standards for curation and discuss how they have provided for the preservation of the samples. Particular attention will be paid to that part of the Lunar Regolith commonly referred to as the Lunar Soil, the fraction less that 1 mm.

The Lunar Sample Laboratory is approaching 30 years old. We have been renewing and replacing aspects of the facility to keep the it functioning at the highest level; these efforts will be summarized. Improvements in the Lunar Database will soon make it possible to search to database for research purposes.

There will be a brief discussion of the kinds of samples collected and the lessons learned from their study and preservation. I will make suggest techniques for future collection that could improve the preservation of their properties.

Supporting Information

Supporting information can be found at our Curation Website

http://curator.jsc.nasa.gov or http://www-curator.jsc.nasa.gov

SCIENCE SUPPORT ROOM OPERATIONS DURING DESERT RATS 2009. G. E. Lofgren[1], F. Hörz[1], and the D-RATS SSR[2], [1]KT, NASA Johnson Space Center, Houston TX 77058 (gary.e.lofgren@nasa.gov), [2]M. S. Bell, B. A. Cohen, D. B. Eppler, C. A. Evans, J. E. Gruener, K. V. Hodges, J. M. Hurtado, B. M. Hynek, D. A. Kring, P. Lee, D. W. Ming, and J. W. Rice.

Introduction: NASA's Desert Research and Technology Studies (D-RATS) field test is a demonstration that combines operations development, technology advances and science in analog planetary surface conditions. The focus is testing preliminary operational concepts for extravehicular activity (EVA) systems by providing hands-on experience with simulated surface operations and EVA hardware and procedures. The D-RATS activities also develop technical skills and experience for the engineers, scientists, technicians, and astronauts responsible for realizing the goals of the Lunar Surface Systems Program. The 2009 test is the twelfth for the D-RATS team.

The Role of Science: D-RATS 2008 invited a science team to integrate science operations into the test using the Apollo model and new technological advancements. The science team provided geological context and traverse protocols for the surface activities. The role of science was expanded in the D-RATS 2009 analog exercise, significantly advancing science operations concepts relative to Apollo. Today's capabilities for real-time digital data allowed for both greatly improved field operations and interactive Science Support Room (SSR) support of traverse activities. Suit-mounted and rover-based video streams were transmitted in real time to the SSR scientists who analyzed and interpreted information on timescales that are unusually short (< minute) by remote sensing or robotic mission standards. This year's exercise demonstrated that timely integration of real time information will be the major challenge for ground scientists. The D-RATS SSR activity will enable the development of new SSR concepts and the definition of science requirements.

Schedule: D-RATS 2009 began with 2 one-day traverses by Crew B (Andy Thomas and Jake Bleacher). This was followed with a 14 day exercise with Crew A (Mike Gernhardt and Brent Garry). That exercise involved 8 days of continuous geologic traverse over an area of 60 sq. km. The SSR team wrapped up the exercise with debriefings and lessons learned.

Science Support Room: D-RATS provided facilities for a dedicated SSR. Each day, eight functions supported the analysis of acquired data for the geologic traverse operations. Participants rotated through functions to acquire cross-training and experience. 1) Science observers' followed the crew in the field to observe and evaluate surface procedures and the crew's performance. 2) The Principal Investigator (PI) was the lead planner for the daily traverse and held ultimate responsibility for executing the science related activities. 3) A Co-Investigator (Co-I) assisted the PI in the assimilation and analysis of the incoming data. Three "expert" stations ("Petrography", "GigaPan", and "Structures") documented crew verbal descriptions and imagery and were responsible for real-time acquisition and interpretation of their collected data and advising the PI on the findings. 4) The Petrography position was responsible for sample documentation using crew suit cameras and verbal description, followed by interpretation of the collected samples. 5) The Structures position was responsible for overall geologic setting and interpretation via crew description and local features appearing in the rover-mounted cameras, and was also responsible for traverse progress and localization in Google Earth. 6) The GigaPan station operated a high resolution panoramic camera mounted on the rover that captured both local and regional features. 7) The SSR also maintained a Science CapCom (SciCom), who communicated directly with the crew during science operations. 8) Finally, the Science OpsLink position provided a direct link to the Mission Control Test Director and was responsible for situational awareness including timeline maintenance and monitoring engineering and communications issues that may impact science.

Lessons Learned: The D-RATS 2009 opportunity to integrate science with realistic rover operations has provided invaluable experience that will help define science requirements for the SSR in support of traverse operations on the lunar surface. These requirements include analysis of imagery streams from the crew and the rover, the technology to support analysis of the acquired data in the SSR, and the physical setup of the SSR. An innovative feature of this years' activity is the SciCom position, providing direct contact with crew on the surface. This position will evolve, but science support requirements should include aspects of this position. Finally, the field demonstration initiated the training of a new cadre of scientists in geological traverse planning and human space mission science support operations. This integration of engineering and science analog activities early in NASA's future lunar program will allow the establishment of timely and realistic requirements related to science and science operations. Lessons learned from this D-RATS 2009 emphasize the continued collaboration between science, engineering and operations for future expeditions.

DISTANCE LEARNING AND LONG DURATION LUNAR MISSIONS ASSISTING MENTAL HEALTH OF ASTRONAUTS. A. A. Mardon[1], [1]Antarctic Institute of Canada (Post Office Box 1223, Station Main, Edmonton, Alberta, Canada T5B 2W4, aamardon@yahoo.ca).

Introduction: Time to think. Time to wonder why one is out between the planets and on other planets might bear on the soul of those selected for the multi year flight to and from Mars and Lunar missions. The presenter proposes that established distance learning techniques be used to bolster the psyche of those Astronauts by giving them a goal something interesting to do with their time along with their duties related to ships maintenance and personal fitness preservation. How many of us have said that if I only had the time I might study something from a field that we did not specialize in but were interested such as archaeology, modern and ancient history. Another idea is to cross train astronauts in the time that they are in flight to Mars or are on long duration missions on the Moon in a secondary field that is necessary to the mission. An example of this would be a pilot learning from online curriculum and from the ships doctor basic first aid. And vis-a-versa for the ships doctor learning basic piloting skills through online curriculum and personal computer simulators and eventual on deck awareness. This would allow the mission a certain amount of redundancy and if casualties or death were to occur the mission might not be totally compromised.

Many of the astronauts have A personalities and as such are driven individuals that are very goal orientated. Giving them tailored online curriculum could artificially dampen that into what might become more mentally productive ways. Many of them will also likely be very intelligent and some might even be polymaths which would use that time in productive ways. One of two courses for the type of distance learning could be done. They are synchronous and asynchronous learning. Synchronous learning is where all of the students and faculty for the course interact with each other at the same time. Students are in an electronic classroom at the same time like a traditional classroom in a college. Asynchronous learning is where the students and faculty do not interact with each other necessarily at the same time but can leave notes and messages for each other. Each with their own potential advantages and disadvantages. Obviously asynchronous learning would have to occur being that the distances involved eventually would prevent simultaneous communication necessitating delayed asynchronous teaching techniques. But the two ways are first an individually tailored individual class with an instructor on Earth or several instructors which would involve time delayed voice and delayed text communication. The other way would be the enrollment in existing or created online class's asynchronous of course with other students and other faculty members enrolled on Earth. This might not necessarily be as useful in terms of data acquisition but might have real social benefits engaging the astronaut in an online classroom environment similar to Earth where with Asynchronous learning the students can be all over the planet in different time zones and communicate by email. Tests would be administered and marks given. This might be more suited for the type of program that I first mentioned where the astronaut student is learning a filed that he was never able to study in depth. It might even be that the learning styles or goals on the outward and inward legs of the journey would not be the same. For the outward first leg of the trip mission redundancy curriculum and cross training might be focused on and on the inward return leg of the mission more individually directed forms of learning would occur. Studies would have to be done to discover the balancing of learning cross skills versus any positive effects of learning. The presenter does not have any ideas on of the balance between these two potential educational needs. It would also potentially generate positive publicity for the mission and the crew. Many mainstream universities employ elements first seen in distance and online education. Just last year I had an editor of one of my books question the validity of a citation because it was not on the internet. I pointed out that I got it from a book that predated the internet and that it was a valid citation. Being a far distance from Earth learning would in many ways be no different from learning in an isolated lab in the Antarctic or online learning in some remote location on the Earth. Also advanced training in their specific area could occur using online learning. It has been estimated that in a few years the difference between online learning and traditional bricks and mortar learning will become blurred. The only thing that generally is lacking in online education is in person social interaction. In our wired world people interact socially through electronic media. The learning experience in some ways is becoming no different.

Asynchronous learning which is learning by those that are not in the electronic classroom at the same time is most suited for this specific learning environment. Test-bed learning could be developed for use on the space station to see psychological and impacts on absorption of curriculum in the unique environment of space. With the long duration of astronauts in orbit it would be a good test bed for positive psychological aspects of different types of learning styles. Asynchronous learning could be tested.

Conclusion: Another ideal test bed for educational programs could be over-wintering personnel in Antarctica by various nations including those at Amundsen-Scott South Pole Station. Various online courses for general undergraduate and graduate study are given to military personnel all over the world. For example the university that I associated with has students from all over the world I communicate with my students and administrators through the internet and the occasional phone call. It is quite similar except for the social aspects to a conventional bricks and mortar university doctorate.

Research Support: This research was supported by the Antarctic Institute of Canada.

USE OF LUNAR LAVA TUBES AS HABITATION STRUCTURES ON MOON. A. A. Mardon[1], [1]Antarctic Institute of Canada (Post Office Box 1223, Station Main, Edmonton, Alberta, Canada T5B 2W4, aamardon@yahoo.ca).

Introduction: Up to the present moment the use of Lunar Lava Tubes as habitation structures has not been seriously looked as an option especially during the first period of manned occupation of a Lunar surface area. Lava tubes should be looked at as potential habitation structures. The first stage would be to map those collapsed ones from Orbit and then send probes to these structures on the Moon specifically to get into them and examine them for their potential. Also looking at analogue sites on Earth would be useful.

We know that Lava tubes likely exist on the Moon a somewhat unaccepted idea is that they might even have ancient ice deposits although that is completely speculative. It would likely sublimate. The author has not seen any investigation as to whether their might be the geological structures related to potential Lunar South Pole landing and habitation locations.

The gravity on the Moon is less than Earth and should therefore affect the size and structure of Lava Tubes on the Moon. They should be larger in width and might be more prevalent than Earth again likely due to lower gravity on the Moon.

Lava tubes give protection from micrometeorites and thin pressure rated structures could be erected and inflated inside of the tubes.

Problems might include the entrance of the lava tubes and how to gain ongoing access and bringing in supplies and structures to be inflated. Also their might be boulders on the floor of the lava tubes.

A collapsed lava tube was viewed during one of the Apollo excursions along with photos being taken of it.

Propositioned supplies and tents could be placed inside the Lava tubes on marked locations for later potential emergency reasons. In Antarctica maintained emergency caches are maintained all over the continent in case of emergencies. Something like this might be considered for the Moon.

Depending on the size of the Lava tubes used substantial tent structures could be erected inside for use.

Conclusion: As an option Lava tubes as habitation structures might give future manned missions to the Moon greater flexibility by increasing the number of potential sites for small stations.

Research Support: This research was supported by the Antarctic Institute of Canada.

Lunar Oxygen Production and Metals Extraction Using Ionic Liquids Matt Marone[1], Mark Steven Paley [2], David N. Donovan [3], Laurel J. Karr [3]. [1]Mercer University Department of Physics 1400 Coleman Ave, Macon, GA 31207 email: marone_mj@mercer.edu, [2]AZ Technology, 7047 Old Madison Pike, Suite 300 Huntsville, AL 35806, [3] Marshall Space Flight Center, Huntsville AL 35812.

Introduction: The objective of this work is to develop a safe, efficient, and recyclable method for oxygen and/or metals extraction from lunar regolith, in support of establishing a manned lunar outpost. The approach is to solubilize the oxides that comprise lunar regolith in media consisting of ionic liquids (ILs) and/or their mixtures at temperatures at or below 300ºC. Once in solution, electrolysis can be performed in-situ to generate oxygen at the anode and hydrogen and/or metals (silicon, iron, aluminum, titanium, etc.) at the cathode. Alternatively, the water that is generated during the solubilization process can be distilled out and condensed into a separate IL and then electrolysized to produce hydrogen and oxygen. In the case of lunar regolith, this method could theoretically produce 44g oxygen per 100g of regolith. The oxygen can be used for human life support and/or as an oxidizer for rocket fuels, and the metals can be used as raw materials for construction and/or device fabrication. Moreover, the hydrogen produced can be used to re-generate the acidic medium, which can then be used to process additional regolith, thereby making the materials recyclable and limiting up-mass requirements. An important advantage of IL acid systems is that they are much "greener" and safer than conventional materials used for regolith processing, such as sulfuric or hydrochloric acids. They have very low vapor pressures, which means that they contain virtually no toxic and/or flammable volatile content. Additionally, they are relatively non-corrosive, and they can exhibit good stability in harsh environments (extreme temperatures, hard vacuum, etc.). Furthermore, regolith processing can be achieved at lower temperatures than other processes such as molten oxide electrolysis or hydrogen reduction, thereby reducing initial power requirements.

Results and Current Experiments:
Initial results using JSC-1 lunar simulant show that ILs appear extremely promising for solubilizing lunar simulant. Results from preliminary water extraction experiments show that over 75% of the oxygen from the simulant can be harvested as water. This is for solubilization at only 150°C-160°C. The water is produced from the reaction of the metal oxides in the simulant with hydrogen supplied by the IL. Electrolysis was used to split the water and produce liquid oxygen. Electrolysis efficiency, based on hydrogen and oxygen gas collected, was greater than 98%; and the efficiency of oxygen liquefaction is around 80%. This set-up also included a portable mass spectrometer for the identification of gases released from electrolysis cells. Recyclability of the IL is a critical factor in limiting up mass and making the process economically viable. Regeneration of the spent ILs through re-protonation on an ion exchange column was also demonstrated. Four sequential regenerations of an IL following solubilization of simulant took place with 97-98% efficiency, and showed no significant decrease in the amount of simulant dissolved. Hydrogen collected from the water electrolysis step can also be used for re-protonation. These experiments are in progress. We have begun a series of experiments to determine the reduction potentials and the electrochemical windows of our electrolytes. Knowledge of the reduction potentials allows us to electro-refine metals from the lunar regolith.

Solubilization of actual lunar material should depend on mineralogy. Owing to the lack of actual Apollo lunar samples, we have started small scale experiments on lunar meteorites. A small sample of Dar al Gani 400 was dissolved using our IL acid. These techniques can be extended to Martian regolith. Solubility of the Martian meteorite Sayh al Uhaymir 05 (SaU 05) has also been studied.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: October 27, 2009

Presenter's Name: Carole A. McLemore
Presenter's Title: Dust Management Project (DMP) Lunar Simulant Task Manager

Presenter's Organization/Company: NASA/Marshall Space Flight Center

Presentation Title: "The Need for Lunar Simulants"

Key Ideas: Lunar Simulant Customers; Testing in Relevant Environments; Risk Reduction; Types of Lunar Simulants Available and Needed to Meet User Test Objective Requirements and Applications; Comparison of Lunar Regolith vs. Simulants; Figures of Merit; Demand for Lunar Simulant Types vs. Supply; Plan for Development of New Simulants to Meet User Needs (Feedstock, Processes, Quality Assurance, etc.)

Supporting Information: Constellation Projects and ETDP Projects and Roadmaps; Simulant Types Availability; Simulant Types Characterization Results; Simulant User Surveys and Needs Assessment; Simulant "Fit for Purpose" Matrices; Current Lessons Learned using Simulants; and other Documentation developed by the Lunar Simulant Team.

HUMAN RISK ASSESSMENT FOR IN-SITU LUNAR DUST MEASUREMENT. T. Miki[1,2] and S. Aoki[3], Y. Morimoto[4], K. Tanaka[1],K. Shimada[2], C. Mukai[1] [1] Japan Space Biomedical Research Office/ JAXA (2-1-1 Sengen, Tsukuba 305-8505 Japan miki.takeo@jaxa.jp), [2]Astronaut Medical Operations Group/ JAXA, [3]Shimizu Corporation, [4]University of Occupational and Environmental Health, Japan.

Introduction: Only acute exposure result to Apollo astronauts is known about lunar dust effects on the human body. Before we will start a Lunar base construction under international cooperation from 2020, we should collect as much information about primary lunar dust as possible. We think that the property of lunar dust contribute to the high percentage of human risk.

We present our risk assessment for in-situ lunar dust measurement.

Approach: J-SBRO (Japan Space Biomedical Research Office), JAXA has promoted Lunar Exploration Medical Research to utilize ISS as a lunar test bed. Research interest of Lunar Exploration Medical Research includes remote medical care, radiation hazard, exercise physiology, gait kinematics and lunar dust toxicology. J-SBRO set up lunar dust medical assessment group and started research of lunar dust human risk to develop strategies of dust mitigation.

Meanwhile, JSPEC (JAXA Space Exploration Center) is planning SELENE-2 robotic lunar Lander and current status is in phase-A. SELENE-2 is planned to carry technology demonstrations as well as science instruments [1].

In-situ measure of lunar dust will contribute to define effects of lunar dust on not only systemic but focal organs through lunar habitation, space suit, pressurized rover and lunar orbital module.

J-SBRO and the lunar dust medical risk assessment group is proposing lunar dust measurement mission for SELENE-2 to investigate unknown lunar dust toxic properties. In the process of finding candidates of lunar dust measurement apparatus, lunar dust human risk assessment and lunar dust property assessment has been conducted.

Following sections briefly describe the lunar dust assessments.

1) **Lunar Dust Human Risk Assessment:** Risk assessment of lunar dust human effects is the first step toward SELENE-2 dust measurement mission.

The scope of the risk assessment is acute and chronic symptoms of pulmonologist, ophthalmology, dermatology and cardiology. Characteristic symptoms and associated segments were figured out and evaluated by risk.

We prioritized the estimated symptoms by lunar dust coupled with life hazard, the mission impacts and so on.

As a result, we found that the respiratory organ symptom: cough, induced sputum, and etc, the eye-symptom: the conjunctivitis, the dermatitis, etc will have influence to the mission in the acute period. In the chronic phase, the malignant-mesothelioma and the cardiovascular disease will had a strong influence on the life hazard of crew.

2) **Lunar Dust Property Assessment:** Lunar dust property assessment is the second step. Result of the risk assessment is correlated with lunar dust properties, such as particle size distribution, particle shape, chemical reactivity and so on. in-situ measurement needs are also evaluated in the dust property assessment.

the particle size distribution and the chemical reactivity should be note in these properties. And particle behavior on the moon is another factor that should not be overlooked.

We are evaluating dust measurement apparatus candidates in the light of the results of the assessments and SELENE-2 resource.

Conclusion: J-SBRO and the lunar dust medical risk assessment group proposed lunar dust measurement mission to SELENE-2. In-situ measure of lunar dust will contribute to define lunar dust contamination level. And, the goal of the lunar dust medical risk assessment group is to mitigate lunar dust under specified contamination level for astronaut occupational safety and health.

We hope this approach is a good start for us to review how we can make a global effort in the investigation of the effects of lunar dust on human beings and we can initiate several research collaborations to accelerate lunar dust research.

References:

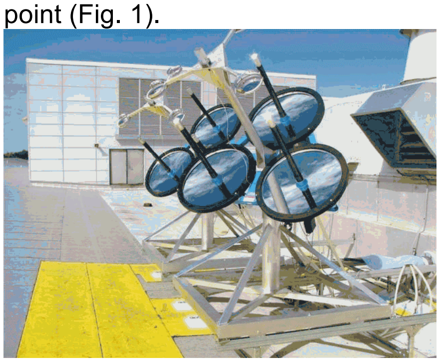
[1]J. Kawaguchi (2008) “Japan’s Lunar Exploration Program”, LEAG presentation.

Energy-Efficient Plant-Growth Lighting: Key to Sustainability of the Lunar Base and Beyond. Cary A. Mitchell[1], Gioia D. Massa[1], Raymond M. Wheeler[2], Gary W. Stutte[2], Neil C. Yorio[2], Oscar A. Monje[2], C. Michael Bourget[3], and Robert C. Morrow[3], [1]Purdue University, West Lafayette, IN 47907. cmitchel@purdue.edu, [2]Kennedy Space Center, FL 32899. Raymond.m.wheeler@nasa.gov, [3]Orbital Technologies, Inc., Madison, WI 53717. bourgetm@orbitec.com

Introduction: Long-duration habitation of the Moon will be sustainable only when food becomes independent of resupply. Reasonable cropping area can provide the calories, nutrients, and oxygen needed to sustain human crews in space habitats [1, 2]. The main obstacle to food production in space is the high energy required for electric lamps and heat rejection [3]. Reduction of energy for crop lighting is required for food production in space. Availability of solar radiation for crop growth is temporally limited at most locations on the Moon. Reliable sources of energy and effective methods to deliver photosynthetically active radiation (PAR: 400-700 nm) to crops growing in protected locations on the Moon are the grand challenges to food sustainability.

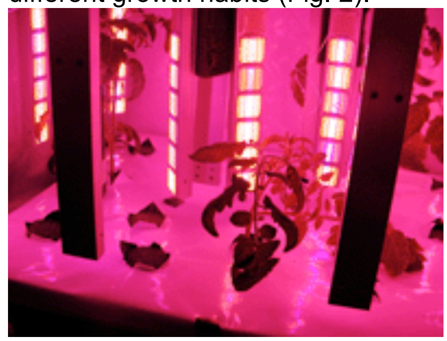
Experimental approach:

Solar collection/PAR transmission: The Kennedy Space Center (KSC) has a device that tracks the sun with six primary-collection mirrors and concentrates solar radiation on dichroic mirrors that allow long-wave radiation to pass through while reflecting PAR to a fiber-optic collection point (Fig. 1).



Collected PAR is transmitted through 10-m-long fiber-optic bundles that deliver 40-50% of the original solar radiation to overhead emitters in a growth chamber.

LED lighting: Both KSC and Purdue University have investigated light-emitting diodes (LEDs) for crop lighting with many advantages over conventional lamps, including durability, lifetime, selectable wavelengths, and relatively cool emitter surfaces. KSC is defining spectral requirements for food crops with LEDs, while Purdue and ORBITEC are developing methods for distributing PAR to crops with different growth habits (Fig. 2).



Results & Discussion: During solar maximum, 350-400 Watts of PAR have been delivered from the 2 m^2 of primary collector surface. This power would be adequate to light a 2 m^2 "salad machine" at the lunar base. Near the lunar south pole, sunlight could be collected most of the time, although how much energy could be collected at oblique angles of incidence is unknown. Intracanopy and close-canopy crop lighting with LEDs have saved considerable energy compared to traditional overhead lighting. During the lunar night or when solar collection alone cannot provide enough PAR, LEDs would provide PAR for crop production, and this would require either stored electrical energy from previous solar collection or an alternative energy source.

Future work: The long-wave solar radiation passing through the cold mirror will be collected by photovoltaic cells to generate electrical current that can power LEDs immediately or be stored in high-capacity batteries for use when PAR is absent. LED lighting will be developed as "smart" lighting systems that target leaves only.

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MAPPING OF HYDROGEN OVER THE LUNAR SURFACE: LEND INSTRUMENT ONBOARD LRO. I. G. Mitrofanov [1] on behalf of LEND Team, [1]Institute for Space Research, Profsojuznaja 84/32, 117997 Moscow, Russia (imitrofa@space.ru).

Description of Lunar Exploration Neutron Detector will be presented together with the first results of instrument operations onboard NASA's LRO

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LUNAR CRUST COMPONENTS FROM PLANETS AT THE GIANT IMPACT EVENT. Yasunori Miura, Graduate School of Sci. & Eng., Yamaguchi University, Yoshia 1677-1, Yamaguchi, Yamaguchi 753-8512 Japan. yasmiura@yamaguchi-u.ac.jp

Introduction: Origins of lunar crust components with anorthosite composition is not discussed so far, though there are various discussions on separation of light crust and heavy mantle components on the Moon applied by magma ocean process [1].

Impact elements of carbon and chlorine [2] can be used for new impact elements remained after as carbon- and chlorine-bearing materials in the lunar rocks of deeper basalts as "metamorphosed impact remnants" [2, 3, 4, 5, 6], which can be applied for the giant impact event between primordial Earth and Mars-size planet to form the Moon after removing of anorthositic components mainly from primordial Earth.

The present purpose of the paper is that lunar crust components are originally from Earth planet at the giant impact process.

Problem of original sources of the lunar crust: Origin of lunar crust components shown as anorthositic composition is considered to be main problem, except separation of light anorthositic crust and heavy basaltic mantle components on the Moon explained by magma ocean process of isotopic heat sources [1].

The following items listed in Table 1 are main problems for estimation of original components of the lunar crust which is considered to be formation mainly by normal planetary accretion model so far. The present model can be explained energy sources (explained by impacts on airless Moon and heat sources of the giant impact and isotopic mixing from target Earth) [1] as shown in Table 1.

Table 1. Main problems for origin of the lunar crust.

1) Origin of light anothositic components:
(previous model) All rocks planetary bodies with light anorthositic rocks
(present model) Separation from primordial Earth by the giant impact event

2) Origin of separated anorthositic crust:
(previous model) normal planetary accretion and giant impact
(present model) Main source of separated planet mainly from primordial Earth

Impact changes of H, He, C, N and Cl elememts: All light elements should be decreased during impact process [1], though only carbon (C) and chlorine (Cl) elements are fixed to solid states [2, 3, 4, 5, 6] as shown in Fig.1. This is mainly because carbon is fixed to solids of graphite, carbites and carbonates during impact process [2, 3]. On the other hand, hydrogen (H) and helium (He) elements are decreased during impact process [1, 2, 3] (cf. Fig.1). Chlorine (Cl) can be remained as chlorine-bearing materials of akaganeite and halite [2, 3, 4, 5, 6] (cf. Fig.1).

This indicates that C and Cl elements are indicators which can remained even after impact process.

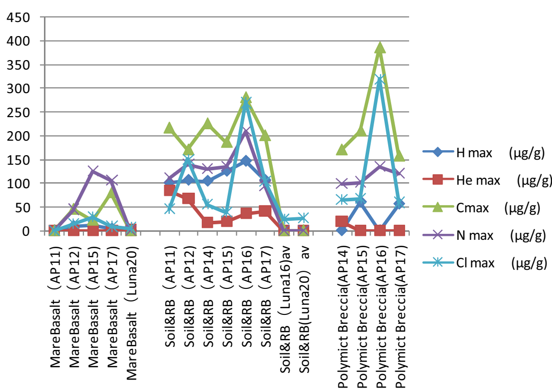

Fig.1 Five elements of H, He, C, N and Cl of three kinds of the Apollo lunar samples [1, 2]. Only C and Cl can remained at polymict breccias during impact process [2].

Impact elements C and Cl in the Mare basalts: The highest amounts of C and Cl of the polymict breccias in the Apollo lunar samples [1, 2] indicate that carbon and chlorine found in the crust of Earth can be remained in deeper lunar basalts [2] during giant impact event [1].

Remnant of terrestrial crust in the Moon: The lunar anorthositic crust is considered to be remnant of primordial Earth during giant impact process [1], which can be explained without terrestrial plate tectonics, earthquake and volcanism [2, 3, 4].

Summary: The lunar crust with anothositc compositions is considered to be derived from primordial Earth during impact, which is found in C, N and Cl elements of lunar basalts.

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LUNAR FLUIDS FROM CARBON AND CHLORINE CONTENTS OF THE APOLLO LUNAR SAMPLES.
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Introduction: Contents of elements H, C, He, N and Cl do not be discussed so well for impact indicators and fluids for the collected lunar samples [1]. The present purpose of the present paper is that contents of H and C in the lunar rocos are very significant to estimate water and carbon dioxides (CO2) as fluids in the lunar interior for next exploration project [2, 3].

Three formation groups of lunar samples: Major three groups of the Apollo lunar samples are divided from the reported analyzed data to check behavior of elements H, He, N, C and l Cl [1] as shown in Table 1:

Table 1. Imformation of three groups of the Apollo lunar samples.

Mare basalt:	Interior contents (due to deep volcanism)
Regolith:	Impact and Solar winds (direct reservoir of impacts)
Polymict breccias	Information during impact (quenched impact materials)

Hydrogen content in the lunar interior: Few content of hydrogen (H) has been obtained in the Mare basalts [1]. Significant H amounts in the regolith and polymict breccias are obtained, which are transported from the solar winds activity with helium (He) content. This indicates that there are dry condition of water in the interior of the Moon as shown in Fig.1 which is the same results in the nitrogen (N) [1].

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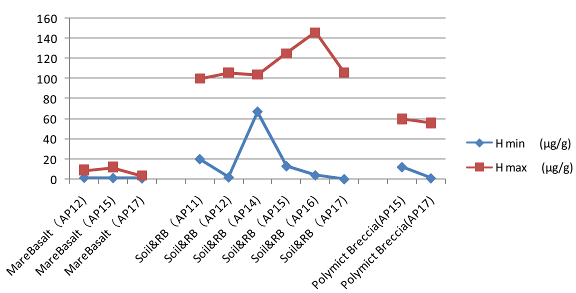


Fig.1 Hydrogen contents of three kinds of the Apollo lunar samples [1]. Poor hydrogen amounts of Mare basalts indicate short of water in the interiors.

Carbon contents in the Mare basalts: Significant content of carbon has been relatively obtained in the Mare basalts, compared with the hydrogen content [1]. Significant amounts in the regolith and polymict breccias are obtained, which are mainly transported from impact processes due to highest contenst in the polymict breccias samples. This indicates that there are CO2 fluids in the interior of the Moon as shown in Fig.2, which is the same results in the chlorine (Cl) [1].

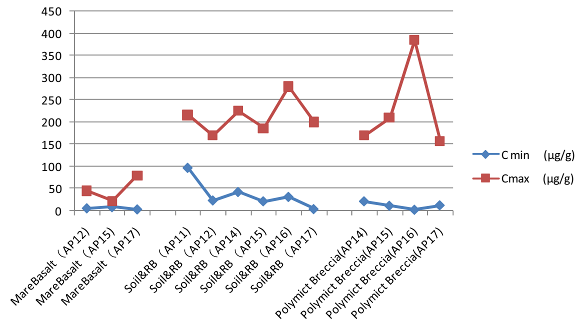


Fig.2. Carbon contents of three kinds of the Apollo lunar samples [1]. Significant carbon amounts indicate CO2-rich fluids in the lunar interiors.

Probable fluids of water and CO2 in the lunar interior: The lunar interior is considered to be CO2-rich fluids which are transported during impact condition shown in Fig.3, originally at giant impact process to deeper places of the Moon [2,3].

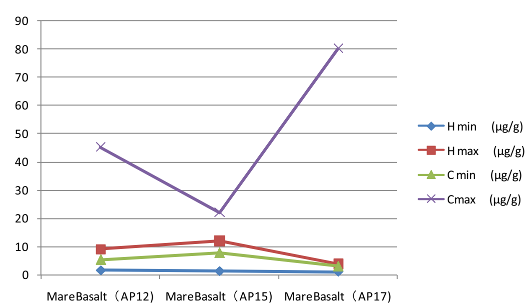


Fig.3. Higher carbon contents in the Apollo basaltic-samples, compared with hydrogen [1].

Summary: The Moon has carbon-rich fluids in the interior, compared with hydrogen (for water) amounts from the Apollo lunar samples. Main origons of carbon are dynamic giant impact between two original planets.

References: [1] Heiken G., Vaniman D. & French B. (1991): Lunar source book (Cambridge Univ.Press). 468-474. [2] Miura Y. (2009): *LPS XL,* Abstract #1090. [3] Miura Y. (2009) *LPS XL,* Abstract #1468.

MODELS FOR LUNAR SUBSURFACE HEAT STORAGES FOR SUPPORTING SURFACE SCIENCE INSTRUMENTS.
S. Nagihara[1], P.E. Clark[2], M.B. Milam[2], B.G. Beaman[2], and J. Ku[2]. [1]Texas Tech University, Lubbock, TX 79409 (seiichi.nagihara@ttu.edu), [2]Goddard Space Flight Center, Greenbelt, MD 20711

Introduction: The large diurnal temperature swing on lunar surface makes it a harsh environment for operating highly sensitive science instruments such as broadband seismometers. At low-latitudes, surface temperature reaches ~380 K at the peak of a lunar day, while it falls below 100 K soon after the sunset [1]. It is a challenge to maintain stability of the instruments' performance between the day and the night, as well as to power them through the long, cold lunar night.

The large diurnal temperature swing is partly due to lunar regolith being a poor thermal conductor. During a lunar day, solar heat accumulates within a thin (~0.4 m) surface layer of regolith. At night, the heat radiates back into space. It might be possible to divert a portion of the energy released over night and use it either to help stabilize the temperature of an instrument package on the surface or to provide electric power by utilizing heat pipes or a stirling engine. The difficulty, though, is again the low thermal conductivity of regolith (<~0.01 W/mK). The power system would draw down heat much more quickly than the surrounding regolith could replenish it. However, if there is a way to artificially enhance thermal conductivity (and heat capacity) of regolith, a thermal power support system may be feasible.

The low thermal conductivity of near-surface lunar regolith can be attributed to its porosity (~40% [2]). One way of thermal enhancement might be to inject fluid into regolith to fill the voids. Thermal grease or ionic liquid [3] may be custom-manufactured so that their viscosity is low enough to percolate through the regolith matrix in the high temperature of the lunar day. When the fluid reaches ~0.4-m depth, it stops spreading by freezing or becoming more viscous.

Wengen et al. [4] previously coined the term "thermal wadi" in describing a lunar subsurface heat storage that utilizes thermally enhanced regolith. Their proposed enhancement techniques were elaborate, and the wadi system proposed was large and intended for supporting rover operations. Here we develop models for a much smaller, simpler thermal wadi system, which minimizes the mass, and is intended for supporting low-power surface science instruments.

Simulation Experiments: In the model presented here, the thermal wadi is a disk of regolith of 2-m diameter, 0.5-thickness, whose pore spaces are filled with conductive fluids so that the bulk thermal conductivity of the matrix is about ten times greater (0.1 W/mK) than untreated regolith (Fig. 1). Untreated regolith surrounding the wadi consists of two layers, similar to the previously proposed thermal models of regolith [1]. The top is a thin (0.02 m) layer of loose soil with very low thermal conductivity (0.001 W/mK). The lower layer is more consolidated and of greater thermal conductivity (0.01 W/mK). The surface heat input is determined as the difference between the solar input and the radiative output. The solar input in the model varies purely sinusoidal during the lunar day and stays at zero through the night. The model regolith extends to 5-m depth where a constant geothermal heat input of 20 mW/m^2 is assumed. The simulation is done in the 2-D cylindrical coordinate system with its vertical axis set at the center of the wadi disk. The finite difference code HEATING7 [5] was used.

Results: After regolith has been thermally enhanced, it begins to accumulate heat in the lower portion of the wadi and untreated regolith immediately below it (Fig. 1). Temperature within this hot zone can rise ~30 K above the surrounding regolith and is maintained through the diurnal cycle. By optimizing the wadi design, it may be possible to draw enough energy to support low-power surface instruments.

References: [1] Keihm S.J. and Langseth M.G. (1973) *LPSC* 2503-2513. [2] Carrier W.D. et al. (1991) *Lunar Source Book*, 475-594. [3] Wu B. et al (2001) *Proc. Solar Forum*. [4] Wengen R.S. (2008) *LEAG*, 4091.[5] Childs K. W. (2005) ORNL PSR-199.

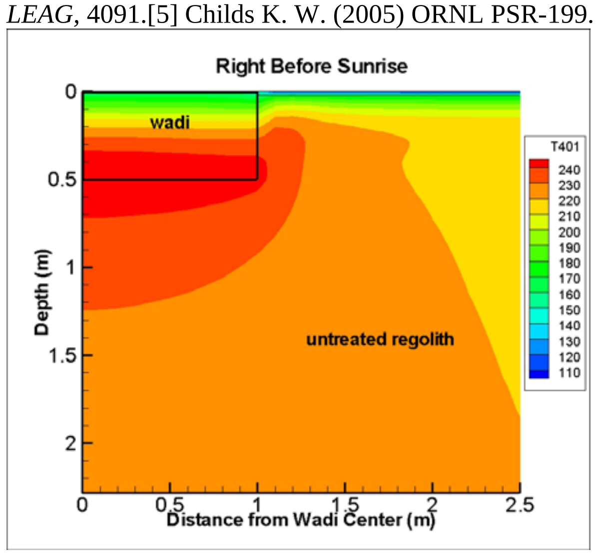


Fig. 1 A cross-sectional temperature distribution of the wadi (a disk of thermally enhanced regolith) and the surrounding. The timing is right before sunrise, when surface temperature is lowest in the diurnal cycle.

Meter-scale Roughness on the Moon from Lunar Orbiter Laser Altimeter (LOLA) Pulse Spreading: Implications for Exploration.

G. A. Neumann[1], D. E. Smith[1,2], M. T. Zuber[1,2], E. Mazarico[1,3], M. H. Torrence[3], J. C. Cavanaugh[2], and LOLA Science Team. ([1]NASA Goddard Space Flight Center, Greenbelt, MD 20771; Gregory.A.Neumann@nasa.gov, [2]Massachusetts Institute of Technology, Cambridge, MA 02139; [3]Stinger-Graffarian Technology, Greenbelt, MD 20770).

Introduction: The Lunar Orbiter Laser Altimeter (LOLA) [1] transmits short (~ 5 ns) pulses at 28 Hz, split into five ~0.1 milliradian-wide beams, providing up to 140 surface measurements per second. The backscattered pulses are lengthened in time due to interaction with the lunar surface. LOLA measures the width and energy of each surface return (Fig. 1). At the same time, the local slope may be estimated from a plane fit to the five adjacent altimetric spots (Fig. 2). The backscattered pulses provide a measure of the root mean square (rms) roughness of the surface at the scale of the laser footprint convolved with the instrument response and surface regional slopes, which are known or measured [2]. Such measures are employed in selection of landing sites for robotic spacecraft, e.g., [3]. Scattering of returns from heights varying by >30 cm (rms) extends the pulsewidth significantly from those over level ground. In the nominal 50-km mapping orbit of the Lunar Reconnaissance Orbiter (LRO), the effective laser footprint is a 2.5-m-diameter circular spot receiving 50% of the photons. The length scale of a single footprint is therefore of importance for exploration and corroborates findings from high-resolution imagers.

The interpretation of pulses to date has been complicated by the Lunar Reconnaissance Orbiter's ~30 km x 200 km commissioning orbit which leads to varying surface spot size and pulse amplitude. LOLA monitors the pulse width at threshold crossing of the backscattered pulse, and this parameter may also be used to infer the transmitted laser-pulse shape. The relationship between the LOLA measured pulse width and the threshold value for Laser 1 and 2 was measured prior to launch for calibration purposes. Pulse widths measured during the first month of commissioning orbit indicate returned pulses spread to as wide as 30 nanoseconds. While these observations require additional corrections, preliminary results show that pulse widths are visibly widened by the aprons of some impact structures and by South Pole-Aitken massifs, among other features. Analysis is underway to calibrate pulse widths against threshold, energy and other instrument parameters to provide a globally consistent quantitative measure of the roughness of the Moon at the scale of a few meters.

LRO attains its 50-km mapping orbit Sept. 17, 2009. Preliminary results from the commissioning period will be presented.

References:

[1] D.E. Smith et al., (2010) *Space Sci. Rev., in press*.
[2] G. A. Neumann et al. (2003) *Geophys. Res. Lett.*, 30(11), 1561, doi:10.1029/2003GL017048.
[3] Anderson, F.S. et al., *J. Geophys. Res.*, 108(E12), 8084, doi:10.1029/2003JE002125, 2003.

Figure 1: Raw pulsewidth measurements, uncorrected for altitude, etc. show surface roughness in hig

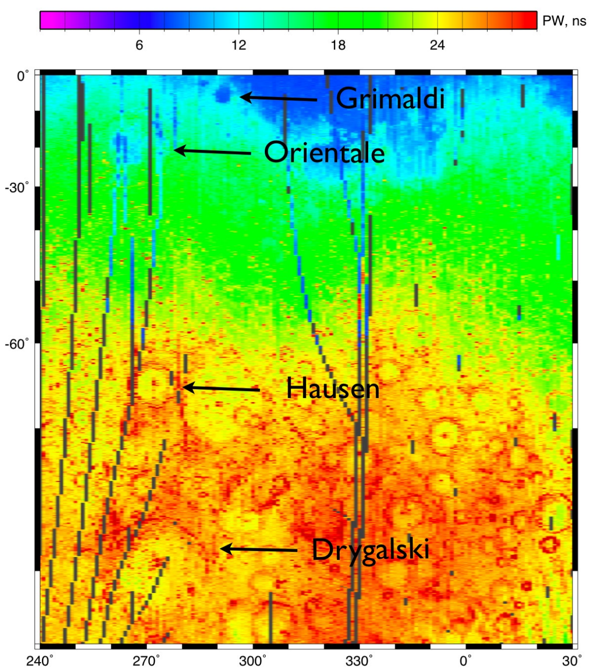
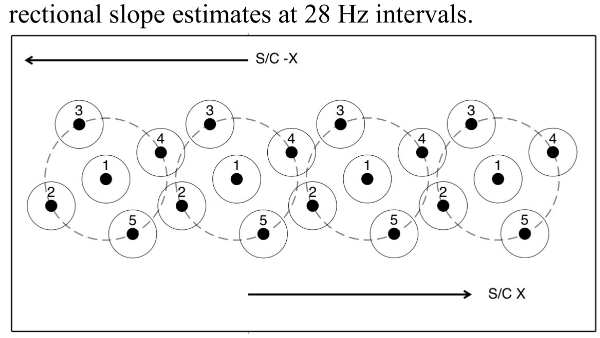


Figure 2: Position of five laser spots provides directional slope estimates at 28 Hz intervals.



THE LUNAR MAPPING AND MODELING PROJECT. S. K. Noble[1,2], R. A. French[1], M. E. Nall[1], and K. G. Muery[1], [1]NASA Marshall Space Flight Center, Huntsville AL 35805, sarah.k.noble@nasa.gov, [2]University of Alabama Huntsville, Huntsville AL 35805.

Introduction: The Lunar Mapping and Modeling Project (LMMP) has been created to manage the development of a suite of lunar mapping and modeling products that support the Constellation Program (CxP) and other lunar exploration activities, including the planning, design, development, test and operations associated with lunar sortie missions, crewed and robotic operations on the surface, and the establishment of a lunar outpost. The information provided through LMMP will assist CxP in: planning tasks in the areas of landing site evaluation and selection, design and placement of landers and other stationary assets, design of rovers and other mobile assets, developing terrain-relative navigation (TRN) capabilities, and assessment and planning of science traverses.

Project Scope and Purpose: LMMP will provide access to this data through a single intuitive and easy to use NASA portal that transparently accesses appropriately sanctioned portions of the widely dispersed and distributed collections of lunar data, products and tools. Two visualization systems are being developed, a web-based system called Lunar Mapper, and a desktop client, ILIADS, which will be downloadable from the LMMP portal.

We are working closely with the LRO team to prevent duplication of efforts and to ensure the highest quality data products. While Constellation is our primary customer, LMMP is striving to be as useful as possible to the lunar science community, the lunar commercial community, the lunar education and public outreach (E/PO) community, and anyone else interested in accessing or utilizing lunar data.

Data Sources: The LMMP will focus predominately on data products resulting from the Lunar Reconnaissance Orbiter (LRO) and Lunar CRater Observation and Sensing Satellite (LCROSS) missions, but will also utilize historical lunar data (e.g., Apollo, Lunar Orbiter, Clementine, Lunar Prospector) and international lunar mission data (e.g., Kaguya, Chandrayaan-1, SMART-1), as available and appropriate, to meet specific near-term product, product type and/or product resolution and accuracy needs.

Data products: LMMP will produce products on a global, regional, and local scale. Local products will be focused on the Constellation program's 50 sites of interest [1]. LMMP will incorporate three different types of products. "Pass-through" products are those which LMMP will ingest and display "as is" from PDS or other sources. Examples of pass though products include the LOLA topography and Clementine and Prospector derived products. In some cases we will modify the data given to us. Examples of modifications include mosaicking the LROC WAC basemap and georeferencing local images. There are also some products that LMMP is producing. Examples of LMMP products include regional and local DEMs from Apollo and LROC NAC imagery, maps of slope and surface roughness, and maps of crater and boulder distributions.

LMMP team members and roles: The project draws on expertise from several NASA and non-NASA organizations (MSFC, ARC, GSFC, JPL, ASU, CRREL – US Army Cold Regions Research and Engineering Laboratory, and the USGS).

The team is well integrated but the major responsibilities are divided as follows:

- MSFC – Management and overall coordination
- Ames - Regional Apollo visible base imagery mosaics and DEMs, EPO web-based neogeography interfaces
- USGS - Local/site visible base imagery mosaics, regional/polar visible base imagery mosaics, local/site DEMs
- JPL - Visualization system infrastructure, web portal and interoperable GIS infrastructure, local/site DEMs (stereo photoclinometry), local/site albedo maps, resource maps, hazard assessment maps
- AZ State U – Local/site DEMs
- CRREL - Web-based visualization system digital overlay tools (Lunar Mapper)
- GSFC - Desktop visualization client – Integrated Lunar Information Architecture for Decision Support (ILIADS)

Schedule: The LMMP project passed formulation review in April of 2009 and a level 3 requirements review in June. Following a series of individual product process validation audits and a preliminary system design audit, a beta version of the portal and visualization systems is expected to be released in late 2009. A version 1 release is planned for early 2011. Our schedule for the release of data products is, however, highly dependent on the timing of acquisition of data from LRO.

References: [1] Noble S. K. et al. (2009) The 50 Constellation Priority Sites. Abstracts to the 2009 Lunar Science Forum, Mountain View CA.

LEAG Annual Meeting
15-18 November 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: 10-15-09

Presenter's Name: Stewart Nozette, PhD

Presenter's Title: Principal Investigator LRO Mini RF, Co Investigator Chandrayaan 1 Mini SAR

Presenter's Organization/Company:
Universities Space Research Association/Lunar and Planetary Institute (USRA/LPI)

Presentation Title

Mini-RF: Topography/Ice

Key Ideas

Review and update of results derived from LRO and Chandrayaan radar observations with focus on polar areas and evidence for extant ice/volatiles.

Supporting Information

Supporting information gathered by ground based observations, Clementine, Lunar Prospector, Kayuga, Chandrayaan, and other LRO instruments will be used.

The LRO Mini RF Technology Demonstration

S. Nozette1 D.B.J. Bussey2 B.J. Butler3 D. Carl2 L.M. Carter4 M. Chakraborty5 J.J. Gillis-Davis6 J.N. Goswami7 E. Heggy8 M. Hillyard2 R. Jensen2 R.L. Kirk9 D. LaVallee2 P. McKerracher2 C.D. Neish2 S. Nylund2 M. Palsetia10 W. Patterson2 M.S. Robinson11 R. K. Raney2 R. Schultze2 H. Sequeira2 J. Skura2 P.D. Spudis1 T.W. Thompson8 B.J. Thomson2 E.A. Ustinov8H. L. Winters2

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7. Physical Research Laboratory, Ahmedabad India
8. Jet Propulsion Laboratory, Pasadena CA
9. U. S. Geological Survey, Flagstaff AZ
10. Vexcel Inc., Boulder CO
11. Arizona State University, Tempe AZ

The Miniature Radio Frequency (Mini-RF) system is manifested on the Lunar Reconnaissance Orbiter (LRO) as a technology demonstration and an extended-mission science instrument. Mini-RF represents a significant step forward in spaceborne RF technology and architecture. It combines synthetic-aperture radar (SAR) at two wavelengths (S and X band) and two resolutions (150 m and 30 m) with interferometric and communications functionality in one lightweight (14kg) package. Previous radar observations (Earth-based, and one bistatic data set from Clementine) of the permanently shadowed regions of the lunar poles seem to indicate areas of high circular-polarization ratio (CPR) consistent with volume scattering from volatile deposits (e.g. water ice) buried at shallow (0.1-1 m) depth, but only at unfavorable viewing geometries, and with inconclusive results. The LRO Mini-RF employs new wide-band hybrid-polarization architecture to measure the Stokes parameters of the reflected signal. These data will help to differentiate “true” volumetric ice reflections from ”false” returns due to angular surface regolith. Additional lunar science investigations (e.g. pyroclastic deposit characterization) will also be attempted during the LRO extended mission. LRO’s lunar operations will be contemporaneous with those of India’s Chandrayaan-1, which carries the Forerunner Mini-SAR (S-band wavelength and 150-m resolution), and bistatic radar (S-Band) measurements may be possible. On-orbit calibration procedures for LRO Mini-RF have been validated using Chandrayaan-1 and ground-based facilities (Arecibo and Green Bank Radio Observatories).

ANALYSIS OF APOLLO SAMPLES WITH THE MULTISPECTRAL MICROSCOPIC IMAGER (MMI).

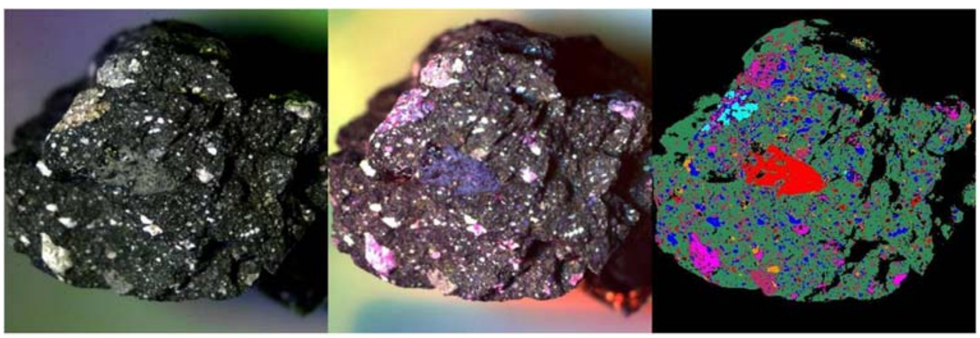
J. I. Nuñez[1], J. D. Farmer[1], R. G. Sellar[2], and C. C. Allen[3], [1]Arizona State University, School of Earth and Space Exploration (Tempe, AZ 85287. jorge.nunez@asu.edu and jack.farmer@asu.edu), [2]Jet Propulsion Laboratory, California Institute of Technology (Pasadena, CA 91109. glenn.sellar@jpl.nasa.gov), [3]NASA Johnson Space Center (Houston, TX 77058. carlton.c.allen@nasa.gov).

Introduction: The Multispectral Microscopic Imager (MMI), similar to a geologist's handlens, generates multispectral, microscale reflectance images of geological samples, in which each pixel consists of a spectrum ranging from the visible to the near-infrared [1], [2]. This spectral range enables the discrimination of a wide variety of rock-forming minerals, especially Fe-bearing phases, within a microtextural framework. The MMI composite images provide crucial geologic and contextual information: 1) for the in-situ analysis of rocks and soils to support hypothesis-driven, field-based exploration; 2) to guide sub-sampling of geologic materials for return to laboratories on Earth; and 3) in support of astronaut investigations during EVAs, or in a lunar base laboratory.

To assess the value of the MMI as a tool for lunar exploration, we used a field-portable, tripod-mounted version of the MMI [1] to image 18 lunar rocks and four soils, from a reference suite spanning the full compositional range found in the Apollo collection, housed in the Lunar Experiment Laboratory at NASA's Johnson Space Center [3]. We present our results from these analyses.

The MMI composite images faithfully resolved the microtextural features of samples, while the application of ENVI-based spectral end-member mapping faithfully revealed the distribution of Fe-bearing mineral phases (olivine, pyroxene and magnetite), along with plagioclase feldspars within samples, over a broad range of lithologies and grain sizes (figure 1). Our MMI-based petrogenetic interpretations compared favorably with thin section-based descriptions published in the literature, revealing the value of MMI images for astronaut and rover-mediated lunar exploration.

References: [1] Sellar R. G. et al. (2008) *Joint Ann. Meet. LEAG-ICEUM-SRR, Abstract #4075*. [2] Nuñez J. I. et al. (2009) *LPSC XL, Abstract #1830*. [3] Allen C. C. et al. (2009) *2nd Lunar Science Forum*.



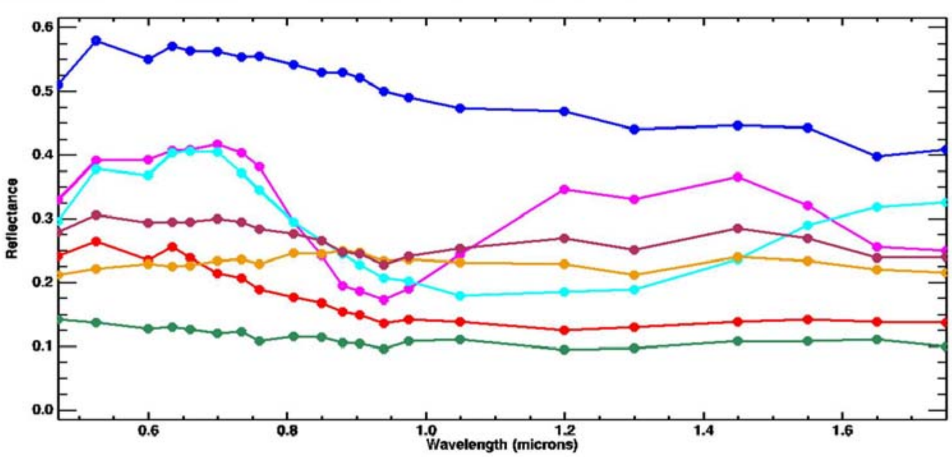


Figure 1. Multispectral images (top left and middle) and corresponding color mineral map (top right) and spectra (bottom) of Apollo sample 15459,53. Subframe field of view: 25 mm x 25 mm (62.5 µm/pixel). Top Left: R = 635 nm; G = 525 nm; B = 470 nm. Top Middle: R = 1450 nm; G = 975 nm; B = 525 nm. Images are 2% histogram stretched. The addition of near-infrared bands enabled the distinction of different rock-forming minerals on the basis of spectral differences.

INDICATIVE BASIC ISSUES ABOUT LUNAR DUST IN THE LUNAR ENVIRONMENT* B.J. O'Brien[1] and J.R. Gaier[2], [1]University of Western Australia, 35 Stirling Highway, Crawley, WA, Perth, Australia, brianjobrien@ozemail.com.au; [1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135, USA, james.r.gaier@nasa.gov

Introduction: In 2009, while images of levitated lunar dust fascinate scientists, memories of clinging dust worry and bewilder engineers and astronauts. "*Dust is the number one environmental problem on the moon.*" And it is not coincidence that the Mars Human Precursor Science Steering Group (MHPSSG) identified dust as the number one operational and human issue for future Martian exploration as well.

Arguably, as a consequence, just as geology was the primary and dominant energising science before and during the Apollo era, lunar dust is becoming the principal and charismatic energising science for future lunar missions themselves and for applications of lunar findings to distant Mars.

Basic issues of lunar dust - including recent discoveries - so fundamental they affect a wide range of lunar research and exploration beyond their immediately obvious scientific disciplines, must be recognised as priorities instead of being often overlooked in scientific, engineering and operational aspects of lunar dust, itself the number one environmental problem on the Moon.

Examples include (i) adhesive and cohesive forces on dust on sensitive surfaces as well as in plasmas; (ii) transport of charged dust due to local and global environments; (iii) nano-dust; (iv) collateral dust; (v) differentiation between composition of surface lunar dust and collateral dust on elevated surfaces which may be carried into a habitat. The unexpected and/or unknown realities of such basic issues can be overlooked in focussed analyses without the consequences to expectations being fully appreciated**.** Such factors are vital for full successes with future robotic and human missions to the Moon and Mars.

Four Recommendations with high or very high priorities are given together with the minimum perceived outcome from each should it be implemented.

Recomendation #1: With very high priority, new experimental and theoretical programs should focus on lunar nanoparticles, their properties if they exist and reasons for their absence if they do not exist. The minimum outcome will complete a gap in knowledge of primeval cosmic and lunar dust size and composition. The knowledge is vital to the height and composition of a lunar exosphere, to understanding processes of uniquely powerful and toxic nano-dust – including those with abundances of nanophase metallic iron (np-Fe^{o}) [1] – and medical applications on earth. The information will fill a "missing link" in descriptions of the lunar environment.

Recomendation #2: Very high priority should be placed on understanding the relationship between surface and adhered lunar dust, with synergistic theoretical support to connect all relevant physical forces associated with charging, lofting, transport, and adhesion/cohesion of lunar dust. The outcomes of this would include strong theoretical and experimental basis for predicting surface adhered type, size distribution, charge and surface forces directly from measured and/or estimated lunar surface dust parameters; Predictability of behaviour in challenging lunar regions (e.g., polar) and during global events; Basis for rational engineering estimates and technology for dust management.

Recomendation #3: With high priority, a working group of space engineers and scientists should analyse lessons from the Apollo era, plus updated developments, to develop protocols to foster synergies between the two cultures. Minimum outcome will include optimised efficient flexibility in Suitcase Science Packages on the moon and in any other landings on a celestial body, particularly those deployed on human expeditions.

Recomendation #4: Programs such as LASER should continue to be given very high priority support recommended by SCEM. The outcome would be that recent peer-reviewed discoveries from revisited Apollo 12 data, although not funded by LASER, are proof of the importance of updated intensive analyses of significant Apollo data [2].

Concluding Comments:
The indicative "basics" in this white paper are examples of fundamental properties of lunar environments that are still little known, little explored and even unexpected by theories and models in 2009, 40 years after Apollo 11. Recommendations about such "basics" include measures that do not all deal directly with lunar science itself, but with the vitally important measures as to how such science should be explored.

References: [1] Liu, Y., et al., Planetary and Space Science (56) 2008, pp. 1517-1523. [2] O'Brien, B.J., Geophysical Research Letters **36** L09201, doi:10.1029 2009/GLO37116.

* From White Paper submitted September 15, 2009 to LEAG as part of the Planetary ScienceDecadal Survey.

TOWARDS A SUSTAINABLE LUNAR SCIENCE COMMUNITY: DEVELOPING THE NEXT GENERATIONS OF LUNAR SCIENTISTS AND ENGINEERS. N.Petro[1], L. Bleacher[1,2], J. Bleacher[1], S. Noble[3], K.R.S. Cahill[4], A. Fagan[5], M. Mader[6], B. Shankar[6]; [1]NASA\GSFC,[2]SSAI.,[3]NASA\MSFC,[4]HIGP, [5]Notre Dame, [6]U.W.Ontario; Noah.E.Petro@nasa.gov

Building a Community: The Lunar Exploration Roadmap (LER) as developed by LEAG contains a sustainability theme that focuses on "Extend Sustained Human Presence to the Moon to Enable Eventual Settlement." Any sustainable human presence on the Moon will require, in addition to commercial partnerships, a long-term investment in future generations of lunar scientists and engineers. Fortunately, due to the recent lunar missions and increase in funding opportunities for lunar science, the number of early career lunar scientists and engineers has grown substantially in the last few years.

With plans for future US and international orbital and landed spacecraft, the Moon will become a place of intense scientific scrutiny. But who will build the instruments and spacecraft and analyze data from these missions? Certainly the current generation of established scientists and engineers will play a major role in these endeavors, but who will follow them? The Next Generation Lunar Scientists and Engineers (NGLSE) is a grass-roots effort at fostering the growing community of early career lunar scientists and engineers. We are fortunate to be in a position to develop the next generation of lunar enthusiasts with the support of the first generation of lunar scientists and engineers, ensuring continuity of a base of lunar knowledge.

The need to foster the next generation of lunar scientists is recognized within NASA, is acknowledged by the NASA Lunar Science Institute (NLSI), and is recognized by the international community (e.g., ILEWG, Lunar Explorers Society, and the Canadian Lunar Research Network). A primary goal of the NLSI is to support "...the development of the lunar science community and training the next generation of lunar science researchers." Additionally, the NASA HQ (OSEWG), which is composed of representatives from the SMD, the ESMD, and SOMD, is tasked with the integration of science and engineering for the successful exploration of the Moon. The NGLSE aims to bring early career scientists and engineers together and help in creating, fostering and supporting the next generation of lunar scientists and engineers.

Currently with over 150 members from academia, industry, and NASA, the NGLSE is building a representative cross-section of the lunar science and engineering communities. The NGLSE has and will meet twice a year in conjunction with the annual LPSC as well as the NLSI Lunar Science Forum. The NGLSE provides opportunities for social and professional networking among our members and across generations. We provide opportunities to give and receive feedback on research in a small setting, and will provide a forum to allow members to suggest and hold topical workshops. Ultimately, the NGLSE will provide communication to the larger community via a website, in addition to our existing Facebook group and email list-serve. Feedback from previous workshops indicates that meeting with community leaders has been beneficial to the NGLSE members. We encourage leaders in the lunar science and engineering field to participate in future workshops as a critical step in sustaining the next and future generations.

Sustaining A Community: In order to maintain a science/engineering community capable of sustaining a long-term presence on the Moon, regardless of when that presence begins, a continuing lunar funding program is required. Should funding for lunar science continue and increase over the next few decades, a lunar science and engineering community should evolve and grow simultaneously, with new community members continually being brought into the fold.

However, if there is a decrease in near-term lunar missions and/or funding over the next few years, maintaining a lunar community should be a top priority. Without the financial support or the promise of upcoming lunar missions, the recent growth of the domestic lunar community would likely wane. Coupled with a potential decline in a lunar community through attrition and age, postponing a lunar program without sustained funding opportunities could lead to a near depletion of the ranks and a loss of the inherited lunar knowledge base, while the international community may continue its growth. While a total depletion of a lunar science community is unlikely, losing members from the recent increase in lunar scientists and engineers would certainly be a setback for the community.

Apart from a sustained lunar funding program, regardless of the near-term future of lunar exploration, what else can be done to sustain a developing lunar community? With the possibility of future commercial lunar exploration, commercial partners should develop relationships with members of the next generation; likely the generation who will be leading the way back to the Moon.

The lunar science and engineering communities need to also begin fostering future generations of scientists and engineers. This generation is currently in grade school and can be reached and engaged through effective, sustained education and public outreach efforts. Building a community of active participants who are dedicated to, and trained in, effective education and public outreach efforts to engage students, policy makers, and the general public is fundamentally important in building a sustainable, long-lived, and publicly supported lunar science program.

DEVELOPMENT OF A SIMULATION TOOL FOR THE PROPULSIVE SUBSYSTEM OF *ESMO* LUNAR MISSION.

Alessandro Pettinari[1], Alessandro Saturni[1] and Luca L. Rossettini[1]
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Introduction: The Moon is the main objective for next decade Space missions. Exploitation, scientific research, robotic and manned exploration are planned by the most important space agencies. This renewed interest involves both the main Space Players down to the academic level.
The European Student Moon Orbiter (ESMO) is the first student mission to the Moon. Promoted and directed by ESA, ESMO represents a "*unique and inspirational opportunity for university students, providing them with valuable and challenging hands-on space project experience in order to fully prepare a well qualified workforce for future ESA missions, particularly those planned by the Exploration and Science programmes in the next decades*" [1].
The mini-satellite class ESMO Orbiter is launched as an auxiliary payload into a highly elliptical low inclination Geostationary Transfer Orbit (GTO) using the Ariane Support for Auxiliary Payloads (ASAP) by Ariane 5 or Soyuz from Kourou. An on-board bipropellant liquid thrusters system accomplishes the lunar transfer and the lunar orbit insertion. After Moon orbit injection several scientific objectives will be achieved during the minimum six months mission time [7].
The main objective of this paper is to describe the whole ESMO propulsion system control algorithm and the corresponding simulator [2], which will be used during mission Phases C, D and especially during mission operations.
More in details, the modelled Fuel Management System is in charge of the control of the entire propulsion system, regulating the propellant flow for the different orbital manoeuvres.

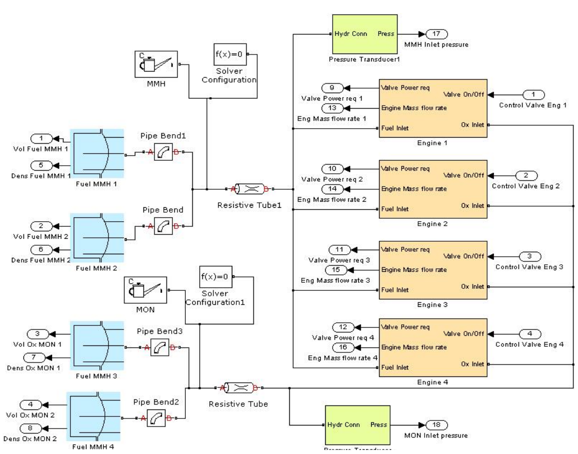

Fig. 1 : Structure of the simulation tool; each coloured block contains other subsystem components.

Design and structure: Orbiter propulsion system is constituted by four R6 thrusters working with MON-3 oxidizer and MMH fuel, contained in four spherical tanks. The propellant is pressurized by 300bar tank of nitrogen, used also as propellant for attitude control cold gas thrusters.
The model here presented includes piping devices - such as valves and filters - simulation in order to have a comprehensive control over the propulsive system behaviour.

Each component has been modelled, step-by-step, in order to follow a "close to reality" approach. Thus line losses, thermodynamic relations and other performance features were considered [3]. Matlab Simulink Simulation Tool is used for the model implementation, as shown in Fig. 1: any coloured block corresponds to another Simulink model, blue blocks for the tanks subsystem, green for the pressure transducers and pink for the thrusters (Fig. 2). The Propulsion System Simulator is connected to the main Orbiter simulator [4] in order to communicate the failure detection system outputs, such as thrust misalignments, leakages, measurement uncertainties and insufficient fuel level.
This highly challenging and demanding project, far over the common expectations for a preliminary design phase, has demonstrated to be complete and completely reliable [5] as well as suitable to be used as the primary mission control system.

Conclusions and further work: The Propulsion System Simulator has been tested and approved by ESA project manager.
Preliminary experimental tests on R6 thrusters conducted in ESA-ESTEC facilities were used to validate the simulator. More detailed functional and performance tests are going to be performed [6], followed by extensive model validation. The Simulator will be improved including dynamic figures for the thrusters, updated frequency and damping, in order to maximize reliability and minimize failure events.
Eventually, Propulsion System Simulator will then be integrated with other Orbiter subsystems models and tested before launch.

References:

[1] Walker R., The ESMO Mission: Education, Outreach and Science. [2] Pettinari A., Theoretical model and functioning test on ESMO propulsive system p.32, bachelor thesis (2009). [3] ESA, Design_Justification_File (2009). [4] ESA, Model_Specification_Document (2008). [5] Moro V., Mengaldo G., Moon Orbiter, Propulsion Issues (2008). [6] ESMO Functioning Test Plan (2009). [7] ESMO_PhaseA_StudyReport p.18-19 (2008).

LEAG Annual Meeting
16-19 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: Oct 16, 2009

Presenter's Name: Carle Pieters [and the M^3 Team]
Presenter's Title: Prof.
Presenter's Organization/Company: Brown University

Presentation Title

Water, Water Everywhere?

Key Ideas

Surficial H2O and OH on the Moon is now undisputed, and there are implications for other airless bodies in the solar system. Detailed research is needed to characterize and utilize this new information.

Supporting Information

Pieters et al., Science 2009
Sunshine et al., Science 2009
Clark, Science 2009

THE INFLUENCE OF LUNAR OUTPOST OBJECTIVES ON OUTPOST CAPABILITIES. J. B. Plescia, Applied Physics Laboratory, The Johns Hopkins University, MP3-E169, 11100 Johns Hopkins Road, Laurel, MD 20723 (jeffrey.plescia@jhuapl.edu).

Introduction: As various countries examine concepts to send humans Moon, the raison d'être for human spaceflight beyond the ISS remains unclear. NASA has suggested grand themes such as human civilization, exploration preparation, economic expansion, scientific knowledge, global partnership and public engagement. But these are vague concepts lacking any specificity and thus decisions about whether an outpost is required, and the objectives, location or capabilities of such an outpost remain undefined.

Depending upon the style and the ultimate goal a nation sets for its lunar exploration program, different requirements are derived. Various concepts have been proposed to make use of lunar resources (ISRU) such as propellant, power beaming, helium-3 mining, and metal mining. The Moon has been suggested as a platform for astronomical observation across the electromagnetic spectrum. Finally, the Moon could serve as a tourist destination.

If the goal is science and the mission set includes only sorties to diverse locations, then there is no infrastructure / precursor information requirement and the site would be dictated by the science objective.

However, a key aspect of the US Vision for Space Exploration is extending human missions beyond low Earth orbit and learning to exploit lunar materials and energy to create new capabilities. That cannot be accomplished by sortie missions (although such are not precluded). Rather a centralized facility with appropriate infrastructure is necessary and this in turn defines the necessary precursor information and demonstration.

Options: Resource utilization can take two forms: (1) resources used close to where they are collected to support surface operations and (2) resource export. In the case of supporting surface operations, H and O can be used for life support, the regolith can be used for shielding, and solar energy can be used for power. For export, hydrogen and oxygen can be used for rocket propellant, helium 3 or various metals could be extracted and returned to Earth, and solar power could be beamed to the Earth. Depending upon which one or combination of these options was selected, or which was paramount, it would dictate the type of precursor information and demonstration necessary before site selection and it would define the outpost capabilities.

***Propellant Production*:** The production of rocket fuel using O and H has the most far reaching implication for enabling long-term presence beyond LEO and enabling exploration beyond cis-lunar space. Specifically which "ore" would be selected and the process for extraction remain unclear. For example, schemes have been proposed to use high Ti regolith for O_2 production as well as mining water ice in shadowed craters.

Using this example, the following requirements might be derived: assess the form, concentration, and distribution of H and O in different materials (mare, pyroclastics, shadowed craters); demonstration of excavation and processing techniques, demonstration of storage and fueling technology, and demonstration of transport. Because different geologic units offer the H and O in different forms, the cost (both energy and dollars) will vary from site to site. Only when the ore is mapped and the costs of production assessed can an outpost location be selected. If one chose a mare site, then the critical issue might be power during lunar night and the energy to extract the O from minerals. If a polar site were chosen, the critical issue might be mining at low temperatures in the dark. These aspects need to be considered such that an appropriate architecture developed. Resource assessment and process demonstration (excavation and production) could be done robotically. For full scale production, some combination of robots and humans would be used.

Radio Astronomy Observatory: The far side of the Moon is a radio quiet area that has been suggested as an ideal location for a radio observatory. If this were the goal, the precursor requirements and outpost capabilities are minimized. One need only select a site in which the observatory could be established and the outpost would need only survival capabilities (as opposed to the ability to make propellant).

Commercial Potential: The exploitation of O and H for fuel, including not only the processing but the storage and transfer activities, could be done either by NASA or a commercial venture. At this stage, however, it seems likely that NASA would be the sole customer. In that context, the commercial option would almost certainly be more expensive as NASA would incur all of the costs it would on its own, and it would also have to pay a profit to the company. If more countries or other commercial activities were present, then the cost to NASA might be appropriate. Development of propellant production capabilities by NASA might be sufficient to spawn other commercial activities at the outpost.

LUNACHEM: AN INSTRUMENT TO ENABLE SUSTAINED HUMAN LUNAR EXPLORATION. J. C. Rask[1], E. Tranfield[1], C. G. McCrossin[1], D. J. Loftus[1]. [1]Space Biosciences Division, NASA Ames Research Center, Moffett Field, CA 94035 (jon.c.rask@nasa.gov)

Introduction: As NASA prepares for sustainable exploration of the Moon, a clear understanding of the chemistry of lunar dust is required for extended duration lunar surface operations. All aspects of the unique environment of the Moon—micrometeorite bombardment, UV light exposure, solar wind radiation, solar particle event radiation and galactic cosmic radiation—influence the mineralogy of the Moon, and are believed to impart a high degree of chemical reactivity to lunar dust. While the basic structure and composition of lunar dust is well known, little is known about its in situ chemical reactivity, which could have significant implications for astronaut health and in situ resource utilization. Ground based studies of lunar dust chemical reactivity are currently underway [1] [2].

Payload Description: We propose LunaChem as an instrument that can be delivered to the Moon to measure the in situ chemical reactivity of lunar dust [3]. While the current design of LunaChem is notional, certain key capabilities are required, including sample acquisition from the lunar surface, partitioning of the sample into uniform aliquots to perform multiple analyses, in order to determine the peak chemical reactivity and decay of chemical reactivity once the lunar dust is brought into a habitat like atmosphere. Within this general framework, an instrument weighing 5 kg with average power consumption of less than 20 W is envisioned. These features make it an ideal payload for small lunar landers that support early science objectives and early exploration technology demonstrations. While LunaChem was originally conceived as an instrument for robotic precursor missions [4], we believe that LunaChem could also be carried by astronauts on crewed missions, so that analysis of lunar soils could be performed more broadly as an ongoing part of exploration activities. The core capabilities of LunaChem could be expanded by adding functionality as identified with input from the lunar science community.

Implications and Synergies: LunaChem aligns with high priority initiatives within the Lunar Exploration Roadmap, enables and supports the goal of collaborative expansion of science and exploration, and will be a key step to engaging commercial activity if flown aboard a commercial launch provider. Science results from LunaChem will validate Earth-based assessment of lunar dust toxicity [5]. Perhaps more importantly, LunaChem would support the establishment and implementation of comprehensive outpost site-selection criteria and processes.

References:

[1] W. Wallace, L. Taylor, B. Cooper, D. McKay, B. Chen, A. Jeevarajan, 2009. Lunar dust and lunar simulant activation and monitoring. Meteoritics & planetary science 44, no. 7, p. 961-970.

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LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: 10-13-2009

Presenter's Name: Kurt D. Retherford
Presenter's Title: Volatiles (LAMP)
Presenter's Organization/Company: Southwest Research Institute

Presentation Title
Volatiles (LAMP)

Key Ideas

We'll discuss observations of the LCROSS impact with LRO/LAMP, and searches for surface reflectance signatures of water frost and emission features for atmospheric constituents.

Supporting Information

http://www.boulder.swri.edu/lamp/
http://soc.boulder.swri.edu/lamp/

ODYSSEY MOON "M-1" MISSION OF OPPORTUNITY– ENABLING SCIENCE, EXPLORATION AND COMMERCE. R. D. Richards, Odyssey Moon Ltd., 300 Interchange Way, Vaughan, Ontario, Canada L4K 5Z8 robert.richards@odysseymoon.com

Introduction: Odyssey Moon is a commercial lunar enterprise supplying payload delivery services to the Moon in support of science, exploration and commerce.

As the world's first multi-national enterprise dedicated to commercial lunar exploration and development, Odyssey Moon plans to meet near term and long term global market needs for low cost, reliable and frequent lunar access currently unaddressed by large government space programs. By creating alternative commercial lunar delivery products and services that provide rapid mission schedules and standardized systems, our goal is to provide value added commercial lunar missions for our government, academic and commercial customers. World-class technologies will be selected and developed into standardized, scalable turn-key solutions that will supply unprecedented value to diverse international customers seeking reliable and cost effective products and services for lunar activities.

Odyssey Moon has established launch agreements with scientific, educational and commercial organizations worldwide and is recognized by NASA as a potential supplier of Commercial Missions of Opportunity for fundable payload delivery services to the Moon. Odyssey Moon has also entered into discussions with other national space agencies worldwide for the provision of hardware and services on a commercial procurement basis.

This paper addresses the Payload Flight Opportunities provided by M-1 along with updates on company and mission status, plans and financing.

The Mission: "MoonOne" (M-1) is a commercial robotic lander mission to the near side equatorial region of the Moon, in support of science, exploration and commerce. The mission is planned for launch in late 2012 utilizing the Odyssey Lunar Lander, developed from NASA's Common Spacecraft Bus (CSB) platform. This "Commercial Mission of Opportunity" has a payload manifest comprised of scientific, educational and commercial payloads with approximately 15 kg of payload capacity still available to the international lunar communities for scientific or technology demonstration payloads. We have minimized individual payload expenses through a "condominium" approach to cost sharing of spacecraft resources and common spacecraft elements. As an official Google Lunar X PRIZE mission, M-1 is the first of a series of mission opportunities designed to enable low cost, rapid, and frequent access to the Moon for government, academic and commercial customers.

The Odyssey M-1 spacecraft processing and launch will occur in the United States with the support of an experienced launch partner in coordination with Odyssey Moon's prime contactor MDA.

Mission baseline: The Odyssey Moon reference mission includes the following baseline elements*:

- Near side equatorial landing site focused on regions containing dark mantle deposits
- A single platform fixed lander
- Operation during a single lunar day

Payload Manifest:

- Raman/LIBS (TNO "Moon4You")
- International Lunar Observatory ("ILO-X")
- UK Educational (ISSET "Moonlink")
- Plant Biosphere (Paragon "Lunar Oasis")
- Memorial Payloads (Celestis)
- Google Lunar X PRIZE instruments
- Additional payloads TBD

NASA Partnership: Odyssey Moon Ventures LLC has partnered with NASA for the development of its "Odyssey" modular commercial lunar lander system based on the NASA Ames Common Spacecraft Bus. This unique public-private partnership combines NASA expertise with commercial space paradigms, resulting in new industrial capabilities for the company and benefits to the American space program.

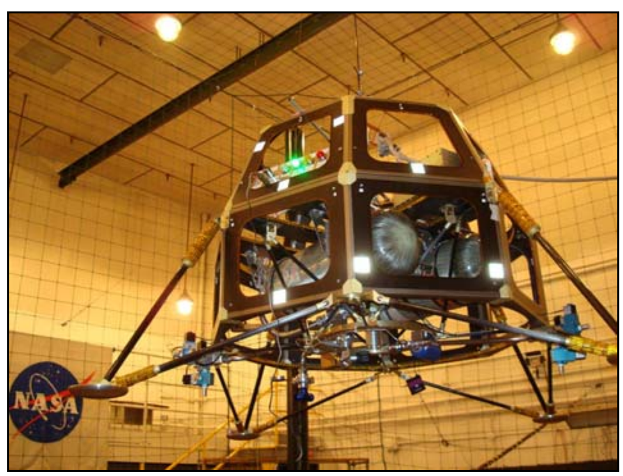

Image Credit: NASA Ames & Odyssey Moon Ltd.

Exploration Sustainability:
Benefits and Hurdles of Incorporating In-Situ Resource Utilization

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ABSTRACT

While the U.S. Apollo program was both technically and scientifically highly successful, it has been argued that the Apollo program was not sustainable once it accomplished its primary objective of landing a man on the Moon and returning him safely to the Earth. To have a sustainable human lunar exploration architecture, it must incorporate both Exploration and Programmatic sustainability attributes. Exploration sustainability attributes include continually improving performance and capability, continually reducing risk to mission and crew, continually reducing cost for performing missions and operations, and continually reducing dependency on Earth supplied logistics and infrastructure. Programmatic sustainability attributes include continually engaging and exciting the public, increasing benefits to countries supporting exploration, establishing a common 'vision' and long-term plan that the public supports, and having a robust and flexible plan and capabilities to allow for new ideas and priorities over time. In-Situ Resource Utilization (ISRU) is an area of development that can significantly change how systems required to sustain a human presence on the Moon are designed and integrated, leading to potentially breaking our reliance on Earth supplied logistics and infrastructure, and promoting the establishment of commercial space products and services. ISRU can encompass many aspects of human exploration such as the extraction and processing of local resources into mission critical consumables (i.e. propellants and life support gases), the ability to modify the lunar landscape for safer landing and infrastructure emplacement, the ability to build structures and habitats, and the creation of in-situ energy generation and storage systems. This presentation will address how ISRU can help the lunar architecture currently under development achieve both Exploration and Programmatic sustainability attributes, and discuss the advantages and difficulties associated with incorporating ISRU systems and capabilities into future human lunar exploration plans even though it has never been flown on a space mission to date.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: 10/08/09

Presenter's Name: David E Smith (place-holder)
Presenter's Title: PI LOLA
Presenter's Organization/Company: MIT

Presentation Title

Initial results from LOLA

Key Ideas

LOLA has collected a very significant altimetry dataset (several hundred million measurements as of Oct 2).
Also, 3-dimensional surface slopes on 25-meter length scales and surface roughness measured within 5-meter spots.

Supporting Information

Not sure what is needed here.

OUR KNOWLEDGE OF LOCATIONS ON THE LUNAR SURFACE AND IN ORBIT AFTER 4 MONTHS OF LRO. David E. Smith[1], Maria T. Zuber[1], Gregory A. Neumann[2], and Erwan Mazarico[2], [1]MIT, Cambridge, MA; smithde@mit.edu, [2]NASA Goddard Space flight center, Greenbelt, MD

The lunar Reconnaissance Orbiter spaceraft has been in lunar orbit for for months. The first 2 months the specacrfat was in a Commissioning orbit between 30 and 200 km altitude. In the last 2 months the spacecraft has been in its designed polar mapping orbit with average altitude of 50 km.

During this time observations have been acquired by the laser altimeter (LOLA), the Earth based laser randing system (LR), and by the S-band tracking networks that have been tracking LRO almost continuously since LRO's arrival at thee moon. All these data have enable us to better assess and understand our knowledge of LRO's orbit and the locations of features on the surface.

A SUSTAINABLE RETURN TO THE MOON Paul D. Spudis, LPI, Hosuton TX 77058 (spudis@lpi.usra.edu)

Our ultimate goal in space is to be able to go anywhere, at any time with whatever capabilities to accomplish any task or job we choose to undertake. We are light-years away from achieving such a goal, largely because we must drag everything we need in space with us from the bottom of a very deep gravity well – the Earth's surface. As long as this paradigm prevails, we will remain mass- and power-limited in space and thus, capability-limited as well.

The Vision for Space Exploration, outlined by President Bush in 2004 and endorsed by two Congresses, is the official space policy of the United States. The Vision is designed to serve national scientific, economic and security interests. It calls for extending human missions beyond low Earth orbit by learning how to use the material and energy resources of the Moon to create new capabilities in space. The VSE was envisioned from the beginning to be accomplished under existing and inflation-growth budgetary envelopes. Thus, our challenge is to design a program in which time (rather than money) is the free variable. We want to make steady, constant progress towards our goals. This requires an architecture that uses small, affordable steps (incremental) that occur at frequent intervals (paced program) and build upon each other with time (cumulative) to create new and lasting space faring capability.

The Moon is key to gaining this new capability. It has the material and energy resources needed to operate and live in space. It is over 45% by weight oxygen, extractable through a variety of well-known industrial chemical processes. Hydrogen is also present; at the equator it occurs in concentrations of up to 100 parts per million, extractable through simple solar thermal heating. But the real "pay dirt" on the Moon is at the poles, where concentrations of hydrogen have been confirmed (the current debate is over what form this hydrogen takes). Water ice likely exists in the permanently dark regions of the lunar poles. Moreover, we have documented areas at both poles that are in near-constant sunlight (a consequence of the low obliquity of the Moon's spin axis). So the Moon's poles contain both the material (water) and energy (sunlight) resources needed for sustainable human presence there.

An incremental architecture designed to take advantage of these possibilities is possible under current budgetary limitations. The key is to pre-emplace much of the assets we need on the Moon robotically, prior to the arrival of humans. Small robotic landers can survey resources and characterize the terrain for an outpost. Slightly larger landers can deliver equipment; rovers with earth-moving attachments can prepare a habitat site. Large solar arrays can be deployed to generate hundreds of kilowatts of electrical power. Small oxygen production equipment can experiment with different processing techniques, characterizing their yields and efficiencies. All of these robotic devices can be teleoperated from Earth (only a three second time delay); each landing incrementally increases our capability on the Moon and independence from terrestrial logistics. When humans finally arrive on the Moon, they move into a turn-key operation – a pre-emplaced outpost, operating and ready for use.

On the Moon, we will learn the skills needed and develop the technologies required to live and work productively on another world. Our objectives are to arrive, to survive and to thrive. Tasks include building a transportation system, preferably with maximum utility and reusability (arrive), closing the life support loop and extracting consumables from local materials (survive), and producing products for export that create new capability in space, such as rocket propellant (thrive). By establishing a space transportation system that can routinely access the lunar surface and return to low Earth orbit, we have created a system that can also routinely access all other points in cislunar space, where all of our commercial and national security assets – and more than 90% of our scientific assets – reside.

Such a strategy has significant implications for the lunar return architecture. The Orion CEV should be designed in a minimalist, Apollo-scale configuration; its function is only to transport crew to and from Earth's surface to staging areas in orbit. Staging can be done from the ISS, making that program an asset in our lunar return. Cargo takes solar-electric "slow boat" routes to an Earth-Moon Lagrangian staging point while the crew arrives later using "fast" chemical transport. The Altair lander is more LM than behemoth; a 20-30 mT vehicle, its only job is to transport crew to and from the lunar surface. The crew lives on the lunar surface in habitats pre-emplaced and built through robotic teleoperation. Vehicles are designed to be reused in space and, eventually, re-fueled on the Moon and in cislunar space.

Creation of this new transportation system completely changes the paradigm of space flight; no longer are we limited to what we can bring up from Earth. Space systems become maintainable and extensible. Very large distributed-aperture sensor systems can be built and upgraded. We will only launch high-information density payloads from Earth, such as complex machines, sensors and computers, and refuel stages in Earth orbit for placement in higher orbits (e.g., GEO) or into interplanetary space. Creating this cislunar transport infrastructure is analogous to building a "transcontinental railroad" in space – it will open up the space frontier to an ever increasing and varied customer base, not just academic science and government.

The Vision's purpose was to break the tyranny of the rocket equation by learning how to use what we find in space to create new capability. It was to be undertaken under existing or modestly enhanced budgetary envelopes. We go to the Moon not touch the surface and blast off for Mars but to learn the skills needed to become a space faring civilization. Fulfilling this goal makes space relevant to many different customers, with a wide variety of interests and purposes. The intent of the Vision was to redirect the agency onto a path that creates new wealth, instead of merely consuming it.

AN EXPERIMENTAL STUDY OF ASTROBIOLOGY FOR SUSTAINABLE DEVELOPMENT AND SETTLEMENT ON THE LUNAR SURFACE Jayashree Sridhar,C-3 Icl Jubilee Apartments, No 16 Second Main Road, Gandhinagar, Adyar, Chennai-600020, Tamil Nadu, India.+91-44-24424969,+91-44-42115269, jayashree92@yahoo.co.in.

Introduction: The human presence on the moon was first marked by the Apollo missions. Now moon is emerging as a testing base for space technology. For a sustainable life on moon biology is the vital subject with which we have to deal. From the examination of the scientific, cultural and political imperatives the moon appears as an important destination. Moon will play a key role in answering the fundamental human questions that we are now poised to address and realistic and achievable investigations can be defined that will meet the science objectives.

- It is amendable to human exploration in the next 50 years , with reasonable investment in foreseeable technologies
- It also represents an important stepping stone towards the following destination and ultimately to mars and establishes an important component of a permanent human presence in the solar system

Robotic Mission: Robotic missions will continue to play an important role in comprehensive human exploration program. From the outset of the space program, human activities have been preceded by and enabled by robotic missions as we move out into the solar system. Permanent human presence will be preceded by intensive Nano- Tech Bionics robotic exploration at each destination as it performs tasks like humans.

EXPLORATION OBJECTIVE	OBSERVATION SITE
Origin of Lunar surface and resources	At the Regolith
Presence of Water and its forms	On the Surface
Search for Lunar Samples	Earth's meteorite effect on the moon
Evidence of sun's history and its effect on earth through time	Regolith and rocks
History of asteroid and comet collision on earth	Local cratering record
Bulk properties and internal structures of NEO	NEO
Utility of resource production	On the moon
In-situ resource production	On the moon
Geological and climatological histories	On the moon
Search for past and current Life	On the surface of the moon
Search for evidence of life in the observational properties of extra solar planets	With a telescope on the lunar surface

Human Mission: If humans are to accomplish exploration objectives to other planetary bodies it requires crew members to survive for long periods of independence from earth. Plants have had and still have a key role in the history of life on Earth. They are responsible for the presence of oxygen, a gas needed for most organisms that currently inhabit our planet and need it to breathe. Plants and plant communities are very important to humans and their environment. Plants can provide food and serve as life support system. There is a significant reduction in equivalent system mass cost concerning storing necessary food and life support apparatus when those resources are supplemented by plant based provisions. These functions highlight the importance of plant growth module design especially those that incorporate the use of ambient light in lunar environment.

Resources: For a sustainable human existence on the lunar surface we have to create certain artificial facilities like our earth.

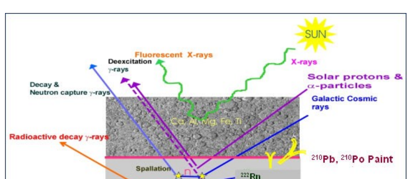
- Determination of radiation tolerance
- Designing lunar plant growth facility
- To grow vitamins & minerals
- Testing of ISRU for crop culture
- Better sun sensor positioning
- Increased drought tolerance
- Drilling on the moon- Apollo 16 and decode sample into regolith

Conclusion: Life sustainability on the moon requires the support of plants and robots. With the help of plants which requires less water and produce more oxygen and improved bionics robots can make our establishment highly successful. By performing the test in earth by creating an artificial atmosphere like our moon, we can reduce our cost, chances of failure and assure a high possibility of sustainable life on the lunar soil.

Acknowledgement: This work evolved from my imagination and current research on astrobiology about a sustainable future exploration and I have also referred several paper works for doing this project. I would also like to thank my family for their support.

Reference:

[1] 50 years of Space by P.V.Manoranjan Rao
[2] Astrophysics by K.D.Abhyankar
[3] The next steps in exploring deep space by Wes Huntress



Radiation Environment of Moon

LUNAR CEMENT CONSTRUCTION WITH SURFACE AND UNDERGROUND ROOMS BASED ON CARBON CIRCULATION SYSTEM. T.Tanosaki1 and Yasunori Miura2, 1 Central Research Inst., Taiheiyo Cement Co. Ltd., 2Graduate School of Sci. & Eng., Yamaguchi University, Yoshia 1677-1, Yamaguchi, Yamaguchi 753-8512 Japan. yasmiura@yamaguchi-u.ac.jp

Introduction: Lunar building construction on the surface with various design are reported so far [1]. On the other hand, various designs of underground building on the Moon are proposed so far [1]. However, these models are not based on material circulation system including carbon (C).

The purpose the paper is to show joint house with surface and underground with lunar cement materials based on carbon cycle system.

Problem and model of lunar surface building: Serious problem for surface building on the airless Moon should be considered to continuous destruction by extra-lunar materials. Previous building models on planet Earth are based on beautiful and economical building on the terrestrial surface without any meteoritic bombardments, which is based on thick atmosphere against serious hazards [1]. Present model for surface building is hard cement building with carbon cycle to show marking location of underground lunar base as shown in Table 1

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Table 1. Problem and model for surface building on the Moon.

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1) **Problem:** Continuous destruction by extra-lunar materials.
2) **Characteristics of surface builing:** Marking spot for the lunar base.
3) **Present model for surface building:** Cyclic building mainly for location of the lunar base

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Problem and model of lunar underground building: Main problem for underground building on the airless Moon is strong hazard building against moonquake, lunar volcanism and bombardments by extra-lunar materials. Previous underground building models are mainly based on material circulation with food supply and chemical reaction of waste material [1]. Present model for underground building is hard and cyclic cement building with carbon cycle to maintain underground lunar base as shown in Table 2.
Material circulation on the Moon in the present model is shown as state changes of carbon (C) by vapor-liquid-solid (VLS) reactions as follows:

Building materiasl with C etc. ⇔ C state-changes (VLS) ….(1)

Table 2. Problem and model for underground buildings on the Moon.

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1) **Problem:** Continuous destruction by extra-lunar materials.
2) **Characteristics of underground building:** Main living and working spaces for the lunar base.
3) **Present model for underground building:** Cyclic building for any hazard of the lunar base with material waste cycles

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Material circulation including destruction of hazard activity: All materials on Earth (and previous Moon) are how to avoid from strong hazards or destructions which are formed by harder and anti-destruction building with cement and so on. From natural system of materials, destruction by any movements
are normal process to material cycle with collection and destruction. The present model is different point of material cycle with any destruction process. It is so expensive to build against any destruction, but it is economical way to material cycles including waste cycle on the Moon and Earth finally [2, 3, 4]. This is mainly because scale of hazard should be endless and no upper limit against any hazard.

Main sources of light elements from lunar rocks: Light elements of hydrogen (H), carbon (C) and nitrogen (N) are inevitable for carbon cycle on the Moon, where all elements are found on the Apollo lunar samples of regolith and polymict breccias [1, 2, 3, 4].

Summary: The lunar base with joint system of surface and underground buildings with carbon-bearing cement should be included as material cyclic system against any hazard and destruction on the Moon as shown by equation (1), which is the most economical way to maintain the lunar base finally.

References:
[1] Heiken G., Vaniman D. & French B. (1991): Lunar source book (Cambridge Univ.Press). p.468-474.
[2] Miura Y. (2009): LEAG-2009 (in this volume), abstract #2049.#2043.
[3] Miura Y. (2009): *LPS XL,* Abstract #1090.
[4] Miura Y. (2009) : *LPS XL,* Abstract #1468.

WHY SETTLE THE MOON? G. Jeffrey Taylor, Hawaii Inst. of Geophys. and Planetology, U. Hawaii, Honolulu, HI 96822 (gjtaylor@higp.hawaii.edu)

Introduction: The space program needs a viable long-term goal. I suggest that the central goal should be to learn to live and work in space by living and working in space. A sustained presence on the Moon, with a vibrant infrastructure in cis-lunar space, is an essential part of that goal. Achieving this goal requires extensive use of lunar resources, active roles by both government and the private sector, and a social contract that the venture is worthwhile and worth funding. But why do it? Here are some reasons for pursuing this goal.

Challenge ourselves. We need grand goals that bring out the best in us. As President John F. Kennedy said about the Apollo program, we go to the Moon not because it is easy, but because it is hard. Settling the Moon, learning to live and work in space, and eventually going to Mars and beyond is certainly hard, much harder than was going to the Moon during Apollo. It will test our educational system, research laboratories, and industries, making all more effective and innovative than they are now.

New perspectives on our world, our problems, and ourselves. Space exploration has already provided us with new perspectives on Earth and our place in the universe. The first full Earth pictures taken by Apollo astronauts during their Moon journeys showed us that we live on an isolated, fragile, and beautiful island in space. Seeing the pale blue dot, as Carl Sagan called it, made everyone realize that we ought to take care of it, which helped fuel the environmental movement during the 1970s and beyond. Lunar settlements far from home may give us new perspectives on addressing other pressing problems, such as energy, health care, and poverty. Perhaps most important, it expands our view of our place in the universe. We are part of something larger than ourselves, our towns, our nations, and even our world.

Inspire all of us to become part of something larger. Many of us have claimed that the Apollo program inspired a generation of students. Maybe. But a sustained human presence will not provide the thrill of a short Apollo mission. What is the equivalent of Apollo 8, its crew reading from Genesis on Christmas Eve, 1968, or of Apollo 11 making the first landing? Instead, the inspiration will come from the new opportunities in commerce, science, arts, and humanities. Students from K through college will see opportunities for them to contribute to culture and knowledge. The new perspectives our human perch on the Moon provides may inspire the creative people in our society to aim high, to see the world differently, to think outside the box.

National pride and prestige. We have a growing number of space-faring nations. Believe it or not, the leaders of those nations are not driven to understand the details of magma ocean crystallization or searching for life in the cold deserts of Mars. They want to show the world that their nations can accomplish great feats.

Establish global partnerships. A good way for nations to work together is to collaborate on ambitious projects of mutual benefit. This is the other side of nationalism. It is pleasant to think about a coordinated effort involving many nations to establish a permanent, international settlement on the Moon, a settlement where differences were set aside for the common good, where governments, NGOs, companies, universities, and other entities from many nations worked together to learn how to live and work in space for the benefit of the citizens of planet Earth. This long shot is not a driving reason for space settlement.

Create the capability to travel to Mars and other destinations. The only way to develop the technical capability to travel anywhere in the solar system at affordable cost is to have a robust infrastructure in cis-lunar space that supports commerce. We need routine access to space, not one-off stunts funded entirely by a government or even an alliance of governments.

It's what humans do. Humans explore. If we did not, we would not find humans living in every nook and cranny of the world. Space is still a wide-open frontier, awaiting adventurous humans who want to become part of something bigger than themselves.

How to begin: Making travel throughout cis-lunar space and lunar settlement affordable requires the use of lunar resources. In turn, this requires a thorough knowledge of how to handle materials on the Moon to extract useful materials, and an understanding of how to protect humans and agricultural products from radiation and other space hazards. Addressing the questions can begin immediately with a series of robotic missions. Commercial ventures can join in this by providing payloads on government-funded landed missions. A rich set of robotic missions can be envisioned while we wait for a cost-effective transportation system to be developed.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: **10/12/09**

Presenter's Name: **Larry Taylor**

Title**: Lunar Sample Requirements Versus Simulants for Engineering and Applied Sciences**

Presenter's Organization/Company: **University of Tennessee, Planetary Geosciences Institute Knoxville, TN**

Presentation Title

: **Lunar Sample Requirements Versus Simulants for Engineering and Applied Sciences**

Key Ideas

The real engineering needs for lunar samples is quite small, IF the proper lunar regolith simulants were to be produces. However, such simulant production has not always been made with the input of knowledgeable lunar soil experts. This is exemplified by the bastardized uses of JSC-1 and JSC-1A.

A review of the required properties of lunar samples for studies in engineering and applied sciences (exclusive of biology) will be addressed. This naturally leads to an evaluation of the requirements for simulants. If not possible to synthesize, itmay be necessary to use the soils from the Apollo lunar sample collection.

Supporting Information

Many of the properties of lunar regolith are not easy to duplicate. For example, with the increased interest in nanophase metallic Fe, one would naturally ask,"What properties of this unique lunar feature are being duplicated?" This is where the discussion should be centered, NOT on "Let's make some because an SBIR and/or NASA has an AO out for some nanophase-bearing simulant!"

The needs for the Apollo samples versus the possibility of producing simulants is the resounding theme of this discussion.

Habitation Logistics Transportation Support for Lunar Commercial Resource Recovery,

T. C. Taylor, Lunar Transportation Systems, Inc., 3705 Canyon Ridge Arc, Las Cruces, NM, 88011, taylort@mac.com

Introduction: Space commerce based on commercial markets may emerge in orbits around Earth and toward the surface on the moon. Based on habitation practices on resource recovery base camps in remote areas on Earth, a place to sleep and eat is always required. Habitation in commercial ventures varies greatly depending on the remoteness, labor morale, and logistics support.

The Remote Lunar Camp: The surface of the moon is 50 times more remote, with greater temperature differences, and orders of magnitude more expensive than any remote natural recovery base on Earth. An established commercial logistics for the lunar surface can provide NASA and other governments with the ability to move to other destinations and beyond. The further from our home planet, the more critical is the logistics support. On Earth vast amounts of staff are dedicated to logistics efforts. The military dedicates 9 logistics people for every front line soldier. Commercial space organizations will use fewer people, but new lunar transportation systems are emerging and propose a logistics architecture that is designed to have sustainable growth over 50 years, financed by private sector partners and capable of cargo transportation in both directions in support of lunar resource recovery. Eventually a Lunar trade route will emerge and economics will govern the evolution of the lunar trade route.

Earth's Remote Camp Experience: The paper's perspective is from the author's 5 years experience living at remote resource recovery sites on Earth and some of the problems experienced in logistics operations that didn't always work. The planning and control of the flow of goods and materials to and from the moon's surface may be the longest and most complicated logistics challenge yet to be attempted by mankind. The price paid, if a single logistics system does not work well is significant. On the Alaskan North Slope, we had four different logistics transportation systems and none work successfully all the time. Sometimes none worked for short periods in the winter. The Lunar Logistics operation should have at least two complete cargo logistics systems to insure sustainment.

Living Off The Land: The Early pioneers learned to live off the land, because an axe was easier to carry than a pallet of lumber. Cost reduction can be achieved by using mass that is already at a remote location rather than transporting the mass again. This development concept is called "Living off the Land" (LOTL) and uses existing local materials whenever possible in a cost reduction attempt to eventually become self-sufficient and sustainable. The author estimates 90% of the mass used to develop the remote Prudhoe Bay Oil Field on the Alaskan North Slope was already there before the oil companies started their first oil field. The oil companies developed LOTL operations first rather than later, because of the huge cost reductions possible. How can LOTL cost reduction applied to the lunar surface?

Lesson's Learned in the Arctic: The lessons learned from previous logistics systems will be discussed and solutions proposed. The industrial sector has, in the past, invested large sums of risk money, $20 billion for example, in resource recovery ventures like the North Slope of Alaska, when the incentive to do so was sufficient to provide a return on the risk investment. They encouraged commercial for profit companies to spend their money by creating future realistic markets. Big Oil companies to develop resources use a number of development financing techniques. The oil companies did not spend their risk money to develop logistics services. Other commercial organizations spent their money to create and operate the logistics system used in Alaska. Stimulating an even larger private investment is needed for the moon's resource development. The development of the moon can build on mankind's successes in remote logistics bases on Earth and learn from the $20 billion in private sector funds used to recover oil assets above the Arctic Circle.

Commercial Financing Techniques: The invested private capital grew to an estimated $200B as commercial financing techniques expanded in the Arctic oil fields and it was all private money. The moon is different than the Earth's surface, but some of the logistics lessons learned in the Arctic can potentially work again on the moon. The proposed commercial lunar trade route of mankind utilizes existing Expendable Launch Vehicles (ELVs) that are commercially available.

Stimulating an even larger private investment in magnitudes like the development of oil fields is needed for the moon's resource development. The lunar investment required is far beyond what a government can provide, but governments can stimulate early resource markets and use other commercial techniques to accelerate the lunar surface development process. The development of the moon can build on mankind's successes achieved remote resource recovery bases and the logistics systems used to support such bases on Earth. We can learn, for example, from the $20 billion in private sector funds used to recover oil assets from the Prudhoe Bay leases containing the oil deposits above the Arctic Circle. Big Oil didn't come to Alaska for the remoteness or the logistics headaches it created, but for the natural resource called oil, which is a marketable commodity. Lunar resources can and will finance the moon's development, just as it has financed mankind's movement around Planet Earth.

Conclusions: Lunar commerce can help accelerate and contribute funds to the moon's exploration and development.

THE VAPoR FIELD UNIT AND FUTURE FIELD TESTING. I. L. ten Kate[1,2], D. P. Glavin[1], and E. H. Cardiff[1]. [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771, inge.l.tenkate@nasa.gov, [2]GEST-UMBC, Baltimore, MD 21228.

Introduction: The Volatile Analysis by Pyrolysis of Regolith (VAPoR) instrument is currently under development at NASA Goddard Space Flight Center. VAPoR is a miniature pyrolysis mass spectrometer instrument suite that is designed to identify water, oxygen, hydrocarbons, noble gases, and other volatiles released from crushed rock and regolith samples on the Moon or other airless bodies. The instrument will analyze regolith samples by ramped heating up to at least 1200 °C and simultaneous measurement of the evolving gases using a mass spectrometer. In order to understand the challenges associated with field operations, the VAPoR instrument will be field tested as part of the 2010 ISRU-Surface Operations Field Test in Hawaii.

Field unit: The first version of VAPoR is a field portable instrument consisting of a stainless steel vacuum cross equipped with a high temperature pyrolysis oven, replaceable sample holders, a quadrupole mass spectrometer (RGA), an atmospheric inlet leak valve, a drag/turbopumping station, an ion gauge, and a power supply and temperature controller for the oven (Fig. 1). The field unit will evolve with time as additional instrument components, including an automated sample manipulation system built by Honeybee Robotics, and a miniature time of flight mass spectrometer built at GSFC, become available for integration and testing.

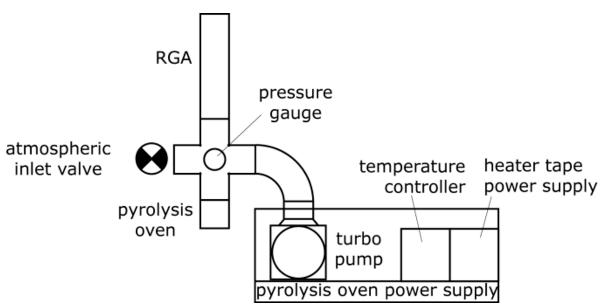

Figure 1. Schematic of VAPoR field unit, not to scale.

Laboratory results: The first measurements of analogue samples in the laboratory using a field-like instrument breadboard have validated the concept. Fig. 2 shows an example of two sets of evolved gas traces obtained by the VAPoR breadboard. Besides a range of organics and/or mineral phases in different terrestrial lunar and mars analogues (Fig. 2, left panel), also helium has been clearly detected in an Apollo 16 regolith sample (Fig. 2, right panel).

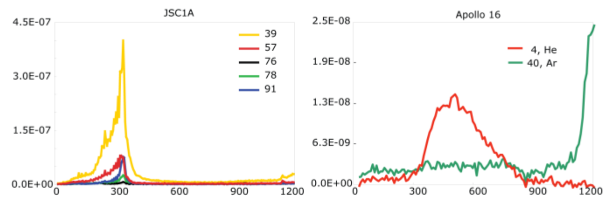

Figure 2. Evolved gas profiles, showing alkane (39, 57) and hydrocarbon fragments (39, 76, 78, 91) in the JSC1A lunar analogue (left panel) and helium and argon in an Apollo 16 regolith sample (right panel).

Planned field work activities: As part of the VAPoR development, the instrument will be deployed during the upcoming ISRU-Surface Operations Field Test most likely at the Pu'hu'hiwahini site located at the Mauna Kea volcano, Hawaii. Different locations on this field site will be sampled, and both soil and rock samples will be collected. Rock samples will be crushed before VAPoR analysis. Samples will then be heated to temperatures up to 1200°C, while the RGA will continuously record spectra of the gases the evolve. With these analyses we will be able to characterize the volatile composition of the fieldsite, as well as provide input for ISRU instruments on where to extract volatiles useful for ISRU purposes.

Besides soil samples, atmospheric samples and gaseous samples from potential venting locations will be analyzed as well.

Objectives: The primary science objective for this years field study is a characterization of the volatile content of rock samples at the field site including concentration data for volatiles of interest for ISRU purposes. The key technical objective is the field testing of the flight prototype pyrolysis heater in a harsh environment at low temperatures and in the presence of dust.

Lunar Hydrogen Distribution after KAGUYA(SELENE)

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1 Abstract

[1] found evidence of hydrogen near the lunar poles using data collected by the neutron spectrometer on board the Lunar Prospector. [2] strongly suggested this hydrogen is concentrated into the permanently shaded ‘cold traps’ near the lunar poles. This is important because if the hydrogen is to be in the form of a volatile compound, then it is only stable within these ‘cold traps’. As the most likely candidate is water ice [3], this is of relevance both for improving the understanding of the solar system and for the upcoming lunar exploration.

If the hydrogen is distributed throughout the polar regions in a more uniform way, then it is more plausible that it is merely the result of the solar wind implanting hydrogen into the regolith [4]. The excess of polar hydrogen would then be a consequence of the lower polar temperatures reducing the rate at which it diffuses out of regolith grains. Discriminating between these two scenarios hinges on an improved determination of the spatial distribution of the polar hydrogen using a more sophisticated method of analysis and a better map of permanent shadow.

This talk presents the results of applying a Pixon image reconstruction approach to the Lunar Prospector epithermal neutron data coupled to the shadow maps drawn from the preliminary KAGUYA (SELENE) laser altimetry observations [5]. These results have been provided to the LCROSS targeting team, which is slated to impact into a potential ice-bearing permanently-shadowed location at the Moon’s south pole.

References

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[2] V. R. Eke, L. F. A. Teodoro, and R. C. Elphic. The spatial distribution of polar hydrogen deposits on the Moon. *Icarus*, 200:12–18, March 2009.

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[5] J. Haruyama, M. Ohtake, T. Matsunaga, T. Morota, C. Honda, Y. Yokota, C. M. Pieters, S. Hara, K. Hioki, K. Saiki, H. Miyamoto, A. Iwasaki, M. Abe, Y. Ogawa, H. Takeda, M. Shirao, A. Yamaji, and J.-L. Josset. Lack of Exposed Ice Inside Lunar South Pole Shackleton Crater. *Science*, 322:938–, November 2008.

EXPERIMENTS AND FIELD WORKS WITH NASA LUNAR SAMPLES AND TERRESTRIAL ANALOGUES BY THE HUNVEYOR SPACE PROBE MODEL. T. N. Varga[1], M. Héricz[1], M. Franko[1], Á. Nagyházi[1], I. Magyar[1], T. P. Varga[2], Sz. Bérczi[3], Gy. Hudoba[4], S. Hegyi[5], [1]Eötvös József High School, H-2890 Tata, Tanoda tér 5. (mirene@freemail.hu), [2]VTPatent Kft. H-1111 Budapest, Bertalan L. u. 20. Hungary (info@vtpatent.hu), [3]Eötvös University, Institute of Physics, H-1117, Budapest, Pázmány P. s. 1/a. Hungary (bercziszani@ludens.elte.hu), [4]Budapest Polytechnik, Regional Information and Education Center, H-6000, Székesfehérvár, Budai út, Hungary (hudoba.gyorgy@roik.bmf.hu), [5]Pécs University, Dept. Informatics and G. Technology, H-7624 Pécs, Ifjúság u. 6. (hegyis@ttk.pte.hu)

Summary: With the application of NASA Lunar Samples and thin sections we made a similar experiment by the Hurveyor space probe model, and we found terrestrial analogue place and materials for execute the experiment and field works for educational purposes.

The field of our studies: For developing new concepts and technologies it is required to acquire or develop proper practical, and material knowledge. In space and Moon research it is continuously required to pass on already known information, so the development of space educational-promotional systems is always an issue. By utilizing the Lunar Samples and thin sections, we were able to execute some similar experiments of those experiments which was first produced by the Surveyor in the 1960s on the surface of the Moon.

The Lunar Samples: Real lunar rock and soil samples according to an international agreement are available in a limited quantity in the Eötvös University, by loan from NASA Johnson Space Center. The Lunar samples are used also in High School education, and there are several group of high school students, who focus on the analyzation of these samples, and study the methods required for the analyzation.

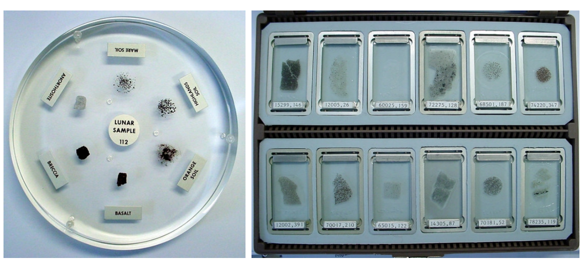

Fig 1. The available NASA Lunar samples NASA disc 112, and a collection of 12 thin sections.

Materials and sources: Basalt (Apollo 11,12,15,17), Anorthosite (Apollo 16), Breccia (Apollo 11,12,14,16,15,17), Soil samples: Orange soil, (Apollo 17), Highlands soil (Apollo 16), Mare soil (Apollo 11,12,15,17).

The Hunveyor space probe model: In the education of space exploration there is a Hungarian innovation, the Hunveyor space probe model, which is based on the concept of the Surveyor Lunar lander. In the Eötvös József High School, Tata we are building and working with a Hunveyor space probe model and we also conduct experiments with its utilization since 2007. During these experiments we try to model those, which were executed already on real planetary surfaces or on the Moon.

Preparation for the experiment: We had to find a place of our analogue experiment, which is similar to the Surveyor 3 landing site, and which contains proper Moon analog material. The Surveyor 3 was landed on the Ocean of Storms on the Moon. The Apollo 12 landed nearby to it in 1969. The Surveyor 3 has been landed on the rim of a small crater, and the local materials were found in the vicinity: breccias, basalts, debris basalt soil, regolith. In the collection available for us there are two thin sections, which originate from this location, these are No. 12002,391 and No. 12005,26.

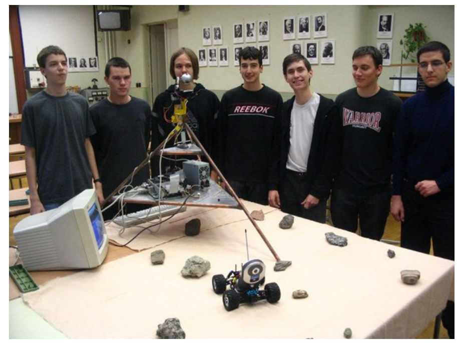

Fig 2. The Hunveyor model with the group of students in the Eötvös József High School

As an analog site we chosed the basalt mine of Diszel, Balaton-Highlands, in middle of Hungary, because of the terrain's similarity to Lunar surfaces, and the basalt local material. The basalt and its debris of this place has several similarities to the original Lunar environment, too.

The process of the experiment: We equipped the Hunveyor model for optical observation of the nearer-farer objects with a rotatable camera was placed on the top of the model. We recorded and rated the pictures. Because of the limits of our self-made equipment our experiments were mainly focused on optical observation, and studies of the external analogue environment and materials.

Conclusion: Paralel with the field works the visual analization of lunar samples, and analization of thin sections in petrographic microscope was carried out. In comparison with terrestrial basalt samples we could observe how fresh is the appearance of Lunar samples, e.g. basalts, because the lack of atmosphere and water vapour affecting terrestrial counterparts. It was also observed how sharp is the fragmentary grains of the Lunar basalts.

Summary: The analization of Lunar samples and the Moon analog field work helped students to get real experiences and understand the ways of space exploration better, and made the teaching of technology and science related subjects easier.

References: [1] Sz. Bérczi, et al. (1998): *LPSC XXIX,* **#1267;** [2] Sz. Bérczi, et al. (1999): *LPSC XXX,* **#1332**; [3] Sz. Bérczi, et al (1999): *LPSC XXX,* **#1037;** [4] Hegyi S. et al. (2000): *LPSC XXXI*, **#1103**; [5] Diósy T. et al. (2000): *LPSC XXXI*, **#1153**; [6] Roskó F. et al. (2000): *LPSC XXXI*, **#1572**; [7] Bérczi Sz. Et al (2001): *LPSC XXXII*, **#1100**; [8] Kovács Zs. I. et al. (2001): *LPSC XXXII*, **#1130**;

ISRU BASED BUILDING CONCEPT FOR PRODUCING MULTIFUNCTIONAL LUNAR BUILDINGS.

T. P. Varga[1], I. Szilágyi[1], Sz. Bérczi[2], T. N. Varga[3], B. Boldoghy[4], J. Kummert[4], G. Hudoba Jr.[5], [1] VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu), [2]Eötvös University, Institute of Physics, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [3]Eötvös József High School, H-2890 Tata, Tanoda tér 5. (vargatomi.net@freemail.hu), [4]Ferroelektric Engineering Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [5]Hudoba Design, 6611 Oakland str. Pennsylvania, 19149 PA, USA. (ghudoba@aol.com)

Summary: According to the ISRU, during the construction process of Lunar buildings based on our concept the usage of local materials (preferably regolith), and technologies which enables constructing with local materials, should be a primary concern.

Joining to previous publications: In our previous publications [1,2,3] we have explained how can structures for industrial or human use with a great inner volume be built in the lunar surface or underground. In this abstract we would like to emphasise, why can these structures be easily built with the utilization of ISRU, unlike other methods which require equipment transported from Earth.

Our aim: It is more beneficial to construct Lunar buildings from local materials instead of equipment transported from Earth. During the upcoming Lunar missions, the construction of Lunar buildings with proper functions and designs will be important.

Practical issues: Main goals of Lunar building construction: - Industrial activities, - Human habitat. In apropos of these, some of the possible utilizations: - supplemental and other services, for example: storage for a longer or shorter period of time, storage of the machines materials or other equipment used on the surface. - To accomodate the life support systems (energy source, water, oxygen supply units, telecommunications), - Transportation, Placement for the vehicles used in the earth-moon contact, - Equipments for the possible further (Mars or other) missions.

The effect of the Lunar enviroment: During the construction of different buildings the lunar enviromental conditions cannot be overlooked, these conditions are the following: 1/6 earth gravitational field, absence of atmosphere, longer daily cycles (14 days/day and night), dusty lunar surface, which behaves like an electricaly charged fog during daytime, high probability of meteor impacts because of the absence of atmosphere, high level of background (cosmic) radiation.

Structure designs created for the long term human habitat and for the long term industrial activity will be required to calculate with the combined effect of these factors, which will quicken the rate of degradation compared to the usual rate in earth. To accomplish this, one way is to use very resistent materials in the construction of outer walls ceilings and locks. It would require large scale transportation to the moon, and in situ construction, which would be very expensive.

In recent times, the idea of re-using the lander unit as a part of an industrial or human activity is widely known. Also the first modules should be manufactured in the Earth, and after their transportation to the moon, they should be useable immediately, but it gives only temporal solutions. Real solutions can be found with the ISRU methods, which focuse on local materials.

The essence of our proposal: The ISRU building concept proposed by us, is that from in situ Lunar materials (regolith) with a construction process applied in the Lunar surface, bricks can be created, and from these bricks the construction of arched structures is possible, even in a larger scale with a span of 60-80 m. these structures could be placed on the surface, but when placed 10-15 below the surface and covered by regolith, an average inner temperature could be achieved. While the surface temperature may fluctuate, the inner temperature will always be about –20 C, with only lesser fluctuations.

The usage of ISRU technologies in our proposal during lunar building procedures: Creation of a building block, Lunar Brick, the used material can be found in the surface (regolith). The used energy (heat) can be acquired via the solar energy the Moon receives without the atmospheres alleviating effects during the long light periods. The 14 day/light period enables the continuous and economical work.

It is an important factor for ISRU to fully utilize the possibilities of the local soil, to use it in the required thickness. The regolith is a good outer layer with good heat insulation abilities, good radiation shading, capable of resisting the micrometeorites which pose a real threat for any Lunar installation. The buildings constructed following our method on or below the surface are using a thick layer of regolith.

Advantages: During the construction of these buildings the reusability of most of the equipment is an important issue. Thus we use simple tools like arched supporting units. These could be recovered after the completion of one unit, and repeatedly used throughout the whole procedure. During the first period these cannot be produced in-situ, they have to be transported. But their reusability makes the transportation economical. In the future, these instruments may be manufactured in-situ , thus making the whole method more effective and economical.

References: [1] Kummert, Boldoghy et al.: Organizational Concept of Buildings of Levelled Temperature Interior Space on the Moon, SRR VII conf. 2005 (*#2007*), [2] Boldoghy, Kummert et. al.: Construction of a Lunar Architectural Environment with Joint Constraints of Thermal Balance, Economic Technologies, Local Material Using: Strategy, Design and on Site Assembly., 37 LPSC 2006 (#1152), [3] Boldoghy, Kummert et. al.: Feasibility Concept Of Creating Protected Spaces With Great Size And Balanced Interior Temperature For Industrial Activities On The Moon, SRR VIII conf. 2006.

LEAG Annual Meeting
15-18 November, 2009
LPI, Houston, Texas

Executive Summary

Date Prepared: October 9, 2009

Presenter's Name: R. Vondrak
Presenter's Title: LRO Project Scientist
Presenter's Organization/Company: NASA GSFC

Presentation Title Overview of the LRO Mission

Authors: Rich Vondrak, John Keller, Gordon Chin, James Garvin

Key Ideas

The Lunar Reconnaissance Orbiter (LRO) was implemented to facilitate scientific and engineering-driven mapping of the lunar surface, identify safe landing sites, search for in situ resources, and measure the space radiation environment.

After launch on June 18, 2009, the LRO spacecraft and instruments were activated and calibrated in an eccentric polar lunar orbit until September 15, when LRO was moved to a circular polar orbit with a mean altitude of 50 km.

LRO will operate for at least one year to support the goals of NASA's Exploration Systems Mission Directorate (ESMD), and for at least two years of extended operations for additional lunar science measurements supported by NASA's Science Mission Directorate (SMD).

LRO carries six instruments with associated science and exploration investigations, and a telecommunications technology demonstration. The LRO instruments are: Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Diviner Lunar Radiometer Exploration Experiment (DLRE), Lyman-Alpha Mapping Project (LAMP), Lunar Exploration Neutron Detector (LEND), Lunar Orbiter Laser Altimeter (LOLA), and Lunar Reconnaissance Orbiter Camera (LROC). The technology demonstration is a compact, dual-frequency, hybrid polarity synthetic aperture radar system (Mini-RF).

LRO observations also support the Lunar Crater Observation and Sensing Satellite (LCROSS), the lunar impact mission that was co-manifested with LRO on the Atlas V (401) launch vehicle.

Supporting Information

www.nasa.gov/lro

SPECTROSCOPY OF THE LCROSS EJECTA PLUME FROM KECK, GEMINI, AND NASA IRTF OBSERVATORIES ON MAUNA KEA. D.H. Wooden[1], E. F. Young[2], M. S. Kelley[3], C.E. Woodward[4], D.E. Harker[5], M. A. DiSanti[6], P. G. Lucey[7], R. B. Hawke[7], D. B. Goldstein[8], D. Summy[8], A. R. Conrad[9], T. R. Geballe[10], J. T. Rayner[11], A. Colaprete[1], J. L. Heldmann[1], [1]NASA Ames Research Center, MS 245-3, Moffett Field CA 94035, Diane.H.Wooden@nasa.gov, dwooden@mac.com, [2]SwRI, Boulder, CO, [3]UMD, College Park, MD, [4]UMN, Minneapolis, MN, [5]UCSD/CASS, San Diego, CA, [6]NASA GSFC, [7]HIGP, Honolulu, HI [8]UT, Austin, TX, [9]W. M. Keck Observatory, [10]Gemini Observatory, [11]Institute for Astronomy, Honolulu, HI

Introduction: Our LCROSS Ground-Based Observation Campaign (GBOC) Mauna Kea Spectroscopy Team will observe the LCROSS impact event with three complementary ground-based instruments: Gemini North's Near-Infrared Integral Field Spectrometer (NIFS), Keck Observatory's NIRSPEC spectrometer, and the NASA IRTF SpeX spectrometer, chosen specifically to achieve the LCROSS mission Science Goals, as follows:

• NIRSPEC will acquire high-resolution spectra (R = 25,000) of non-resonant fluorescent water vapor emission lines between 3380 and 3530 cm-1. Of the three proposed observations, NIRSPEC is uniquely sensitive to water vapor and is our most diagnostic experiment for the presence of water in the permanently shadowed regolith.

• SpeX will acquire the widest contiguous spectral range (2 - 4 µm, although saturation is possible longward of 3.4 µm). This range is expected to characterize the shape of the non-H2O-ice continuum as a function of ejecta grain size and mineralogical composition. SpeX will also sample the H2O-ice fundamental band at 3.0 µm.

• NIFS will acquire infrared spectra (1.9 - 2.3 µm) over a 3"x3" (6 km x 6 km) field of view, encompassing the entire ejecta plume for the first 30 seconds after impact and resolving the dense core of the plume (where the highest column of H2O-ice would be seen). NIFS records the ejecta plume as a function of time and distance from the impact, with some sensitivity to the presence of H2O-ice grains through the 2 µm absorption band. NIFS provides the critical spatial and temporal context for the SpeX and NIRSPEC observations. Unlike the LCROSS downward-looking spectral observations (the spacecraft will peer through the plume from above), the sideways-looking NIFS observations will capture the height dependence of the ejecta plume spectra. The height dependence is expected to be diagnostic of the size distribution, since smaller particles will have faster post velocities and be lofted higher.

Together, these three data sets will address 3 of the 4 LCROSS Science Goals, including (a) experiments to look for water, both as vapor (NIRSPEC) and as ice grains (SpeX and NIFS); (b) experiments to measure the non-water vs. water composition of the ejecta plume, and (c) experiments to characterize the grain size and mineralogy of the impacted regolith. The fourth goal, identifying the form/state of hydrogen observed by Lunar Prospector, may also be obtainable if there is a non-water hydrocarbon or hydrated mineral constituent that is observable in the NIRSPEC, SpeX or NIFS spectra.

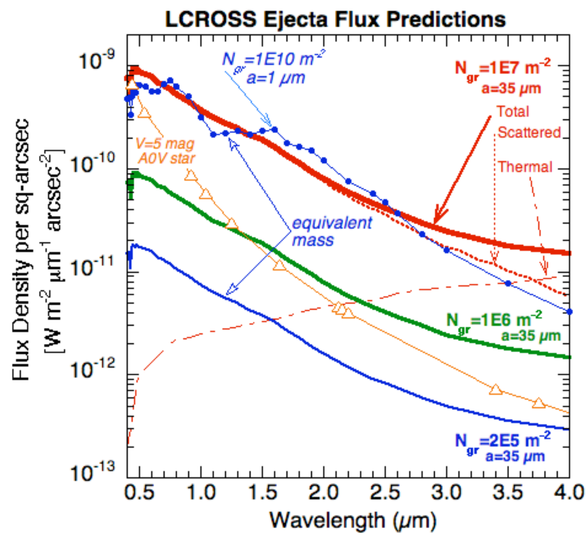

FIGURE: LCROSS Ejecta Plume Flux Predictions. Flux density per square-arcsec (Total = Scattered + Thermal) for a grain column density of 35 µm-radius grains of N=1E7 m-2 and Ngr=2E5 m-2, representing post-impact intervals of 4 to 30 s and 60 to 90 s (Goldstein model, [1]), respectively. If a column density of Ngr=2E5 m-2 of 35 µm grains are disaggregated to 1 µm grains, the flux density is much brighter (because a unit mass of ejecta has greater surface area as smaller grains, and because smaller grains have higher albedos at near-IR wavelengths) and the shape of the spectrum better reveals the composition. In the figure, if the mass-equivalent of N=2E5 m-2 of 35 μm radii grains disaggregate to N=1E10 m-2 of 1 μm grains, the flux density is approximately the same as if the the case for N=1E7 m-2 of 35 μm grains except for the discernment of mineral bands. Preliminary flux calculations use pyroxene (Mg0.5,Fe0.5)SiO3 grains to mimic regolith composition.

References: [1] Goldstein D.B., et al. (2008) *AIP, 1084,* 1061.

Additional Information: For impact observation tools, please contact dwooden@mac.com

PERCUSSIVE DIGGING APPROACH TO LUNAR EXCAVATION AND MINING. K. Zacny[1], R. Mueller[2], J. Craft[1], J. Wilson[1], and P. Chu[1], [1]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com); [2]NASA KSC.

Introduction: Terrestrial earth-moving machines such as bulldozers, bucket wheel excavators etc., rely on shear force to break up and excavate the soil and softer rocks. They use hydraulic systems which have inherent advantages, over electromechanical systems including the ability to generate larger forces, small size, simplicity, robustness etc. Another advantage that terrestrial earth moving machines have is their large weight, reaching hundreds of tons and more. This approach will not be feasible on the Moon, not only because of lower gravity (1/6th that of the Earth's), but also because of large launch costs ($50k-$100k to place 1kg on the Moon).

The requirements for regolith moving such as trenching, clearing, building berms, habitat shielding for lunar outpost development and ISRU are in the range of thousands of tons [1]. A system that is most effective, robust, and efficient will potentially save billions of dollars.

Percussive Digging Approach: The solution to the problem of low excavator mass in low gravity environment is to use a percussive digging approach [2]. A scoop with a percussive actuator can dig deeper and faster with force that is much lower than a corresponding non-percussive scoop. This directly translates into lighter excavator, and in turn billions of dollars saved by not launching heavier systems. Apart from much higher efficiencies, percussive and vibratory systems will enhance particle discharge into the bin (the scoop can be vibrated during the regolith discharge cycle to speed up the discharge of particles). Other applications include vibrating blades/plows like the one attached to the Chariot rover in the most recent field test at Moses Lake, WA. Vibrating surfaces reduce sliding friction between the blade and soil particles, and in turn forces and power required to move regolith . The impulse magnitude and frequency can be tuned relative to soil strength to further improve efficiency.

There is, of course, always a trade off. In the case of a percussive system, the trade-off is between the additional energy to drive the actuator and the additional mass that would be required in the absence of the percussive system. However, in the trade between more mass and more energy, energy wins since it can be harvested from the Sun.

Testing of Percussive Approach: In the ambient tests the percussive digger breadboard was attached to a linear slide which was mounted on an aluminum frame (Figure 1). The percussive digger deployment scheme used weights and pulleys to passively apply a constant weight-on-bit throughout an individual test. The weight-on-bit was adjustable for any given test by changing the stack of weights. A laser rangefinder mounted to the side of the linear slide was used to obtain penetration rate data.

All tests were run at 2.7 Joules per blow and at full speed (1750 bpm.) All tests used a Lunar Surveyor-style scoop as a soil penetrator.

Three soils were used: GRC-1, GRC-3 and JSC-1a. For each soil, two densities were tested, and for each density at least two iterations of both the percussive digger and the static penetrator were run.

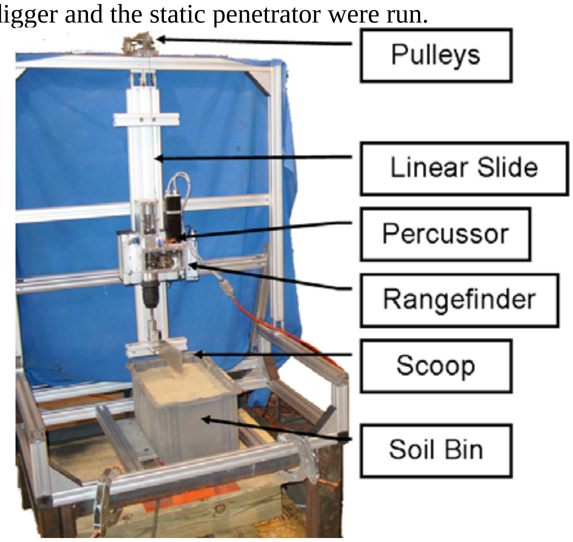

Figure 1. Percusssive digger set-up.

Results: The results have shown that that the Surveyor-like scoop could be pushed 80 mm into compacted JSC-1a with 250N force. In low density JSC-1a, the same scoop could be pushed 100 mm with 170 N force. The same scoop with a percussive actuator could be pushed into both fluffy and dense soils with only 5N of force. This represent a ratio of forces in the range of 45. Thus, with a percussive scoop, the weight of an excavator can be up to 45 smaller.

References: [1] Mueller, R. and King, R., Trade Study of Excavation Tools and Equipment for Lunar Outpost Construction, STAIF 2008; [2] Zacny, K. et al., Novel Approaches to Drilling and Excavation on the Moon, AIAA-2009-6431, Space 2009.

NOVEL METHODS OF HEAT FLOW DEPLOYMENT FOR THE INTERNATIONAL LUNAR NETWORK MISSION. K. Zacny[1], E. Mumm[1], N. Kumar[1], S. Smrekar[2], S. Nagihara[3], P. Morgan[4], P. Taylor[5], and B. Milam[5], [1]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com); [2]NASA JPL, [3]Texas Tech University; [4]Nothern Arizona University; [5]NASA GSFC.

Introduction: The heat-flow probe directly addresses the goal of the Lunar Geophysical Network, which is to understand the interior structure and composition of the Moon [1]. The International Lunar Network (ILN) is a near-term mission that requires a heat-flow probe. ILN is a set of four small landers, scheduled for launch in the 2016-2018 time frame, that will deploy up to four instruments. The ILN payload is limited to ~25kg and its power will most likely be provided by a ASRGs.

To place 1kg on the surface of the Moon costs ~$50k to$100k. Thus, any scientific instruments must be efficient with respect to limited spacecraft resources such as mass, power, and volume without compromising on quality scientific measurements.

A key challenge for a heat-flow probe will be getting to a 3m depth at which the endogenic thermal gradient can be measured, i.e. below the depth of penetration of the annual thermal wave, within ILN Payload limitations. The Apollo 17 two heat flow probes reached 2.4m. A heat flow probe must create a minimal disturbance to the thermal environment.

Heat-Flow Probe Concepts: We have been developing two highly innovative low mass and low power heat-flow probe systems (robotic, but can be also astronaut deployable). Each system consists of two parts: 1) a method of reaching 3m depth in lunar regolith, and 2) a method of deploying thermal sensors [2].

Percussive System: The first system uses a percussive (hammer-like) approach to drive a small diameter (20mm) cone penetrometer to >3 meter depth (Figure 1). Ring-like thermal sensors on the penetrometer rod (heaters and temperature sensors) are deployed into the regolith every 30 cm as the penetrometer goes down to 3 m. The penetration rate of the percussive penetrometer can be correlated to regolith density; this added measurement will help with thermal conductivity correlation. The system leaves only small sensors in the borehole. The deployment rod is removed once depth is reached, maximizing measurement sensitivity by eliminating thermal path to lander except for the electrical tether.

Pneumatic-Proboscis System: The second system uses a pneumatic (gas) approach to lower the temperature and thermal conductivity sesnors attached to a lenticular (bi-convex) tape to > 3 meters (Figure 2).The second system uses a pneumatic (gas) approach to lower the heat flow probe, a lenticular (bi-convex) tape, to > 3 meters (Figure 2). The system is a revolutionary innovation for ILN as it has extremely low mass, volume, and simple deployment. This system is dubbed the “Proboscis” because of its similarity to a butterfly proboscis. Helium gas, used for pressurizing liquid propellant, and is typically vented once on the surface, can be scavenged from the lander propulsion system, making the thermal probe system lighter. Should spacecraft helium not be available, a simple gas delivery system may be added specifically for the heat flow probe. Honeybee demonstrated that 1 gram of N_2 at 5 psia can lift 6000g of JSC-1a in lunar conditions (vacuum, 1/6g) [3]. Thus, a only a small amount of gas would be required to penetrate to 3 m.

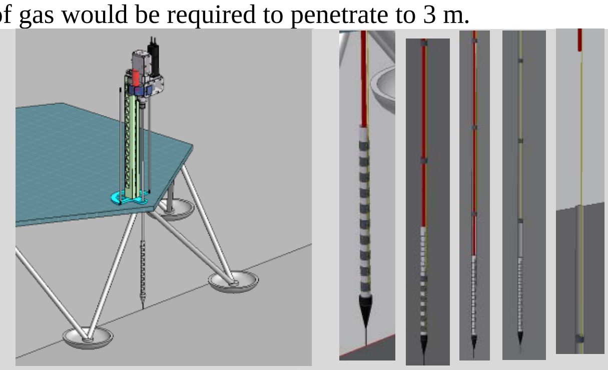

Figure 1. Percussive Penetrometer deployment of heat flow sensors. Upon reaching the depth, the rod is pulled out and sensors are left in a hole.

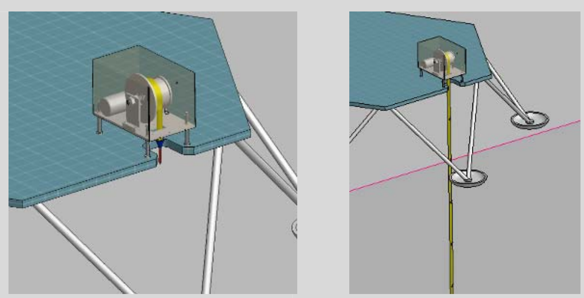

Figure 2. Pneumatic Proboscis deployment of heat flow probe uses compressed helium gas to advance below the regolith surface.

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3.5m VACUUM CHAMBER FACILITIES ENABLING FULL SCALE DIGGING, DRILLING AND PENETROMETRY TESTS.

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Introduction: In order to bring the sampling technologies into the required Technology Readiness Level (TRL) of 6, the hardware has to be extensively tested under relevant environmental conditions. These conditions are always much different than the conditions we find on Earth, and the exact conditions depend on where (what extraterrestial body) the system will be deployed on. For example, if the target planet is Venus, the hardware has to be tested at ~90 bar pressure, CO2 atmosphere and 460 °C temperature. For Mars, the conditions are more benign: low pressure of 1-11 torr, and temperature of the order of -80°C.

Simulating accurate environmental conditions not only is required for demonstrating the hardware, but also to investigate how a sample is behaving during a sample acquisition. Sticking of sample onto a scoop surface on the Mars Phoenix lander would not have occur if the same sampling system was deployed on the Moon, for example.

In addition to atmospheric conditions (pressure, gas, temperature), it is also important to simulant the appropriate formation (soil, rock, ice). For example, drilling into icy-soils will be different than drilling into icy-soils containing salts (as found by the Phoenix lander). Salts depress freezing point of water and in turn make a sample stickier at even sub-freezing temperatures. Sample acquisition of icy-soils will also be different than sample acqusition of rocks.

In order to address environmental testing of drills, diggers and penetrometers for Mars applications (and to some extent the Moon, and the Asteroids) we developed a large environmental chamber system.

Vacuum Chamber Description: Vacuum chamber consists of two smaller chambers assembled on top of each other in such a way that the inner walls are flush (Figure 1). The bottom chamber is 84in tall by 38in x 38in, while the top chamber is 48in by 38in x 38in. Having two chambers instead of one allows the two smaller chambers to be used independently of each other.

The chamber has 20inch flanges on the top and the bottom. This allows inserting additional cylindrical vacuum extension on top in order to accommodate longer penetrometer stage. Putting a similar 20in diameter cylindrical extension at the bottom, allows the vacuum chamber to extend below the floor (into a trench, for example). A rock or a soil sample could be placed in this lower cylindrical section.

The chamber reached 0.01 torr with two pumps. Current pumping system allows the chamber to reach ~1 torr with just one rouging pump and while the chamber was filled with sand (Figure 1). A pressure of 5 torr (Mars pressure) can be reached in just under 15 minutes. The cooling of sample is achieved via a closed loop cooling system.

The chamber so far has been used to test different Mars and Lunar drill systems to a depth of >1 meter.

The chamber was also placed in a horizontal position (Figure 2) to test lunar mining system.

Figure 1. Vacuum chamber in an upright position for testing drills and penetrometers.

Figure 2. Vacuum chamber in a horizontal position for testing lunar mining systems.

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Introduction: In 2004, the world's iron steel consumption exceeded 1 billion tons. [1] Spectroscopic studies suggest certain asteroids contain much needed material such as "nickel-iron metal, silicate minerals, semiconductor and platinum group metals, water, bituminous hydrocarbons, and trapped or frozen gases including carbon dioxide and ammonia." [2] Platinum metals found in asteroid have significant richer grades (up to 20 times richer) as compared to levels found on Earth. [3] As a starting point to "asteroid colonization", Near-Earth asteroids (NEA) orbiting Earth could potentially be the first locations to excavate asteroid mines. 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.

Missions of that caliber 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. [4] ISRU is a concept to increase the efficiency of space missions by reducing the amount of material brought from Earth. This is a difficult obstacle and ISRU researchers are striving to greatly reduce expenses by proposing technologies that will enable missions to be self-sufficient. In addition, mission consumable production, surface construction, manufacturing and repair with in-situ resources and space utilities and power from space resources are technological areas that would significant advanced through advanced research in ISRU. [5] NASA currently has centers directly involved in the research of ISRU technology. The cost/benefit ratio of such a technology is still a widely debated topic amongst the academic community.

Conclusion: The horizon for this is not the current moment but resources are running out on Earth and companies and governments are looking at this. What needs to be done is a cost analysis of rare minerals that could be accessed eventually. Robotic surveys of the NEA would be the precursor to the development of in situ resources. Methods for comparing different asteroids based on trajectory and other criteria to maximize project economic feasibility needs to be further researched and explored.

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Are Living Systems the Key to Sustainable Lunar Exploration?

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Introduction: Elements of sustainability in science, operations and politics, should be incorporated into long range planning for Lunar Exploration [1]. Before lunar exploration (on, of, and from the Moon) can enter a sustainable phase it must first experience a growth phase. Alternative definitions for sustainability, models and metrics for sustainability, and a survey of analogs should be acquired, analyzed and synthesized. - leading to recommendations for further research and a timeline for refinement. Exploration in the national interest [2, 3] also offers a broad set of development perspectives with the insight of greater payback from longer duration or more intensively populated missions. The issues of Living Systems and Sustainable Exploration span the possible mission option space – whether to enable a lunar base, Mars mission or other missions with long duration cruise phases [Augustine] with lower crew risk and lower launch mass requirements than a brute force approach.

Sustainability: A design for sustainability must take many factors into consideration. Alternative definitions of Sustainability are evolving in different contexts, whether with regard to the environment, science, politics, economics or operations. It also implies a steady state, which, in this case, would be preceded by a growth phase whose goals, scope, scale and pace are yet to be defined. In a culture often defined by growth, it is a challenge to understand and operate within steady state boundaries. During the formulation stage, these definitions should be refined and supporting models, metrics and analogs should be analyzed. The development of a reference model (framework) will be helpful going forward – both to establish a management model and a communications tool to engage the community and facilitate consensus building. The LEAG Roadmap is still evolving and will be an essential planning tool. Sustainability is still a long way from autonomous self-sufficiency. Political sustainability may be the greatest challenge [6].

Living Systems: Living Systems is the term of reference [4] where overall system performance and viability (mission success) depend on the reliable functioning of interacting complex biological systems and their environments. Humans are in the loop in all possible exploration missions, whether remotely through robotic proxies or physically present at the surface of the object being explored. Knowledge gained from basic research will enable future systems with enhanced reliable performance and enable mission planners to reduce risks and costs while defining systems requirements for future missions. Space Biology holds the key to space based living systems.

Biology:

Space Biology: Biology (Human - effects & countermeasures, cellular or plant systems used in a closed ecological environmental support system (CELSS)) may hold the key to sustainable lunar exploration - both in terms of public support and operational efficiencies for life support. It is still an open question as to whether humans can truly live on other worlds [5] – not merely for days, weeks of months but for extended duration missions of years – much less permanently in long term settlements. The transportation logistics and costs imply that long duration stays are attractive, yet the risk mitigation is not well understood. The opportunities to study regulatory mechanisms – spanning radiation tolerance, immunology, bone turnover and DNA repair, and opportunistic microbial evolution in a closed environment may have significant implications for long duration operations as well as earth based human health and environmental protection.

Astrobiology: The origin of life on Earth and its subsequent evolution to our current state were influenced by the early and continued bombardment of the inner solar system and the solar radiation environment. Studying the Moon as a witness plate will provide insights into how they influenced our evolutionary past

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