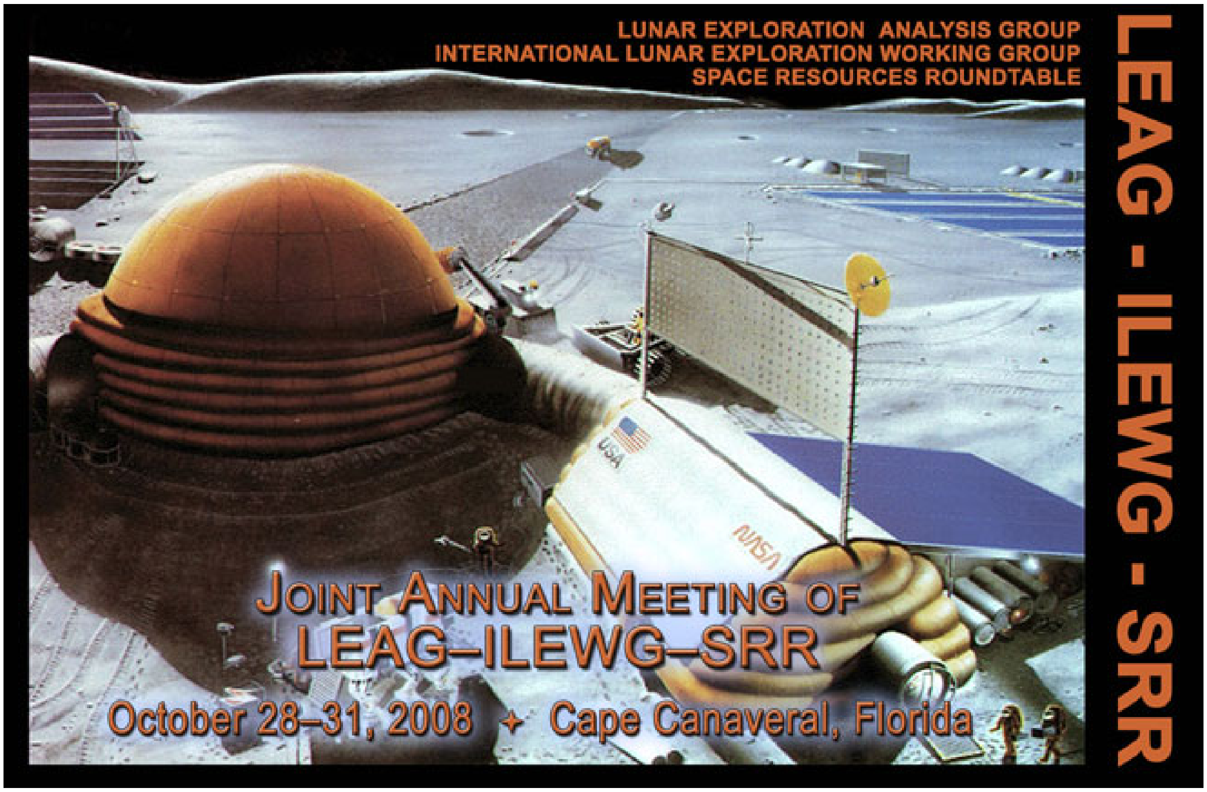

Program and Abstracts

LUNAR AND PLANETARY INSTITUTE

LPI Contribution No. 1446

Joint Annual Meeting of

LEAG-ICEUM-SRR

October 28–31, 2008

Cape Canaveral, Florida

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National Aeronautics and Space Administration
NASA Lunar Exploration Analysis Group
International Lunar Exploration Working Group
Space Resources Roundtable

CONVENERS

Clive Neal, *University of Notre Dame*
Steve Mackwell, *Lunar and Planetary Institute*
Bernard Foing, *European Space Agency, International Lunar Exploration Working Group*
Leslie Gertsch, *Missouri University of Science and Technology*

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

This volume contains abstracts that have been accepted for presentation at the Joint Annual Meeting of LEAG-ILEWG-SRR, October 28–31, 2008, Cape Canaveral, Florida.

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.

Contents

Program

Tuesday, October 28, 2008
OPENING PLENARY
8:00 a.m. Salon I

8:00 a.m. Welcome

8:05 a.m. Yoder G. *
ESMD: Community Update

8:30 a.m. Adams J.
NASA's Lunar Science Program: An Overview **[#4128]**

8:55 a.m. Hale N. W. *
SOMD: Community Update

9:20 a.m. Culbert C. *
Constellation and Lunar Architecture Overview **[#4131]**

9:50 a.m. Gruener J. E.
Lunar Exploration Surface Scenarios Measured by Scientific Goals and Objectives **[#4118]**

10:20 a.m. Broadwell M. *
Optimizing Science and Exploration on the Moon **[#4130]**

10:40 a.m. Conley C.
Planetary Protection for the Moon: Policy and Implementation **[#4127]**

11:00 a.m. Davidian K.
Plans for Involving the Commercial Sector in Space Exploration **[#4129]**

11:25 a.m. Foing B. H. * International Lunar Exploration Working Group
Report from ILEWG on Science and Exploration Questions **[#4101]**

11:45 a.m. Neal C. R. *
The Lunar Exploration Roadmap **[#4132]**

12:05 p.m. DISCUSSION
Moderated by C. R. Neal

12:30 p.m. ADJOURN FOR LUNCH

Tuesday, October 28, 2008 (continued)

1:30 p.m. Olson J. *
ISECG Update

1:50 p.m. Baltuck M. Curtis J. W. Espinasse S. * Favier J. J. Gibbs G. Hufenbach B. Kawaguchi J. Lorenzoni A. Newman N. R. Parker D. Yoder G. L.
From the Global Exploration Strategy (GES) to the International Space Exploration Working Group (ISECG) **[#4079]**

2:10 p.m. TBD
ESA

2:30 p.m. TBD
KARI (Korea)

2:50 p.m. TBD
Australia (CSIRO)

3:10 p.m. Curtis J. *
BNSC (United Kingdom)

3:30 p.m. TBD
CNES (France)

3:50 p.m. TBD
DLR (Germany)

4:10 p.m. TBD
Roscosmos (Russia)

4:30 p.m. Kendall D. *
CSA (Canada)

4:50 p.m. TBD
ASI (Italy)

5:10 p.m. TBD
NSAU (Ukraine)

5:30 p.m. DISCUSSION
Moderated by TBD

5:45 p.m. ADJOURN

Tuesday, October 28, 2008
PLENARY (continued)
7:00 p.m. Salon I

7:00 p.m. TBD
JAXA (Japan): Kaguya and SELENA 2

7:30 p.m. Wu W. *
CNSA (China): Chang'e-1 and Chang'e-2

8:00 p.m. Karnik D. *
ISRO (India): Chandrayaan-1 and Chandrayaan-2

8:30 p.m. Vondrak R. *
Lunar Reconnaissance Orbiter

8:50 p.m. Colaprete A. Briggs G. Ennico K. Wooden D. Heldmann J. Sollitt L. Asphaug E. Korycansky D. Schultz P. Christensen A. Galal K.
An Overview of the Lunar Crater Observation and Sensing Satellite (LCROSS) Mission — An ESMD Mission to Investigate Lunar Polar Hydrogen **[#4050]**

Wednesday, October 29, 2008
DEFINING THE PATH FOR HUMAN RETURN TO THE MOON
8:30 a.m. Salon I

What technologies need to be developed now for human return to the Moon (and beyond)?
What are the critical elements for robotic development, habitats, and hazard prevention?

Chair: **B. H. Foing**

8:30 a.m. Hovland S.
ESA Preparation for Human Exploration **[#4085]**

8:50 a.m. Raja R. P. * Rakesh A. Krishna T. N.
A Study of Transnational Mission Crew Management **[#4018]**

9:10 a.m. Boche-Sauvan L. * Foing B. H.
Constraints on the Pre-Design of a Minimal Human Lunar Outpost **[#4115]**

9:30 a.m. Boldoghy B. Kummert J. Varga T. P. * Szilágyi I. Darányi I. Bérczi Sz. Varga T. N. Hudoba G. Jr.
Complex Architectural Concept and Technology for Creating Buildings of Great Inner Space on the Moon, with Low Asset Requirement and High Efficiency **[#4074]**

9:50 a.m. Mitchell C. A. * Both A. J. Bourget C. M. Brown C. S. Ferl R. J. Gianfagna T. J. Janes H. W. Lomax T. L. Massa G. D. Monje O. Morrow R. C. Orvis K. O. Paul A. L. Sederoff H. W. Stutte G. W. Wheeler R. M. Yorio N. C.
Enabling Sustainable Habitation at the Lunar Base **[#4097]**

10:10 a.m. Cardiff E. H. Hall B. C. *
A Dust Mitigation Vehicle Utilizing Direct Solar Heating **[#4100]**

10:30 a.m. Thangavelu M. *
Critical Strategies for Return to the Moon: Altair Dust Mitigation and Real Time Teleoperations Concepts **[#4056]**

10:50 a.m. Crosby K. M. * Agui J. Pennington C. Sorensen E. Martin E. Fritz I. Frye B.
Inertial Filtration of Lunar Dust in Reduced Gravity **[#4073]**

11:10 a.m. Smith D. J. Roberson L. B. * Mueller R. Metzger P.
Rapidly Deployable Blast Barriers for Lunar Surface Operations **[#4045]**

11:30 a.m. Clegg R. N. * Metzger P. T. Huff S. Roberson L. B.
Lunar Soil Erosion Physics for Landing Rockets on the Moon **[#4122]**

11:50 a.m. Tranfield E. * Rask J. C. McCrossin C. Wallace W. T. Kuhlman K. R. Taylor L. Jeevarajan A. S. Kerschmann R. Loftus D. J.
Chemical Reactivity of Lunar Dust Relevant to Humans **[#4110]**

12:10 p.m. Scolese C. *
NASA

Wednesday, October 29, 2008
DEFINING THE PATH FOR HUMAN RETURN TO THE MOON (continued)
1:30 p.m. Salon I

What technologies need to be developed now for human return to the Moon (and beyond)?
What are the critical elements for robotic development, habitats, and hazard prevention?
What is the current state of ISRU development?

Chair: **C. K. Shearer**

1:30 p.m. Zacny K. * Craft J. Wilson J. Chu P. Davis K.
Percussive Digging Tool for Lunar Excavation and Mining Applications **[#4046]**

1:50 p.m. Rodriguez G. * Slane F. Johnson L. Westfall R.
With Endpoints Defined, an ISRU Roadmap Takes Shape **[#4032]**

2:10 p.m. Nakamura T. * Smith B. K. Gustafson R. J.
Solar Thermal Power System for Oxygen Production from Lunar Regolith: Engineering System Development **[#4011]**

2:30 p.m. Cardiff E. H. * Maciel T. R. Banks I. S.
In-Situ Production of Oxygen Through Lunar Regolith Pyrolysis **[#4084]**

2:50 p.m. Ash R. L. *
Phoenix Lander Implications on In Situ Resource Utilization for Robotic Exploration of Mars **[#4030]**

3:10 p.m. Krishna T. N. * Rakesh A. Raja R. P.
In-Situ Resource Management (ISRU): Extraction of Lunar Oxygen Resources (ELOR) **[#4020]**

3:30 p.m. Paul A.-L. * Ferl R. J.
Telemetric Biology: Evaluating In Situ Resources for Biological Payloads in a Lunar Lander **[#4070]**

3:50 p.m. Shearer C. * Lofgren G. Neal C.
Preparing for the Next Generation of Lunar Sample Return **[#4105]**

4:10 p.m. De Angelis G. * Badavi F. F. Blattnig S. R. Clem J. M. Clowdsley M. S. Tripathi R. K. Wilson J. W.
Models for the Lunar Radiation Environment **[#4009]**

4:30 p.m. Archinal B. * Acton C. Bussey B. Campbell B. Chin G. Colaprete A. Cook A. Despan D. French R. Gaddis L. Kirk R. Mendell W. Lemoine F. Nall M. Oberst J. Plescia J. Robinson M. Smith D. Snook K. Sweetser T. Vondrak R. Wargo M. Williams J.
International Standards and the NASA Lunar Geodesy and Cartography Working Group **[#4052]**

4:50 p.m. Piccolo F. * Perino M. A. Borriello G. Tuninetti C.
Valuing Exploitation of Moon Resources Using Real Options **[#4054]**

Wednesday, October 29, 2008
TECHNOLOGY DEVELOPMENTS FACILITATING
EXPLORATION AND INTERNATIONAL "ON-RAMPS"
1:30 p.m. Salon III

What technologies need to be developed now for human return to the Moon (and beyond)?
What are logical architectures/open implementation to allow effective integration of international elements?

Chair: **D. T. Blewett**

1:30 p.m. Weisbin C. * Lincoln W. Elfes A. Smith J. Adumitroaie V. Hua H. Shelton K. Mrozinski J.
Determining Technology Priorities to Enhance Lunar Surface Science Mission Productivity **[#4015]**

1:50 p.m. Blewett D. T. * Patterson G. W. McGovern J. A. Lopez N. R.
Assessing Safe Lunar Landing Site Statistics with Synthetic DEMs **[#4093]**

2:10 p.m. Patterson G. W. * Lopez N. R. Blewett D. T. McGovern J. A.
Characterizing Potential Lunar Landing Sites Using Synthetic DEMs **[#4095]**

2:30 p.m. Akin D. L. *
Developing an Aerial Transport Infrastructure for Lunar Exploration **[#4096]**

2:50 p.m. Hufenbach B. * Leshner R.
The NASA-ESA Comparative Architecture Assessment **[#4005]**

3:10 p.m. Mongrard O. * Schlutz J. Hufenbach B.
European Architecture for Lunar Exploration **[#4023]**

3:30 p.m. Peter N. *
Global Space Exploration Until 2025 a European Perspective **[#4088]**

3:50 p.m. Rodriguez G. * Slane F.
Integrating a Modular Excavator as a Smart Tool into the Space Exploration Infrastructure Using Small Satellite Systems Protocols **[#4031]**

4:10 p.m. Lebeuf M. * Mader M. M. Williamson M. C.
Analogue Missions as an Integration Mechanism to Develop Lunar Exploration Strategies **[#4033]**

4:30 p.m. Wills D. E. * Foing B. Wills H. H.
Astrobiology and Exposure Experiments from the Lunar Surface **[#4120]**

4:50 p.m. Berg D. * Briscoe J. Chandhok K. Coello E. Colver J. Cox A. Douglas S. Ellsberry A. Fields S. Gers D. Hasnain Z. Hasain A. Kirk M. Laing J. Lam M. Leggett J. Levashov M. Levin R. Lisee J. Manning O. Mariano T. Mayerovitch J. McCall B. McLaren D. Mirvis A. Murphy R. Nacev A. Oberoi H. Onukwubiri U. Petillo S. Russell T. Schaffer M. Shishineh A.-R. Zwillinger J.
Project TURTLE: Terrapin Undergraduate Rover for Terrestrial Lunar Exploration **[#4124]**

Wednesday, October 29, 2008
POSTER SESSION
7:30 p.m. Pavilion

Bart G. D. Colaprete A.
Characterizing the LCROSS Impact Site **[#4113]**

Joy K. H. Crawford I. A. Kellett B. J. Grande M. C1XS Science Team
The Scientific Case for the Chandrayaan-1 X-Ray Spectrometer **[#4014]**

Heldmann J. L. Colaprete A. Wooden D. Asphaug E. Schultz P. Plesko C. S. Ong L. Korycansky D. Galal K. Briggs G.
Lunar Crater Observation and Sensing Satellite (LCROSS) Mission: Opportunities for Observations of the Impact Plumes from Ground-based and Space-based Telescopes **[#4051]**

Ennico K. Colaprete A. Heldmann J. Kojima G. Lynch D. Shirley M. Wooden D.
Lunar Crater Observation and Sensing Satellite (LCROSS) Science Payload Ground Development, Test, and Calibration **[#4055]**

Foing B. H. Koschny D. Grieger B. Josset J.-L. Beauvivre S. Grande M. Crawford I. Swinyard B. Huovelin J. Alha L. Keller H. U. Mall U. Nathues A. Malkki A. Noci G. Sodnik Z. Kellett B. Pinet P. Chevrel S. Cerroni P. de Sanctis M. C. Barucci M. A. Erard S. Despan D. Muinonen K. Naranen J. Shevchenko V. Shkuratov Y. Ellouzi M. Peters S. Bexkens F. Borst A. Odum C. Boche-Sauvan L. Monaghan E. Wills D. Almeida M. Frew D. Volp J. Heather D. McMannamon P. Camino O. Racca G.
SMART-1 Results and Lessons Learned for Preparing Future Exploration **[#4099]**

Despan D. Erard S. Barucci A. Josset J.-L. Beauvivre S. Chevrel S. Pinet P. Koschny D. Almeida M. Grieger B. Foing B. H. AMIE Team
High Resolution Maps of the Moon Surface with AMIE/SMART-1 **[#4039]**

Monje O. Wheeler R. M. Jones S. Mitchell C. A.
Design of Root Modules for a Lunar Salad Machine **[#4071]**

McGovern J. A. Blewett D. T. Patterson G. W. Lopez N. R.
Simulating Lunar Landing Site Illumination with Synthetic DEMs **[#4094]**

Street K. Greenberg P. Gaier J.
Structural, Physical, and Compositional Analysis of Lunar Simulants and Regolith. **[#4114]**

Sellar R. G. Farmer J. D. Robinson M. S.
Multispectral Hand Lens and Field Microscope **[#4075]**

Mengaldo G. Moro V. Rossettini L. Bandera A. Maggi F.
Moon Orbiter, Propulsion Issues **[#4028]**

Quinn L. P.
Excavation of Habitat Trench by a Single Precision Kinetic Bombardment **[#4040]**

Quinn L. P.
Orbiting "Earth-Safe" Atomic Explosives for Defense Against Asteroids **[#4026]**

Irwin S. A. Durrance S. T. Buhler C. R. Calle C. I.
Method to Investigate the Charging Characteristics of Lunar Dust Particles **[#4108]**

Kawamoto H. Inoue H. Abe Y.
Electromagnetic Cleaner of Lunar Dust Adhered to Spacesuit **[#4004]**

Long J. M. Lane J. E. Metzger P. T.
A Modification and Analysis of Lagrangian Trajectory Modeling and Granular Dynamics of Lunar Dust Particles **[#4058]**

Rieber R. R. Seibert M. A.
Two Problems, One Solution — Microwave Sintering of Lunar Dust **[#4111]**

Brown I. I. Garrison D. H. Jones J. A. Allen C. C. Sanders G. Sarkisova S. A. McKay D. S.
The Development and Perspectives of Bio-ISRU **[#4048]**

Schuerger A. C. Smith D. J.
The Moon's Surface May be a Self-sterilizing Environment for Terrestrial Microorganisms **[#4029]**

Losiak A. Kohout T. O'Sulllivan K. Thaisen K. Weider S. Kring D.
Establishing a Precise Absolute Chronology of the Moon — A Need for Robotic Missions **[#4072]**

Kohout T. O'Sullivan K. Losiak A. Kring D. Thaisen K. Weider S.
Robotic and Human Exploration of the Schrödinger Basin **[#4078]**

O'Sullivan K. Kohout T. Losiak A. Kring D. Thaisen K. Weider S.
Schrödinger Basin: A Geologically Diverse Landing Area **[#4081]**

Peters S. T. M. Monaghan M. P. Foing B. H.
Future Robotic Study of Lunar Basins: Goals for Geochemistry and Geophysics **[#4080]**

Borst A. M. Bexkens F. Foing B. H.
Geological and Geochemical Study of South Pole–Aitken Basin and Future Sample Return Missions **[#4116]**

Clark P. E. Lewis R. Millar P. S. Yeh P. S. Lorenz J. Feng S. Powell W. Beaman B. Choi M. Cooper L. Leshin L.
Enabling Minimal Mass Science Packages for Lunar Surface Studies **[#4086]**

Weinberg J. D. Neal C. R. Delory G. T.
Global Lunar Geophysical and Exospheric Science Network **[#4125]**

Thaisen K. G. Losiak A. Kohout T. O'Sullivan K. Weider S. Kring D.
Geographic Information Systems: An Enabling Tool for Lunar Exploration **[#4098]**

Rizzo M. Hall B. C. Pérez M. K.
A Multi-Purpose Analysis and Logistics Device for Lunar Exploration **[#4077]**

Kissi-Ameyaw J. Monaghan E. P. Foing B. H.
Astronomy from the Moon: Possible Science Investigations and Precursors **[#4102]**

Kroening K. Sollitt L. S. Segura T. Spittler C.
Secondary Payload Architecture for Lunar Comm Relay Satellites **[#4119]**

White W.
A Proposal for "The [Insert Sponsor Here] L2 Cup" **[#4106]**

Guest A. N. Hofstetter W. K. Cunio P. M. McLinko R. Grosse E. Hoffman J. A.
Living on the Lunar Surface — A Minimalist Approach **[#4123]**

Lee P. Abercromby A. Braham S. Deans M. Fong T. Glass B. Hoffman S.
McKay C. P. Wilkinson N.
Terrestrial Analogs for Lunar Science and Exploration: A Systematic Approach **[#4126]**

Hou X. Y. Liu L. Zhang W.
On Station Keeping of Spacecrafts with Solar Sail Around the Earth-Moon Collinear Libration Points **[#4012]**

Thursday, October 30, 2008
PRECURSOR MISSIONS I
8:30 a.m. Salon I

What are the needs/advantages of robotic missions for advancing lunar science/benefiting human exploration? What technology developments in robotic exploration are being conducted by various countries/agencies?

Chair: **J. B. Plescia**

8:30 a.m. Plescia J. B. *
Robotic Exploration of the Moon: Prelude to Human Settlement and ISRU Exploitation **[#4043]**

8:50 a.m. Fong T. * Deans M. Lee P. Heldmann J. Kring D. Heggy E. Landis R.
Improving Lunar Surface Science with Robotic Recon **[#4049]**

9:10 a.m. Cohen B. A. * ILN Science Definition Team MSFC/APL ILN Engineering Team
The International Lunar Network **[#4117]**

9:30 a.m. Mimoun D. * Lognonne P. Gagnepain-Beyneix J. Giardini D. Nebut T. Tillier S. Gabsi T. Garcia R.
Seismic Measurements on the Moon: Objectives and Network Architectures **[#4083]**

9:50 a.m. Crawford I. A. * Smith A. Gowen R. A. MoonLITE Science Working Group UK Penetrator Consortium
MoonLITE: A Cost Effective Proposal for Advancing Multiple Objectives in Lunar Science and Exploration **[#4007]**

10:10 a.m. Gowen R. A. Smith A. *
Progress of the MoonLITE Penetrators **[#4013]**

10:30 a.m. Carpenter J. D. * Houdou B. Koschny D. Crawford I. Falcke H. Kempf S. Lognonne P. Ricci C. Pradier A.
The MoonNEXT Mission: A European Lander at the Lunar South Pole **[#4037]**

10:50 a.m. Visentin G. * Foing B. Walker R. Galvez A.
ESA's Lunar Robotics Challenge **[#4112]**

11:10 a.m. Alkalai L. * Elliott J.
Lunette: A Global Network of Small Lunar Landers **[#4103]**

11:30 a.m. Gurvits L. I. * Falcke H.
Toward Moon-based Very Long-Wavelength Radio Astronomy Facility: Science Drives and Technological Challenges **[#4057]**

11:50 a.m. Noda H. * Hanada H. Iwata T. Kawano N. Sasaki S. Araki H. Imamura T.
Optical and Low Frequency Radio Observatory on the Moon **[#4034]**

Thursday, October 30, 2008
BACK ON THE MOON
1:30 p.m. Salon I

How can future lunar surface activities be optimized?

Chair: **G. J. Taylor**

1:30 p.m. Hufenbach B. * Mongrard O. Carey W.
European Lunar Landing System **[#4024]**

1:50 p.m. Lupisella M. Eppler D. Arnold L. Landis R. Gates M. Hovland S. Foing B. Olds J. DePasquale D. Lewis R. Hyatt M. Conley C. Mandl D. Talabac S. McNamara K. Perino M. A. Alkalai L. Morrow C. Burke J.
Addressing International Lunar Surface Operations **[#4065]**

2:10 p.m. Eppler D. B. *
Geologic Preparation for Exploring the Moon and Planets: Using the Past as a Key to the Present **[#4082]**

2:30 p.m. Carey W. * Hufenbach B. Mongrard O. Haese M.
Lunar Surface Explorations Scenarios **[#4022]**

2:50 p.m. Osinski G. R. * Barfoot T. Ghafoor N. Jasiobedzki P. Tripp J. Richards R. Haltigin T. Banerjee N. Izawa M. Auclair S.
Optimizing Lunar Surface Activities: LiDAR and mSM as Scientific Tools? **[#4061]**

3:10 p.m. Crawford I. A. * Fagents S. A. Joy K. H.
Exploring the Basaltic Lava Flows of Oceanus Procellarum: Requirements for an Exploration Architecture that Optimises Scientific Return from Geological Field Activities **[#4006]**

3:30 p.m. Taylor G. J. * Blake D. Gillis-Davis J. Chipera S. J. Bish D. Hammer J. Lucey P. Vaniman D. T. Sarrizin P.
X-Ray Diffraction in the Field and Lab on the Moon **[#4025]**

3:50 p.m. Prabhakaran V. S. *
Automated Multi-Conditional Exploration Rover Series (AMCERS) — Low Cost Lunar Exploration **[#4036]**

4:10 p.m. Boulware J. C. * Angomas F.
Lunar Concrete as a Means of Reducing the Dust Hazard **[#4060]**

4:30 p.m. Christoffersen R. * Lindsay J. F. Noble S. K. Lawrence J. A.
Lunar Dust Effects on Spacesuit Systems: Insights from the Apollo Spacesuits **[#4090]**

4:50 p.m. Croukamp L. *
A Proposed Geotechnical GIS for Lunar Exploration **[#4069]**

Thursday, October 30, 2008
PRECURSOR MISSIONS II
1:30 p.m. Salon III

What are the needs/advantages of robotic missions for advancing lunar science/benefiting human exploration? What precursor lunar surface experiments are highest priority for space settlement/commercial development?

Chair: **P. Eckert**

1:30 p.m. Wegeng R. S. * Mankins J. C. Balasubramaniam R. Sacksteder K. Gokoglu S. A. Sanders G. B. Taylor L. A.
Lunar Rovers and Thermal Wadis Based on Processed Regolith **[#4091]**

1:50 p.m. Hintze P. E. * Curran J. P. Back T. A.
The Use of Solar Heating and Heat Cured Polymers for Lunar Surface Stabilization **[#4062]**

2:10 p.m. Kohut J. N. * Gump D. P.
Commercial Lunar Data Collection and Licensing to Reduce Exploration Costs **[#4066]**

2:30 p.m. Singh J. P. *
Possibility of a Moon Based Terrestrial Defence System for the Earth **[#4068]**

2:50 p.m. Milam M. B. * Lewis R.
Unpressurized Cargo ORION a Launch Opportunities for Lunar Missions **[#4092]**

3:10 p.m. Dunlop D. A. *
Contract Incentives for an Open Architecture International Lunar Network Including Google Lunar X-Prize **[#4042]**

3:30 p.m. Durst S. *
International Lunar Observatory Association (ILOA): 3 Mission Update — ILO-X Precursor, ILO-1 Polar, ILO Human Service Mission **[#4053]**

3:50 p.m. Konesky G. A. *
Enhanced GPS Accuracy Using Lunar Transponders **[#4041]**

4:10 p.m. Zacny K. * Wilson J. Ashley A. Santoro C. Sudano M. Lee S. Kobayashi L. Fong T. Deans M.
Geotechnical Property Tool on NASA Ames K-10 Rover **[#4001]**

4:30 p.m. Gibson E. K. * Pillinger C. T. McKay D. S. Wright I. P. Sims M. R. Richter L. Waugh L. Lunar Beagle Consortium
Lunar Beagle: A Science Package for Measuring Polar Ice and Volatiles on the Moon **[#4027]**

4:50 p.m. ten Kate I. L. * Malespin C. A. Glavin D. P. VAPoR Team
VAPoR Breadboard Development, First Pyrolysis Results **[#4038]**

Thursday, October 30, 2008
SPECIAL SESSION: WHAT IS THE STATUS OF SPACE LAW AS IT RELATES TO THE MOON?
7:00 p.m. Salon I

What policy/regulations issues should be addressed?

Chair: **B. H. Foing**

7:00 p.m. Rakesh A. * Raja R. P. Krishna T. N.
A Strategic Technological, Ethical and Socio-Legal Frame Work for a Sustainable Lunar Colonization **[#4019]**

7:20 p.m. Sinclair A. H. *
US Space Policy for Global Leadership **[#4067]**

7:40 p.m. Schrogl K.-U. * Peter N.
Legal Aspects of Space Exploration **[#4089]**

8:00 p.m. Schrunk D. G. *
The Science of Laws: Application to Lunar Governance **[#4104]**

Friday, October 31, 2008
FACILITATING EXPLORATION AND SETTLEMENT USING ROBOTIC MISSIONS, HUMAN-ROBOTIC PARTNERSHIPS, AND ISRU
8:30 a.m. Salon I

What are the needs/advantages of robotic missions for advancing lunar science/benefiting human exploration?
How can human-robotic partnerships be used to develop/build a long-term presence on the Moon?
What are the drilling challenges on planetary surfaces/in regolith/regolith-ice mixtures/rock and at ultra-low temperatures?

Chairs: **C. Neal**
B. H. Foing

8:30 a.m. Sasaki S. * Araki H. Hanada H. Namiki N. Iwata T. Asari K. Goossens S. Ishihara Y. Ishikawa T. Kawano N. Kikuchi F. Liu Q. Matsumoto K. Noda H. Tazawa S. Tsuruta S. Kurosawa K. Sugita S. Takano T.
Global Topography and Gravity Fields of the Moon by Kaguya (SELENE) **[#4064]**

8:50 a.m. Matsumoto K. * Hashimoto T. Hoshino T. Tanaka S. Otsuki M. Kawaguchi J.
Japanese 1st Moon Lander SELENE-2 as SELENE Follow-On **[#4076]**

9:10 a.m. Grande M. * Maddison B. J. Sreekumar P. Huovelin J. Kellett B. J. Howe C. J. Crawford I. A. Smith D. R. C1XS Team
C1XS — The Chandrayaan-1 X-Ray Spectrometer **[#4059]**

9:30 a.m. Walker R. * Cross M.
The European Student Moon Orbiter (ESMO): A Small Mission for Education, Outreach and Lunar Science **[#4087]**

9:50 a.m. Ehrenfreund P. * Foing B. H.
What Astrobiology Investigations are Needed and Possible on the Moon? **[#4109]**

10:10 a.m. Sridhar J. *
An Experimental Study of Lunar Reconnaissance Base with the Robotic Emplacements **[#4044]**

10:30 a.m. Zacny K. * Fink P. Milam B. Nagihara S. Taylor P.
Heat Flow Probe Deployment in Lunar Regolith Simulant Using a Percussive Penetrometer **[#4021]**

10:50 a.m. Stoker C. R. *
The Scientific Rationale and Technical Challenges of Drilling on the Moon and Mars **[#4010]**

11:10 a.m. Zacny K. * Maksymuk M. Wilson J. Santoro C. Chu P. Paulsen G. Passaretti M. Roberts D. Kusack A. Kumar N.
Rotary Percussive Drilling in a Vacuum Chamber: A Test Bed for Lunar and Mars Drilling **[#4002]**

11:30 a.m. Kawamoto H. * Uchiyama M.
Electrostatic Cleaner of Lunar Dust on Solar Panel and Optical Lens **[#4003]**

LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL,

Executive Summary

Date Prepared: September 5, 2008

Presenter's Name: Jim Adams
Presenter's Title: Deputy Director, Planetary Science Division
Presenter's Organization/Company: NASA Headquarters

Presentation Title (brief descriptive title)

NASA's Lunar Science Program an Overview

Key Ideas (2-3 sentences)

Provide an overview of NASA's Lunar Science Program. This will include a discussion of plans associated with Lunar Research and Analysis as well a summary of planned missions and the progress of international cooperation efforts.

Supporting Information

Developing an Aerial Transport Infrastructure for Lunar Exploration

David L. Akin
Space Systems Laboratory
University of Maryland

Thorough scientific exploration of the lunar surface will be dependent on access to remote and restricted sites. While pressurized and unpressurized rovers are planned to extend human range beyond the outpost location or sortie landing site, these systems will not be capable of reaching the bottom of a rille, the top of a mountain, or sites hundreds of kilometers away from the outpost. Using operations in Antarctica as an analogue to lunar exploration, these extreme operating locations are serviced by aerial systems: helicopters and fixed-wing aircraft. This paper explores the use of rocket propulsion to provide lunar transport infrastructure in the roles filled by aerial vehicles in Antarctica. The paper reviews the basic physics of rocket transport on an airless body, focusing on two competing approaches: ballistic hopping (thrusting at takeoff and landing while following a ballistic trajectory in between), and propulsive gliding (traveling at constant altitude and horizontal velocity while using thrust to continuously offset gravity.) The basic theory is derived, and extended to include cases including multiple hops, hopping and gliding between sites with differing altitudes, and hybrid approaches involving elements of both hopping and gliding. Once the basic theory is derived, past design concepts for lunar flying vehicles are reviewed, and Constellation outpost operations are examined to arrive at a baseline design for a lunar transport vehicle capable of reaching locations inaccessible to wheeled transports. The baseline system is used to derive an concept of operations for aerial transport at the lunar outpost, and requirements established for lunar-derived propellants, operational support, and contingency operations. In addition, a small unmanned vehicle design is developed for use in deploying instrument packages, performing autonomous sampling, and for early demonstration of aerial transport prior to the development and deployment of human systems.

Lunette: A Global Network of Small Lunar Landers

L. Alkalai and J. Elliott
NASA Jet Propulsion Laboratory, Lunar Robotics Exploration Office

Introduction: For the past two years, JPL's Lunar Robotic Exploration Office has been studying the technical feasibility and cost of a network of small lunar landers for the distributed measurement of both scientific and exploration objectives. The networks considered include 1) a local area network of up to six small landers deployed as a piggy-back launch off an EELV Secondary Payload Adapter (ESPA) ring; 2) multiple individual global landers that can be deployed anywhere on the Moon and can be launched on an EELV-class launch vehicle; 3) the combination of the two previous approaches. Each individual lander is designed with existing technologies including proven and space qualified propulsion technologies, power sources, avionics, thermal design, ACS, telecom, etc. The simple landers are designed for operations over multiple years and for continuous operations during the night, without the use of nuclear power sources. Each lander can deliver between 10 – 15 kg of science or exploration focused payload to the surface. A sample payload suite will be shown in the point design.

This publication will detail the *Lunette* mission design, including the low-energy trajectory to the Moon, lander carrier braking burn and control, deployment approach, landing system, terminal descent approach, and complete system design including mass and power allocations and margins. In addition, the paper will discuss multiple trade-studies that were considered including choice of the launch vehicle, mass margin strategy, technical maturity of the design, preliminary cost estimates, schedule, and risk.

The proposed *Lunette* architecture is particularly suitable for international collaboration in which each lander can carry payloads from different agencies or institutions, or each lander can be built by different institutions according to an open-architecture approach which includes inter-operability, international data standards, etc.

Finally, the paper will discuss on-going as well as future work and key technical challenges.

INTERNATIONAL STANDARDS AND THE NASA LUNAR GEODESY AND CARTOGRAPHY WORKING GROUP. Lunar Geodesy and Cartography Working Group, including: B. Archinal[1] (chair), C. Acton, B. Bussey, B. Campbell, G. Chin, A. Colaprete, A. Cook, D. Despan, R. French, L. Gaddis, R. Kirk, W. Mendell, F. Lemoine, M. Nall, J. Oberst, J. Plescia, M. Robinson, D. Smith, K. Snook, T. Sweetser, R. Vondrak, M. Wargo, and J. Williams. [1]U. S. Geological Survey, Astrogeology Team, 2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov.

Introduction: Several of the session questions for this meeting address what types of standards and infrastructure are needed for lunar exploration. E.g. Question 2-2 essentially asks what international standards are needed for robotics development, habitats, and hazard prevention. The NASA Lunar Precursor Robotic Program (LPRP) has established a Lunar Geodesy and Cartography Working Group (LGCWG) with U. S. and international membership. This group is addressing precisely these sorts of questions in regard to standards for lunar mapping and map products, which are critical for use in lunar landing and surface operations.

The LGCWG has recognized that with the acquisition of large volumes of new imaging data for the Moon and the resurgence of lunar mapping programs worldwide, there is an urgent need for international adoption of lunar cartographic standards. Use of such standards facilitates and enhances both creation and use of lunar data products. Because such uniform products are coregistered into common reference frames and can more readily be analyzed and compared, they are essential for both efficient lunar mission operations and scientific investigation of the Moon.

WG Operation: Although primarily formed to ensure that products for the Constellation program [1] adhere to fundamental cartographic standards, the LGCWG also provides a forum for cooperation and coordination with the international lunar exploration community. The LGCWG accepts recommendations from lunar experts, and makes decisions by consensus of a core membership representing data providers and users as well as NASA management. LGCWG meetings are occurring primarily by teleconference, with some in-person meetings and regular e-mail communication. Presentations (such as this one) to the broader lunar community are also being made to increase awareness of our work.

The LGCWG will follow – or, as necessary, recommend changes to – the basic lunar standards of the International Astronomical Union / International Association of Geodesy Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE, the international advisory group that sets high-level cartographic standards for all solar system bodies) [2]. Further, the LGCWG will define and extend geodetic and cartographic requirements and recommendations to lower level standards than considered by the WGCCRE. The LGCWG thus provides the essential level of detail for development of new cartographic products from lunar data that is necessary to support ongoing and future lunar exploration.

Activities: Since its inception in late 2007, the LGCWG has addressed the following: a) Use (including further updating) of the white paper “A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter” [3]; b) Use of the mean Earth/polar axis (ME) coordinate system for the Moon for creation of cartographic products (per recommendation of the WGCCRE); c) Use of the new JPL DE 421 ephemeris [4] to specify the initial lunar body-fixed frame in the principal axes system, and associated Euler angles, to define a ME frame; d) Development of draft recommendations for a standard for creating lunar mosaics and global map products; and e) Development of draft recommendations for verifying and publishing lunar products such as digital elevation models. Teleconferences and meetings include presentations on mission and instrument teams’ data processing and product plans, as well as reports on newly available lunar cartographic products.

Future Plans: In the future, the LGCWG will: a) Continue to update the above recommendations, b) Recognize and make recommendations on the use of updated lunar reference frames; c) Define gravity field standards and updates as needed; d) Recommend a new model for the lunar reference shape when results from new missions are available; e) Develop recommendations for controlled, semi-controlled, uncontrolled, mosaicked, and/or projected image products; and f) Assist organizations such as the NASA Planetary Data System (PDS) and/or the International Planetary Data Alliance (IPDA) with data archiving requirements, including formats, mapping conventions, scales and projections for digital images and mosaics.

Acknowledgements: This work is funded under the NASA Lunar Precursor Robotic Program.

References: [1] Cohen, et al. (2008), *Lunar Planet Sci.*, XXXIX, Abstract #1640. [2] Seidelmann, et al. (2007), *Cel. Mech. & Dyn. Ast.*, 98, 155. [3] LRO Project (2008), http://lunar.gsfc.nasa.gov/library/451-SCI-000958.pdf. [4] E.g. NAIF (2008), http://naif.jpl.nasa.gov/naif/lunar_kernels.txt.

PHOENIX LANDER IMPLICATIONS ON *IN SITU* RESOURCE UTILIZATION FOR ROBOTIC EXPLORATION OF MARS.

Robert L. Ash, Aerospace Engineering Department, Old Dominion University, Norfolk, VA 23529, RAsh@odu.edu

Introduction: Sample return and manned Mars missions benefit greatly from *in situ* resource utilization (ISRU) by substituting hardware for consumables mass, thereby reducing initial Earth launch requirements [1,2]. It has been 30 years since a Sabatier/electrolysis ISRU system was first proposed for near-term Mars missions and the current Mars orbiters, surface rovers and the Phoenix Lander are generating data that, when coupled with the remarkable advances in computational and unmanned vehicle systems technology, justify a re-examination of Mars mission planning and ISRU development priorities. This paper will put forth logic for establishing a robotic base of operations at Mars that can enable mission planning *from* Mars rather than the serial missions *to* Mars being employed currently.

Following the Water: If water ice exists at some locations just beneath Mars' surface, it is possible to commit to a permanent operational base that exploits access to water. However, in doing so it will be necessary to assume that water ice contains organic molecules and other evidence of extent or fossilized biological activity, impacting its use as a feedstock. Furthermore, if a commitment is made to an operational base, reduced access to other future sites must be overcome.

This paper will discuss the engineering challenges associated with manipulating permafrost and other surface materials in a 3/8g, environment whose average surface temperatures is 210 ^{o}K, along with discussing how Mars' low ambient pressures can enable an "archeological approach" for water feedstock extraction.

Breaking the Serial Mars Mission Development Cycle: Since 1976, the typical time interval between committing to a Mars follow-on mission and an actual arrival at Mars have varied between 7 and 10 years. Only about half of the executed Mars missions to date can be considered successful. In addition, the opportunities for low-energy flights between Earth and Mars are constrained by the 779.86-day synodic period, making it very difficult to explore a 1.4441×10^8 km^2 surface area.

Establishment of high data-rate communication links between Mars and Earth is a continuing need and electric power levels approaching 100 kW will be needed for any sort of extended human presence. Early development of an orbiting satellite network that can provide persistently high communication rates while serving as a precision navigation platform can be exploited during the robotic exploration phase. A 10-kWe electric power generation capability can be used to demonstrate nuclear fission power generation or solar derived alternatives such as a very large solar array with energy storage or an orbiting solar power satellite with microwave transmission. Furthermore, that capability can be exploited to enhance system reliability and to demonstrate realistic methane and oxygen production and storage rates while providing the thermal energy required for archeological water extraction. At that point, it is possible for much of the Mars exploration mission planning and execution to start from the Martian surface.

This paper will discuss propulsion systems utilizing liquid methane and oxygen for powering reusable airplanes and hoppers from the Martian surface. The planned *Sky Crane* for the 2009 Mars Science Laboratory mission could have used methane-LOX as its primary propellant enabling its reuse for future exploration missions. Subsequently, fleets of unmanned exploration vehicles can be fueled and deployed on relatively short cycle round-trip surface sortie missions to virtually any location on the Martian surface via ISRU.

Compressed carbon dioxide as an auxiliary propellant: In addition to exploiting water as a feedstock, this paper will report on work by undergraduate students at Old Dominion University that has focused on condensing solid dry ice out of the Martian atmosphere utilizing a Peltier refrigerator and subsequently reversing the polarity of the device to act as a heat pump, producing supercritical carbon dioxide fluid at very high pressures for rocket propulsion and compressed gas tool operation. By using small solar arrays to generate the electrical power, these systems can be used for emergencies and as a local energy source away from the main base.

References:

[1] Ash, R.L., Dowler, W.L., and Varsi, J. (1978) *Acta Astronautica,* 5, 705-724. [2] Hoffman, S.J. and Kaplan, D.I. (1997) *NASA Special Publication 6170*.

FROM THE GLOBAL EXPLORATION STRATEGY (GES) TO THE INTERNATIONAL SPACE EXPLORATION WORKING GROUP (ISECG). M. Baltuck[1], J.W. Curtis[2], S. Espinasse[3], J.J.Favier[4], G. Gibbs[5], B. Hufenbach[6], J. Kawaguchi[7], A. Lorenzoni[3], N. R. Newman[8], D. Parker[9], G. L. Yoder[8], [1]CSIRO Information and Communication Technology, PO Box 1035 Tuggeranong ACT 2901 Australia, [2]BNSC - British National Space Centre 151 Buckingham Palace Road London SW1W 9SS United Kingdom, [3]ASI- Italian Space Agency, Viale Liegi 26 - 00198 Roma – Italy – sylvie.espinasse@asi.it, [4]CNES - Centre National d'Etudes Spatiales, 18 avenue Edouard Belin 31 401 Toulouse Cedex 4 France, [5]CSA – Canadian Space Agency, 6767 route de l'aéroport, St- Hubert (Qc) J3Y 8Y9 Canada, [6]ESA – European Space Agency ESTEC Keplerlaan 1, 2201 Noordwijk, The Netherlands, [7]JSPEC – JAXA Space Exploration Center, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510 Japan, [8]NASA – National Aeronautics and Space Administration NASA HQ -300 E Street SW – Washington DC 20546 – USA, [9]STFC - Science & Technology Facilities Council - Polaris House North Star Avenue Swindon SN2 1SZ United Kingdom

Abstract: In 2006, 14 space agencies began a series of discussions on global interests in space exploration. Together they took the unprecedented step of elaborating a vision for peaceful robotic and human space exploration, focussing on destinations within the Solar System where humans may one day live and work, and developed a common set of key space exploration themes. This vision was articulated in "The Global Exploration Strategy: The Framework for Coordination" (the Framework Document), which was released on May 31, 2007.

The process of creating, editing, and producing the Framework Document has nurtured a strong consensus and partnership among the fourteen founding space agencies. This spirit of openness, flexibility, and mutual respect that marked the Framework Document development process yielded a truly cooperative effort and the starting point for broader discussions.

A key element of the Framework Document was the need to establish a voluntary, non-binding international coordination mechanism through which individual agencies may exchange information regarding interests, objectives and plans in space exploration with the goal of strengthening both individual exploration programmes as well as the collective effort. The coordination mechanism is now called the International Space Exploration Coordination Group (ISECG) whose members are working together since the adoption of its Terms of Reference by the participating agencies in November 2007.

The presentation will present the contents of the Framework Document, describe the activities performed by ISECG and discuss its relationship with other existing groups like ILEWG.

CHARACTERIZING THE LCROSS IMPACT SITE. G. D. Bart[1], A. Colaprete[2], [1]*Carl Sagan Center, SETI Institute, 515 N. Whisman Rd., Mountain View, CA 94043 (gbart@seti.org)*, [2]*NASA Ames Research Center, M/S 245-3, Moffett Field, CA 94035*.

Introduction: LCROSS, the Lunar CRater Observation and Sensing Satellite, will be launched on the same rocket as the Lunar Reconnaissance Orbiter (LRO) later this year (http://lcross.arc.nasa.gov). The LCROSS scientific objectives are: (1) Confirm the presence or absence of water ice in a permanently shadowed region on the Moon. (2) Identify the form/state of hydrogen observed by at the lunar poles. (3) Quantify, if present, the amount of water in the lunar regolith, with respect to hydrogen concentrations. (4) Characterize the lunar regolith within a permanently shadowed crater on the Moon. The presence of water ice is hypothesized based on evidence found by the Lunar Prospector neutron spectrometer for hydrogen in permanently shadowed regions at the poles [1].

The LCROSS spacecraft will set the rocket's Centaur Earth departure upper stage (EDUS) on an impact trajectory with the Moon. Once the trajectory is set, the spacecraft will release the EDUS, which will then impact the Moon in a permanently shadowed region characterized by high concentrations of hydrogen according to the Lunar Prospector neutron spectrometers. Following four minutes behind the EDUS, LCROSS will fly through the impact plume, using its 9 instruments (5 cameras (1 visible, 2 Near IR, 2 Mid IR), three spectrometers (1 visible, 2 NIR) and one photometer) to search for water ice.

Impact Site Candidates: Four south-pole regions are currently candidates for the LCROSS impact (Fig. 1): Shoemaker crater (88.1 S, 44.9 E, 50.9 km diameter), Shackleton crater (89.9 S, 0.0 E, 19 km diameter), Faustini crater (87.3 S, 77.0 E, 39 km diameter), and Cabaeus (85 S, 35 E). Due to the launch date swap, several north-pole areas are now candidates as well.

Target Selection Criteria:

Target selection will be key to the success of this mission. The constraints on the impact site selection are: (1) the ejecta plume must be observable by ground-based and orbital observatories. (2) the ejecta must be illuminated by sunlight, since the instruments primarily measure reflected light. (3) the target should have known surface properties (low roughness and slopes, deep regolith cover.) (4) the target should be in a region with an observed concentration of increased hydrogen, which could indicate presence of water [2].

Impact Site Characterization:

Characterizing the expected terrain within the crater will be difficult because the target impact site is required to be permanently shadowed. Because of lack of high resolution visible imaging at the poles, we use high resolution Earth-based radar data [3], which can directly observe some parts of the permanently shadowed regions. Once the tools and analysis methods are established, we will be ready to quickly assess new data provided by the instruments on LRO, which will begin taking data 2-3 months prior to the LCROSS impact.

Conclusion:

This study will be critical to providing the best scientific return from the LCROSS mission. Understanding the target as well as possible will both optimize the quality of data return and improve the analysis of the data.

Although this study is critical to the success of the LCROSS mission, it will also return scientific results relevant to:

- NASA lunar exploration initiatives
- Future landing site selection
- Understanding cratering processes
- Dry craters (Moon) vs. possibly wet craters (Mars)
- Ice deposits elsewhere, such as Mercury

References:

[1] Feldman W.C., Maurice S., Binder A.B., Barraclough B.L., et al. (1998) *Science*, *281* 1496–1500.

[2] Elphic R.C., Eke V.R., Teodoro L.F.A., Lawrence D.J., et al. (2007) *Geophys Res Lett*, *34* L13204.

[3] Campbell B.A. and Campbell D.B. (2006) *Icarus*, *180* 1–7.

[4] Margot J.L., Campbell D.B., Jurgens R.F., and Slade M.A. (1999) *Science*, *284* 1658–1660.

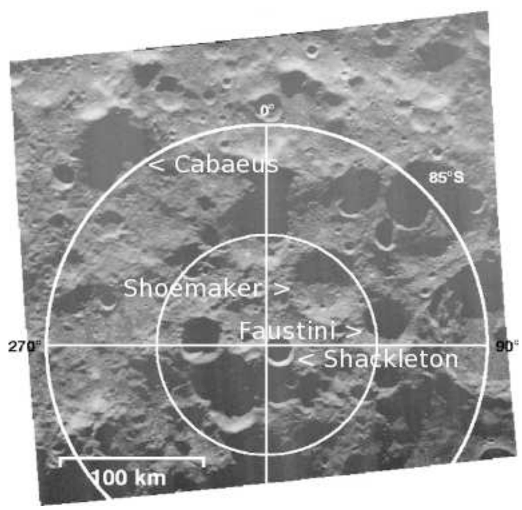
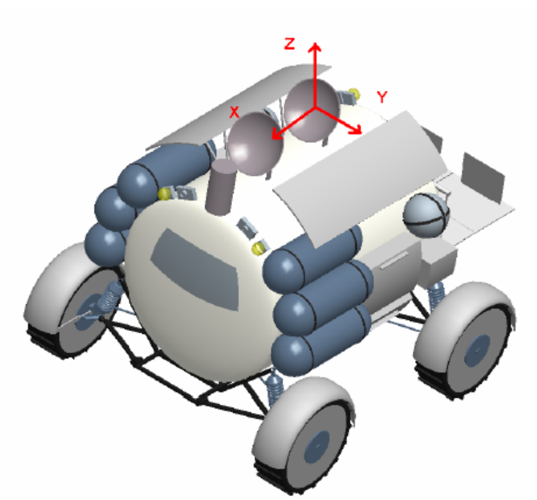


Figure 1: Illustration of the location of possible candidate impact locations for LCROSS, superimposed on a radar backscatter map of the lunar south pole from [4].

Project TURTLE: Terrapin Undergraduate Rover for Terrestrial Lunar Exploration. David Berg, James Briscoe, Kanwarpal Chandhok, Enrique Coello, Joshua Colver, Aaron Cox, Stuart Douglas, Andrew Ellsberry, Sara Fields, David Gers, Zohaib Hasnain, Ali Husain, Madeline Kirk, Jason Laing, May Lam, Jason Leggett, Michael Levashov, Ryan Levin, Joseph Lisee, Omar Manning, Thomas Mariano, Jessica Mayerovitch, Brian McCall, David McLaren, Adam Mirvis, Ryan Murphy, Aleksandar Nacev, Hasan Oberoi, Ugonma Onukwubiri, Stephanie Petillo, Tiffany Russell, Matt Schaffer, Ali-Reza Shishineh, Jacob Zwillinger. University of Maryland, College Park.

Introduction: The Constellation program is the current driving force behind NASA's future manned space program. In the quest to return to the moon, NASA is focusing its attention to developing a permanent lunar outpost, and focusing its entire infrastructure at that site. However, many of the scientifically interesting sites will not be within surface access distance from the outpost, and can be reached only via a dedicated sortie-mode exploration mission.

The Terrapin Undergraduate Rover for Terrestrial Lunar Exploration (TURTLE) concept is designed to complement and enhance the Constellation program, by exploring the minimum size and mass limits for a pressurized rover while developing a concept of operations that allow the rover to be deployed to the sortie landing site independent of the Altair lander. The TURTLE concept will augment sortie missions on the moon by providing increased exploration range for astronauts. It allows a pair of astronauts to venture up to 25 km away from the lander during a three-day traverse, and supports two such traverses during the sortie mission. This represents a twelve-fold increase in exploration area and duration as compared to an Apollo-style unpressurized rover, without requiring additional Ares V launches; the resultant lunar exploration program is significantly enhanced without impact to the development of the baseline Constellation architecture.



Design: Throughout the development of the TURTLE concept, great attention was paid to designing a complete lunar rover. The cabin pressure shell, sized to provide crew comfort with minimal mass, has an outside diameter of 1.8 m and is 2.4 m long. It consists of two layers of graphite epoxy, wrapped around an aluminum-alloy frame. The rover is 3.4 m long between the tip of each wheel, 3.2 m wide, and 2.9 m high. Ingress and egress for the astronauts are provided by a pair of suitports on the back of the cabin which are accessible via an adjustable external platform, which also provides a control station for driving the vehicle externally during an EVA. Rover structures are sized to have positive margin of safety for launch (6g axial, 2g lateral), landing, and suspension loading cases.

Mobility is provided by a DC brushless magnetic motor in each of the four wheels, which powers TURTLE to a top speed of 15 km/hr. The rover is able to clear a 0.5 meter obstacle, and can traverse a 20 degree slope in any direction in all expected loading configurations.

Mock-up Rover: To perform human factors testing and design an optimal cabin interior, a full-sized mock-up version of the rover was constructed. The pressure shell is a repurposed water storage tank and the interior simulates the planned cabin. The mock-up allowed for testing while designing the cabin layout, as well as determining the feasibility of many interior components. A low fidelity suitport system was also incorporated to allow for simulations of astronaut ingress and egress. After construction was completed, the mock-up rover was incorporated into the research team's outreach effort; the mock-up was presented as a visual aid during design reviews, and was used for tours during publicity events at the University of Maryland.

Project TURTLE was designed by the University of Maryland Space Systems Design capstone course during the Fall 2007 and Spring 2008 semester with advisors Dr. David Akin and Dr. Mary Bowden.

ASSESSING SAFE LUNAR LANDING SITE STATISTICS WITH SYNTHETHIC DEMs.

David T. Blewett[1], G. Wesley Patterson[1], J. A. McGovern[1], and N. R. Lopez[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 USA (david.blewett@jhuapl.edu).

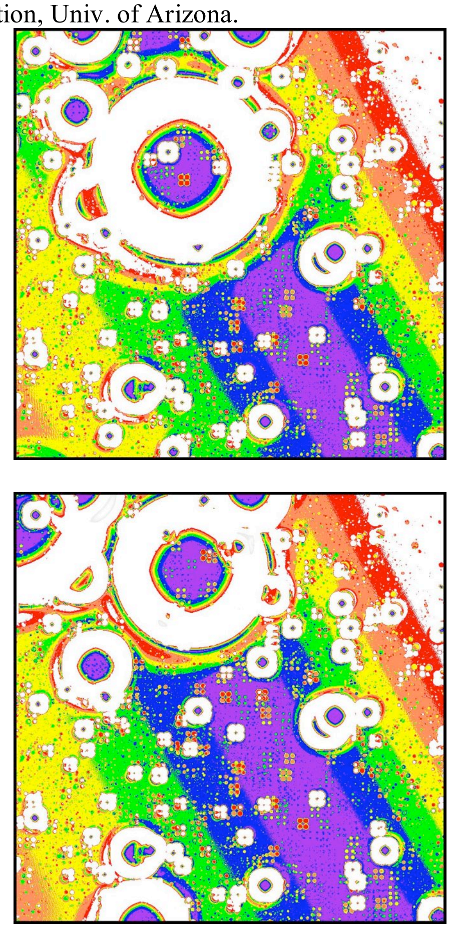
Introduction: As part of the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project, the Applied Physics Lab has developed software to generate high-resolution synthetic digital elevation models (DEMs) for the Moon. The code can read in a list of crater diameters and locations for placement in the DEM, or can generate synthetic craters according to a specified size-frequency distribution [1]. We have been studying the statistics of finding a safe landing site by performing simple image processing on DEMs generated to represent surfaces of known ages in an attempt to help answer the question "Is there a safe landing site at location *X*?"

Landing Site Hazards: Any planetary lander, whether piloted or robotic, must either navigate to a site known to be free of hazards, or must be capable of assessing the hazards present at a given landing location and redirecting to a nearby safe site if necessary. "Safe" means a site that is free of steep slopes or boulders large enough to cause tipping or damage to the spacecraft. The criterion for safety is often expressed as the maximum tilt that lander can experience when it settles onto the surface. For the Apollo Lunar Excursion Modules (LEM), the tilts ranged from 2.5° at Apollo 16 to 11° at Apollo 15; 11° was considered to be near the design limit for the LEM.

Digital Elevation Models: Ideally, high-resolution imagery at the appropriate lighting geometry would be available to assess the safety of a potential landing site. Topographic maps could be generated from stereo photography or high-resolution laser altimeter mapping. This is one of the major objectives of the Lunar Reconnaissance Orbiter mission [2]. Until such data becomes available, it is desirable to have another means by which to judge the general suitability of specific sites or classes of sites. Synthetic DEMs allow exploration of the statistical topography of the surface at resolutions finer than that of the LRO data.

Safety Criterion: It is straightforward to compute the tilt that a lander of a given size would experience if it landed at any point in the DEM image. We make the following assumptions: the lander has four legs, each at the vertex of a square, with leg spacing D. The footpads are of diameter d. For the preliminary work here, we assumed D = 15 m, and d = 1 m. The lander is placed at every pixel in the image, and the maximum and minimum elevation beneath the four footpads are found. The lander tilt, τ, is computed from $\tau = \arctan[(elev_{max} - elev_{min})/D]$. Example tilt images for the rim of a synthetic Shackleton are shown in the figure. We can also compute parameters such as the percentage of the image with a tilt less than a specified threshold, and the minimum divert distance from any point to a safe area of a given size. By analyzing multiple synthetic DEMs with randomly placed craters, we can determine the approximate conditions to be expected at a particular landing site. Future work will include rock distributions [e.g., 3] in addition to craters.

References: [1] G. W. Patterson et al. (2008) LEAG-ICEUM-SRR meeting abstracts. [2] G. Chin et al. (2007) *Space Sci. Rev.* [3] G. D. Bart (2007) Ph.D. dissertation, Univ. of Arizona.



Color-coded tilt maps for rim of synthetic Shackleton (see [1] for location). Purple 0-2°, blue 2-4°, green 4-6°, yellow 6-8, orange 8-10°, red 10-12°, white >12°. Images each cover 1 km^2. *Top:* "average mare" crater distribution. *Bottom:* "highland" distribution. The "highland" surface has a greater number of craters >200 m in diameter; distributions on the two surfaces are the same for craters <200 m.

CONSTRAINTS ON THE PRE-DESIGN OF A MINIMAL HUMAN LUNAR OUTPOST.

L. Boche-Sauvan[1] and B. H. Foing[1], [1]ESTEC SRE-S, Postbus 299, 2200 AG Noordwijk, NL, ludivine.boche-sauvan@rssd.esa.int, Bernard.Foing@esa.int

Introduction: We propose a conceptual analysis of a first minimal lunar base, in focussing on the system aspects and coordinating every different part as part an evolving architecture [1-3]. We justify the case for a scientific outpost allowing experiments, sample analysis in laboratory (relevant to the origin and evolution of the Earth, geophysical and geochemical studies of the Moon, life sciences, observation from the Moon).

Research: Research activities will be conducted with this first settlement in:

- science (of, from and on the Moon)
- exploration (robotic mobility, rover, drilling),
- technology (communication, command, organisation, automatism).

Life sciences. The life sciences aspects are considered through a life support for a crew of 4 (habitat) and a laboratory activity with biological experiments performed on Earth or LEO, but then without any magnetosphere protection and therefore with direct cosmic rays and solar particle effects. Moreover, the ability of studying the lunar environment in the field will be a big asset before settling a permanent base [3-5].

Lunar environment. The lunar environment adds constraints to instruments specifications. SMART-1 and other missions data will bring geometrical, chemical and physical details about the environment (soil material characteristics, on-surface conditions …).

Lunar outpost predesign modular concept.

To allow a human presence on the moon and to carry out these experiments, we will give a pre-design of a human minimal lunar base. Through a modular concept, this base will be possibly evolved into a long duration or permanent base. We will analyse the possibilities of settling such a minimal base by means of the current and near term propulsion technology, as a full Ariane 5 ME carrying 1.7 T of gross payload to the surface of the Moon (Integrated Exploration Study, ESA ESTEC [1,2]).

We will focus on the easiest and the soonest way in settling a minimal base immediately operational in scientific experimentation, but not immediately autonomous. It will prepare the next permanent lunar base by assessing its technologies, and give scientific results about the environment. The autonomy will be gained in the evolution of the base, and added equipment.

A lunar outpost in a polar region would allow missions shorter than 14 days (period of possible return to an orbiter anywhere else), and a frequent addition of equipments. Moreover, a polar outpost will get the both advantages of far-side for communications and dark-side for observations. The low solar rays incidence may permit having ice in deep craters, which will be beneficial for the evolution of the outpost into a autonomous base. The South Pole, by its position on the edge of the South Pole Aitken (SPA) Basin, will allow different fast new data in analysis mantle samples, easily reachable due to the crater morphology. These samples will constrain the putative Late Heavy Bombarment (LHB). After a robotic sample return mission, a human presence will allow deeper research through well chosen geological samples [6].

In this modular concept, we consider various infrastructure elements:

- core habitat,
- EVA,
- crew mobility,
- energy supply,
- recycling module,
- communication,
- green house and food production
- operations.

Many of these elements have already been studied space agencies' architecture proposals, with the technological possibilities of industrial partners (lunar landers, lunar orbiter, rovers …). A deeper reflection will be therefore done about the core habitat and the laboratory equipment, proposing scientific priority experiments. Each element will be added in a range considering their priority to life support in duration [7]. Considering surface operations, protocols will be specified in the use of certain elements.

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COMPLEX ARCHITECTURAL CONCEPT AND TECHNOLOGY FOR CREATING BUILDINGS OF GREAT INNER SPACE ON THE MOON, WITH LOW ASSET REQUIREMENT AND HIGH EFFICIENCY. ***B. Boldoghy*[1], *J. Kummert*[1], *T. P. Varga*[2], *I. Szilágyi*[2], *I. Darányi*[2], *Sz. Bérczi*[3], *T. N. Varga*[4], *G. Hudoba Jr.*[5],** [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [2] VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu), [3]Eötvös Loránd University, Institute of Physics, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu). [4]Eötvös József High School, H-2890 Tata, Tanoda tér 5. (mirene@freemail.hu), Hungary, [5]Hudoba Design, 6611 Oakland str. Pennsylvania, 19149 PA, USA.

Introduction: The essence of our proposal is a comprehensive, complex construction and architectural concept, a building technology for creating buildings of great space, great inner volume with a method of low asset requirement and high efficiency on the lunar surface. That buildings of arch structure should be created from the local materials, which can be used on the lunar surface as well as in lunar valleys, ditches and craters.

Main considerations: 1. minimal asset requirement – devices, equipment to be delivered to the site, 2. devices, equipment to be produced on site, 3. maximum achievement – from the point of view of the inner space, volume of the building to be constructed, 4. marginal additional requirements, 5. energy consumption, 6. human resources requirement, 7. other supplementary technologies, devices.

This structure can be built on lunar surface and in lunar ditches, valleys as well. In case it is built in lunar ditches or valleys and covered with a lunar regolith layer of proper thickness according to our previous proposals, then a structure of balanced inner space temperature can be made. Besides this however creating buildings on the lunar surface should not be disregarded either.

In case of several applications there is a demand for buildings on the lunar surface as well (shop-floors, hangars, silos), however those ones would not be of balanced inner temperature. Though they can be made of great size, great inner space structures. These structures could be covered with lunar regolith in a similar way to our concept made known earlier [1-2]. Several suggestions were published regarding the method beforehand as well. The cost-effective solution of their construction is however not yet clarified.

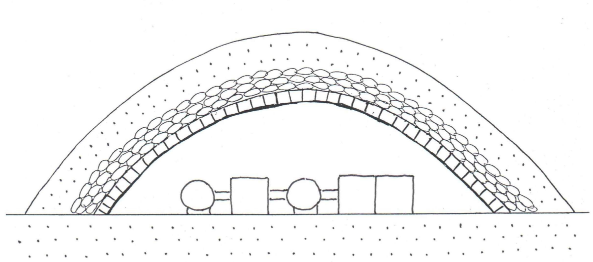

Fig. 1 *Industrial building of arched structure and of great inner space on the Lunar surface*

The necessary prime and supplementary technologies: 1. Making solid, load-bearing building elements from regolith, the lunar dust - 'lunar building brick factory' This is the essence of our present concept. 2. Bagging of regolith, the lunar dust – creating modular units – which can be easily transported, moved, used on the required spot in the required quantity. 3. Moving and leveling of the lunar dust, soil: conveyor belts, worm gear control excavators, bulldozers. 4. Use of available well-known supplementary technologies is necessary, respectively sufficient.

Considerations of the building element - Lunar brick: Main parameters: material, strength of material, dimension, side convergence (wedge mechanism), balanced forces. The sides of the building elements can be parallel or convergent.

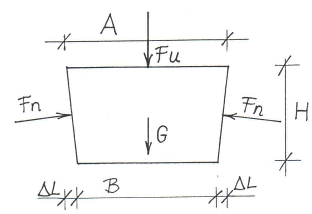

Fig. 2 Geometrical shaping of the Lunar building element (brick), dimension, geometrical formation, and forces

Feasibility study: Main steps and necessary devices of a production technology of a lunar building element: 1. Finding a proper production technology. If it exists, it should be fitted to the lunar conditions, or a novel technology for lunar conditions should be found. 2. To achieve this it is necessary to find and open up regolith resources of appropriate quality and quantity. 3. It is important, that the place of exploitation and production should not be too far from the place of application (transportation problems).

Making of a solid "brick" unit of lunar regolith is possible in two ways: with the use of a binding material, or with caking, burning. The binding material can be produced on the Moon, or it must be transported – then the costs are considerably higher. For caking, burning it could be used with local materials of silicate base, e.g. lunar basalts or anorthositic rocks. It requires more facilities and energy, but it can be more const-effective in the long run.

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GEOLOGICAL AND GEOCHEMICAL STUDY OF THE SOUTH POLE-AITKEN BASIN AND FUTURE SAMPLE RETURN MISSIONS

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Introduction

The South Pole - Aitken (SPA) Basin, situated on the southern farside of the Moon, is currently one on of the highest priority targets for sample future return missions. This PreNectarian basin (>3.9 Ga) measures 2500 km in diameter with a depth of up to 13 km and is commonly alleged to have excavated deep into the lunar crust. Consequently the SPA Basin floor may provide a unique opportunity to sample and study deep seated lunar materials.

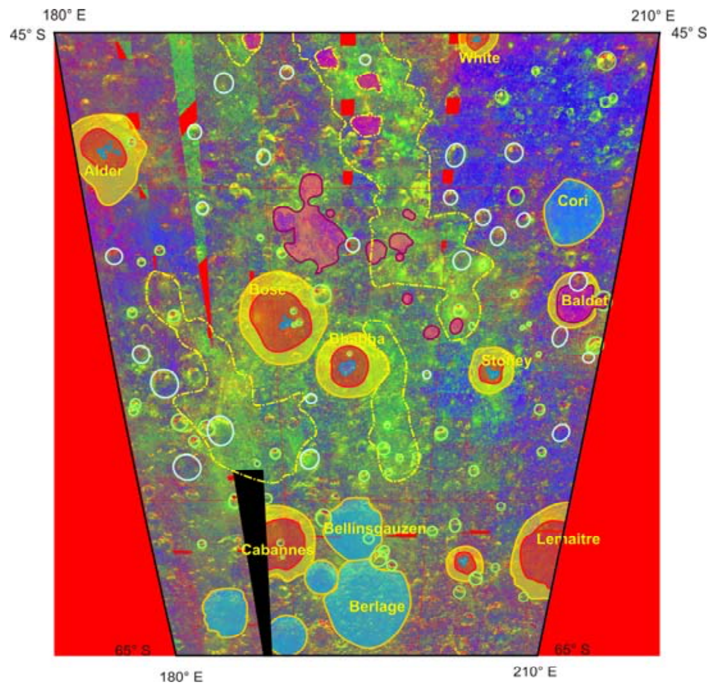
Furthermore, the basin is assumed to have formed due to a large oblique impact during the Late Heavy Bombardment [1]. Returning samples of the impact melt breccia produced during this event allows exact age determination of the impact, which permits verification of the LHB concept. As yet, most evidence on the LHB relies on ages provided by the Apollo and Luna samples, which is severely biased towards the near-side equatorial regions. Exploration of the South Pole- Aitken Basin would therefore not only provide information on the Lunar interior and evolution, but will also greatly improve insights in the dynamics and origin of the Late Heavy Bombardment and its influence in the evolution of the early Solar System [4].

However, rocks initially exposed by the impact event have been heavily altered or hidden from view, due to subsequent weathering and impact processes over the last 4 billion years. Consequently the identification of the most suitable landing sites to ensure sampling of pristine SPA Basin floor material and impact melt breccia has become rather complicated and extensive ground-based remote sensing studies are necessary .

SPA Geology and geochemistry. Here we combine structural and geochemical analyses of the SPA Basin, in order to improve descriptions of geological units and mafic rock types exposed within the South Pole - Aitken Basin. Multispectral data from Clementine ultraviolet/visible and near-infrared cameras are used and processed in ENVI following a similar approach as described by Tompkins and Pieters [2,3]. The method relies on diagnostic shapes of band absorptions for key mafic minerals as olivine and high Ca-pyroxene, in order to discriminate between geologic units of noritic, gabbroic and troctolitic compositions.

The global geological structure of the SPA Basin has been studied using Clementine altimetry and gravity data, obtained by LIDAR instruments. SMART-1 high resolution AMIE images will provide improved geological context for areas identified as candidate landing sites.

In particular we have studied the Bhabha-Bose region located in central SPA Basin, which is a previously proposed possible landing site (central SPA, Fig 1). The Bhabha crater is interesting as it shows a noritic central peak (blue unit), which might represent either deep pristine crustal material or the uplifted impact melt sheet from the SPA Basin impact event. Other areas identified for sampling are the fresh crater rims of Bhabha, Bose or Stoney (yellow unit) or Olivine hill (dashed area below Bhabha)



[2,3].

Fig. 1 Geological units overlayed on a false color image produced in ENVI using the method described by Pieters [2,3]. Flooded basins are indicated in purple, crater morphology is subdevised in yellow (crater walls), red [1](floor), dark blue (central peak) and light blue (altered crater). Dashed areas represent geochemically different regions, possibly impact meltsheet or cryptomaria.

With the prospect of future sample return missions, careful studies of the exposed materials and considerations on science/technology trade-off are required. This study aims to contribute in identifying locations which ensure optimal scientific gain in the next phase of Lunar exploration.

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LUNAR CONCRETE AS A MEANS OF REDUCING THE DUST HAZARD. J. C. Boulware[1] and F. Angomas[2], [1]Mechanical and Aerospace Engineering, Utah State University (j.c.boulware@aggiemail.usu.edu), [2]Civil and Environmental Engineering, Utah State University

Abstract: The threats and hazards associated with lunar dust are arguably the greatest challenge towards surface operations and a sustained presence on the Moon, perhaps secondary only to costs and launch capabilities. Designing components and machinery which shield the dust can also be costly and often may sacrifice capability. This paper proposes creating a thin layer of lunar concrete applied over a large area designated for base operations.

Typical terrestrial dust suppression consists of spraying water over dirt and dust kicked up by machinery either accidently or intentionally. Clearly this is not possible on the Moon, but lunar dust suppression is vital to sustained lunar presence. By sending a rover to pave a large area years before other equipment arrive, a firm, stable, and known platform would be established. Aside from the obvious benefits from lack of dust, this stable platform would also assist in landing/takeoff operations, mobile surface rovers, and could give scientists a wealth of data on regolith years before humans ever arrive.

Concrete engineering has evolved for thousands of years and is today taking advantages of breakthroughs in chemistry and structural dynamics. Since the return of the first lunar sample with Apollo 11, scientists have theorized creating concrete from regolith[1-10]. Many have succeeded, thus showing its feasibility, however most have had the intention of creating large, habitable structures for that sense never made it into application. Using concrete for a paved lunar surface greatly reduces the constraints, and the studies transition from feasible to practical.

Currently, the amount of water within the lunar surface is being investigated by satellites, astronomers, engineers, geologists, chemists, and potential astronauts among others. Clearly, water within the surface is the key to survival and a geographic location for the lunar base will be chosen based on water content. Therefore, it is safe to assume that the regolith to be converted to concrete will have ice within it in the form of crystals. A lunar rover sent to the surface could scoop up a small sample (~1ft^3), close it off into a sealed volume, pressurize it, heat it, mix it, and then release it back to the surface to let it dry. The rover may have to stay in place to maintain the pressure over the sample as it dries, but considering the timeline for establishing a sophisticated lunar base, this is minute.

Once finished, the rover moves onto the next spot and repeats the process. Running off of solar power and fuel cells, the rover could pave a large area almost autonomously for as long as needed; all the while sending back data on soil composition. Depending on the amount of water in the soil, additional feedwater could be required, however, it is also likely extra water could be extracted, absorbed and stored by the rover during the drying process. Other chemical admixtures may also need to be resupplied, however the volume fraction is small.

This idea was presented at the 2008 Lunar Ventures Student Business Plan Competition in Golden, Colorado and there was suggested as a topic of discussion for the Joint Annual Meeting of LEAG-ICEUM-SRR. It is hoped the idea will ignite a dialogue which leads to the next stage of development and the concept is carried out to synthesis.

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LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL,

Executive Summary

Date Prepared: 10/9/08

Presenter's Name: Marguerite Broadwell
Presenter's Title: Strategic Partnerships & Integration Manager
Presenter's Organization/Company: NASA ESMD

Presentation Title (brief descriptive title)
Optimizing Science and Exploration on the Moon

Key Ideas (2-3 sentences)

- OSEWG past and future - 18 months of action ahead!
- Goals and strategy for collaborating with the science community
- Recent accomplishments

Supporting Information

THE DEVELOPMENT AND PERSPECTIVES OF BIO-ISRU. I. I. Brown[1], D. H. Garrison[1], J. A. Jones[1], C.C. Allen[1], G. Sanders[1], S. A. Sarkisova[1], D. S. McKay[1]. [1]NASA JSC (Mail code: ARES-KA, 2101 NASA Road One, Houston, TX, 77058; igor.i.brown@nasa.gov; david.s.mckay@nasa.gov).

Introduction: In-situ production of consumables using local resources (In-Situ Resource Utilization-ISRU) will significantly facilitate current plans for human exploration and settlement of the solar system. With few exceptions [1], nearly all technology development to date has employed an approach based on inorganic chemistry [2]. None of these technologies include concepts for integrating the ISRU system with a bioregenerative life support system and a food production system. The investigation of Biotechnological (Bio) ISRU based on the metabolism of lower order photosynthetic organisms with ability to leach rocks and minerals appears to be very timely and relevant. Cyanobacteria (CB) are known as very effective producers of O_2, proteins, vitamins, immunomodulators [3] and as very effective litholyts [4] to supply themselves with different elements.

Using organic acids, bacteria are able to dissolve different rocks, including such hard rocks as volcanic glass [5], granites, hornblende, and basalts [6]. Bioweathering of lunar regolith has been considered by studies on the preparation of lunar-derived soil [7]. Because the Moon is practically free of organic compounds but is rich in inorganic elements, it makes sense to use autotrophic CB for future extraterrestrial biotechnologies [8].

Results: We have found that CB secrete organic acids when mixed with lunar regolith; secreted organic acids possess chelating properties. These chelators react with Fe^{2+} in lunar minerals such as ilmenite ($FeTiO_3$), ferrous oxides, and iron-bearing silicates (Fe_2SiO_4). Iron oxide interacts with acids liberating iron and generating water1 (equation. 1):

$$FeO + 2\,H^+ \rightarrow Fe^{2+} + H_2O \quad (1).$$

If protons are generated by organic carboxylic acids, Fe^{2+} ions will coordinate with carboxylate oxygens (equation 2):

$$FeO + 2\,RCOOH \rightarrow (RCOO)2Fe^{2+} + H_2O \quad (2).$$

Newly generated water can be split into molecular O_2 and H_2 by CB, electrolysis, or both. The freed H_2 can be recycled in many (bio)chemical reactions. Dissolved iron species can be recovered by electrolysis of the growth medium at low temperatures.

Our concept of the development of a biotechnological loop for *in-situ* resources extraction, propellant and food production at the lunar outpost is based on the cultivation of litholytic CB with lunar regolith in a sunlight driven geobioreactor (Figure 1).

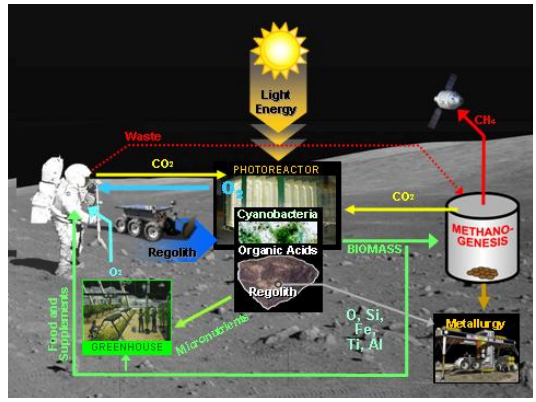

Fig. 1. Author's concept of a biotechnological loop for in situ resources extraction, propellant, and food production at the lunar outpost.

As a result of pilot studies, we are developing a concept for a semi-closed integrated system that uses a bioreactor containing CB for extracting useful elements from the regolith. This bioreactor, powered by sunlight, can revitalize air by utilization of CO_2 and production of O_2. Some components of cyanobacterial biomass can be used directly as nutritional supplements [3]. Such a system could be the foundation of a self-sustaining extraterrestrial outpost [9].

Perspectives: The most critical conclusion is that a semi-closed life support system tied to an ISRU biofacility might be more efficient for support of an extraterrestrial outpost than closed environmental systems. Such a synthesis of technological capability could decrease the demand for energy, transfer mass and cost of future exploration.

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[1] Personal communication of Dr. E. Rybak-Akimova

A DUST MITIGATION VEHICLE UTILIZING DIRECT SOLAR HEATING. E. H. Cardiff[1] and B. C. Hall[2], [1]NASA GSFC, Building 11 Room E135, Greenbelt, MD 20771. Eric.H.Cardiff@nasa.gov, [2]University of Maryland, College Park, MD 20742. hall@umd.edu.

Introduction: Lunar dust contamination is one of the paramount problems that need to be addressed before NASA returns to the surface of the Moon. One way to reduce the problem is to remove the source of the dust by paving the surface. A dust mitigation vehicle (DMV) is currently being developed at NASA Goddard Space Flight Center that utilizes only the native solar flux present *in-situ*. Concentrated solar flux has enough power to sinter and melt lunar regolith simulant [1]. This resulting surface provides a hard, dust-free platform for surface operations.

During the Apollo program, lunar dust was the cause of several technical problems; these included losses in radiator efficiency, loss of traction, damage to gauges and visors, seal contamination, and adverse health effects for astronauts. The primary dust transportation mechanisms were observed to be rover and foot traffic, and the ascent and decent of spacecraft. Natural mechanisms, including electrostatic levitation, have also been observed [2]. In order to mitigate the lunar dust, vehicles have been proposed that would 'pave' select areas of the lunar surface, specifically areas around habitats and landing pads [3].

Vehicle Design: The vehicle consists of a chassis that supports a ~1m lens used to focus the solar flux. The position of the vehicle and of the lens is determined remotely via the radio control system.

Design Variants. Several variants of the dust mitigation vehicle have been designed. The testing version, denoted 'variant A', is designed to opeated in the solar environment present at NASA GSFC (Fig. 1). Variant B was designed to operate where incident sunlight is nearly horizontal, such as is the case at the lunar poles. This variant features a large aluminum mirror that redirected the solar flux through the Fresnel lens. Preliminary work has begun on variant C, which would replace the planar mirror and Fresnel lens with a single low-mass parabolic reflector with a linear focus.

Figure 1: Variant A of the Dust Mitigation Vehicle.

Testing: A high-vacuum, large-aperture vacuum chamber was constructed in order to better simulate the lunar environment. The solar flux was focused through a large quartz window, heating the simulant inside. By manipulating the lens, the focal area and intensity can be altered – thus allowing characterization of the effectiveness of direct solar heating as a dust mitigation method. In the first round of testing, the lens was articulated to provide the smallest, most intense focus possible (~0.5 MW/m^2); a single pass was made on the sample, resulting in a linear area of melting and sintering (Fig. 2, left). Later tests aimed to sinter/melt larger areas (Fig. 2, right). Testing has yielded rates as high as 13 cm^2/min. Instantaneous as well as average rates were measured during the tests – the coverage rate was principally determined by the solar flux. Rate control was maintained by visual inspection of the regolith surface by the operator.

Figure 2: Two examples of sintered & melted lunar regolith samples (crucibles are 8.25" in diameter).

Discussion and Conclusions: Current testing has yielded rates that could produce a 100 m^2 landing pad on the Moon in as little as 55 days using the current DMV. In addition, this rate may be artificially low due to the lower solar flux present on Earth, as well as low-vaccuum conditions present during testing (1 E -3 torr). Additional work is required to further characterize and optimize the direct solar heating technique for dust mitigation.

Acknowledgements: The authors would like to thank Tamela Maciel, Maria Lyon, and Stuart Banks for their assistance during testing.

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IN-SITU PRODUCTION OF OXYGEN THROUGH LUNAR REGOLITH PYROLYSIS. E.H. Cardiff[1], T.R. Maciel[2], I.S. Banks[3]. [1]NASA GSFC, Building 11, Room E135, Greenbelt, MD 20771. Eric.H.Cardiff@nasa.gov, [2]NASA GSFC, Building 11, Room S130, Greenbelt, MD 20771. tmaciel@uoregon.edu, [3]NASA GSFC, Code 552, Greenbelt, MD 20771. Ian.S.Banks@nasa.gov.

Introduction: A variety of techniques have been proposed to extract oxygen from the metal oxide-abundant lunar soil. Taylor reviewed these techniques and suggested regolith pyrolysis as the optimal method of oxygen production [1]. Experimental testing at NASA GSFC is continuing to determine the feasibility of pyrolysis by indirect resistive heating for a number of applications, including oxygen production on the Moon.

Previous Work: The original prototype focused solar radiation through a large Fresnel lens and vaporized a sample of lunar regolith at temperatures upwards of 1500°C. Previous work has demonstrated that in the process, the metal oxide bonds within the soil will be broken [2]. The reduced oxides can then be rapidly condensed out while the oxygen remains gaseous and can be collected for later use. Terrestrial experiments to model this method have involved both solar radiation and resistive heating to vaporize different types of simulant lunar regolith, including MLS-1A and JSC-1A [3].

Current Progress: A new experimental setup is currently being assembled that improves on the prototype resistively-heated crucible. A larger vacuum chamber houses an uncovered, high-grade zirconia crucible wrapped with tungsten wire for heating, as shown in Figure 1. This wire connects to a power input from the bottom, delivering up to 160 DC volts. The crucible and stands are surrounded by several layers of tungsten foil shields, as shown in Figure 1 (Right).

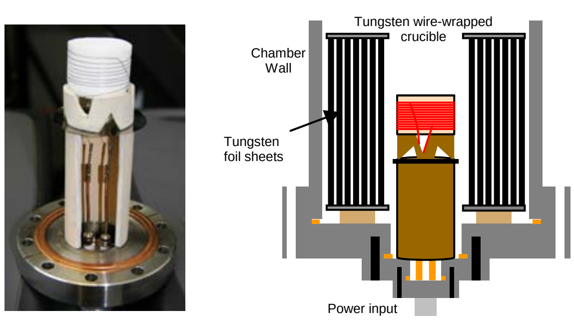

Figure 1. (Left) Wired-wrapped 1.65" diameter crucible connected to power. (Right) Side-view diagram of the chamber interior.

Thermocouples fed through the top of the chamber measure the temperature of the simulant regolith as it is being heated, as well as the temperature of various points around the chamber itself. The turbo pump, pressure gauge, and an RGA mass spectrometer are mounted above the vacuum chamber, as shown in Figure 2. A window and shutter at the top of the chamber allow for IR temperature measurements and visual inspection during testing. This setup is designed to prove the possibility of releasing significant levels of oxygen and other volatiles from simulant regolith. A cryogenic condensation and collection module has also been developed.

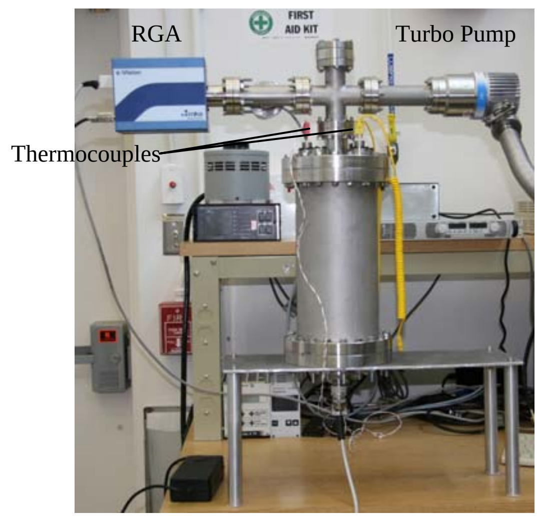

Figure 2. Current setup for regolith pyrolysis without a cryocooler.

In addition, this setup will be used to perform tests for the Volatile Analysis by Pyrolysis of Regolith (VAPoR) project. VAPoR is a triage instrument designed to identify samples with scientifically significant volatiles via mass spectrometry.

Conclusion: The new setup seeks to improve the resistively-heated vacuum pyrolysis setup, and is designed to achieve a higher maximum crucible temperature and improved thermal efficiency. The previous chamber was limited to 1000°C, and the current setup can attain temperatures in excess of 1300°C.

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Lunar Surface Explorations Scenarios. W. Carey[1], B. Hufenbach[2], O. Mongrard[3] and M. Haese[4], [1] ESA, The Netherlands, william.carey@esa.int, [2] ESA, The Netherlands, bernhard.hufenbach@esa.int, [3] ESA, The Netherlands, olivier.mongrard@esa.int, [4] ESA, The Netherlands, marc.haese@esa.int

Introduction: In the context of developing a long-term strategy for European human spaceflight and exploration ESA has been conducting several activities with stakeholder communities as well as architecture and system studies with industry. A significant part of the architecture work was dedicated to the analysis of different options for Human surface exploration, assessing crew size, stay times, tasks and operations, surface infrastructures, mobility and logistics of these scenarios.

The lightest approach involves simple surface sortie missions of up to 14 days, where full habitation is provided by the lander element and no pre-deployed surface elements are strictly required. For sortie missions the following mission operations and associated activities have been identified: geological fieldwork (observations, assistance through telerobotic robotic survey, collection (and caching) of samples, including drilling), mapping of lunar resources (ground truth confirmation of orbital measurements).

Assuming global access capability of the crew lander, reasonable science return can be obtained through multiple missions to different surface sites. The mobility at each site is severely limited by the rover capability and contingency requirements. This could potentially improved by delivery of a redundant mobility element on a logistics lander, which could also enable further science through dedicated equipment delivery. However, the sortie scenario is highly hardware-intensive since no reusability of surface systems is possible.

Super-Sortie scenarios involve a pre-deployed pressurized rover for extended surface mobility as well as logistics delivery with an Ariane 5 based landing system. They therefore offer significantly increased surface exploration range and duration, enabling higher science return. Reusability of the pressurized mobility on the surface for subsequent missions depends on its autonomous roving capability to reach other sites, but could be envisioned, thus reducing the hardware investment cost for multiple missions.

The outpost scenario is designed to support a crew of two astronauts visiting a particular site of interest more than once for short time duration (typically 14 days). The interest in this site might be linked to highly valuable science to be done around the same location that would require more than a single sortie mission or the construction, operations and maintenance of some high value assets such as telescopes or very deep driller that would need to be located for scientific reasons far from the main base.

Finally, a lunar surface base provides fully developed systems for sustained permanent presence, enabling six-months crew rotation. The base location, contrarily to the outpost, is selected primarily for engineering reasons offering the more favorable illumination conditions to facilitate the support of astronauts for extended stays of up to several months. The following activities have been identified as major outpost tasks, based on analysis of the European stakeholder objectives: Life and physical sciences experiments, geological fieldwork, laboratory analysis of collected samples, construction and commissioning of a large cosmic ray telescope, ISRU processing and various support tasks associated with the base.

Furthermore, establishing a sustained human presence in a base on the Moon has a critical role for preparation of further exploration. It is an opportunity to learn how to support astronaut crews living far from home in harsh environments for long duration and to operate effectively on another planet.

THE MOONNEXT MISSION: A EUROPEAN LANDER AT THE LUNAR SOUTH POLE. J. D. Carpenter[1], B. Houdou[1], D. Koschny[1], I. Crawford[2], H. Falcke[3], S. Kempf[4], P. Lognonne[5], C. Ricci[6] and A. Pradier[1], [1] ESA ESTEC, Keplerlaan 1, Noordwijk, Netherlands, James.Carpenter@esa.int, [2] School of Earth Sciences, Birkbeck College, London, UK,.[3] Department of Astrophysics, Faculty of Science, Radboud University, Nijmegen, Netherlands, [4] MPI für Kernphysik, Heidelberg, Germany, [5] IPGP, Paris, France, [6] Univ. Milan, Milan, Italy.

Introduction: ESA's Aurora Exploration Programme recognizes the key role of the Moon in the path of exploration and is currently leading several feasibility studies of a Lunar Lander mission, also called "MoonNEXT". This mission, expected to be to be launched from Kourou with a Soyuz in the 2015-2018 timeframe, combines technology, exploration and science objectives, consistent with the broader context of international lunar exploration. The nominal landing site for MoonNEXT is edge of the South Pole Aitken basin (SPA).

Technology Objective: The main technological objective of MoonNEXT is to perform an autonomous soft precision landing with hazard avoidance at a well illuminated site near to the Moon's South Pole. This autonomous approach to landing will complement that of the ExoMars mission, while validating a key technology for more ambitious exploration missions, enabling landing on rough and unpredictable terrain, targeting special areas of interest and surface rendezvous. The closed-loop use of new-generation terrain-relative sensors for navigation and hazard detection will be required. The mission builds on a significant technology development effort ongoing in Europe in the area of Guidance, Navigation and Control.

Braking will be performed entirely by propulsive means, thus paving the way towards the capability to land increased masses on low gravity bodies.

Exploration and Science Objectives: In addition to enhanced landing technology, MoonNEXT includes instrumentation to address major objectives related to preparation for future human exploration activities and unresolved scientific questions.

Geophysics. MoonNEXT will make seismic measurements from the South Pole of the Moon. These data can be combined with those from Apollo to determine the size and state (and thus likely composition) of the Lunar core and indicate whether the seismic discontinuity at ~500 km [1] depth is Moon wide. Realising the global, or otherwise, nature of this phenomenon is essential to constrain the magma ocean / magmasphere model of the Moon (e.g. [2]). Determinning the level of seismic acivity is also important for the development of future human habitats.

Measurements of heat flow at depths of several meters into the regolith, will improve our understanding of the Moon's internal temperature distribution by providing a data set from a location very different from the Apollo missions [3], which were not representative of the Moon as a whole.

Environment. The radiation, dust and meteoroid environment on the Moon will also be investigated. Of particular importance are the factors which drive the charging, levitation and transport of lunar dust [5], identified as a potential hazard for the surface operations of future human missions. During the Apollo mission lunar dust was found to be abrasive, adhesive and problematic following migration into habitats [5].

The flux of micrometeoroids will be investigated, with emphasis on micrometeoroids in the size range of ~10 mg, for which fluxes are highly uncertain and which have been identified as posing the greatest potential risk to human activities.

A proper characterization of the radiation environment, resulting form both cosmic and highy variable solar sources will also be characterized, to determine potential risks to human activities.

Geology and Geochemistry. SPA offers the unique possibility to sample material, which has been excavated from the lower crust and perhaps even the upper mantle offering unique insight into the Moon's history and evolution [6]. In addition the regolith at the South Pole may contain volatiles, deposited by the solar wind.

Life Sciences. MoonNEXT will include an experiment coupling two microorganism cultures in a closed loop ecosystem. By monitoring the evolution of the system the effect of the lunar environment on living cells' behaviour will be investigated, as well as technical concepts pertaining to future life support systems.

Radio Science and Astronomy. The Moon provides a superb location for radio astronomy because it provides access to radio frequencies inaccessible from the Earth [7]. MoonNEXT will demonstrate the feasibility of radio astronomy on the Moon by characterising the radio environment.

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LUNAR DUST EFFECTS ON SPACESUIT SYSTEMS: INSIGHTS FROM THE APOLLO SPACESUITS.
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Systems and components of selected Apollo A7L/A7LB flight-article spacesuits worn on the lunar surface have been studied to determine the degree to which they suffered contamination, abrasion and wear or loss of function due to effects from the dust size fraction of the lunar soil (<10 μm diameter). The study materials included the outermost soft fabric layers on Apollo 12 and 17 Lunar Module Pilot (LMP) Integrated Thermal Micrometeoroid Garments (ITMG), and the wear surfaces of the Apollo 16 LMP Pressure Glove Assembly (PGA) wrist rotation bearings. The Apollo 17 ITMG is notable for having a high level of residual dust contamination due to the duration and nature of the EVA, and the relative lack of post-mission cleaning. A Scanning Electron Microscopy (SEM) study of particles sampled from the Apollo 17 ITMG outer fabric using adhesive tape shows about 70% lunar grains and 30% terrestrial contaminants. Plagioclase feldspar (25-30%) and glass (30-35%) are dominant in the particle count with lesser amounts of pyroxene, ilmenite and olivine. Although pyroxene is minor in the particle count, the grains are large, so that pyroxene dominates the modal abundances, and has a much higher mode on the fabric than in the lunar soil at the Apollo 17 site, especially relative to lunar soil glass. We attribute this to the higher friability of the glass grains, which makes them more likely to comminute and leave the fabric when it is brushed or rubbed. SEM examination of the bearing race surface on the Apollo 16 EVA PGA shows no evidence of increased wear relative to the bearings on intravehicular gloves used on the same mission. This suggests that, at least for the relatively short lunar exposure of the Apollo 16 EVA, the glove gauntlet and bearing designs were sufficient to prevent dust from entering the bearing.

ENABLING MINIMAL MASS SCIENCE PACKAGES FOR LUNAR SURFACE STUDIES.

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Introduction: Lunar surface science packages must survive ultra cold (during extended dark periods) and extreme variations in thermal conditions, operating autonomously with stand-alone power systems whether delivered robotically or by a human crew. From the time of the Apollo era, radioisotope (Pu238) based power systems (RPS) have met the need to supply both power and heat in the coldest and darkest environments like those experienced periodically on the lunar surface, but, despite the recent announcement of several advanced stirling radiothermal generators, the systematic availability of radioisotope based power systems over the next decade and a half is uncertain. Our preliminary study demonstrated that when conventional (non-RPS) approaches are used in designing instrument packages, performance suffers and mass and cost parameters grow significantly as a result of increased thermal protection and battery power requirements necessary to withstand lunar environmental conditions within needed operational constraints. The efforts described in detail here demonstrate that alternative state-of-the-art design and components for generic state-of-the-art science packages can at least meet the power and mass constraints of earlier packages without requiring the use of Pu238. We also identify strategies required to exceed them to produce min-payloads.

Instrument package considered in initial study: LEMS, a lunar environmental monitoring station, is a stand-alone automated package concept powered by solar panels with batteries with a suite of instrument and instrument capable of providing comprehensive measurements critical to understanding the interactions between radiation, plasma, solar wind, magnetic and electrical fields, exosphere, dust and regolith. Some version of LEMS would be a primary candidate for early deployment before contamination of the lunar exosphere. Instruments include spectrometers to measure neutral gas species of the exosphere, X- and Gamma-radiation, energetic neutrons and protons from the solar and galactic radiation environment; particle analyzers to measure the spatial and energetic distribution of electrons and ions; a dust experiment to measure diurnal variations in the size, spatial, and velocity distribution of lunar and micrometeorite dust; and electric and magnetic field instruments to indicate changes resulting from variations in solar activity, and terrestrial magnetic field interactions.

Using a Conventional Design Approach: The LEMS faced the challenges typical of autonomous lunar surface science packages. Lunar surface conditions are quite different from conventional deep space conditions where one side of the spacecraft is almost always illuminated and heat dissipation is the thermal issue. On the lunar surface, battery mass was driven by the need for power for survival heaters during periods of prolonged darkness and became the overwhelming driver of the total mass to 500 kg with only 19% allocated for the instrument payload and 53% for the power system. The power allocation was 180W (85W for the instruments) during the day, 60W for thermal heaters alone at night with the instruments turned off, even though measurements made during periods of darkness are essential.

Table 1: Reduction in Mass and Power for LEMS

Design Regime	Conventional Electronics	Cold Electronics	New Pack-Concept	ALSEP approx
Performance	-10oC Op -20oC Surv	-40oC Op -50oC Surv	-40oC Op -50oC Surv	9 instru-ments
Battery Mass	240	120	60	30
Remaining Mass	260	260	184	70
Total Mass	500	380	244	100
Min Power	60	30	15	10

High Performance Electronics and Alternative Thermal Design: Just by introducing more robust electronics capable of operating over a wider temperature range, and particularly at colder temperatures, we reduced the required battery power by a factor of 2, as indicated in Table 1. We have introduced 2 thin insulating fiberglas layers (multi thin layer or MLT), a material used on JWST, as external packaging, along with heat pipes attached to radiators in each package, packaging instruments together when possible. These strategies combined with operating instruments on reduced duty cycles, reduce thermal loss, mitigate the need for active survival heaters, and reduce the thermal and power system masses. The preliminary results (Table 1) indicate that we can reduce the total package mass of the package by at least of factor of 2. We estimate that if we reduced the number of instruments slightly and used sold state versions of the instruments when possible, we would be operating in the ALSEP regime without the use of Pu238.

LUNAR SOIL EROSION PHYSICS FOR LANDING ROCKETS ON THE MOON. Ryan N. Clegg[1], Philip T. Metzger[1], Stephen Huff[1], and Luke B. Roberson[1], [1]NASA Kennedy Space Center, Mail Code KT-D-3, Kennedy Space Center, Florida, 32899, USA, Philip.T.Metzger@nasa.gov or Luke.B.Roberson@nasa.gov.

Introduction. To develop a lunar outpost, we must understand the blowing of soil during launch and landing of the new Altair Lander. For example, the Apollo 12 Lunar Module landed approximately 165 meters from the deactivated Surveyor III spacecraft, scouring its surfaces and creating numerous tiny pits. Based on simulations and video analysis from the Apollo missions, blowing lunar soil particles have velocities up to 2000 m/s at low ejection angles relative to the horizon, reach an apogee higher than the orbiting Command and Service Module, and travel nearly the circumference of the Moon [1-3]. The low ejection angle and high velocity are concerns for the lunar outpost.

Figure 1: Carbon Fiber (A), Kevlar (B), Hybrid (C), and Vectra (front) (D) textiles after exposure to lunar simulant spray.

Experimental. As a first step in investigating this concern, we have performed a series of low-velocity impact experiments in a modified sandblasting hood using lunar soil simulant impacted upon various materials that are commonly used in spaceflight hardware. The impacted materials include glass, gold foil blankets, multi-layer insulation (MLI) for cryogenic tanks, and several textiles that are under consideration for building a blast barrier around the lunar landing pad.

Velocity Calibration: The velocities of individual soil particles of different diameters were calibrated with a high-speed video camera that recorded their trajectories through the chamber. Their velocities were in the range of 30-85 m/s, depending on the particle size and the experiment settings. This is much slower than will occur in a lunar landing. However, even in the lunar case the impacts are not hyper velocity and so the resulting damage can be compared through the Sheldon-Kanhere equation [4],

$$V = K_D v^3 D^3 \sigma^{3/2} H_V^{-3/2}$$

which predicts the volume V of a pit caused by a single impacting particle of diameter D and velocity v, when the particle has a material density σ and the target material has a Vicker's hardness value H_V. (K_D is related to the angle of impact upon the target.) We integrated this equation across the particle size and the velocity distributions as determined by [1] for lunar soil in actual landings and for lunar stimulant (JSC-1A) in our experiment. Taking the ratio of these (or similar) integrals, the material parameters cancel out, and we determine what quantity of lunar simulant will produce the same total volume (or surface area) of pitting in the target to simulate a specified number of lunar landings.

Lunar Simulation: We applied this methodology to simulate the same area and volume of pitting damage as experienced by Surveyor III. We exposed five different sheets of glass to the equivalent of between one and five lunar landings at 200 m distance. After one landing equivalent of spray, the glass was severely eroded and unusable. Thermal control gold foil blankets exposed to this spray lost all of their gold coating. Candidate lunar fence impact barrier materials [5] were blasted with 1 landing equivalent JSC-1A. Kevlar (Figure 1B) experienced surface erosion. Woven carbon fiber samples (1A) and hybrid Kevlar-carbon fiber (1C) failed. Vectra fabric (1D), used in the Mars rover balloons, showed no significant impact damage when impacted on the front, finished portion of the fabric; however, the back, unfinished part of the fabric showed erosion similar to Kevlar.

Further Work: On-going work aims to verify the predictions of the Sheldon-Kanhere equation and quantify the damage that lunar outpost hardware will experience. We also plan to functionally test thermal control blankets for loss of reflectivity and solar cells for loss of received power. Future work must also include impacts at realistic lunar velocities at an appropriate NASA facility.

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THE INTERNATIONAL LUNAR NETWORK. B. A. Cohen, the ILN Science Definition Team, and the MSFC/APL ILN Engineering Team, [1]NASA Marshall Space Flight Center Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov).

Introduction: A new lunar science flight projects line has been introduced within NASA's Science Mission Directorate's (SMD's) proposed 2009 budget, including two new robotic missions designed to accomplish key scientific objectives and, when possible, provide results useful to the Exploration Systems Mission Directorate (ESMD) and the Space Operations Mission Directorate (SOMD) as those organizations grapple with the challenges of returning humans to the Moon. The first mission in this line will be the Lunar Reconnaissance Orbiter, an ESMD mission that will acquire key information for human return to the moon activities, which will transition after one year of operations to the SMD Lunar Science Program for a 2-year nominal science mission. The second mission, the Lunar Atmosphere and Dust Environment Explorer (LADEE) will be launch in 2011 along with the GRAIL Discovery mission to the moon. The third is delivery of two landed payloads as part of the International Lunar Network (ILN). This flight projects line provides a robust robotic lunar science program for the next 8 years and beyond, complements SMD's initiatives to build a robust lunar science community through R&A lines, and increases international participation in NASA's robotic exploration plans.

The International Lunar Network is envisioned as a global lunar geophysical network, which fulfills many of the stated recommendations of the recent National Research Council report on The Scientific Context for Exploration of the Moon [2], but is difficult for any single space agency to accomplish on its own. The ILN would provide the necessary global coverage by involving US and international landed missions as individual nodes working together. Ultimately, this network could comprise 8-10 or more nodes operating simultaneously, while minimizing the required contribution from each space agency. Indian, Russian, Japanese, and British landed missions are currently being formulated and SMD is actively seeking partnership with these and other space agencies to establish the ILN.

Mission Science: A global geophysical network has been a lunar science community desire since the Apollo seismic stations were turned off in 1977. The science motivation has been detailed in numerous community and independent reviews, reports and recommendations [most recently, 1-4]. Several mission proposals/concepts have been developed by the science community for similar network missions to the moon and Mars (e.g. Lunar-A, NetLander, ExoMars, MoonLite, LuSeN, ALGEP, etc.), including science drivers and options for deployment, instrumentation, and operations, though none have yet successfully flown.

The goal of a lunar geophysical network is to understand the interior structure and composition of the moon. As a differentiated body, the moon provides fundamental information to our understanding of the evolution of terrestrial planets. The current structure on the moon arises from its bulk composition, formation via crystallization of a magma ocean, and subsequent loss of heat produced by radiogenic elements. The narrow extent and instrumental limitations of the Apollo seismic network resulted in very little information about crustal variations, limited resolution of upper mantle mineralogy, and no details about the lower mantle or the lunar core. Therefore, the major goals of a lunar geophysical network include:

- Determine the thickness of the lunar crust (upper and lower) and characterize its lateral variability on regional and global scales.
- Characterize the chemical/physical stratification in the mantle, particularly the nature of the putative 500-km discontinuity and the composition of the lower mantle.
- Determine the size, composition, and state (solid/liquid) of the core of the moon.
- Characterize the thermal state of the interior and elucidate the workings of the planetary heat engine.

A Science Definition Team (SDT) is working to set science objectives and measurement goals to accomplish lunar surface and interior science uniquely enabled by the availability of multiple sites for the Anchor Nodes. The charter of the SDT is to define and prioritize the scientific objectives for the ILN Anchor Nodes, define measurements required to address the scientific objectives, and define instrumentation required to obtain the measurements (e.g. seismometry, heat-low probes, EM sounding laser retroreflectors, etc.). Because of the stringent cost cap, the SDT understands that this mission must be highly focused and will se its priorities accordingly.

The SDT will also address implementational issues such as criteria for selection of the initial two sites and technical challenges to deployment and operations. SDT findings and recommendations will be reported to the Planetary Science Division Director, and to the Associate Administrator for the Science Mission Directorate as final report in mid-September.

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 in July. The statement marked an expression of interest by the agencies to study options for participating in a series of international lunar missions as part of the ILN. The statement of intent does not completely define the ILN concept, but leaves open the possibility for near and long-term evolution and implementation. Initially, participants intend to establish potential landing sites, interoperable spectrum and communications standards, and a set of scientifically equivalent core instrumentation to carry out specific measurements.

US Participation: NASA's Science Mission Directorate and Exploration Systems Mission Directorate (ESMD) have partnered to provide two so-called Anchor Nodes of the ILN. These two US stations may not necessarily be the first to become operational on the lunar surface, but are the first committed and planned missions to contribute to the ILN, flying no later than 2014 (with a possibility of sending two more, identical nodes in the 2016 timeframe).

The ILN Anchor Nodes mission is a cost-capped, \$200M mission to deliver two geophysical instrument packages to different places on the lunar surface. The nominal mission length is for 2 years of surface operations, including operating the instruments through lunar night. The two nodes will launch between 2012 (goal) and 2014 (threshold), depending on resource availability. The mission is a Class-D, directed mission jointly implemented by NASA Marshall Space Flight Center (MSFC) and the Johns Hopkins University Applied Physics Laboratory (APL). The mission will leverage use of previous concept designs and studies from MSFC, APL, JPL, ARC and DOD, as well as industry. Acquisition strategy will be formulated during the Pre-Phase A studies and submitted to HQ/SMD for approval.

This mission is technically and programmatically challenging, including a not-to-exceed cap of \$200 million (including launch vehicle and reserves), the placement of multiple nodes with one delivery system, and powering instruments through tens of day/night cycles. Because nodes may be desired on the lunar far side, NASA SOMD is studying a lunar communications relay satellite capability as part of its contribution to this endeavor. Currently, the project is operating in a "skunk works" philosophy at MSFC and APL, involving a very small number of key personnel in Pre-Phase A study.

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. Each ILN node will be a core set of instrument to make measurements requiring broad geographical distribution on the Moon, but these instruments may be flown on any lunar lander, thus making the ILN mission more than the sum of its parts. 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 habitat.

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An Overview of The Lunar Crater Observation and Sensing Satellite (LCROSS) Mission – An ESMD Mission to Investigate Lunar Polar Hydrogen 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], 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.

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.

Deposits of ice on the Moon could have practical implications for future human activities on the Moon. A source of water could enable long duration human activities and serve as a source of oxygen, another vital material that otherwise must be extracted by melting and electrolyzing the lunar regolith. Hydrogen derived from lunar ice could be used as a rocket fuel. These attractive considerations influence the architecture and plans for human activities on the Moon. Thus, the determination of the *non*-existence of water ice at the poles may cause a re-alignment of the architecture and plans. Operations from a lower latitude near side base would lead to substantially simpler communications approach, would focus exploitation on regolith processing instead of ice processing and would negate the challenge of developing robotic technologies capable of working in cryo-craters and nearly perpetual darkness.

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 2000 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 Earth Departure Upper Stage (EDUS) into a permanently shadowed polar region (Figure 1). The EDUS is guided to its target by a Shepherding Spacecraft (S-S/C), which after release of the EDUS, 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. The S-S/C then becomes a 700 kg impactor itself, to provide a second opportunity to study the nature of the Lunar Regolith. 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. This paper will overview the rationale and goals for the mission, impact expectations and the mission design.

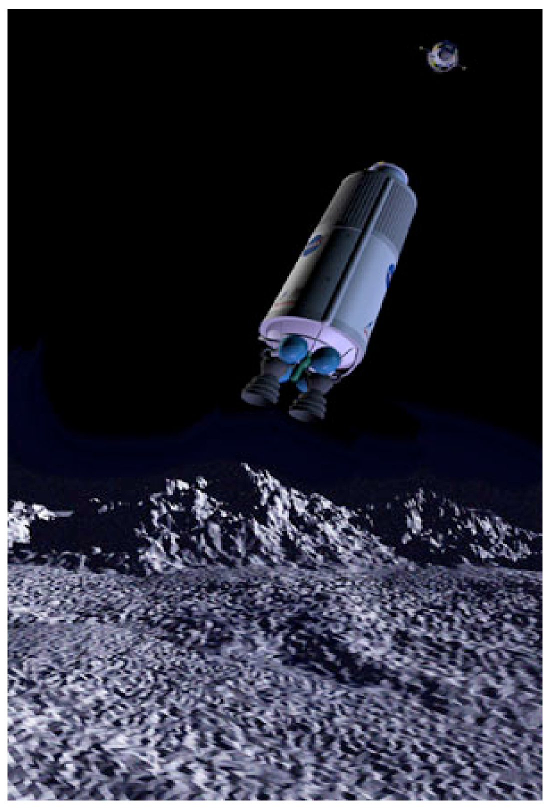

Figure 1. Artist concept of the EDUS (a Centaur upper stage) on its final descent toward the Moon. The smaller Shepherding satellite is shown in the upper right hand corner of the image.

LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL,

Executive Summary

Date Prepared:	20 August
Presenter's Name:	Catharine Conley
Presenter's Title:	Planetary Protection Officer
Presenter's Organization/Company:	NASA Headquarters

Presentation Title (brief descriptive title)

Planetary Protection for the Moon: Policy and Implementation

Key Ideas (2-3 sentences)

The purpose of planetary protection is to avoid the harmful contamination of other solar system bodies and adverse effects on the Earth from returned materials, in accordance with the 1967 Outer Space Treaty and guidelines developed by Committee on Space Research (COSPAR) of the International Council for Science, an advisory body to the United Nations. NASA's Planetary Protection Policy is maintained in accordance with the Treaty and COSPAR guidelines.

Volatile materials deposited in permanently-shadowed regions at the lunar poles may record a history of solar system evolution. For this reason, the Moon has recently been determined by COSPAR to be a Category II body, which will require documentation of mission operations and an inventory of organic materials carried by visiting spacecraft.

Ensuring compliance with the Outer Space Treaty agreements on planetary protection, as elaborated by COSPAR, is the responsibility of whichever nation launches any particular mission.

Supporting Information
NASA Planetary Protection Policy:
<http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=8020&s=7F>

NASA Requirements for Robotic Missions:
<http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8020&s=12C>

Outer Space Treaty: <http://www.state.gov/t/ac/trt/5181.htm>

COSPAR Planetary Protection Policy (not yet including July '08 revisions):
<http://cosparhq.cnes.fr/Scistr/Pppolicy.htm>

NASA Planetary Protection website: <http://planetaryprotection.nasa.gov/pp/>

EXPLORING THE BASALTIC LAVA FLOWS OF OCEANUS PROCELLARUM: REQUIREMENTS FOR AN EXPLORATION ARCHITECTURE THAT OPTIMISES SCIENTIFIC RETURN FROM GEOLOGICAL FIELD ACTIVITIES. I.A. Crawford[1] (i.crawford@ucl.ac.uk), S.A. Fagents[2] and K.H. Joy[1]. [1]Birkbeck/UCL Research School of Earth Sciences, Gower Street, London, WC1E 6BT, [2]Institute of Geophysics and Planetology, University of Hawaii, 1680 East-West Road, Honolulu, HI 96822, USA.

Introduction: One of the principal scientific reasons for wanting to resume *in situ* exploration of the lunar surface is the record it contains of the early geological evolution of a rocky planet, and of early Solar System history more generally [1,2,3]. Accessing this record will be greatly enhanced by a renewed human presence on the Moon, especially if supported by an exploration architecture designed to facilitate geological field activities (of which provision for long-range mobility, e.g, in pressurized rovers, will probably be the most important element).

The example of Oceanus Procellarum: A specific example (albeit only one of many) of how future lunar science would benefit from the speed and efficiency of human explorers in the field would be the study of the young basaltic lava flows in northern Oceanus Procellarum. This area consists of a patchwork of discrete lava flows with estimated crater-count ages ranging from about 3.5 to 1.2 Gyr (Fig 1) [4,5].

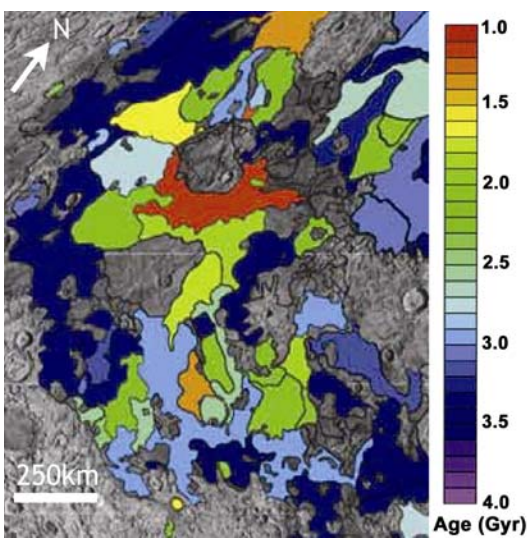

Fig. 1. Estimated ages of lava flows in Oceanus Procellarum (Gyr) based on crater counts, as mapped by Hiesinger et al. [5]. (Image courtesy Dr. H. Hiesinger; © AGU).

This is a far greater range of ages than any basalt samples collected by the Apollo missions (which occupy the narrow age range ~3.8 to 3.1 Gyr). Thus, collecting samples from a number of these different lava flows, and returning them to Earth for radiometric dating, would greatly improve the calibration of the lunar cratering rate for the last three billion years (see [6] for a review of the importance of such an improved calibration). Moreover, geochemical studies of these basalts would yield information on the evolution of the lunar mantle over this time period. Finally, as the younger lava flows are superimposed on older ones, we may expect to find layers of ancient regoliths ('palaeoregoliths') sandwiched between them which may contain a variety of records of the near-Earth cosmic environment through Solar System history [1,7-9]. Taken together, this would be a very rich scientific harvest and the developing exploration architecture should be developed so as to permit extensive geological field activities of this kind.

Implications for the exploration architecture: In order to conduct a sufficiently detailed geological investigation of a range of discrete lava flows, in Oceanus Procellarum, or comparable localities, the exploration architecture would have to support:

- The ability to conduct 'sortie-class' expeditions to non-polar localities.
- Adequate provision for sample collection and return capacity (estimated at several 100 kg/sortie)
- Provision for surface mobility – in the specific case of the Procellarum basalt flows shown in Fig. 1, a range of order 250 km would permit access to a number of different units with a wide range of ages. This implies provision of a pressurized rover (or alternatively a hopping lander of some kind)..
- Provision of the means to detect and sample palaeoregolith deposits. For detection, ground penetrating radar may be a suitable technique (see discussion in [10]). For access, unless suitable outcrops can be found a the boundaries between flows, provision of a drilling capability (perhaps to c. 100m depths) may be required. This implies provision for storage and transport of the drill cores.

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MOONLITE: A COST EFFECTIVE PROPOSAL FOR ADVANCING MULTIPLE OBJECTIVES IN LUNAR SCIENCE AND EXPLORATION. I. A. Crawford[1], A. Smith[2], R. A. Gowen[2], and the MoonLITE Science Working Group[3] and UK Penetrator Consortium[4]. [1]School of Earth Sciences, Birkbeck College, London, WC1E 7HX, UK. [2]Mullard Space Science Laboratory, University College London, UK. [3]Members identified in the Acknowledgements. [4]http://www.mssl.ucl.ac.uk/general/news/UKLPC/UKLPC.pdf. (Email: i.crawford@ucl.ac.uk).

Introduction: MoonLITE is a proposal for a UK-led mission to the Moon that will place four instrumented scientific penetrators in the lunar surface for the purpose of making geochemical and geophysical measurements that cannot be made from orbit [1,2]. It has the potential to make major contributions to lunar science, while at the same time providing knowledge that will be of central importance in the planning of future human missions to the Moon.

Scientific objectives: The principal scientific objectives of the MoonLITE penetrator mission are:

- To further our understanding of the origin, differentiation, internal structure and early geological evolution of the Moon;
- To obtain a better understanding of the origin and flux of volatiles in the Earth-Moon system;
- To obtain 'ground truth' geochemical data to complement orbital remote-sensing observations;
- To collect *in situ* surface data that will help in the planning of future lunar exploration.

These top-level science objectives require that the penetrators emplace instruments capable of contributing to several different areas of scientific investigation, including seismology, heat-flow, geochemistry, volatile detection, radiation monitoring and magnetometry.

Seismology: The Apollo seismic network covered less than 2% of the lunar surface, and there is now a need for more widely spaced measurements [3,4]. The MoonLITE seismometers will have the following objectives: (a) determine the size and physical state of the lunar core; (b) explore the deep structure of the lunar mantle; (c) determine the thickness of the lunar crust outside the region covered by Apollo; (d) study the distribution and origin of natural moonquakes; and (e) Further constrain the current meteorite flux in the inner solar system via the seismic detection of lunar impacts.

Heat-flow: Measurements of surface heat-flow provide valuable constraints on the composition and thermal evolution of planetary interiors. An important measurement would be to determine the heat-flow as a function of distance from the anomalous Procellarum KREEP Terrain (PKT; [5,6]). Existing heat-flow data are only available from the Apollo 15 and 17 sites [7], and MoonLITE will extend these measurements to new localities (e.g. the polar regions and the farside).

Geochemistry: The only places on the Moon from which samples have been collected *in situ* are the geographically restricted Apollo and Luna sample return sites, limiting our knowledge of lunar geological processes. A precursor to additional sample-return missions would be to make *in situ* geochemical measurements, and MoonLITE would achieve this through penetrator-deployed X-ray fluorescence spectrometers. Such measurements would provide additional 'ground truth' for the calibration of remote-sensing instruments on forthcoming lunar orbital missions.

Polar volatiles: Confirmation of the tentative detection of water ice (and by implication other volatiles, [8]) at the lunar poles poles is important both for what it will reveal about the flux and composition of cometary volatiles into the inner Solar System, and because such volatiles could be a valuable resource in the context of future human exploration of the Moon. MoonLITE can address this question through the deployment of volatile detection instruments on penetrators targeted within permanently shadowed craters.

Magnetometry and radiation sensing: These are currently under consideration for penetrator deployment by MoonLITE. Surface magnetic field measurements would permit *in situ* studies of lunar remanent crustal magnetisation, and magnetic sounding of the deep lunar interior. Radiation monitoring at the 2-3m depth of the penetrators would be directly relevant to assessing the efficacy of lunar regolith as radiation shielding in the context of future human exploration.

Conclusions: By deploying a range of instruments to diverse locations on the Moon from which geochemical and geophysical measurements have not yet been obtained (including the poles and the farside), the MoonLITE penetrators have the potential to make major contributions to lunar science. At the same time, they will provide knowledge (e.g. of lunar seismicity, polar volatile concentrations, and the radiation environment) that will be of central importance in the planning of future human missions to the Moon.

Acknowledgements: Members of the MLSWG are as follows: I.A. Crawford (Birkbeck), M. Anand (OU), A.J. Ball (OU), J.C. Bridges (Leicester), A.J. Coates (MSSL), A.C. Cook (Aberystwyth), Y. Gao (Surrey), A. Hagermann (OU), M.A. Hapgood (RAL), A.P. Jones (UCL), K.H. Joy (Birkbeck), W.T. Pike (Imperial), L. Wilson (Lancaster), J. Woodhouse (Oxford). We thank Dave Parker (BNSC), Chris Castelli (STFC) and the UK-NASA Joint Working Group for their help in developing the MoonLITE concept.

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Inertial Filtration of Lunar Dust in Reduced Gravity

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We report experimental results on the collection efficiency of an air cyclone operating with a lunar dust simulant under lunar gravity. Microgravity collection efficiency is, to within experimental uncertainty, not different from collection efficiencies obtained in one-g experiments. CFD modeling of cyclone operation in reduced gravity supports this conclusion.

Introduction Lunar dust has been identified as a significant hazard to future lunar missions due to its presumed human toxicity[1]. In the vernacular of physiological effects associated with particulate pollution, approximately 5% of lunar dust by volume is *respirable*, having aerodynamic diameters of less than 4 μm. The adverse effects of lunar dust on machinery has been well-documented. The pervasive presence of respirable dust in the lunar environment necessitates a robust and economical means of filtration. Air cyclones are currently used in a variety of industrial and manufacturing environments as first stage filtration technologies, and may prove suitable in a similar role in lunar habitats. Here, we demonstrate that the reduced gravity of lunar environments does not preclude the use of an air cyclone on the Moon.

Central Question An air cyclone is a device that separates particles from a carrier air stream by means of a centrifugal force acting on the particles. Dust particles, initially entrained in the air flow, enter a tangential inlet near the top of the cyclone, and follow the downward spiral of the air vortex. Centrifugal force and inertial effects act on the particles to move them outward toward the inner wall of the cyclone where they are trapped in the boundary flow. Trapped particles eventually move down the inner wall and are collected in a dust cup at the base of the cyclone while the air flow reverses direction near the base of the cyclone, and exits the through the vortex finder at the top of the cyclone. The viability of air cyclones in the lunar environment is contingent on the degree to which gravitational settling is the dominant mechanism of particle collection. This is the question addressed in the present work.

Results and Discussion To investigate the role of gravitational settling in the performance of an air cyclone, an experiment designed to assess collection efficiency of an air cyclone was flown aboard the *Weightless Wonder*, a modified C-9 aircraft used in the parabolic flight program operated by NASA's Reduced Gravity Office [2]. Lunar

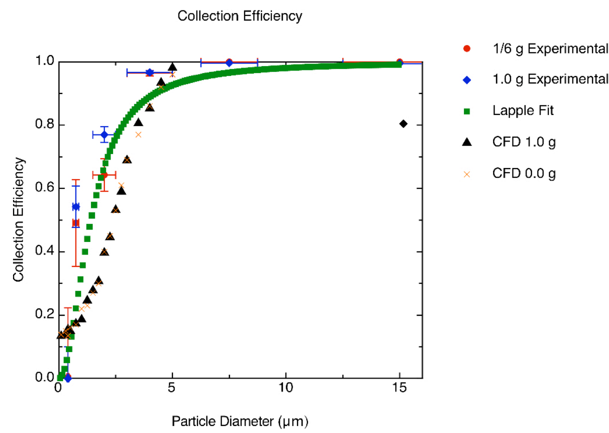

Figure 1: Experimental results (● and ◇), CFD results(▲ and ×), and Lapple Model predictions (■) for the performance of the model cyclone used in this study.

dust simulant JSC-1AF (Orbitec, Inc.) was fluidized in an airstream at 10 cfm and pulled through a reverse-flow cyclone separator.

Collection efficiencies across the particle diameter range $0.3\mu m \leq d_p \leq 15\mu m$ were obtained under both 1/6 g and 1.0-g gravitational loading. To within experimental uncertainty, reduced gravity cyclone performance is not significantly different than 1.0-g performance.

CFD calculations and an analytical model of particle motion in cyclone flow were developed to understand this surprising result. Our analysis shows that particle trapping occurs primarily by entrainment of particles in the boundary flow at the cyclone wall and subsequent deposition at wall surface. Gravitational settling in the axial direction does not contribute significantly to particle collection because the time scale for centrifugal motion of particles from the cyclone interior to the wall is much shorter than the axial settling time.

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A PROPOSED GEOTECHNICAL GIS FOR LUNAR EXPLORATION. Leon Croukamp[1], [1]Council for Geoscience, South Africa, leonc@geoscience.org.za.

Introduction: Future Lunar exploration depends to a large extent on the knowledge of the geological properties but even more so on the geotechnical properties of the soil and underlying bedrock. The role of the geologist during rover and manned missions is critical. Both from control on earth as well as for decision making during actual field excursions.

GIS as a tool:

Using GIS as a decision making tool is nothing new and numerous examples exist where it had been applied successfully, especially in the terrain of utility monitoring for Metropolitan Councils, client distribution maps and even defense strategies or emergency service providers for shortest and quickest routes to fires and accident scenes.

At the Council for Geoscience (CGS) a geotechnical GIS [1] had been designed and implemented to support the ever increasing demand for housing in semi-urban areas. During this, it became apparent that GIS is not just a tool for creating maps but can actively support decision making at different levels of authority.

The proposed geotechnical GIS for Lunar exploration will incorporate the following proposed datasets but is not limited to those.

Envisaged Data layers required for Lunar exploration.

- Slope angle
- Slope aspect
- Surface roughness
- Geology
- Geotechnical properties
- Boulder size
- Etc

Using these data layers in combination and posing different questions could help in the finding of resources whilst also contributing to the best (most cost-effective) path of travel to choose. In effect a maneuverability map will be the end result. Input from on-board monitoring equipment such as stereo cameras and others would be crucial to make on the spot decisions either automatically or by relaying information back to earth to mission control.

Special areas of interest that need investigation.

As there is a strong possibility of finding water-ice or conditions conducive to the formation of water-ice on some areas in permanent shadow it would be important during the design of the GIS to allow for friction coefficients such as slippery areas, mushy areas, etc in permanent shadowed areas. This factor, combined with slope angle could play a significant role during the investigation of the South Pole Aitken Basin, an area of interest and probably first area for future investigation.

Some questions that may need answering.

- What have been done so far ?
- What methods did not work ?
- What do we know ?
- What do we need to know ?
- What don't we know ?
- What can be determined/measured from earth ?
- What needs to be determined on the moon or near-surface ?
- Is earth-based methodologies appropriate at all ?
- Is earth-based planning approaches relevant ?

Proposal:

It is proposed that a Geotechnical based GIS be developed for use during exploration of the Lunar surface to be utilized both during unmanned missions and manned missions to the moon.

As some of the data required will only become apprarent during actual field excursions, a methodology to update decision making should be developed and implemented in the final version of the GIS.

References:

[1] Croukamp L. (1996): Unpublished MSc thesis *A Geotechnical GIs for use by Engneering Geologists,*. Univ. Of Pretoria.

LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL

Executive Summary

Date Prepared:	10/10/08
Presenter's Name:	Chris Culbert
Presenter's Title:	Manager, Lunar Surface Systems Office
Presenter's Organization/Company:	Constellation Program, NASA/JSC

Presentation Title (brief descriptive title)
Constellation and Lunar Architecture Overview

Key Ideas (2-3 sentences)
A brief overview of the Constellation program, describing the Initial Operational Capability vehicles, the Lunar transportation System vehicles, and the related elements. It will then providing an update on the options that have been reviewed for establishing a Lunar Outpost.

Supporting Information
This talk will primarily summarize information produced for the Constellation Lunar Capability Concept Review in June of 2008, the first program milestone associated with the Human Lunar Return.

LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL,

Executive Summary

Date Prepared:	15 Oct 2008
Presenter's Name:	Ken Davidian
Presenter's Title:	Lead, Commercial Development Policy
Presenter's Organization/Company:	NASA HQ ESMD

Presentation Title (brief descriptive title)

Plans for Involving the Commercial Sector in Space Exploration

Key Ideas (2-3 sentences)

The Exploration Systems Mission Directorate adopted a Commercial Development Policy in the first portion of fiscal year 2008. It's goal is to encourage the development of a private sector that provides commercial space capabilities that can be used by both government and non-governmental customers. Currently, NASA is in the process of formalizing this policy at an agency level.

To implement its new policy, ESMD developed a new process to understand trends in the emerging commercial space marketplace. This awareness helps coordinate NewSpace agreement opportunities with those of prime contractor and international partners.

Supporting Information

Clive,

This talk will fit into the "10-20-30" format I like to use… 10 slides, 20 minutes, 30-point font. If you want to allow 5-10 minutes for questions, then the total time slot should probably be expanded to be 25-30 minutes instead of the 20 originally allotted.

Thanks for the opportunity to present this material to your group!

Ken

MODELS FOR THE LUNAR RADIATION ENVIRONMENT.

G. De Angelis[1], F. F. Badavi[2], S. R. Blattnig[2], J. M. Clem[3], M. S. Clowdsley[2], R. K. Tripathi[2] and J. W. Wilson[2]
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Introduction: Radiation protection is one of the two NASA highest concerns priorities [1]. In view of manned missions targeted to the Moon [2], for which radiation exposure is one of the greatest challenges to be tackled [3], it is of paramount importance to be able to determine radiation fluxes and doses at any time on, above and below the lunar surface [4]. With this goal in mind, models of radiation environment due to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) on the Moon have been developed, and fluxes and spectra hereby computed [5]. The work is described [6] as models of incoming cosmic ray [6-10] and solar primary particles [6] impinging on the lunar surface, transported through the subsurface layers, with backscattering taken into account, and interacting with some targets described as material layers. Time dependent models for incoming particles for both GCR and SPE are those used in previous analyses as well as in NASA radiation analysis engineering applications [10]. The lunar surface and subsurface has been modeled as regolith and bedrock, with structure and composition taken from the results of the instruments of the Luna, Ranger, Lunar Surveyor and Apollo missions, as well as from groundbased radiophysical measurements (see discussion in [4-6], [10]). Similar models have been developed for Mars [11].

Results: In order to compare results from different transport techniques, particle transport computations have been performed with both deterministic (HZETRN) [12] and Monte Carlo (FLUKA) [13] codes with adaptations for planetary surfaces geometry for the soil composition and structure of the Apollo 12 Oceanus Procellarum landing site [14,15], with a remarkable agreement between the results from the two techniques [6,10]: GCR-induced backscattered neutrons are present at least up to a depth of 5 m in the regolith, whereas after 80 cm depth within regolith there are no neutrons due to SPE [6,10]. Moreover, fluxes, spectra, LET and doses for many kinds of particles, namely protons, neutrons, alpha particles, heavy ions etc., for various other lunar soil and rock compositions have been obtained with the deterministic particle transport technique [6]. Results have in particular been obtained for orbital scenarios, for surface (i.e. landers, habitats and rover) scenarios, for subsurface scenarios, and for lunar polar locations, with regards to ways to infer and detect locally the presence of water and/or volatiles. The results from this work can only be compared in literature with previous versions of the same models or with very simplistic models [4-6,10], as also mentioned in [16]. These models will be soon tested against spacecraft data (e.g. RADOM onboard ISRO CHANDRAYAAN-1 spacecraft, CRaTER onboard NASA LRO).

Conclusions: Models for the Moon radiation environment (on, above and below surface) due to GCR, SPE and backscattering effects have been developed. A good agreement has been found between results from deterministic and Monte Carlo transport techniques. The large differences in the time and effort involved between the deterministic and Monte Carlo approaches favor the use of the deterministic approach in computations for scientific and technological space radiation analysis. This approach looks promising for lunar polar locations studies. These models will be soon tested with the data from spacecraft instruments.

Acknowledgements: The authors are indebted with M. Caldora, K.Y. Fan, S.H. Husch, G.D. Qualls and W.A. Mickley for their invaluable help. This work has been performed under the ASI Grant I/033/06/0 and NASA Research Grant NCC-1-404. This work is dedicated to the so dear memory of Diana Bondanini.

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High Resolution Maps of the Moon Surface with AMIE/SMART-1. D. Despan [1], S. Erard [1], A. Barucci [1], J.-L. Josset [2], S. Beauvivre [3], S. Chevrel [4], P. Pinet [4], D. Koschny [5], M. Almeida [6], B. Grieger [6], B.H. Foing [5] and the AMIE team. [1]LESIA, Observatoire de Paris, France (daniela.despan@obspm.fr), [2]Space Exploration Institute, Neuchâtel, Switzerland, [3]Micro-cameras & Space Exploration, Neuchâtel, Switzerland, [4]UMR 5562 CNRS/GRGS, Toulouse, France, [5]ESA/ESTEC, Noordwijk, The Netherlands, [6]ESA/SCI-OS, Spain.

Introduction: The Advanced Moon micro-Imager Experiment (AMIE) on board the ESA lunar mission Smart-1 has performed color imaging of the lunar surface in three filters centered at 750, 915 and 960 nm [1]. The low pericenter, polar orbit, allowed to obtain a complete image coverage with high resolution at low to medium latitudes. From the 300 km pericenter altitude, the field of view (5.3°x5.3°) corresponds to a pixel size of about 27 m, a spatial resolution higher than Clementine [2]. The 1024x1024 pixels images are shared by the various filters, allowing to derive mosaics of the surface in up to 3 colors depending on pointing mode.

Maps of the lunar surface: The high resolution imaging makes possible detailed analysis of the morphological features and physical characteristics of the lunar surface. In order to construct AMIE data maps, systematic analysis and processing is being carried on using the whole data set. Figure 1 shows one of the results: a high resolution mosaic of the lunar North pole in the none filter area of the detector and details of the surface elements are visualized in Figure 2.

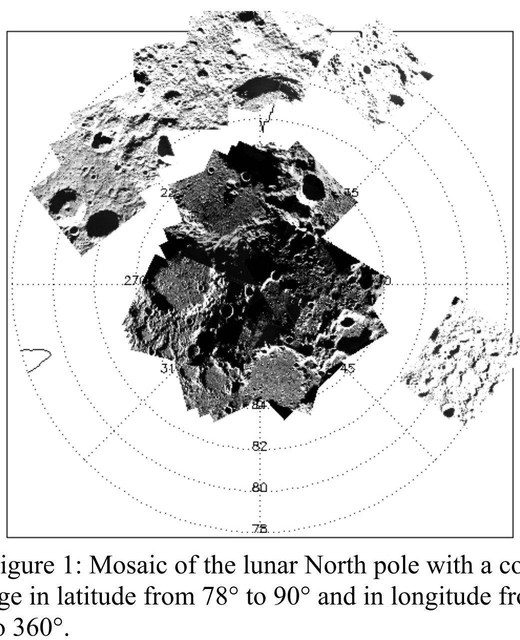

Figure 1: Mosaic of the lunar North pole with a coverage in latitude from 78° to 90° and in longitude from 0 to 360°.

Images from various orbits are first identified for each selected region of interest. These images are then selected according to signal to noise ratio, spatial coverage, and spatial resolution. Geometrical analysis of AMIE images relies on the SPICE system: image coordinates are computed to get precise projection at the surface, and illumination angles are computed to analyze the photometric sequences. The best images obtained with the neutral filter are calibrated, and mosaicked using the coordinates of the image frames corners. In the polar areas, images are selected so as to provide the best possible viewing of surface topography, depending on solar illumination angle, while preserving images continuity in shadowed areas.

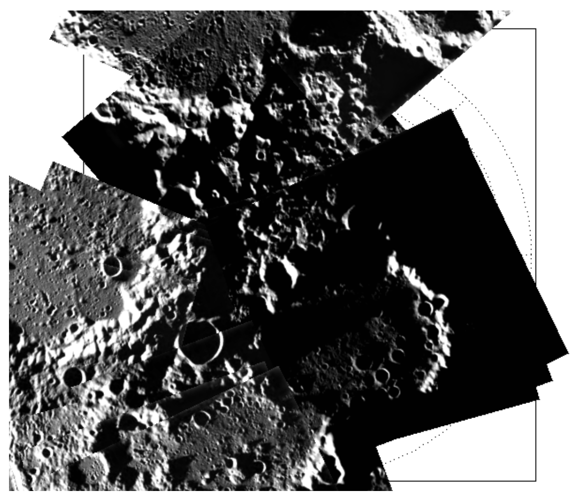

Figure 2: A North pole mosaic with a range in latitude from 87° to 90° and in longitude from 0 to 360°.

Mosaics of other regions of interest are provided with the AMIE high resolution observations of the lunar surface, typically a factor of 3 higher than the Clementine UV-vis camera. These regions are located at latitude ranging from 80° to 40°S, specially in the eastern hemisphere.

Prospects: Eventually, this method will be applied in all areas where AMIE has provided high resolution observations of the Moon surface.

Acknowledgements: Support to the AMIE data processing activity in France is provided by CNES, and is gratefully acknowledged.

References: [1] Josset et al. (2006), *Adv. Sp. Res* 37, 14-20. [2] Pinet et al. (2005), *Planet. Space Sc.* 53, 1309-1318.

Contract Incentives for an Open Architecture International Lunar Network Including Google Lunar X-Prize, David A. Dunlop[1], (Moon Society, 410 N. Ashland, Green Bay, WI 54303.

Introduction

There is a lunar community of interest in how an "open architecture" can be designed into "infrastructure" to increase opportunities for entry by commercial providers. This community of interest includes those who would wish to see costs of going to the Moon reduced, the pace of scientific and commercial projects accelerated, and the flexibility of planning and contracting for lunar missions increased.

Now there is interest in creating a commercial paradigm of space transportation providers. The Google Lunar X-Prize competition is the most visible expression of this movement. According to Dr. Pete Worden, Director of NASA AMES Research Center, the cost challenge is to pioneer "micro" lunar lander missions that can perform useful functions "in the low tens of millions range from "perhaps a low of $ 28 M to $ 48M to $ 68M at the high end." [1]

As one example, the NRC final report on the Scientific Context for the Exploration of the Moon mentions the utility of an increased network of laser reflectors on the lunar surface.[2] It would make economic sense for agencies such as NASA, ESA, JAXA, ISRO, Roscosmos, and CNSA to provide potential contracts to any Google Lunar X-Prize teams that would deliver, in this example, a laser retro reflector to the lunar surface. A variety of scientific instruments that are recognized as elements of a lunar science network might be contractually placed in this manner on private landers.

Google Lunar X-Prize Contracts:

Under the Google Lunar X-Prize there are the first and second prizes to be won. When those prizes are won the remaining teams would remain without the financial incentive from the Google Lunar X-Prize. Many teams might simply disband once the financial prizes are gone and even the prestige and recognition of being winners of the competition was secured by others. It would seem to be a tragic loss of capital and intellectual resources to have many teams which have gone in essence through phases A,B, and C of their mission development to fail to realize their goal of achieving a lunar landing and demonstrating innovative technologies by reason of simply not being first. **Contract incentives of equal proportion to the Google Lunar X-Prize by the national funding agencies might create many "winners" in the realm of both education, science, technology, and the ability to demonstrate greatly improved cost efficiency.** For the national space agencies to offer contracts to establish a lunar sensor network may be a way to quickly and cost effectively "harvest" the capital investment and technology innovations of the Google-X Prize competition and develop a more commercial space model in the process.

National space agencies would have to develop their own criteria in assessing the credibility of potential contractors. NASA has in fact proposed something of this sort in conjunction with its ASMO mission proposal. This is a paradigm shift in the way business has traditionally been conducted by NASA. It is also the paradigm followed by the ESMO ESA mission.

Having a known and publicly described set of such instruments with fixed priced contracts also facilitates planning on the part of those who might wish to include the possibility of such contracts in their mission and financial plans.

To propose science contract packages from national space agencies for ILN sensors would create a financial climate equivalent to the Google Lunar X-Prize and create a "commercial market" for such micro landers. $ 150 million represents a third of one NASA Discovery mission. A **$ 25million by each of the 6 major space agencies would be the equivalent of more than 7 Google Lunar X-Prize Competition First prizes or 30 second prizes.** ILEWG might encourage early budget and contract commitments by national space agencies especially if their impact is spread over a 5 or 6 year period or longer.

This contract model could focus on payments for a more complex set of milestones for criteria such as: a. design, b. construction, c. launch, d. deployment, e. data return. Phased contract incentives equivalent to the Google Lunar X- Prize first prize might provide financial sustainability of those teams whose engineering and mission planning credibility warrants such contracts and that remain intact after the fist and second prizes have been awarded.

The aggregation of contracts for a variety of sensors defining a ILN network node would fall into the low range of lunar lander costs projected by Dr. Worden but not preclude other private, commercial, or national efforts and projects on these teams. This could also make "national flag" lunar mission commitments from the 14 ILN signatory nations much more likely and foster financial collaborations between such national flag agencies and commercial organizations.

Collaborative commitments by national space agencies in this model result in a mix of successful public science, "national flag", and corporate lunar landing missions. [1] Personal communication. [2} The Scientific Context of the Exploration of the Moon:Final Report, NRC, Space Studies Board, 2008, p. 53,65,66.

INTERNATIONAL LUNAR OBSERVATORY ASSOCIATION (ILOA): 3 MISSION UPDATE -- ILO-X PRECURSOR, ILO-1 POLAR, ILO HUMAN SERVICE MISSION. Steve Durst, ILOA / Space Age Publishing Company, 65-1230 Mamalahoa Highway D20, Kamuela, Hawai`i, 96743, USA, info@iloa.org, news@spaceagepub.com, phone 808-885-3474, fax 808-885-3475.

Introduction: The ILOA - Odyssey Moon Ltd announcement of July 20, 2008 in Mountain View, California, regarding the ILO-X Precursor / OM-1 mission and the ILO-1 Polar / OM-2 mission; the ILOA Board of Directors meeting 23-25 July in Vancouver, Canada, with major participation from India, China and Europe; and the ILOA meetings projected for October 2009 in Japan, China and Korea to advance the ILO Human Service mission -- all point to robust development of the Hawaii USA-based ILOA, and its three Moon missions.

ILOA's ILO-X Precursor Mission, now being designed by MDA of Canada, will utilize a small, dual function instrument to demonstrate astronomical and other observation and communication techniques aboard the OM-1 lander, Odyssey Moon's inaugural "MoonOne" mission of scientific and commercial payloads planned for 2011 and destined for the lunar equator in pursuit of the Google Lunar X Prize.

ILOA's ILO-1 Polar Mission, designed since 2003 by SpaceDev Inc of USA, will establish permanent astrophysical observation and lunar commercial communications systems in the Moon's mountainous South Pole region aboard Odyssey Moon's "MoonTwo" lander early next decade.

ILOA's Human Service Mission, with studies completed in 2005 and 2006 by SpaceDev and advanced by Benson Space Company in 2007, is being planned as part of an independent-national-international science and commerce collaboration to service and support the ILO/s and parallel robotic village facilities, by 2015, and the emerging lunar base settlements.

The ILOA is an interglobal enterprise incorporating in Hawaii as a 501 (c) (3) non-profit to help realize the multifunctional ILO -- to advance human knowledge of the Cosmos through observation from our Moon -- and to participate in lunar base build-out. The ILOA also in 2008 is co-sponsoring with its Space Age Publishing Company affiliate an international series of Galaxy Forums and a Lunar Commercial Communications Workshop.

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WHAT ASTROBIOLOGY INVESTIGATIONS ARE NEEDED AND POSSIBLE ON THE MOON?

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Abstract: The Moon played a key role in early Earth evolution and provides a unique platform to perform Life Sciences and Astrobiology research [1-16]. We discuss Astrobiology investigations that are needed and possible on the Moon. Furthermore we review how to acquire knowledge to make the Moon habitable (using advanced and sustained technological support), and expand life beyond planet Earth.

Moon and Astrobiology: The Moon presents compelling science opportunities. The major Astrobiology science goals include the investigation of the

- Bombardment history
- Solar history recorded in regolith
- Origin of the Moon
- Volatiles (sources and prebiotic chemistry)

Studying the bombardment history of the Earth-Moon system help us to determine how impacts affected the habitability on the early Earth. The lunar regolith acts as a recorder of our Sun's history. Organic material may be found in the permanently shadowed polar environment. The Moon can also be used as a science platform for astronomy, Earth and solar activity observations. Opportunities for Astrobiology investigations that support future exploration missions include:

- Chemical and microbiological studies on the effects of terrestrial contamination and microbial survival
- Future in situ investigations on the Moon by highly sensitive instruments designed to search for biologically derived organic compounds
- Use of the Moon and lunar transit/orbits as testbeds for procedures and technology involved with implementing human Mars mission requirements, prior to Mars missions being flown
- Developing technologies for effective containment of samples collected by humans to prevent forward and backward contamination (preliminary to Mars use)

Astrobiology and Life Sciences on the Moon: The Moon can be used for life sciences, astrobiology laboratories, human bases and biospheres that will play a key role in the future space exploration. Investigations that can be conducted through robotic missions are:

- Analysis of organics from extraterrestrial samples
- Bacteria and extremes of life
- Survival, replication, mutation and evolution
- Extraterrestrial botanics: Growing lunar plants
- Animals: physiology and ethology
- Closed Ecological Life Support Systems
- Greenhouses and Food production
- Living off the land

Expanding Life & Humans on the Moon: Having reached maturity in human space-flight with the development and operation of the International Space Station (ISS), the next step for humankind is to reach out to other planets in the solar system. Humans will start first as explorers and then spend extended living and working periods on lunar and planetary bases. Testing life support systems, EVA technology, mission operations and science objectives on the Moon support the development of future human missions to explore Mars, including the search for life**.** Current lunar missions will continue to answer open questions about the origin of the Earth–Moon system, the early evolution of life, the planetary environment and habitability. Already in the next decade a series of soft landing missions to the Moon could ensure a global robotic presence performing precursor life science experiments.

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LUNAR CRATER OBSERVATION AND SENSING SATELLITE (LCROSS) SCIENCE PAYLOAD GROUND DEVELOPMENT, TEST, AND CALIBRATION. K. Ennico[1*], A. Colaprete[1], J. Heldmann[1], G. Kojima[1], D. Lynch[1], M. Shirley[1], D. Wooden[1], [1]NASA Ames Research Center, Moffett Field, CA 94043, *Kimberly.Ennico@nasa.gov

Introduction: The Lunar CRater Observation and Sensing Satellite (LCROSS) is a lunar impactor mission designed to target and impact a permanently shadowed region at a lunar polar latitude to create and measure the characteristics of an ejecta cloud of regolith and possibly ice and water vapor. The LCROSS mission is co-manifested with the Lunar Reconnaissance Orbiter (LRO) whose six science instruments will survey the Moon to prepare for and support future human exploration of the Moon. The LCROSS mission uses the United Launch Alliance's Atlas Centaur launch vehicle Earth Departure Upper Stage as the primary impactor. The impact creates an ejecta plume whose properties, including water ice and water vapor content, will be observed by the LCROSS shepherding spacecraft (S-S/C) plus Earth- and space- based telescopes, providing additional information at other wavelengths and/or timescales. 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 LCROSS mission is managed by NASA Ames Research Center (ARC) with industry partner Northrop Grumman Space Technology. LCROSS is a NASA Class-D mission.

LCROSS Science Payload Design: The LCROSS payload consists of nine science instruments, their supporting electrical, mechanical and optical harnesses and a central data handling unit assembled onto one of six radiator panels on the LCROSS space vehicle. The nine science instruments include one visible wavelength context imager provided by Ecliptic Enterprises Corporation, two near-infrared (1-1.4 micron/ 1-1.7 micron) cameras from Goodrich Sensors Unlimited, one mid-infrared (5-9.4 micron) thermal imager from Thermoteknix Systems, Ltd., one mid-infrared (5-15 micron) camera from FLIR Systems/Indigo Operations, a custom-built highly sensitive total luminance photometer (0.4-1 micron), a UV-visible spectrometer (260-650 nm) provided by Ocean Optics, and two compact low power near-infrared spectrometers (1.2-2.4 micron) built by Polychromix. The three spectrometers are connected via fiber optics to specially designed fore-optics provided by Aurora Design & Technology. These nine instruments are powered and controlled by a Data Handling Unit (DHU) provided by Ecliptic Enterprises. The DHU is interfaced with the space vehicle command and data handling and power systems. Thermal control of the science payload is provided using heaters and thermostats.

LCROSS Science Payload Testing: As many units of the LCROSS science payload are COTS (Commercial Off-the-Shelf) or modified-COTS, the LCROSS payload test program stressed early verification testing of Engineering Test/Development Units (ETU/EDUs) which, for the most part are identical in form and function to the vendor-proposed flight version. These ETU tests were primarily development tests in the process to bring "COTS-like to flight." Development tests were shared between NASA/ARC and the vendors to alleviate schedule burden and promote rapid turn-around for flight unit development. This proved to be a successful paradigm to increase the robustness of this Class-D payload over the course of a few months. The flight science instruments are tested for functionality and performance at both the unit and assembly level, the latter which is more representative of "test-as-you-fly" approach. After flight environmental acceptance testing, the payload is delivered to the spacecraft provider, Northrop Grumman, for integration at the space vehicle. Testing at the space vehicle level continues until the space vehicle is ready for transport to Cape Canaveral for integration with the LRO in the fairing of the Atlas Centaur.

LCROSS Science Payload Calibration Status: The calibration plan for the LCROSS science payload is a multi-faceted approach relying on 1) vendor-provided specifications, 2) in-situ radiometric and performance characterization at the NASA/ARC Calibration Laboratory facilities, and 3) in-orbit calibrations. The flight spectrometers and total luminance photometer have been radiometrically, spectrally, thermally, and temporally calibrated. This data provides a benchmark to compare against future in-orbit calibration checks. The flight cameras are being tested for image quality, responsivity and co-alignment. This paper will summarize the current ground calibration of these instruments in the context of the overall LCROSS test program. The several month cruise phase of the LCROSS mission profile will provide a number of opportunities to obtain instrument health, performance, alignment and contamination checks, before the final descent. In particular, a lunar swing-by is planned at launch + 5 days, by which the science instruments are pointed at several places along the lunar surface and measurements along lunar limb. Additional earth and space looks are part of the in-orbit calibration plan.

GEOLOGIC PREPARATION FOR EXPLORING THE MOON AND PLANETS: USING THE PAST AS A KEY TO THE PRESENT. D.B. Eppler, SAIC-Constellation Lunar Surface Systems Office, Mail Code ZS, NASA-Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, dean.b.eppler@nasa.gov.

Introduction: Preparation for Apollo included extensive astronaut geologic training, including classroom training and multiple field excursions to locations throughout the US. The scientific payoff of Apollo was, in part, the result of this training – despite the fact that only one lunar crewmember considered geology his profession, each crew returned critical geologic observations and a carefully collected suite of samples upon which our understanding of lunar geology is based.

For the Constellation Program, preparing to geologically explore the Moon is taking several paths: (1) reviewing the history of Apollo geologic training as model of successful field training; (2) familiarizing the engineers and managers with geologic exploration and its impact on our approach to lunar exploration; and, (3) updating the astronaut training curriculum to reflect lunar exploration mission.

Apollo Training History: The success of crewmember's efforts on the Moon was based on careful field observations. These observations formed the basis for subsequent sample collection, and were founded on a combination of classroom training and geologic field trips. Field training was considered paramount, particularly for the crews that flew on Apollo 15, 16 and 17 – in the ≈2 years between crew assignment and flight, each surface crew completed >15 field trips which continued up to 1 month prior to launch. These trips involved instruction by a cadre of geologists, field exercises by the crewmembers ("playing the Moon game"), and full-up, joint integrated simulations where a CAPCOM and a science backroom worked with crewmembers wearing simulated life support systems and using field cameras and geologic field tools identical to those used on the Moon.

In April 2008, 8 Apollo geologic trainers, 2 Apollo surface crewmembers and 1 lead flight director participated in a workshop to pass on lessons learned. The most important lesson was that success in geologic training and in a crew's performance on the lunar surface was directly related to mission commanders' and flight directors' enthusiasm for the task – mission commanders, in particular, could carry the whole enterprise with their excitement for the surface science mission. Second, the quality of the instructors is absolutely critical – enthusiastic, gifted instructors create competent lunar field geologists, regardless of crews' initial backgrounds. Third, the logistics associated with field training is extensive and critical to success.

Geology Familiarization Training: Recognizing that the best way to understand what geologists do is to take people in the field, Constellation has begun a series of 2-3 day field trips to familiarize non-geologists with the activities associate with field work. In each case, 2 students are paired with an experienced geologist in a field location mimics the lunar geology to conduct a program of geologic mapping and field observations. A brief classroom familiarization is conducted prior to going into the field, after which each team spends 2-3 full days of mapping. After each day, teams individually review their activities, and make plans for the following day. Initially, the geologist is in "teaching mode", but quickly transitions the students to making the observations and drawing contacts themselves. This program has been enthusiastically received by all students; the most common response from the students has been, "Now I see what you've been trying to tell us."

Rewriting the Geologic Training Curriculum: Since 1978, Shuttle and ISS astronauts have been receiving limited geologic training in their first year as astronauts. This training consisted of ≈2 hours of classroom activity in recognizing geologic processes from orbit, followed by a 1-week field trip to look at field relations first hand. This curriculum was appropriate for observations from LEO, but will be inadequate for lunar operations. To meet the requirements of Constellation, the first step is institute a program of paired field and classroom exercises. Observations in the field will prompt detailed classroom study and self-directed activities to expand on knowledge gained in the field. The initial plan is to conduct 2 field activities the first year of training, with an increase in classroom activities that include exercises with returned lunar samples. Subsequent year plans include additional field one-on-one field mapping exercises with geologist instructors. This activity will continue on a regular basis until crew assignment to a lunar crew. At that point, it is expected the crew will participate in dedicated field exercise similar to those conducted during Apollo. The transition to this curriculum will, of necessity, be gradual, but it is expected by the first human lunar landing in 2020, Constellation crewmembers will be as competant as their Apollo brethren in exploring geology of the Moon.

REPORT FROM ILEWG ON SCIENCE AND EXPLORATION QUESTIONS. B.H. Foing and International Lunar Exploration Working Group (ILEWG), *ILEWG* c/o *ESTEC/SRE-S, postbus 299, 2200 AG Noordwijk, NL, Europe*, (Bernard.Foing@esa.int) http://sci.esa.int/ilewg

Abstract: We shall report, with focus on science and exploration questions, on the ILEWG charter, goals and activities, on ICEUM "lunar declarations" and follow-up activities.

ILEWG charter: ILEWG , the International Lunar Exploration Working Group is a public forum created in 1994, sponsored by the world's space agencies to support "international cooperation towards a world strategy for the exploration and utilization of the Moon - our natural satellite". The charter of ILEWG is:

- To develop an international strategy for the exploration of the Moon
- To establish a forum and mechanisms for the communication and coordination of activities
- To implement international coordination and cooperation
- In order to facilitate communication among all interested parties ILEWG agrees to establish an electronic communication network for exchange of science, technology and programmatic information related to lunar activities

ILEWG meets regularly, at least, once a year, and leads the organization of an International Conference in order to discuss the state of lunar exploration.

Formal reports are given at COSPAR meetings and to space agencies.

ILEWG is sponsored by the world's space agencies and is intended to serve three relevant groups:

- actual members of the ILEWG, ie delegates and representatives of the participating Space Agencies and organizations - allowing them to discuss and possibly harmonize their draft concepts and plans
- team members of the relevant space projects - allowing them to coordinate their internal work according to the guidelines provided by the Charter of the ILEWG
- members of the general public and of the Lunar Explorer's Society who are interested and wish to be informed on the progress of the Moon projects and possibly contribute their own ideas

ILEWG activities and working groups: ILEWG task groups include science, technology, human aspects, socio-economics, young explorers and outreach, programmatics, roadmaps and synergies with Mars exploration. Users can obtain information on how to participate, as well as details on the latest news and events regarding lunar exploration, forthcoming meetings, relevant reports and documents of importance for the work of the ILEWG, summary descriptions of current lunar exploration projects (such as SMART-1, Chang'E1, Selene, Chandrayaan-1, LRO, LCROSS) funded by various space agencies, and basic data on the Moon itself. Activities of the related space agencies and organizations can also be found.

ILEWG has been organising International Conferences on Exploration and Utilisation of the Moon (ICEUM) since 1994, whose proceedings are published. It has also sponsored a number of activities, workshops, tasks groups and publications in collaborations with other organisations: COSPAR, space agencies, IAA, IAF, EGU (see references below). In accordance with its charter, ILEWG reports to COSPAR, and a summary was given at Montreal COSPAR2008 on ILEWG activities conducted since the previous COSPAR2006 assembly in Beijing. The recent ILEWG International Conference on Exploration and Utilisation of the Moon, were held respectively in Udaipur, India (ICEUM6, 2004), in Toronto, Canada (ICEUM7, 2005), in Beijing (ICEUM8, 2006) and Sorrento (ICEUM9, 2007).

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SMART-1 RESULTS AND LESSONS LEARNED FOR PREPARING FUTURE EXPLORATION

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Abstract: We shall report at LEAG/ ICEUM10 Lunar Conference 2008 on SMART-1 lunar highlights relevant for future lunar exploration. The SMART-1 spacecraft reached on 15 March 2005 a lunar orbit 400-3000 km for a nominal science period of six months, with 1 year extension until impact on 3 September 2006.

Overview of SMART-1 mission and payload: SMART-1 is the first in the programme of ESA's Small Missions for Advanced Research and Technology [1,2,3]. Its first objective has been achieved to demonstrate Solar Electric Primary Propulsion (SEP). SMART-1 science payload, with a total mass of some 19 kg, featured many innovative instruments and advanced technologies [1], with a miniaturised high-resolution camera (AMIE) for lunar surface imaging, a near-infrared point-spectrometer (SIR) for lunar mineralogy investigation, and a very compact X-ray spectrometer (D-CIXS) [4-6] for fluorescence spectroscopy and imagery of the Moon's surface elemental composition. The payload also included plasma studies (SPEDE and EPDP), deep-space telemetry (KaTE), a radio-science (RSIS), a Laser-Link and autonomous navigation (OBAN) investigations.

SMART-1 lunar science and exploration results:
AMIE (Advanced-Moon micro-Imager Experiment). AMIE is a miniature high resolution (35 m pixel at 350 km perilune height) camera, equipped with a fixed panchromatic and 3-colour filter, for Moon topography and imaging support [7,10,11]. Lunar North polar maps (Fig. 1) and South pole repeated high resolution images have been obtained, giving a monitoring of illumination to map potential sites relevant for future exploration .
D-CIXS (Demonstration of a Compact Imaging X-ray Spectrometer). DCIXS is based on novel detector and filter/collimator technologies, and has performing the first lunar X-ray fluorescence global mapping in the 0.5–10 keV range [4,5,9]. D-CIXS has been improved for the C1XS instrument on ISRO Chandrayaan-1.
SIR (Smart-1 Infra-Red Spectrometer). SIR has been operating at 0.9-2.6 μm carrying out mineralogical survey of the lunar crust. SIR has been improved for the Chandrayaan-1 SIR2 instrument.

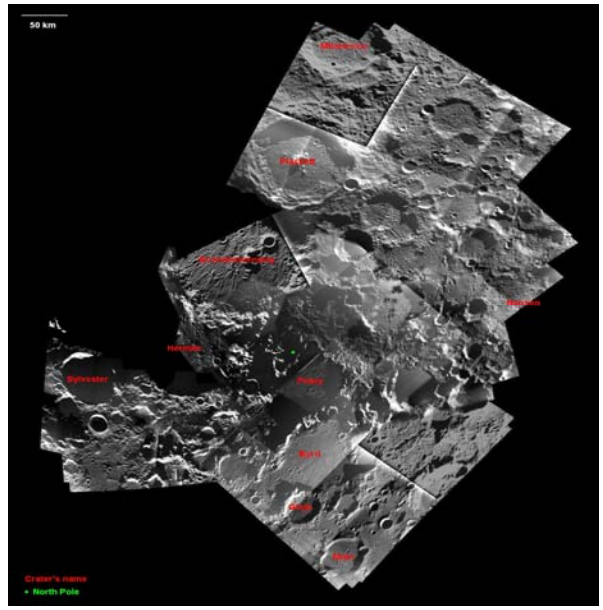

Fig. 1: SMART-1 /AMIE mosaic of the lunar North pole, covering an area of about 800 by 600 km, composed of about 30 images . These travel maps are used to prepare future polar lunar exploration.

The SMART-1 team collaborated with upcoming missions (Kaguya, Chandrayaan-1, Chang'E 1, LRO, LCROSS) and subsequent lunar landers (MoonNEXT, International Lunar Network). SMART-1 is contributing to prepare the next steps: survey of resources, monitoring polar illumination, mapping of sites for potential landings, international robotic villages and for future human activities and lunar bases.

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http://sci.esa.int/smart-1/, http://sci.esa.int/ilewg/

IMPROVING LUNAR SURFACE SCIENCE WITH ROBOTIC RECON. T. Fong[1], M. Deans[1], P. Lee[2], J. Heldmann[1], D. Kring[3], E. Heggy[3], and R. Landis[4]. [1]NASA Ames Research Center, Moffett Field, CA, terry.fong@nasa.gov. [2]SETI and Mars Institutes. [3]Lunar and Planetary Institute. [4]NASA Johnson Space Center.

Introduction: When humans return to the lunar surface near 2020, three key goals will be to setup infrastructure, build a lunar outpost, and conduct science. To help achieve these goals, we are developing integrated human robotic systems, including robotic reconnaissance to improve lunar traverse science[1].

Robotic Recon: In NASA's current lunar architecture, surface missions will be spaced on six month intervals. Initially, crew will be on the lunar surface less than 10% of the time. During the 90% of time between crew visits, robots will be available to perform surface tasks to prepare for subsequent missions, reduce risk, and make surface operations more efficient.

Prior to these surface missions, spacecraft in lunar orbit will be used to map the surface. However, remote sensing data may not be of sufficient resolution, nor view angle, to fully plan surface activity, such as crew traverses for field geology. Thus, it will be important to acquire supplemental data on the lunar surface.

One method for this is *robotic reconnaissance*, i.e., using a planetary rover to scout traverses, or sites, prior to human activity. Recon is a key phase of exploration and can be traverse-based (examining stations along a route) or survey-based (systematically collecting data in a bounded area). Instruments can be used to collect data about both the surface and subsurface. The data can then be used to triage and prioritize targets of interest to improve the productivity of crew traverses.

Approach: In our work, we use two third-generation K10 planetary rovers (Figure 1). Each K10 has four-wheel drive and all-wheel steering with a passive rocker suspension.

For robotic recon, the K10's are equipped with:

- 3D lidar. Provides *cm* to *m* measurements of topography (>2x resolution of the LRO LOLA)
- Color panoramic imager (60º x135º). Provides up to 2x resolution of the LRO LROC-NA, as well as oblique, surface views.
- Microscopic imager with 70 μm/pixel. Provides very high-resolution images of terrain.
- Ground-penetrating radar (wide-band, polarimetric, 900 MHz). Enables characterization and mapping of subsurface to 2m depth.

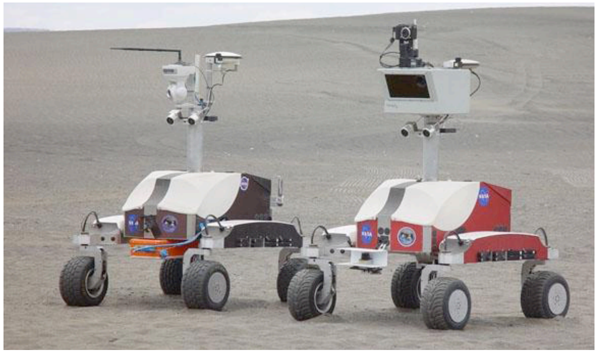

Figure 1: K10 robots with science instruments.

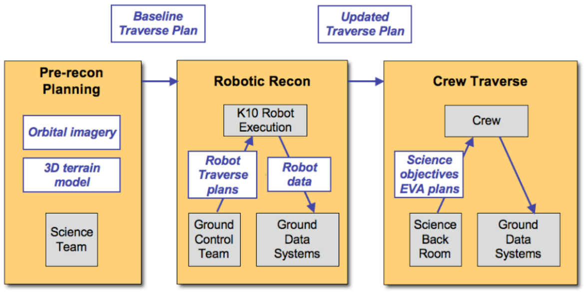

Figure 2: Traverse planning process

Figure 2 illustrates the science-driven traverse planning process that we use. Initially, a science team creates a baseline crew traverse using only orbital data and considering science objectives. Robotic recon is then performed to scout on, and near, the traverse route. Next, the robotic recon data is used to generate an updated crew traverse plan, which is then executed by crew with support from a science "backroom".

2008 Moses Lake Sand Dunes Field Test: In June 2008, we tested our robotic recon approach at Moses Lake Sand Dunes. During the test, we operated K10 rovers in robotic recon mode for four days at Moses Lake followed by a one hour crew EVA [1].

Our operations concept is derived from lessons learned by Apollo, Space Shuttle, Space Station, and the Mars Exploration Rovers [3]. Data collected during robotic recon is automatically processed by our geospatial ground data system. We use Viz[4], Google Earth, and web-based interfaces for data display.

Lessons Learned. For sites that were visited by the robot, the science team obtained detailed ground-level data that was used to improve a baseline traverse plan and briefing for the EVA crew. Overall, the test highlighted the differences between *robotic recon* and *robotic exploration*, such as done by MER. Whereas robot explorers are primarily science tools, the purpose of recon is to *high-grade* for subsequent human activity. This has a significant impact on science operations and how humans and robots work together.

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LUNAR BEAGLE: A SCIENCE PACKAGE FOR MEASURING POLAR ICE AND VOLATILES ON MOON. E.K. Gibson[1], C.T. Pillinger[2], D.S. McKay[1], I.P. Wright[2], M.R. Sims[3], L. Richter[4], L. Waugh[5] and the Lunar Beagle Consortium. [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]Dept. of Space Sciences, Leicester University, Leicester, UK. [4]Institute for Space Sciences, DLR, Bremen, Germany. [5]EADS-Astrium, Stevenage, UK. [everett.k.gibson@nasa.gov].

The Beagle 2 science package developed to seek the signatures of life on Mars 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 [1]. It can support the Space Exploration and Constellation Programs. The Beagle 2 scientific package has been selected by NASA for the Lunar Science Sortie Opportunity (LSSO) Concept Study. The Lunar Beagle package is envisioned as a separate payload on a lunar surface lander, or deployed by an astronaut, or carried by a lunar rover.

The Beagle system is analogous to the ALSEP instruments used on the Apollo missions [2]. It could operate with minimal human interaction or completely autonomously after deployment on the lunar surface.. The adaptation for sortie missions of scientific payloads developed for other planetary missions, such as the Beagle 2 science payload, has the major advantage of having already established engineering requirements, mass, power, data transmission rates, and costs [1]. A lunar modification of Beagle 2 should require decreased system overhead because of the elimination of the entry aeroshell, the vacuum system and possibly other components already budgeted for elsewhere in the carrier mission(s).

The Beagle 2 payload consisting of the Gas Analysis Package, Sample Acquisition System with subsurface sampling device, the mole, suite of scientific instruments (i.e. XRF, Mossbauer, cameras and spectrometers, power supply), was designed to operate on the Martian surface in a completely autonomous manner [1]. The key instrument is a magnetic sector mass spectrometer to analyze volatile species H, D/H, water abundances and other potential carbon and nitrogen containing molecules [3,4] trapped in cold regions of the moon. The Gas Analysis Package (GAP) combined a number a number of mass spectrometric functions including static and dynamic operation. It was the first instrument with a full chance of documenting *in situ* isotopic signatures in the soil and rock record.

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. Extensive testing already done on Earth demonstrate its sensitivity, precision and other operational parameters. The primary Beagle 2 sampling device (mole) can obtain subsurface samples as deep as two meters and would be ideal for seeking out subsurface ices [1] and implanting subsurface geophysical science instruments. The mole is envisioned to operate in two modes: (a) a subsurface sample collection device for obtaining samples for the Sample Handling and Processing Device prior to introduction into the furnaces connected to the mass spectrometer. and (b) emplacement of subsurface sensors such as seismic, heat flow, thermal conductivity and water detection; a variety of subsystems such as an onboard ion trap mass spectrometer are available for the instrumented mole. New power supply concepts are being investigated which may offer alternatives [5] and allow lunar night operations.

The Beagle payload is the ideal suite of instruments which are at a high degree of technology readiness for answering the critical questions about volatiles in permanently shadowed regions of the moon, including lunar transient environments and potential contamination of the lunar environment by human development on the moon.

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PROGRESS OF THE MOONLITE PENETRATORS. R. A. Gowen and A. Smith[1], of the U.K.Penetrator Consortium, [1] University College London, Mullard Space Science Laboratory, Holmbury St Mary, Dorking, Surrey, Rh5 6NT, UK. Members identified in the Acknowledgements. (Email: rag@ucl.ac.uk).

Summary: We present the latest results from the full scale impact trials held on May 19-21 2008; the current program status including funding; and the possibilities for international contributions to this MoonLTIE mission arising from collaboration with communications and the natural but dramatic and useful ending of your mission with a valuable contribution to knowledge of the internal structure of the Moon. We also outline the next steps which hopefully lead to a launch in 2014.

Introduction: The MoonLITE mission is planned to operate for 1 year and involves implanting 4 penetrators globally spaced at impact speeds of ~300m/s. Each coming to rest a few metres under the lunar surface will provide a solid emplacement for an effective seismic network and for geochemical and heat flow investigations. Polar emplacement will also allow an exciting ability to characterize the presence of water-ice currently indirectly inferred in the permanently shaded craters. They will also allow investigation of the presence of other volatiles, possibly including organics of astrobiologic interest.

This mission will inform future ILN (International Lunar Network) missions of the global seismic environment; provide key information on regional sites at potentially high risk for damaging surface seismic events; and key information of the existence of IRSU water. Radiation monitors will also allow characterisation of the lunar regolith for astronaut shielding.

Potential International Collaboration: The timing of this mission may allow arrangement of coincident impacts of other spacecraft which are at the end of their natural mission lifetime, to provide strong artificial seismic signals to allow probing the deep interior of the Moon. Perhaps no better way to end an otherwise very successful mission ?

In addition, the presence of multiple Lunar orbiting spacecraft may allow the possibility of inter-communication between different missions to enhance telemetry rates from the lunar surface and provide mission fault tolerance.

Acknowledgements: Members of the U.K. Penetrator consortium are as follows: R.A.Gowen (MSSL/UCL), A.Smith (MSSL/UCL), R. Ambrosi (Leicester), M. Anand (OU), A.J. Ball (OU), S. Barber (OU), J.C. Bridges (Leicester), P.Brown (IC), A.Bruce (QintiQ), P.Church (QinetiQ), A.J. Coates (MSSL/UCL), P.Coker (MSSL/UCL), G.Collinson (MSSL/UCL), A.C. Cook (Aberystwyth), I.A. Crawford (Birkbeck), Y. Gao (Surrey), K. Green (QinetiQ), A.Griffiths (MSSL/UCL), P.Guttridge (MSSL/UCL), A. Hagermann (OU), G.Hainsworth (QinetiQ), M.A. Hapgood (RAL), T. Hopf (IC), A.P. Jones (UCL), K.H. Joy (Birkbeck), M.Knapmeyer (DRL), S. Kumar (IC), A.Phipps (SSTL), N.Penny (QinetiQ), W.T. Pike (Imperial), K.Rees (MSSL/UCL), K. Ryden (QinetiQ), R.F.Scott (QinetiQ), S.Sheridan (OU), M.Sims (Leicester), P. Smith (MSSL/UCL), D.Talboys (Leicester), C. Theobald (MSSL/UCL), V.Tong (UCL), N.Wells (QinetiQ), M.C.R. Whillock (MSSL/UCL), L. Wilson (Lancaster), B.Winter (MSSL/UCL), J. Woodhouse (Oxford).

C1XS - THE CHANDRAYAAN-1 X-RAY SPECTROMETER. Manuel Grande[1], Brian J. Maddison[2], P. Sreekumar[3], Juhani Huovelin[4], Barry J. Kellett[2] Chris J.Howe[2], Ian. A. Crawford[5], D.R. Smith[6] and the C1XS Team[7], [1]Institute of Mathematical and Physical Sciences, University of Wales, Aberystwyth, SY23 3BZ, UK, M.Grande@aber.ac.uk, [2]Rutherford Appleton Laboratory, Chilton, UK, [3]Space Astronomy & Instrumentation Division, ISRO Satellite Centre, Bangalore, India, [4]The Observatory, Univ. of Helsinki, Finland, [5]School of Earth Sciences, Birkbeck College London, London, UK, [6]Brunel University, Uxbridge, UK, [7] See below

The Chandrayaan-1 X-ray Spectrometer (C1XS) is a compact X-ray spectrometer for the Chandrayaan-1 lunar mission. It exploits heritage from the D-C1XS instrument on ESA's SMART-1 mission. By comparison with SMART-1, Chandrayaan-1 is intended as a science rather than a technology mission, leading to far more favourable conditions for science measurements. C1XS is designed to measure absolute and relative abundances of major rock-forming elements (principally Mg, Al, Si, Ti, Ca and Fe).

The baseline design consists of 24 nadir pointing Swept Charge Device (SCD) detectors, which provide high detection efficiency in the 1 to 7 keV range, which contains the X-ray fluorescence lines of interest. Micro-machined collimators provide a 14 degree FWHM FOV, equivalent to 25 km from 100km altitude. A deployable door protects the instrument during launch and cruise, and also provides a Fe55 calibration X-ray sources for each SCD. Refinements to the electronics, onboard software and thermal design greatly increase detector stability and signal to noise ratio compared to D-C1XS. This will result in a significantly improved energy resolution which should be better than 200eV throughout the lifetime of the mission (Fig 2). In order to record the incident solar X-ray flux at the Moon, essential to derive absolute lunar elemental surface abundances, C1XS carries an X-ray Solar Monitor (XSM). In comparison to D-C1XS, C1XS and XSM has been far better calibrated.

C1XS will arrive at the Moon in the ascending phase of the solar cycle, and the high incident X-ray flux coupled to an orbit optimized for science, means that we will obtain composition data accurate to better than 10% of major elemental abundances over the entire surface. Hence C1XS will be well-placed to make significant contributions to lunar science. The ~25 km spatial resolution enables C1XS to address a number of smaller-scale geological issues which also refine our understanding of lunar geological evolution.

C1XS is built and operated by an international team led from the Rutherford Appleton Laboratory. The PI is Prof M. Grande at Aberystwyth University. A major science and design contribution comes from ISRO Satellite Centre, Bangalore, India, and the XSM comes from the University of Helsinki, Finland. The Science team is chaired by I. A. Crawford.

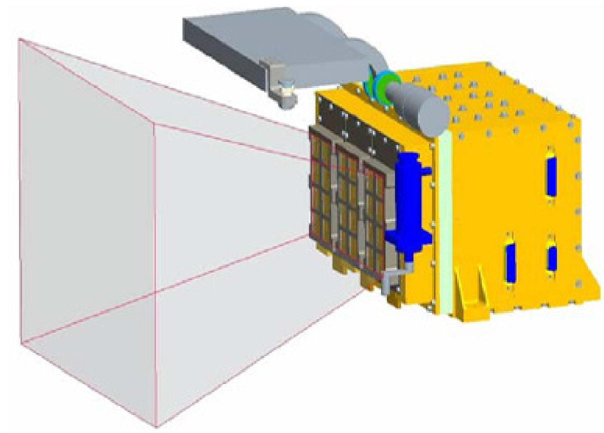

Fig 1: CAD image of C1XS showing coalligned front detectors, deployable radiation shield and 14^{O} FOV.

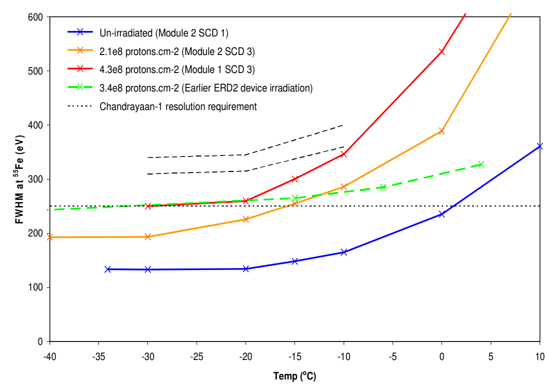

Fig 2: SCD FWHM at Mn-Kα vs. temperature, before and after irradiation. Maximum operating temperature is 17.5^{O} Note favourable comparison with D-C1XS performance shown in between the dashed lines

The C1XS Team: M Grande, A Cook, M. Wilding, (Aberystwyth Univ, UK), BJ Maddison, BJ Kellett, CJ Howe (Rutherford Appleton Lab, UK), P. Sreekumar, A Shrivastava, S Narendranath, (ISRO, India), J Huovelin (Helsinki Univ, Finland), I Crawford, K Joy (Birkbeck Coll. London, UK), C L Duston ,O Gasnaut, S Maurice, (OMP, Toulouse, France), DR Smith (Brunel Univ, UK), D Rothery, A Holland M Anand (Open Univ UK), S Russell, Natural History Museum, UK), JN Goswami, N.Bhandari (PRL India), D Lawrence, (Los Alamos National Lab, USA), V Fernandes, (U Berkley, USA), T. Okada, (ISAS, Japan), B Foing (ESTEC), C Pieters (Brown University, USA), M Wieczorek (IPG Paris, France)

LUNAR EXPLORATION SURFACE SCENARIOS MEASURED BY SCIENTIFIC GOALS AND OBJECTIVES J.E. Gruener, NASA-Constellation Lunar Surface Systems Project Office, Mail Code ZS, NASA-Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, john.e.gruener@nasa.gov.

Introduction: The current United States Space Exploration Policy emphasizes a human return to the Moon as a location near the Earth where the nation can learn how to work and live on a planetary body. Major goals for this progarm are to: extend human presence to the Moon to enable eventual settlement; pursue scientific activities that address fundamental questions about the history of Earth, the solar system and the universe - and about our place in them; test technologies, systems, flight operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond; provide a challenging, shared and peaceful activity that unites nations in pursuit of common objectives; expand Earth's economic sphere, and conduct lunar activities with benefits to life on the home planet; and use a vibrant space exploration program to engage the public, encourage students and help develop the high-tech workforce that will be required to address the challenges of tomorrow. The National Aeronautics and Space Administration (NASA) is conducting engineering trade studies to develop lunar transportation architectures, lunar surface system concepts, and lunar surface scenarios. This presentation discusses the current lunar exploration surface scenarios and their ability to address the goals and objectives of the scientific community.

Science Objectives: In 2007, several reports were published discussing the goals and objectives of the scientific community for lunar exploration activities. The National Research Council's (NRC) “The Scientific Context for Exploration of the Moon” primarily focused on the science concepts and goals of the planetary science community. More recently, the NRC report “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond” focused on earth science. The NASA Adisory Council's (NAC) “Workshop on Science Associated with the Lunar Exploration Architecture” listed recommendations based on the NAC's Planetary Science, Astrophysics, Heliophysics, Earth Science, and Planetary Protection subcommitees, while the NAC “Lunar Biomedical Workshop” focused on life science. NASA's recent report “Heliophysics Science and the Moon” lists the goals and objectives of the heliophysics community.

Reference Scenarios: During the past several years, NASA has developed a number of lunar surface scenarios describing the types of systems needed on the Moon to allow humans to work and live in that hostile environment. Through the work of the Lunar Architecture Team (LAT) and the Constellation Architecture Team-Lunar (CxAT-lunar), conceptual designs for habitats, power systems, surface mobility, and other surface systems have been developed. The accumulation of the these systems on the Moon provides certain sets of capabilities for user communities, such as the scientific community. Most of the surface architecture work has focused on the lunar South Pole, particulary the area near Shackleton crater. The primary drivers for the location of these scenarions were engineering in nature, namely the relative ease of access to the landing site as opposed to other locations on the Moon, almost continuous sunlight in elevated locations near the south pole, and the relatively benign thermal environement of the poles compared to the rest of the lunar surface. New scenarios are currently being worked that include not only a polar outpost, but also human sortie missions to other locations on the Moon.

Scenario Evaluation: Traditionally, the merit of a lunar surface scenario, has been measured and evaluated by engineering and cost parameters. However, how well a particular scenario addresses scientific goals and objectives is also an important metric to consider. To that end, work is underway within NASA’s Constellation Program Office to not only measure how well the existing lunar scenarios are addressing the goals and objectives of the scientific community, but to influence new lunar scenarios during their creation, and also the surface system concepts that the scenarios are built around.

LIVING ON THE LUNAR SURFACE – A MINIMALIST APPROACH. A. N. Guest, W. K. Hofstetter, P. M. Cunio, R. McLinko, E. Grosse, and J. A. Hoffman. Massachusetts Institute of Technology.

Introduction: NASA's current plans for returning to the Moon include the build-up of a lunar outpost at the South Pole [1]. Currently planned architectures propose an outpost consisting of several connected modules, each one being delivered on its own cargo flight. This concept requires three discrete, complex operations: offloading the elements from the lander, translation of the elements along the surface, and in-situ assembly and connection.

Due to their complex nature, these operations introduce several disadvantages into the campaign architecture including:

- Increase in operational cost and risk
- Increase in development cost and risk
- Mass penalty
- Potential program schedule delay

Because of these disadvantages, it is beneficial to examine other possible architectures that eliminate these operations.

The Non-Connected Architecture: To "side-step" the technical challenges of developing the required hardware for offloading, translation, and assembly, the authors present a revolutionary lunar outpost architecture that focuses on transporting the crew and supplies across the lunar surface instead of the habitation modules. This architecture is made feasible by the use of the Small Pressurized Rovers (SPRs) that are included in the campaign for long-distance surface exploration.

The outpost infrastructure includes a habitat module, a laboratory module, and several pressurized logistics modules. Each of these elements remains on the lunar surface and the crew uses the SPR to transfer between them as necessary. Two types of transits are envisioned: hab-lab transits and logistical re-supply transits. Analysis shows that only 5% of the crew's productive time will be spent on these transits. Using the mass savings made available through this architecture to deliver extra logistics to extend the overall campaign surface time can offset this loss of time.

Element Design: This paper includes discussion of the required design of the subsystems of the major elements in the architecture (habitat, laboratory, and Pressurized Logistics Modules) that both make a "non-connected architecture" feasible and optimize the elements for the new architecture. The main design features analyzed are the structural components, such as tunnels and berthing adapters, necessary for allowing the crew to transfer from the habitat, situated on top of the lander, to the SPR on the lunar surface, and the Environmental Control and Life Support System (ECLSS). The architecture incorporates an ECLSS system that is split between the habitat and laboratory, which is made feasible by having the crew transfer consumables during their transits.

Assessment of Program-Level Impact: The programmatic details involving cost, schedule, and risk are discussed in terms relative to NASA's proposed architecture. Several metrics are developed to demonstrate the benefits of the proposed architecture in terms of performance, cost, schedule, and risk. The non-connected architecture is either similar or better for all metrics considered when compared to NASA's currently planned architecture.

Public Outreach: As part of this projects, the team members visited a local elementary school in Boston to discuss how humans will live and work on the moon. A 30-minute presentation was followed by one-on-one time with each of the students to answer their various questions about space exploration.

Conclusion: This report outlines a minimalist lunar surface system architecture concept, which significantly reduces the amount of surface assembly operations and associated infrastructure required. By having the crew transit between elements on the lunar surface, as opposed to offloading, translating, and assembling habitation modules, lower risk and cost is achieved without any loss in performance for the overall lunar campaign when compared to NASA's currently planned architecture.

References: [1] Cooke, D. et al. (2008) *Lunar Architecture Update*, AIAA 3rd Space Exploration Conference. Denver, CO.

TOWARD MOON-BASED VERY LONG-WAVELENGTH RADIO ASTRONOMY FACILITY: SCIENCE DRIVES AND TECHNOLOGICAL CHALLENGES.

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Scientific laboratories at manned and un-manned Moon bases are top priorities for the next wave of exploratory missions. Environmental conditions on the Moon are beneficial for various types of experimental research. Very Long Wavelength Astronomy (VLWA) is among the most attractive scientific disciplines for the suit of Moon-based laboratories.

Space-based facilities has revolutionised astronomy by opening up several hitherto inaccessible windows in the spectrum. The opening of each new spectral window has resulted in unexpected discoveries and made it possible to obtain a comprehensive picture of physical processes in celestial sources. One of the last remaining unexplored regions of the spectrum is at the lowest radio frequencies. Radio emission below 10 MHz (wavelengths longer than 30 m) is inaccessible from the Earth surface due to absorption and scattering in the ionosphere.

Unique new science areas for VLWA studies include: (i)Investigation of radio sky at so far inaccessible regime of electromagnetic radiation; (ii) Cosmological “experiments” with “fossil” relativistic electrons; (iii) Investigation of ultra-high-energy cosmic rays via VLWA emission from particle interactions with the Moon; (iv) Solar system “weather”, including coronal mass ejections, (v) Searches for Jupiter-like exoplanets.

In addition to the astrophysical tasks mentioned above, the VLWA facility on the Moon can be implemented as a Wide Area Network, as pioneered by the Earth-based Low Frequency Array (LOFAR). Inclusion of non-astronomy sensors, such as seismic detectors to conduct selenological studies, can greatly enhance scientific and “exploratory” return of the mission. The LOFAR is being constructed in The Netherlands. It will operate in the frequency range 20 - 220 MHz. Several other projects will aim at addressing cosmological problems by studying the Universe at the range of frequencies below 100 MHz. These and other new radio astronomy facilities will lay the scientific and technological ground for VLWA on the Moon.

We will present a multi-step approach toward creating a permanent VLWA observatory on the Moon. Its first phase would include a demonstrator to be deployed as a small-scale scientific payload onboard one of the lunar missions of the next decade. A concept of an affordable full-scale observatory will be presented in the context of a long-term Moon exploration programme.

LUNAR CRATER OBSERVATION AND SENSING SATELLITE (LCROSS) MISSION: OPPORTUNITIES FOR OBSERVATIONS OF THE IMPACT PLUMES FROM GROUND-BASED AND SPACE-BASED TELESCOPES. J.L. Heldmann[1], T. Colaprete[1], D. Wooden[1], E. Asphaug[2], P. Schultz[3], C.S. Plesko[2], L. Ong[2], D. Korycansky[2], K. Galal[1], and G. Briggs[1], [1]NASA Ames Research Center, Moffett Field, CA, 94035, [2]University of California at Santa Cruz, Santa Cruz, CA, 95064, [3]Brown University, Providence, RI, 02912

Introduction: The primary objective of the LCROSS (Lunar Crater Observation and Sensing Satellite) mission is to help advance the Vision for Space Exploration by investigating the presence of water on the Moon. The LCROSS mission, which is a comanifested payload launching with the Lunar Reconnaissance Orbiter, will use the Atlas V Centaur Earth departure upper stage of the launch vehicle as a 2000 kg kinetic impactor. The impact creates an ejecta plume whose properties, including water ice and vapor content, will be observed a shepherding spacecraft (S-S/C) plus Earth- and space-based telescopes. Following a similar trajectory of the EDUS, the S-S/C will fly through the EDUS impact plume and then the 700 kg 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 Characterization: The LCROSS mission uses the impact of the Centaur to excavate and eject lunar surface material from a permanently shadowed region into sunlight where the ejecta can be imaged and spectroscopically studied at visible through mid-IR wavelengths by the LCROSS S-S/C. Modeling the impact facilitates effective planning and execution of the observational campaign.

Models for the LCROSS impact are based on numerical hydrodyanamic codes, impact experiments with the NASA Ames vertical gun, and analytical models using semi-empirical scaling relations derived from laboratory experiments. All approaches contribute information to the task of guiding the design of the LCROSS mission and observational campaign. Such a variety of approaches and the corresponding ranges of results will very likely prove more useful in bracketing the expected outcomes.

To aid in the formulation of the LCROSS mission and measurement design, a compilation of model results has been built which summarizes the current best estimate for the impact event. This summary, called the Current Best Estimate Impact Model (CBEIM), includes both high and low values for a variety of relevant physical quantities including crater dimensions and ejecta velocities. In most cases the "current best estimate" was used for design purposes, however, on a case-by-case bases additional "margin" was allowed for by using the model results between the best estimate and the modeled low estimate (e.g., often the values closer to the low-end expectation for the total ejected mass above 2 km were used in order to build in margin). To date, models for the impact indicate that the impact flash will evolve in tens of milliseconds and the impact ejecta will rise into sunlight and fall back to the lunar surface in less than about 2 minutes, thereby motivating the use of rapid measurement techniques for ground- and space-based telescopes. Only the temporal evolution of the OH^- exosphere is expected to persist for more than tens of minutes.

Observational Support: Ground-based and orbital observatories can observe the dust and water vapor plume caused by the two impacts into the lunar surface. Compared to the Deep Impact (DI) Mission encounter with comet 9P/Tempel, LCROSS's Centaur impact plume will have 100 times less mass at 360 times closer range, so the surface brightness will be higher. However, the dust-to-ice ratio for the impact location regolith is expected to be orders of magnitude greater, perhaps ~100 in comparison to ~0.5 for Deep Impact. Therefore, ground-based telescopes can observe the thermal evolution of and the properties of the dust in the ejecta plume, and 8-10 m class telescopes will be required to search for water vapor using the non-resonant fluorescent lines at ~3 μm. The longer time scale evolution of the OH^- exosphere can be followed by telescopes around the world. The timing of the two impacts should allow for simultaneous observations from Hawaii, the Continental US, and possibly from South America (e.g. Chile). We encourage astronomers to consider observing these impact events and the LCROSS team will make all efforts to provide the necessary information regarding the impacts to interested observers in a timely manner.

The use of Solar Heating and Heat Cured Polymers for Lunar Surface Stabilization. P. E. Hintze[1], J. P. Curran[2] and T. A. Back[2]. [1]NASA Corrosion Technology Laboratory, Mail Stop KT-E3, Kennedy Space Center, FL 32899 Paul.E.Hintze@nasa.gov, [2]ASRC Aerospace, Mail Stop ASRC-24, Kennedy Space Center, FL 32899, Jerome.Curran-1@ksc.nasa.gov, [2]ASRC Aerospace, Mail Stop ASRC-24, Kennedy Space Center, FL 32899 Teddy.Back-1@ksc.nasa.gov.

Introduction: Dust ejecta can affect visibility during a lunar landing, erode nearby coated surfaces and get into mechanical assemblies of in-place infrastructure. Regolith erosion was observed at many of the Apollo landing sites. This problem needs to be addressed at the beginning of the lunar base missions, as the amount of infrastructure susceptible to problems will increase with each landing. Protecting infrastructure from dust and debris is a crucial step in its long term functionality. A proposed way to mitigate these hazards is to build a lunar launch pad.

Other areas of a lunar habitat will also need surface stabilization methods to help mitigate dust hazards. Roads would prevent dust from being lifted during movement and dust free zones might be required for certain areas critical to crew safety or to critical science missions.

Work at NASA Kennedy Space Center (KSC) is investigating methods of stabilizing the lunar regolith including: sintering the regolith into a solid and using heat or UV cured polymers to stabilize the surface. Sintering, a method in which powders are heated until fusing into solids, has been proposed as one way of building a Lunar launch/landing pad. A solar concentrator has been built and used in the field to sinter JSC-1 Lunar stimulant. Polymer palliatives are used by the military to build helicopter landing pads and roads in dusty and sandy areas. Those polymers are dispersed in a solvent (water), making them unsuitable for lunar use. Commercially available, solvent free, polymer powders are being investigated to determine their viability to work in the same way as the solvent borne terrestrial analog.

This presentation will describe the ongoing work at KSC in this field. Results from field testing will be presented. Physical testing results, including compression and abrasion, of field and laboratory prepared samples will be presented.

Methods and results: A solar concentrator with a 1 m^2 collection area has been constructed for field testing at KSC, as shown in figure 1. The solar concentrator consists of a large lens mounted on a frame that allows the lens to move and follow the sun. The focal point of the lens is pointed downward to allow for rastering across a surface. The highest measured temperature created by the solar concentrator has been 1350°C. The solar concentrator easily achieves the temperatures needed to sinter or melt JSC-1 lunar simulant.

Initial experiments using the solar concentrator have focused on evaluating how thick a surface can be sintered and how best to sinter large areas. The first tests involved simply focusing the light on a bed of JSC-1. When this is done the top surface quickly melts at the focal point. Within two to three minutes, a combination of melting and sintering occurs to a depth of about 6 mm. Continued heating after this time does not increase the thickness of the sintered area at the same rate.

We are investigating the use of UV or heat cured polymers as additives or topcoats for the sintered product. The heat cured polymers are powders, that when heated, melt together and cure. We have been investigating products that are commercially available powder coatings used in various industries including high temperature applications. The powders do not contain or require a solvent, and can be applied by an electrostatic spray or simply by distributing over a surface. Abrasion testing is being performed on the powder coatings by themselves and in various mixes with JSC-1 ranging from 10 – 50% powder by weight. Testing is currently underway to identify the amount of polymer needed to cover an area, so that accurate masses can be calculated.

We have demonstrated that the polymer can be cured with the solar concentrator. Both 33% and 50% polymer:JSC-1 simulant mixes have been cured with the solar concentrator. A small area about 6 cm in diameter and 1 cm deep was solidified with the solar concentrator. This demonstration shows the ease in which the polymers can be used form a solid surface.

Figure 1: Solar concentrator used in sintering experiments at KSC.

ON STATION KEEPING OF SPACECRAFTS WITH SOLAR SAIL AROUND THE EARTH-MOON COLLINEAR LIBRATION POINTS X. Y. Hou[1,2] , L Liu[1,2] and W. Zhang[1,2], [1]Astronomy Department, Nanjing University, Nanjing 210093, China, lliu@nju.edu.cn , [2]Institute of Space Environment and Astronautics, Nanjing University, Nanjing University, Nanjing 210093, China.

Introduction: The conditional stability and fixed position of collinear libration points in the earth-moon system make them potential candidates for future moon explorations. Due to the essential instability of these points and various perturbations in the real solar system, orbit control is necessary for spacecrafts moving around these points. Spacecrafts sent to collinear libration points till now all fulfill their station keeping with impulsive maneuvers. However, station keeping strategies with continuous low-thrust were also studied in concept.

One alluring kind of continuous thrust is the solar radiation pressure. With the resurgence of solar sailing technology, various applications of solar sails in the collinear libration point missions have been studied, including station-keeping, transfer between orbits around collinear libration points and formation flying. Most of these studies are about the Sun-Earth+Moon system for which Circular Restricted Three-Body Problem (CRTBP) is a good approximation. For the Earth-Moon system, however, the circular restricted three-body problem is no longer a good approximation due to large gravitational perturbations from the sun. Besides, the geometrical configuration of the spacecraft with respect to the sun in the earth-moon system is different from that of the sun-earth moon system where the radiation body is one of the primaries.

With these differences, orbit design and control with solar sail around the collinear libration points in the earth-moon system should be different from those in the sun-earth+moon system. In our paper, a low-order analytical solution considering the gravitational perturbations from the sun for a sun-facing spacecraft were firstly constructed. Then a loose control strategy with solar sail was proposed. Two modes were considered. One mode is to keep the lightness parameter constant and change the yaw and pitch angle of the solar sail. The other one is to keep the yaw and pitch angles constant and change the lightness parameter of the solar sail. Some numerical simulations were made and the results were discussed in comparison

Paper Title:
ESA Preparation for Human Exploration

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Organization(s):
European Space Agency, ESTEC, Directorate of Human Spaceflight, Microgravity and Exploration Programmes

Abstract Text:
The long term goal of the Aurora Exploration Programme is Human exploration of Mars. In preparation for this, exploration of the Moon is a necessary step to provide demonstration of capabilities, mandatory for long duration human spaceflight.

With the European Columbus module attached to the ISS, Europe has access to a world class laboratory in space for microgravity research, technology demonstration and preparation for future human exploration missions.

The ongoing phase of the exploration programme has been focused on defining the overall European strategy and exploration architecture within the global exploration environment. System studies as well as focused technology developments are in progress (e.g. development of regenerative life support).

The European Space Agency is now preparing the next steps for human space exploration by continuing the exploitation and utilisation of the ISS, by analysing the European use of the ISS w.r.t. possible evolution and overall lifetime extension, by addressing crew transportation developments, by studying particular European elements for human Lunar exploration and general human space exploration technologies.

THE NASA-ESA COMPARATIVE ARCHITECTURE ASSESSMENT. B,. Hufenbach [1] and R. Leshner[2], [1]ESA, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands, Bernhard.Hufenbach@esa.int , [2]NASA, 300 E St SW, Washington, DC, 20546, USA, richard.b.leshner@nasa.gov

The National Aeronautics and Space Administration (NASA) is currently studying lunar outpost architecture concepts, including habitation, mobility and communication systems, to support U.S. lunar exploration and science objectives. Elements of a surface architecture will rely on the Ares I and Ares V launch vehicles, the Orion crew exploration vehicle, and the Altair lunar lander for transport to the Moon. The European Space Agency (ESA) is currently studying scenarios and associated architectures for human space exploration to follow the International Space Station Program. These studies are at their earliest conceptual stage and fall into three general scenario categories (see below), each with their own technical capabilities and related timeframes, and each having the potential to constitute a distinct European contribution to future lunar exploration missions.

In January 2008, NASA and ESA agreed to conduct a comparative architecture assessment to determine if their respective lunar architecture concepts could complement, augment, or enhance the exploration plans of the other. Representatives from NASA and ESA engaged in a series of joint, qualitative assessments of potential ESA capabilities as applied to NASA's architecture concepts. Initial findings from these assessments, with respect to each potential ESA category under study, are as follows:

1) Provision of Stand-Alone Capabilities

<u>Automated Lunar Cargo Landing System</u>: This capability (approximately 1.5 metric tons of payload to the lunar surface) would significantly extend surface exploration opportunities by enabling enhanced mobility or extended habitation, and creates more opportunities for science. Further quantitative analysis is required to determine how an ESA lander, combined with various mission scenarios could enhance global lunar surface exploration and enable potential joint missions.

<u>Communication and Navigation Systems:</u> Beyond a basic capability for communication to be secured by NASA, ESA systems for enhanced communication and navigation could provide significant mission enhancement for all NASA mission scenarios. There are also opportunities for international commercial engagement for the provision of communications services. In both cases, opportunities for detailed collaboration merit further dialogue.

2) Crew Transportation Elements Development

<u>Human Crew Transportation to low-Earth orbit (LEO), including a human-rated Ariane 5 launch vehicle and a crew transportation vehicle:</u> Experience on the ISS demonstrates that redundant transportation is welcome. However, real redundancy with NASA's architecture requires a transportation capability that has at least access to lunar orbit.

<u>Orbital Infrastructures:</u> A low lunar orbiting station as analyzed within the ESA transportation architecture studies and that can be utilized by NASA has the potential to enhance mission safety and performance, and could enable different mission profiles. To fully understand the benefits of this station would require further dialogue. Other ESA orbital infrastructure concepts (LEO, Lagrange points) do not have synergy with NASA's architecture.

3) Development of Lunar Surface Elements

<u>Surface Habitation Elements or a Surface Rover</u>: Each of these is a fundamental, enabling component of any surface architecture. These capabilities merit further quantitative analysis to determine how they may enable joint lunar exploration missions or enhance total mission capabilities.

There are differences between what NASA believes to be its key capabilities and the three categories of potential ESA contributions to space exploration. For NASA, the key capabilities identified include the transportation elements of the Constellation Program that NASA is committed to developing; they are part of NASA's mandate to explore, as expressed in both the 2004 U.S. Space Exploration Policy and 2005 NASA Authorization Act. For ESA, future contributions to human space exploration are similar to NASA's key capabilities in that they address areas of high strategic interest to the agency and to Europe as a whole, but final decisions on their development and implementation have yet to be made, and likely will not be made final until 2011. In this respect any particular ESA contribution is more like the surface exploration elements NASA has examined during its LAT exercises, which will not receive funding for development until 2011. An important goal of the of the CAA therefore is to provide the reader an early perspective on opportunities for long-term collaboration between NASA and ESA; a perspective which can be valuable in the near-term as programmatic and funding decisions are being made. Details of the joint NASA-ESA work which has lead to the above findings will be presented together with updates on the continuing joint work.

European Lunar Landing System. B. Hufenbach[1], O. Mongrard[2] and W. Carey[3], [1] ESA, The Netherlands, bernhard.hufenbach@esa.int, [2] ESA, The Netherlands, Olivier.mongrard@esa.int, [3] ESA, The Netherlands, William.carey@esa.int

Introduction: Human lunar exploration requires access to the lunar surface for crew and cargo. While a large payload performance is a pre-requisite for crew access and initial outpost build-up, a variety of missions do not necessitate such capacity. Therefore a cargo lander system can be a key element of a lunar exploration architecture.

A lunar lander using the full Ariane 5 capability to Lunar Transfer Orbit could deliver up to about 2 tons of gross payload mass to the lunar surface depending on the launcher version considered. The lunar cargo lander needs to be operational in the timeframe of the human return to the moon around 2018-2020. In order to develop such a vehicle several capabilities including soft precision landing, hazard avoidance (LIDAR, camera), night-time survival on the lunar surface (e.g. RHU) are required together with an engine class not available currently in Europe.

The medium thrust engine development which is a pre-requisite for the lunar cargo lander could have applications within other programs such as VEGA upper-stage, crew space transportation vehicle (abort to orbit) and could open further opportunities in Exploration/science missions (e.g. Mars soft landing).

The payload capacity of the Ariane 5 based lander opens a broad range of lunar exploration scenarios, even though they may have quite distinct mission objectives. The cargo lander could form a significant contribution as a major element in an international lunar exploration architecture while providing a versatile and flexible system for utilisation in a broad range of lunar missions based on European own interests and objectives.

The possible scenario options for the cargo lunar lander include:

- Independent lunar exploration missions for science, technology demonstration and research;
- Delivery of regular logistics to a lunar base;
- Provision of consumables for extended surface exploration range and duration;
- Delivery of surface assets, be they stationary or with mobility, in order to support and accelerate lunar outpost build-up or for science and technology demonstration.

For example, the provision of two logistic landers a year during the early lunar base build-up can improve significantly the early crew surface stay duration through the deployment of life support and crew consumables and can also save a full AresV/Altair cargo mission after a few years.

The availability of such a logistic vehicle would simplify the operations of the large crew lander and extend crew surface activities by providing a dissimilar redundancy in the critical delivery of supplies to the crew and thus improving the overall mission assurance.

Such a system could especially be utilised by NASA in its proposed lunar activities as mentioned before, but could also be of high interest for other potential International Partners interested in the Moon, such as China, Russia, India and Japan.

METHOD TO INVESTIGATE THE CHARGING CHARACTERISTICS OF LUNAR DUST PARTICLES.
S. A. Irwin[1], S. T. Durrance[1], C. R. Buhler[2], and C. I. Calle[3], [1]Department of Physics and Space Sciences, Florida Institute of Technology, Melbourne, FL 32901, [2]ASRC Aerospace, Kennedy Space Center, FL 32899, [3]Electrostatics and Surface Physics Laboratory, NASA Kennedy Space Center, FL 32899.

Introduction: Previously, Buhler, et al. had previously had devised a test method for *in situ* measurement of electrostatic properties of lunar dust [1]. We have designed a laboratory experiment to investigate the induction charging and charge decay characteristics of lunar dust particles. The induction and charge decay characteristics of granular materials depend on the surface resistivity of the material. Since the surface resistivity properties of hydrophilic materials can be easily controlled with humidity, we have conducted initial experiments with borosilicate glass beads in a 10-20 kV constant electric field at various humidities in a controlled environmental chamber. We report on the results of these initial experiments.

Experimental Setup: The trials are conducted in an environmental chamber at 23 C and at a particular humidity. The apparatus producing the electric field consists of two parallel brass electrodes, 25 cm in diameter, with a separation of 1.0 cm, mounted in an adjustable dielectric frame (Figure 1). The top electrode is connected to a DC high voltage power source, and the bottom electrode is connected to earth ground. Borosilicate glass beads of diameter 1 mm are cleaned with 91% IPA solution and dried through baking. The beads are placed in the chamber for 24 hours to allow for adequate adsorption of humidity [2]. Six beads are placed on the bottom electrode and spaced approximately uniformly. It was important that the specimens not contact each other as this will affect charge acquisition and decay time [3]. The chamber is then flooded with positive and negative ions to remove any residual electrostatic charge on the beads and electrodes. After disconnecting the ion source, the trial is recorded by camera as we initiate the high voltage. A trial duration lasts three hours and provides us with many samples for analysis.

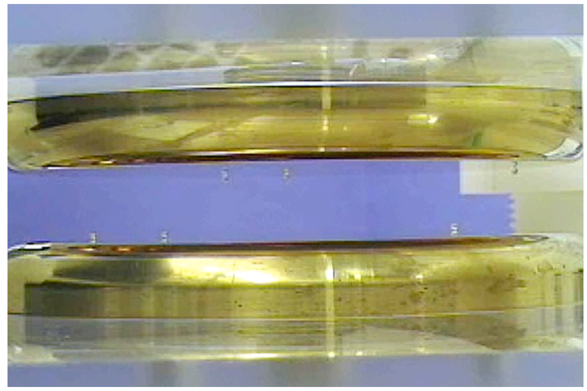

Figure 1. A configuration of glass beads between brass electrodes at 18 kV, 60% RH and 23 C. Three beads are in resident phases on the top plate, and three are in resident phases on the bottom.

Preliminary Results: Thus far, we have identified very interesting behaviors at 60% relative humidity and 18 kV. Most notably, after beads come in contact with either electrode, they tend to remain for a particular amount of time before acquiring or losing enough charge and departing from it. Early results suggest that resident times measured on the bottom plate are generally greater than those on the top plate. More trials are forthcoming.

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THE SCIENTIFIC CASE FOR THE CHANDRAYAAN-1 X-RAY SPECTROMETER. K.H. Joy[1,2], I.A. Crawford[1], B.J. Kellett[2], M. Grande[3] and The C1XS Science Team[4]. [1]Birkbeck/UCL Research School of Earth Sciences, Gower Street, London, WC1E 6BT, UK. [2]The Rutherford Appleton Laboratory, Didcot, Oxon, OX11 0QX, UK. [3]Institute of Mathematical and Physical Sciences University of Wales, Aberystwyth, SY23 3BZ, UK.[4] Members of the C1XS Science Team are identified in the Acknowledgments. (Email: K.Joy@ucl.ac.uk).

Introduction: The Chandrayaan-1 X-ray spectrometer (C1XS) will be launched during 2008 on the Chandrayaan-1 spacecraft, India's first mission to the Moon. The UK flew a Demonstration version of a Compact Imaging X-ray Spectrometer (D-CIXS) on the European Space Agency's SMART-1 mission to the Moon between 2003 and 2006 [1]. The new C1XS instrument builds on the technology innovations [2] inherited from this precursor instrument.

C1XS is a scientifically more powerful instrument than D-CIXS, both because Chandrayaan-1's low circular orbit (100 × 100 km) will result in higher spatial resolution of the lunar surface (~25 km FWHM), and because it will operate during a more active period of the solar cycle, resulting in higher X-ray fluxes and greater sensitivity to compositional variations [3].

C1XS Scientific Objectives: C1XS's principal objective is to map the global abundance ratios and abundances of the major rock-forming elements (principally Mg, Al, Si, Ca and Fe) in the lunar crust. It is hoped that C1XS will constrain the composition of regions of the Moon that have not been visited by sample return missions (i.e. the far-side highlands, the giant South Pole-Aitkin impact basin, far-side mare basalts and distinct mare basalt lava flows within individual maria). A more complete understanding of global geochemical variation is an important requirement for constraining the compositional makeup of complex differentiated planetary bodies like the Moon.

Specifically, localised and global elemental maps of the lunar surface will enable us to search for outcrops and/or determine the major element composition of regoliths dominated by lithologies such as High-Mg Suite (HMS) rocks; High-Alkali Suite (HAS); 'unusual' mare basalts (i.e. high-Al basalts); exposures of presumed pre-mare volcanism; cryptomaria and dark mantles surrounding endogenic craters (pyroclastic picritic glasses). C1XS will also be able identify the location of regoliths dominated by rock types that have not been previously identified in the lunar sample collection.

C1XS elemental datasets will help to address many outstanding questions regarding the stratigraphic structure and geological evolution of the Moon:

- Determine the compositional heterogeneity of the anorthositic highlands in different crustal regions (near-side, farside, polar): constraining models of lunar magma ocean petrogenesis [4-6];
- Measure the refractory element (Al, Ca) budget of the lunar crust: helping to constrain the composition of the bulk Moon, and models of lunar magma ocean melting [7,8];
- Determine the regional variations in the Mg# [Mg/(Mg+Fe) ratio]: constraining models of lunar crustal evolution [9];
- Probe the stratigraphy of the lunar crust by studying central peaks and/or ejecta blankets of impact craters [10]: better understanding of lunar differentiation and magma ocean evolution;
- Study mantle evolution through compositional changes in volcanic products (mare basalts etc.) over time: understanding the thermal and magmatic history of the Moon [5];
- Identify the regional settings from which different lunar meteorites are derived [11]: better constraining the petrological history of previously unsampled regions of the Moon throughout lunar history

Instrumental Parameters: Consideration of the principal science aims has led to the following capabilities of the C1XS instrument [3, 12]:

- Spatial resolution. The C1XS collimator stack permits X-rays from a 28 degree-wide aperture to fall on each SCD detector, corresponding to 50 km on the lunar surface (25 km FWHM) from Chandrayaan's circular 100 km orbit.
- Spectral resolution. Pre-launch ground based calibrations indicate a spectral resolution of ≤110 eV (at Fe Kα) [12], ensuring separation of the low-energy lines. In particular, the Mg Kα line is clearly resolvable from the adjacent low energy 'noise peak' and the neighbouring Al Kα line.

Acknowledgements: Members of the C1XS Science Team are as follows: M. Anand (OU), N. Bhandari (PRL) L. d'Uston (CESR), V. Fernandes (Berkeley), O. Gasnault (CESR), J. Goswami (PRL), J. Huovelin (Helsinki), D. Lawrence (JHU-APL), S. Maurice (CESR), S. Narendranath (ISRO) C. Pieters (Brown University), T. Okada (JAXA), D. Rothery (OU), S.S. Russell (NHM), P. Sreekumar (ISRO), B. Swinyard (RAL), M. Wieczorek (IPGP), M. Wilding (Aberystwyth), D. Koschny (ESA).

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ELECTROMAGNETIC CLEANER OF LUNAR DUST ADHERED TO SPACESUIT. H. Kawamoto,[1] H. Inoue and Y. Abe, [1]Dept. of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, kawa@waseda.jp.

Introduction: Cleaning of lunar dust adhered to spacesuits of astronauts is of critical importance for the long-term lunar exploration. We are developing some kinds of conventional cleaning devices utilizing electrostatic and magnetic forces. Although electrostatic method is potentially the most versatile technique, we have started the development of the magnetic cleaning device based on the fact that some fraction of the lunar dust is magnetic.

System Configuration: Figure 1 shows a conceptual drawing of a continuous electromagnetic cleaner of lunar dust. It consists of a shaft made of non-magnetic material, stationary multi-pole magnetic roller, rotating sleeve, plate magnet, and collection bag. Magnetic particles in the lunar dust are attracted to the stationary magnetic roller, and by the magnetic and friction forces, they are transported around by the rotating sleeve. The magnetic roller is designed so that repulsive force is applied to the particle at a certain position (arrowed). When particles are transported at this position, particles separate from the sleeve, attracted to the plate magnet faced to the repulsive position, and then gathered in the collecting bag that covers the plate magnet. The system has a merit that it is very simple and works without power consumption.

Results and Discussion: A key of this system is the design of magnetic roller that has the function of the particle release. The magnetic force $\boldsymbol{F}$ of the particle in the magnetic field $\boldsymbol{B}$ is given by the following expression under the assumption that the particle behaves as a magnetic dipole placed at the center of the magnetized particle and the magnetic interaction between particles is neglected.[1]

$$\boldsymbol{F} = \frac{4\pi}{\mu_0}\frac{\mu-1}{\mu+2}\frac{a^3}{8}\left(\boldsymbol{B}\cdot\nabla\right)\boldsymbol{B}. \qquad (1)$$

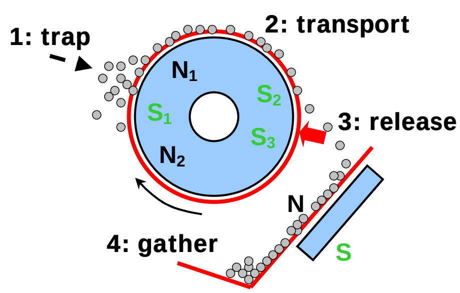

Figure 1: Concept of continuous electromagnetic cleaner of lunar dust.

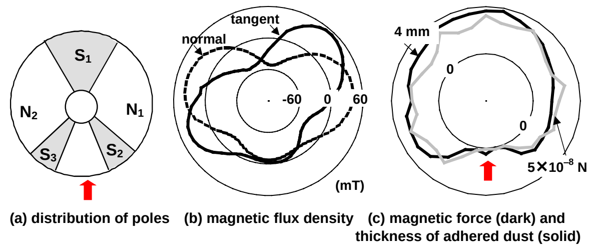

Figure 2: Circumferential distribution of magnetic flux density, magnetic force applied to magnetic particles, and thickness of adhered dust on the surface of the roller.

where μ_0 is the magnetic permeability of free space, μ is the relative permeability of particles, a is the diameter of the particle. Because the magnetic force is proportional to $(\boldsymbol{B}\cdot\nabla)\boldsymbol{B}$, the magnetic flux density $\boldsymbol{B}$ must be increased to the radial direction to realize the repulsive feature. This condition is realized by arranging the poles as shown in Fig. 2 (a). The magnetic roller, provided by Fuji Xerox, is originally designed and manufactured for the magnetic dual-component development system in electrophotography.[2]

The magnetic field $\boldsymbol{B}$ formed by the magnetic roller is estimated from measured discrete data of the magnetic flux density on the sleeve surface based on the assumption that magnetic dipoles distributed on the roller and two-dimensional distribution of the magnetic flux density was calculated by superposing the magnetic flux density created by each dipole.[1] Figure 2 (b) shows the measured distribution of the magnetic flux density on the sleeve.

The dark line in Fig. 2 (c) designates the magnetic force applied to the particle on the sleeve deduced by Eq. (1). It is clearly seen that the force is almost attractive but slightly repulsive at the lower position (arrowed). It is confirmed that particles are released at this position as shown in the solid line in Fig. 2 (c) that is the measured thickness of the adhered dust on the sleeve.

References: [1] Kawamoto H (2007) *NIP23*, 43-46. [2] Kawamoto H (1996) *J. Imaging Sci. Technol*, 40, 168-170.

ELECTROSTATIC CLEANER OF LUNAR DUST ON SOLAR PANEL AND OPTICAL LENS. H. Kawamoto[1] and M. Uchiyama, [1]Dept. of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, kawa@waseda.jp.

Introduction: Because a cleaning system of lunar dust on the solar panel and optical lens is of great importance for the lunar exploration, we are developing a self-cleaning device of lunar dust utilizing electrostatic force.[1]-[4] Although it has been demonstrated that particles can be transported by the traveling-wave electric field formed by the parallel electrodes, some specific issues must be overcome to utilize this system for the lunar exploration. In this study, we have developed the electrostatic cleaner system that can be used in the lunar environment.

System Configuration: The developed cleaner system is shown in Fig. 1. The conveyer consists of transparent ITO electrodes printed on a glass substrate. The surface of the conveyer is covered with an insulating film to prevent from electrical breakdown between electrodes.

Traveling-wave propagation was achieved utilizing a set of positive and negative amplifiers controlled by a microcomputer. Four-phase rectangular voltage was applied to electrodes because it was most efficient compared to the sine or triangular wave. The power system is designed simple, small, and lightweight for the space application.

Lunar soil simulant FJS-1 (Shimiz Corp.) and JSC-1A (PLANET LLC.) were used for experiments.

Results and Discussion: The cleaning rate of more than 90% was realized with this system under conditions of 700 V voltage and less than 100 Hz frequency. The reduced transmission efficiency of light and the reduced generation efficiency of the solar cell after cleaning were both only several %. Figure 2 shows photograph of the demonstration. Although some fraction of large particles larger than 0.5 mm were not transported, they were cleaned by the application of the ultrasonic vibration. However, very small particles adhered mainly on the electrodes, probably due to the image force, and they were not transported even though the ultrasonic vibration was applied. Cleaning of small particles, less than 1 μm, is the next challenge.

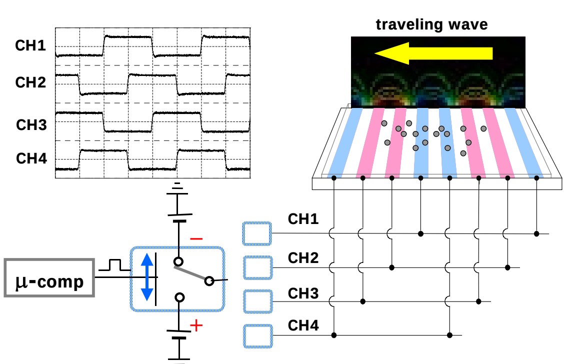

Figure 1: Electrostatic dust cleaner system.

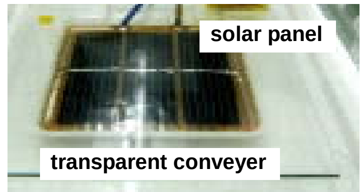

Figure 2: Operation of the electrostatic cleaner system

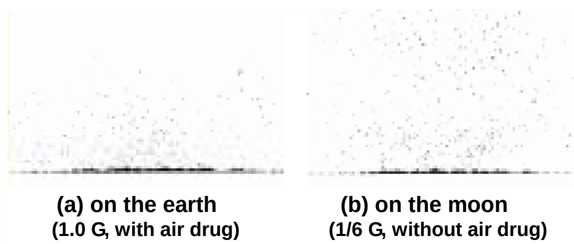

Figure 3: Calculated performance of the cleaner.

Because it is assumed that the lunar dust is charged by the irradiation of the solar wind and the cosmic ray, it was investigated whether initially charged particles can be cleaned efficiently with this system. Particles were mounted on the conveyer and then charged by utilizing the positive and negative corona discharges generated at the tip of the pin electrode settled on the upper side of the conveyer. The cleaning rates with positively charged particles (+0.6 μC/g) and negatively charged particles (–0.6 μC/g) were almost the same to the rate without charge.

The operation in vacuum was demonstrated and it was confirmed that the cleaning rate is increased in vacuum. The reduced gravity will be also of advantage on the moon as predicted by the numerical calculation. Figure 2 shows the cleaner performances calculated by the hard-sphere model of the Distinct Element Method.

The power consumption of this system was measured and it was estimated that it takes only 0.04 Wh for once operation of a 1 m^2 conveyer.

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ASTRONOMY FROM THE MOON: POSSIBLE SCIENCE INVESTIGATIONS AND PRECURSORS. J. Kissi-Ameyaw, E.P. Monaghan, B.H. Foing. ESA/ESTEC, SRE-S, Postbus 229, 2200AG Noordwijk, Netherlands. jkissi@rssd.esa.int, euan.monaghan@rssd.esa.int, bernard.foing@esa.int

Background: The invention of the telescope heralded the birth of modern astronomy. As technology and our understanding of optics developed, these telescopes increased in both size and complexity. Despite these advances, ground-based telescopes are held back by our planet's turbulent atmosphere. It may sustain life on Earth, but it also provides the greatest obstacle to an unencumbered view of the universe.

Limitations of Earth-based Telescopes: There are several issues with Earth-based astronomy. The first and most important of these is weather. It is no coincidence that the main research telescopes on Earth are in areas of high altitude and consistent, arid climate. Light pollution is also a big problem. Not only this, but terrestrial radio sources produce a considerable amount of pollution in the EM spectrum. Other factors include: the blurring effect caused by elements in the atmosphere, which limits telescope resolution; and the fact that absorption means that the atmosphere is opaque to whole ranges of wavelengths.

Limitations to Current LEO-based Astronomy: Current missions such as the Hubble Space Telescope (HST) take advantage of the much clearer conditions outside the bulk of the Earth's atmosphere. However, even here there are problems. While these spacecraft are pointed to the stars, LEO is still exposed to the constant EM noise from Earth as well as the ionosphere.

Another problem is one of stability. There is of course no surface in LEO on which to anchor a telescope, and this can cause issues with pointing the instruments, which are generally solved by gyroscopes and other such systems. This increase in complexity can potentially lead to problems. Indeed, the HST is the only telescope ever to have been repaired by astronauts.

Benefits of Moon-based astronomy: The Moon has an incredibly tenuous exosphere. Direct contact with what is essentially the vacuum of space results in almost no attenuation or absorption when conducting observations in any frequency. Astronomy conducted from the lunar far side would also be shielded from terrestrial radio and ionospheric interference. Current NASA plans for a scientific outpost on the Moon also means that servicing and installation of such a telescope can also be met with greater ease[1].

Limitations of Moon-based astronomy: No atmosphere means no protection from cosmic rays and solar particles. Large shifts in temperature on the lunar day-night cycle (ranging from 100 K to 390 K at the equator) may also cause problems with optical equipment. The shipment of replacement parts etc. is still expensive. The effect of the lunar dust on operational performance must be assessed with precursor missions.

Potential projects: There have been many proposals for telescope technologies based on the Moon. A simple project such as a small radio array of ~10 dipole antennas would be an ideal precursor for Moon-based astronomy[2]. Covering an area of around 2 km, the Lunar Array for Radio Cosmology (LARC), proposed by a team at MIT, would be a logical progression in this process. Probing signals from the early universe and shielded from interference from the ionosphere and terrestrial signals, such an array would not be operable on the surface of the Earth, due to the extreme low frequency of the searched-for signals. Indeed, the 50 kHz - 30 MHz frequency window is the only one through which we have yet to image the universe.

Lunar Transit Telescopes (LTT) have been proposed to survey the sky in multiple wavelengths, and to monitor a variety of cosmic objects. LTTs could provide image quality to measure weak gravitational microlensing and therefore map the distribution of dark matter in the universe.

Another proposal is the Liquid Mirror Telescope (LMT). These make use of parabolic shape formed when a fluid spins. Such spinning fluids become – in essence – mirrors, when reflective liquid metal is used. The main advantage to these types of telescopes are that the weight of the mirror is considerably less than that of it's glass counterpart. The cost is also much less, which can lead to larger 'mirrors' being built. Currently these have to be pointed straight up, as any tilt will cause the mirror to lose its shape. However, there are areas in which these telescopes are ideal. LMT's of 20-100 m diameter could be placed on the Moon to detect objects 100 times fainter than achievable with the James Webb Space Telescope. Such an LMT would also be able to observe the first high red-shift stars and galaxies, for the same reason. Locations ideal for deep-sky cover and long integration times have been identified[3].

Lunar telescopes can perform continuous uninterrupted observations that can aim at exoplanetary transits. Lunar interferometers could be used to detect habitable Earth-like planets around other stars, and measure spectral fingerprints (O_2, O_3, CH_4) of possible biological activity.

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Linkage between Future Combat Systems and Human Exploration of Planetary Surfaces

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The purpose of this project is to identify the overlapping technologies needs of NASA and those technologies developed on the Future Combat Systems (FCS) program. The Future Combat Systems (FCS) program is an Army modernization initiative designed to link soldiers to a wide range of weapons, sensors, and information systems by means of a mobile ad hoc network architecture that will enable unprecedented levels of joint interoperability, shared situational awareness and the ability to execute highly synchronized mission operations.

FCS uses advanced communications and technologies to link soldiers with both manned and unmanned ground and air platforms and sensors. Soldiers who are linked to these platforms and sensors have access to data that can provide a much more accurate picture of what's going on around them.

The FCS program, considered the core building block of the Army's future force, consists of the following elements:

1) The network (information and communications)
2) 14 individual manned and unmanned combat systems
3) The soldier

Central to FCS' power is the fact that it is a networked system of systems – all designed to maximize the strength of each individual system by linking it to all other systems in the network – including systems that are part of the FCS family and those considered "complementary systems" that work with FCS. This project focuses on the relationships between the soldier and astronaut: the soldier/astronaut and everything they wear, carry, and consume -- embodying the concept of the "soldier (astronaut) as a system" (SaaS).

Some key focus areas of the project are:
1) Systems that could be deployed in the suit taking careful consideration of suit volume and system ergonomics
2) Systems that would support field work for an astronaut explorer
3) Surface Operations Management

(Presentation pending required final approvals)

ROBOTIC AND HUMAN EXPLORATION OF THE SCHRÖDINGER BASIN. T. Kohout[1, 2, 3], K. O'Sullivan[4], A, Losiak[5], D. Kring[6], K. Thaisen[7] and S. Weider[8, 9], [1]Department of Physics, University of Helsinki, Finland, tomas.kohout@helsinki.fi, [2]Department of Applied Geophysics, Charles University in Prague, Czech Republic, [3]Institute of Geology, Academy of Sciences of the Czech Republic, Prague, Czech Republic, [4]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN, USA kosulli4@nd.edu, [5]Michigan State University, East Lansing, MI, USA, [6]Lunar and Planetary institute, Houston, TX, USA, [7]University of Tennessee, Knoxville, TN, USA, [8]The Joint UCL/Birkbeck Research School of Earth Sciences, London, UK, [9]The Rutherford Appleton Laboratory, Chilton, Oxfordshire, UK.

Introduction: The Schrödinger impact basin provides numerous scientific opportunities due to its location and relatively young age. Located near the South Pole on the far side of the Moon, it is the second y-oungest impact basin (after Orientale), thus remains well exposed. Schrödinger intersects the pre-Nectarian Amundsen-Gainswindt basin (AG), as well as the inner rings of the South Pole-Aitken basin (SPA). Modeling suggests [1] that Schrödinger's inner ring originates from a depth of 10-30 km and therefore may contain indigenous SPA materials.

Scientific objectives for the human exploration within Schrödinger basin: The following main scientific goals can be accomplished within Schrödinger [2]:

- Date the Schrödinger impact event.
- Collect and date SPA material, thus, anchoring the Earth-Moon impact flux curve.
- Study material produced by various basaltic volcanic events (Upper Imbrian and Eratosthenian in age [3, 4]).
- Study deep seated explosive volcanism (Eratosthenian or Copernician in age [3, 4]).
- Study potential products of crustal and mantle degassing along deep fractures.
- Study ghost craters flooded by melt sheet.
- Study secondary craters on the basin floor.

We propose a landing site for human exploration on a relatively smooth terrain ([3, 4]) within the inner ring of Schrödinger. This location can provide access to the features outlined above and meet the planned ~20 km extra vehicular activity (EVA) limit [2].

Robotic precursory mission concept: In order to maximize the scientific success of a human landing in Schrödinger basin, a precursory robotic mission is proposed to identify and characterize the best sampling localities to be later visited by astronauts during their EVAs. The following instrument package is proposed for the robotic rover (fig. 1):

- Panoramatic camera for high resolution imaging and for terrain evaluation (e.g. roughness, slope)
- Alpha Particle X-ray Spectrometer (APXS), or similar, to determine rock chemical composition.
- Microscopic Imager (MI) for rock texture studies.
- Rock Abrasion Tool (RAT) similar to that on Mars Exploration Rovers to expose the flat fresh rock surface for chemical and mineralogical studies.
- Robotic arm for sample manipulation / collection.
- Seismic receiver to record seismic signals from a static mechanical seismic generator located on the rover's lander platform. This configuration creates a seismic profile through recording repetitive seismic signals at various distances as the rover moves away from its lander platform. The subsurface structure as the thickness of regolith, melt sheet and basaltic units can be determined from the data.
- Ground Penetration Radar (GPR) for near subsurface studies of the site (e.g. regolith thickness).
- Penetrometers to measure the physical and mechanical properties of the regolith.

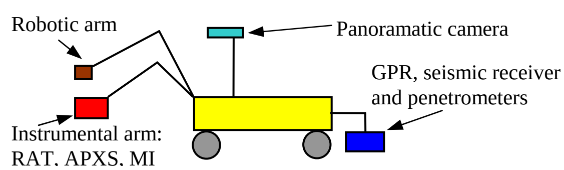

Figure 1: The concept of the robotic rover.

Conclusions: A precursor robotic rover can reduce the risk, requirements, and cost of a human exploration [5] and provide site characterization to enhance the efficiency of human exploration by identifying the highest priority traverse stations. It could also collect and deliver samples from remote areas to the human mission landing site or conduct complementary research after the human mission departure [5].

Acknowledgements: This work is part of the 2008 LPI Lunar Exploration Summer Intern program. We would like to thank LPI staff for their help and support.

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COMMERCIAL LUNAR DATA COLLECTION AND LICENSING TO REDUCE EXPLORATION COSTS. J.N. Kohut[1] and D. P. Gump[2], [1]Chief Executive Officer, Astrobotic Technology, 301 Grant Street, Suite 4300, Pittsburgh, PA 15219, john.kohut@astrobotictech.com; [1]President, Astrobotic Technology Inc., david.gump@astrobotictech.com,

Introduction: Space agencies traditionally have offered one-time funding events to attract ad hoc teams of academics and aerospace contractors to develop special-purpose hardware to acquire planetary data sets. Following most missions, the team is disbanded and the hardware designs might never be used again. The worldwide interest in sustained lunar activities offers an opportunity to change this paradigm by sustaining stable teams repeatedly using familiar and lunar-tested hardware designs. This will lead to cost savings for the governments seeking lunar data.

There now is an opportunity for commercial operators to create precursor lunar robotic activities that feature frequent missions using the previous mission's hardware as the template. Rather than provide lunar missions on a cost-plus basis to various governments, a new business model is possible:

1) Selling payload accomodations to specific instruments that goverments, universities and corporations want delivered to the lunar surface;

2) Conducting activities on the lunar surface for multiple customers on the same mission; and

3) Collecting science and engineering data for sale or licensing to government and private sectors.

As a company completes each mission, its library of essential lunar data will grow. Access to the library can be on a subscription basis, similar to the methods used by software companies that sell their programs on a subscription basis.

Commercial operators also will be able to earn revenue by carrying out exclusive marketing and media activities that NASA and most other space agencies are legally unable to service. This will reduce the amount of funding commercial operators will need to collect for the science and engineering data sought by governments and researchers.

In July 2008, Astrobotic Technology was awarded a NASA contract to study the most effective regolith moving approaches for site preparation prior to emplacement of the agency's first lunar outpost. It plans to eventually conduct these site prep activities for NASA, other space agencies and commercial entities on a fixed-cost basis.

Astrobotic's approach to this new space mission paradigm is based on the field robotics experience of Dr. Red Whittaker of Carnegie Mellon University, who won the 2007 Urban Challenge sponsored by the Defense Advanced Research Projects Agency by modifying a Chevy Tahoe to autonomously maneuver in simulated city traffic. Dr. Whittaker also has deployed autonomous exploration robots to Antarctica, the Atacama desert and other extreme locales. He has completed more than 80 government contracts for NASA, the Energy Dept. and other agencies; one of the most recent is creation of the "Scarab" robot for NASA, designed to traverse the steep slopes of lunar polar craters in the search for water ice.

Astrobotic's team has built and tested several prototype lunar robots, the first of which will be launched in May 2010 to compete for the Google Lunar X Prize and to document the Apollo 11 site via high-defintion video.

Drive mechanisms and wheel designs have completed several kilometers of terrestrial testing in lunar stimulant, using a counterweighted arm to mimic one-sixth gravity.

ENHANCED GPS ACCURACY USING LUNAR TRANSPONDERS. G. A. Konesky, SGK Nanostructures, Inc., 3 Rolling Hill Rd., Hampton Bays, NY 11946-3716, g.konesky@att.net

Introduction: The position measurement accuracy of the Global Positioning System (GPS), as well as similar satellite-based systems (Glonass, Galileo), depends on how well the ephemerides of these satellites are measured [1]. The process of determining these ephemerides involves ranging to and from stations located on the surface of the Earth, in addition to checks for consistency between satellites. Variations in atmospheric effects from the ionosphere and troposphere, especially in refraction, are often unpredictable and can result in ephemeris errors of several meters [2].

Placing one or more transponders on the Moon [3] and ranging to and from it eliminates any atmospheric-induced errors. The ephemeris of the Moon is well-established and its orbit is not significantly changed by solar wind and radiation, as GPS satellites are. A radio or optical pulse would be sent from each GPS to the lunar transponder periodically, and the transponder would echo back its response. The round trip delay, minus the latency response time of the transponder, would provide the GPS satellite with a distance to the previously known position of the lunar transponder.

We first consider placement strategies of transponders on the lunar surface. A significant advantage of the synchronous rotation of the Moon is that only a small number of transponders are needed since one side of the Moon always faces Earth. If the transponders are solar powered, it would also be desirable to locate them so at least one is always in sunlight. Examples of these locations include the poles [4] of the Moon, and opposite edges of the lunar disc as seen from Earth [5].

Tradeoffs are next considered in terms of radio [6] versus optical [7] ranging pulses between the GPS satellite constellations and the lunar transponders. Issues include aperture, transmitter power and receiver sensitivity, and pointing accuracy, using a link margin approach. High available bandwidth [8] is usually the determining factor in selecting an optical approach. However, in this transponder application, the high gain afforded by a relatively small aperture is more important, and is given by:

$$G_a = 10 \log_{10} (\pi D / \lambda)^2 \qquad (1)$$

Where G_a is the ideal gain, expressed in dBi, D is the aperture diameter and λ is the wavelength. A 25 cm (10 inch) aperture, for example, will produce almost 120 dBi gain at a wavelength of 830 nm. A 10 meter aperture operated in the microwave S-band, for comparison, provides less than 50 dBi gain.

In addition to compact physical size, the high gain with small aperture afforded by an optical approach implies that the transmitter power can be significantly reduced, both on a given GPS satellite, and on the lunar transponder. This has ripple-down effects on other parameters such as required solar array area, and ultimately payload launch weight. Every pound saved on payload delivered to the lunar surface saves on the order of about 1000 pounds in launch vehicle weight [9].

One drawback of an optical approach is target acquisition and tracking due to the relatively narrow beam footprint. Wide beam search and then narrow beam lock-on procedures have been used [10] effectively. Additional considerations include long term operation of the transponders in the lunar environment, and battery reserves to maintain proper internal temperatures during the roughly two week long lunar night. Other optical considerations include the need to add backscattered sunlight from the lunar albedo [11] to link margin calculations (as seen from a GPS satellite), and the need to protect optics from lunar dust and micrometeorite hazing.

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In-Situ Resource Management (ISRU): Extraction of Lunar Oxygen Resources (ELOR)

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ABSTRACT

Extraterrestrial resources hold great potential for enabling humanity to build a permanent presence in Outer Space, moving beyond the Earth-Moon system and into the Solar System at large. The renewed opportunities for lunar exploration have rekindled interest in extraterrestrial resource utilization and thus have become a substantial topic interest in all space fairing leading nations. Oxygen is the major propellant for rockets. Oxygen depots on Moon will lead to more cost effective space missions, since its transport from Earth to Moon requires an extensive and costly mass transport and logistic. Lunar regolith consists of about 45 weight% of oxygen, which processing will be mandatory for future space exploration especially regarding propulsion aspects. The process is based on the reduction of Ilmenite (FeTiO3) at a temperature of about T = 1000°C using solar heat. For the feedstock a volcanic lunar soil simulant is used, which will be collected with a robotic unit, facing the following challenges: a) lunar regolith consists of interlocking dust-like particles in a highly compacted soil, which requires high penetrating forces and special bearing techniques. b) The collection-unit has to be light-weight, energy-efficient and autonomously controllable. Currently the conception design process for the three modules of the plant is running: the regolith robotic collection unit, the process chamber and the oxygen post processing and storage unit.

SECONDARY PAYLOAD ARCHITECTURE FOR LUNAR COMM RELAY SATELLITES. K. Kroening[1], L. S. Sollitt[1], T. Segura[1], and C. Spittler[1] [1]Northrop Grumman, One Space Park, Redondo Beach, CA, 90278.

Introduction: Future manned and unmanned exploration of the Moon will require the return of large amounts of data from the lunar surface, with constant coverage of any manned systems. A comm. satellite system based on the seconday payload concept used by the Lunar CRatering Observation and Sensing Satellite (LCROSS) could provide a low-cost solution. Such a satellite could be delivered to lunar orbit from any commercial MEO or higher mission; with appropriate planning, it may be possible to use certain LEO launches, extending the versatility of this system. Obviating the need for a dedicated launch vehicle would represent a large cost savings to NASA for this program.

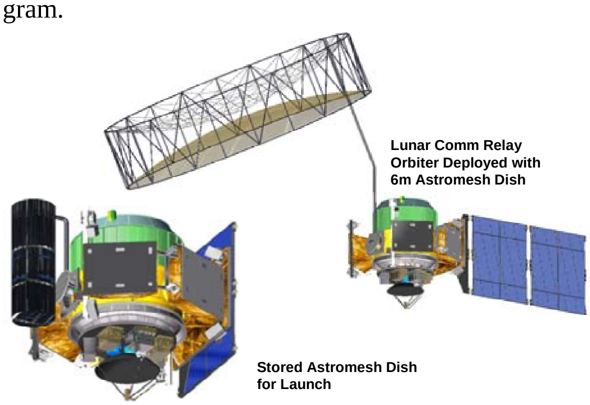

Figure 1. LCROSS-based satellite

An ESPA-based architecture: LCROSS is an existing example of a secondary payload built by Northrop Grumman. This spacecraft is built around an EELV Secondary Payload Adapter (ESPA), using the ports of the ESPA not for individual payloads, but rather as attachment points for spacecraft hardware. All of the various systems are separately installed on panels which fit into the ports; this allows for parallel integration of the spacecraft systems. For instance, the LCROSS science payload was integrated and tested at NASA/ARC on the actual flight panel while the rest of the spacecraft was assembled at NG facilities in Southern California. A notional comm. satellite based on this architecture is shown in Figure 1. Such a system might use avionics similar to those on NASA's Lunar Reconnaissance Orbiter (LRO) and have a 3-5 year mission life. The antenna shown is an Astromesh deployable perimeter truss type; larger examples than the one shown here have flown previously.

Options to extend mission lifetime: Mission life can be extended by a variety of parameter changes. This poster will explore these options and rate their feasibility vs cost supporting architecture trades. Simple methods such as adding enclosing panels to reduce micrometeoroid impact and improvement of the Faraday Cage electric protection can slightly increase lifespan. More complex modifications such as adding internal redundancy and component watchdog software to trigger swap to back-up work well for higher NRE dollar custom development. A more inclusive yet less costly approach would be to swap the LRO avionics out for another fully developed set. These three methods, their impacts and potential mission impacts will be presented in this poster.

System Architecture Example: Many different comm. systems are possible with the secondary architecture, including those presented in [1]. For a manned base at the lunar South Pole, one architecture example would use satellites in Molniya orbits with apolunes above the South Pole, as shown in Figure 2. These "locked orbits" are stable against perturbations arising from fluctuations in the Moon's gravitational field, and would allow satellites to use minimal delta-V to maintain a long service life. We find that two satellites in 12-hour orbits would provide 100% coverage between the Earth and any spot south of approximately 65° South latitude on the lunar surface.

References:

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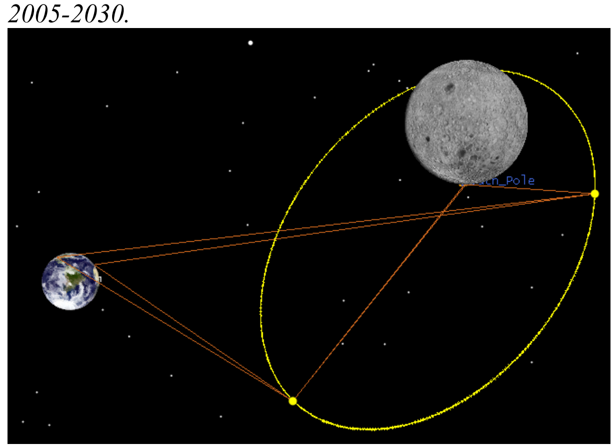

Figure 2. Comm example for a South Pole station

Additional Information: This work was supported under internal funding at Northrop Grumman Corporation. For further information, please contact Keith Kroening at keith.kroening@ngc.com.

ANALOGUE MISSIONS AS AN INTEGRATION MECHANISM TO DEVELOP LUNAR EXPLORATION STRATEGIES. Lebeuf, M. [1], M. M. Mader[2], and M. C. Williamson[3], [1]Canadian Space Agency, St-Hubert, Qc, Canada, Martin.Lebeuf@space.gc.ca; [2]Carleton University, Ottawa, ON, Canada, Marianne.Mader@space.gc.ca; [3]Canadian Space Agency, St-Hubert, Qc, Canada, Marie-claude.Williamson@space.gc.ca

Introduction: Designing, planning, and executing Analogue Missions on Earth will be vital in order to achieve human lunar missions to the Moon by 2020. They provide an opportunity for multidisciplinary and international interaction and become a focal point for training people and testing technologies. While engaging in an Analogue Mission, the team gradually develops an understanding of key science and technology drivers and key field operational requirements, which will help with eventual planetary missions.

Analogue Missions: In the context of Planetary Exploration, analogue missions are simulations of planetary surface operations that take place at analogue sites on Earth. The selected terrestrial analogue sites resemble, in some concrete way, the surface environment of another planetary body. The role of an Analogue Mission is to integrate several scientific/technology activities to simulate entire mission designs or narrowly focus on specific aspects of future planetary exploration missions (e.g., initial lunar sortie missions, in-situ resource utilization, etc.). Implicit in this definition, is the notion that the planetary exploration mission of interest is pre-determined and the Analogue Mission is a reflection of selected key conditions (e.g., degree of infrastructure, communication capabilities, human-robotic interactions, appropriate tools, etc.).

Canadian Space Agency's Exploration Core Program: The Canadian Space Agency's Exploration Core Program targets the development of technology infrastructure elements in key areas of science, technology and robotics in preparation for its role in the future exploration of the Moon and Mars. Within this Program, Analogue Missions specifically target the operations requirements and lessons learned that will reduce costs and lower the risk of planetary surface missions. As well as using analogue missions to meet agency programmatic needs, the Canadian Space Agency encourages scientists and engineers to make use of opportunities presented by analogue missions to further their own research objectives.

Specific objectives of Analogue Missions are to
(1) Foster a multidisciplinary approach to planning, data acquisition, processing and interpretation, and telemetry during mission operations;
(2) Integrate new science with emerging technologies;
(3) Test technologies in a relevant geological and operational environment; and
(4) Develop an expertise on exploration architecture design from projects carried out at terrestrial analogue sites.

The expertise gained through Analogue Missions will contribute to the development of exploration architectures, including key areas such as planetary mobility requirements and astronaut training.

TERRESTRIAL ANALOGS FOR LUNAR SCIENCE AND EXPLORATION: A SYSTEMATIC APPROACH. Pascal Lee[1,2,3], Andrew Abercromby[4], Stephen Braham[2], Matt Deans[1], Terrence Fong[1], Brian Glass[1], Stephen J. Hoffman[4], Christopher P. McKay[1], Jonathan Nelson[2], Marcelo Vasquez[5], and Nicholas Wilkinson[2]. [1]NASA Ames Research Center (MS 245-3, Moffett Field, CA 94035-1000, USA, pascal.lee@marsinstitute.net), [2]Mars Institute, [3]SETI Institute, [4]NASA Johnson Space Center, [5]National Space Biomedical Research Institute.

Summary: The planning of a range of future human activities on the Moon requires the use of terrestrial analogs to help these activities be as safe, productive, and cost-effective as possible. We discuss key features of a systematic approach to selecting terrestrial analogs for lunar exploration operations planning.

Introduction: A *terrestrial analog for a planetary body* may be defined as *an environment, feature, process, or activity on Earth, outdoors or indoors, representating, or relevant to, one or more aspects of an environment, feature, process, or activity on that planetary body* [1].

Terrestrial analogs for the Moon are needed to serve all four fundamental *functions* of analogs: to help i) learn, ii) test, iii) train, and iv) engage [2]. While the overarching goals of analog campaigns are to help retire risk, maximize productivity, and minimize program costs, they are also key to engaging the public, students, local experts, and international partners.

Selecting Lunar Analog Sites: Key factors to be considered in the evaluation and selection of any analog are: 1) aspect(s) of interest, 2) application(s), 3) function(s), 4) fidelity, 5) cost-effectiveness [3, 4]. While no place on Earth offers a high fidelity analog to all aspects of the lunar surface environment – in particular, there is no single all-encompassing high fidelity "science analog" for the Moon -, a number of sites can be found that may be considered adequately representative or relevant to the Moon for the purpose of planning specific lunar surface science *operations* and more generally lunar *exploration operations.* As planning for human exploration operations on the Moon advances, it is anticipated that in addition to day to day small scale testing of specific system elements on site (in a "moonyard") or in the field, larger-scale, integrated analog campaigns will increasingly be needed to bring together episodically in an operationally challenging and relevant field setting, major system elements ready for integrated testing and validation.

The factors to be considered in the selection of an analog site for integrated exploration operations work go beyond the inherent scientific or terrain attributes of the location. Ease of access (which includes the logistics of transportation, the preexistence of local infrastructure, land access permits required, etc.) is critical. The main source of cost in any analog field campaign generally lies in deployment logistics, in particular in transportation. Maximum advantage should be taken of any preexisting field infrastructure with proven and affordable means of access. An ideal systematic approach to selecting lunar analog sites is a compromise between reusing whenever possible known field sites with established scientific and operational relevance, infrastrcture and access conditions, and preserving the option to access new sites as needed. An optimal balance therefore lies in: 1) identifying a limited number, N_{ss}, of "Strategic Sites" where substantial field infrastructure remains available permanently and site access is both reliable and cost-effective; *and* 2) having the cability (a set of deployable assets) to flexibly access an open number, N_{TS}, of "Tactical Sites" for short-term and more targeted deployments as needed. Different approaches to minimizing N_{ss} while maximizing N_{TS} can be adopted, but the process should include broad-based consultation with the lunar science and exploration communities to ensure that the full range of lunar science and exploration requirements are captured.

2008 Integrated Lunar Analog Campaign Sites

Three analog sites were selected in 2008 to host NASA Constellation Project field campaigns requiring substantial integration and field infrastructure:
1) Moses Lake Sand Dunes, Moses Lake, WA (Jun)
2) Haughton-Mars Project, Devon Island, Arctic (Aug)
3) Black Point Lava Flow, Flagstaff, AZ (Oct).

Each one of these sites was selected in consideration of a specific set of functions to be fulfilled. Our presentation will offer details on how these sites served the needs of their respective campaigns, and lessons learned for future integrated analog campaign efforts.

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A MODIFICATION AND ANALYSIS OF LAGRANGIAN TRAJECTORY MODELING AND GRANULAR DYNAMICS OF LUNAR DUST PARTICLES. Jason M. Long[1], John E. Lane[2], Philip T. Metzger[3], A.M.ASCE. [1]*NASA/KSC-XA Granular Mechanics and Surface Systems Laboratory, KSC, FL 32899, USA (Jason.M.Long @nasa.gov)* [2]*ASRC Aerospace, Kennedy Space Center, FL 32899, USA (John.E.Laneg@nasa.gov)* [3]*NASA/KSC Granular Mechanics and Surface Systems Laboratory, KSC, FL 32899, USA (Philip.T.Metzgerg@nasa.gov)*

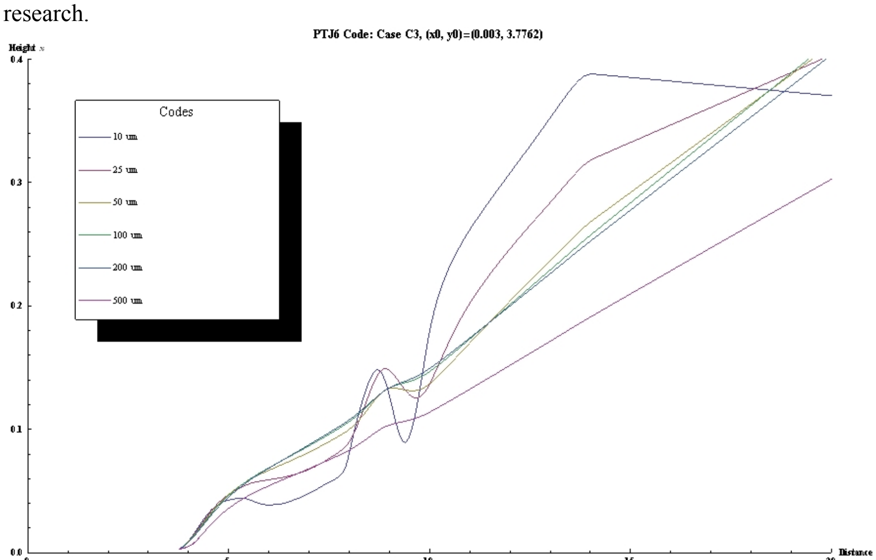
Abstract

A previously developed mathematical model is amended to more accurately incorporate the effects of lift and drag on single dust particles in order to predict their behavior in the wake of high velocity gas flow. The model utilizes output from a CFD or DSMC simulation of exhaust from a rocket nozzle hot gas jet. An extension of the Saffman equation for lift based on the research of McLaughlin (1991) and Mei (1992) is used, while an equation for the Magnus force modeled after the work of Oesterle (1994) and Tsuji et al (1985) is applied. A relationship for drag utilizing a particle shape factor (ϕ = 0.8) is taken from the work of Haider and Levenspiel (1989) for application to non-spherical particle dynamics. The drag equation is further adjusted to account for rarefaction and compressibility effects in rarefied and high Mach number flows according to the work of Davies (1945) and Loth (2007) respectively. Simulations using a more accurate model with the correction factor (Є = 0.8 in a 20% particle concentration gas flow) given by Richardson and Zaki (1954) and Rowe (1961) show that particles have lower ejection angles than those that were previously calculated. This is more prevalent in smaller particles, which are shown through velocity and trajectory comparison to be more influenced by the flow of the surrounding gas. It is shown that particles are more affected by minor changes to drag forces than larger adjustments to lift forces, demanding a closer analysis of the shape and behavior of lunar dust particles and the composition of the surrounding gas flow.

Introduction

The necessity for permanent surface structures on the moon is unavoidable, with future missions to the moon planned and expeditions to Mars in our near future. With this comes the requirement for protection not only from the planetary elements, but also from our own vehicles. Understanding the effects of our interactions with the surrounding environment is imperative if we are to properly prepare for extended missions and protect permanent habitats and structures. In the final stages of decent, the high temperature, supersonic gas flow creates an environment in which lunar dust, gravel, soil, and rocks are driven out radially at high velocities. Evidence of this effect is noted in several videos of the Apollo landings; the thickness of the dust layer and angle of trajectory were estimated from these videos (Immer, 2008), and confirmed using mathematical modeling and software implementation (Lane and Metzger, 2008).

Updates are made to the Lane and Metzger (L&M) model in order to better account for lift forces, rarefaction and compression effects, and interparticle reactions. With these new equations, simulations are run under several different rocket exhaust conditions to stimulate the movement of lunar soil, and to determine the final conditions and trajectories of the lunar particles. The equations used in the L&M model are outlined, as are the changes and modifications made to these equations, and the interpolation code where necessary. Simulations are performed using four new versions of the trajectory code in order to more accurately designate the changes to the proper forces. The main alteration is the replacement of a constant lift coefficient with the extended Saffman lift equation and the addition of the Magnus effect. Variations on the drag force through interparticle reactions are also examined to see what effect, if any, they have on the final trajectory of the particle. Each set of results from the separate versions of the code are compared, and weighed against the L&M model. Finally, suggestions are made for future changes and direction for research.



An Example of Particle Trajectory Simulation Output

ESTABLISHING A PRECISE ABSOLUTE CHRONOLOGY OF THE MOON – A NEED FOR ROBOTIC MISSIONS.
A. Losiak[1], T. Kohout[2], K. O'Sulllivan[3], K. Thaisen[4], S. Weider[5], D. Kring[6] [1]Michigan State U. losiakan@msu.edu, [2]Department of Physics, U. of Helsinki tomas.kohout@helsinki.fi, [3]Department of Civil Engineering and Geological Sciences, U. of Notre Dame kosulli4@nd.edu, [4] Deptpartment of Earth and Planetary Sciences U. of Tennessee – Knoxville kthaisen@utk.edu, [5]UCL/Birkbeck School of Earth Sciences s.weider@ucl.ac.uk, [6]Lunar and Planetary Institute kring@lpi.usra.edu.

Introduction: Establishing a precise absolute chronology is one of the highest priority goals listed by the National Research Council in "The Scientific Context for Exploration of the Moon" [1]. It is therefore necessary to determine the absolute ages of numerous craters and maria (representatively distributed temporally and geographically) that have well detemined relative ages (particularly those that definine or fall close to the chronological boundaries) by returning samples from their surfaces to Earth for radioisotope dating. The number of features that need to be dated is much greater than the number of locations that can be realistically visited by manned missions in the initial phase of exploration. Robotic sample return missions have been successfully used in the past with the Luna 16, 20 and 24 missions [2]. Samples from Luna 16 allowed the age of a section of Mare Fecunditatis to be established as 3.41 Ga; dating samples from Luna 24 established the age of part of Mare Crisium as 3.4 - 3.6 Ga [3].

Proposed approach: Robotic sample return missions could be used to establish the absolute ages of selected surfaces and features in order to establish a precise absolute chronology. Compared to manned landings on non-complex surfaces (which can play a crucial role in establishing a precise lunar chronology), they are more cost effective. Surfaces that could be dated through robotic landings should be selected based on the following criteria: 1) their relative age (younger surfaces are better), 2) surface roughness (smoother and flatter surfaces are preferred), 3) the predicted ease with which a particular sample can be linked to the specific lunar surface feature (the "linkage potential"), 4) size of selected unit (large enough to allow high quality crater counting).

Although it is sufficient to merely sample the selected surfaces and return the samples to Earth in order to establish an absolute chronology, the mission payload should include additional instruments for other scientific goals. These could include: panoramic camera, microscopic imager, spectrometers, seismometers, ground penetrating radars [4]. The landing site selection process should be preluded by an orbital reconnaissance mission that includes; high-resolution imaging (for crater counting and terrain roughness) and mineralogical mapping (in order to determine between melt deposits basalt or regolith).

Proposed landing sites: There are two types of localities which could be selected as landing sites for these robotic sample return missions:

1) Mare surfaces with relative ages (based on crater counting) between 3 and ~1 Ga [5]. At least a few points from this time range are required in order to calibrate impact flux curves [3]. Landing at a few sites within Oceanus Procellarum [5] should be sufficient to fulfill this aim. Selecting a landing site on the boundary between different lava flows or on the rim of small craters (located on the younge flow and with an excavation depth sufficient to penetrate beneath the flow) should allow multiple surfaces to be dated during a single mission.

2) Craters with easily visible (and therefore accessible) large melt sheets or ponds. Most craters younger than ~3 Ga and larger than 30 - 50 km in diameter [6] contain such units. An example of such a locality is King crater (5.0 N, 120.5 E) (Figure 1). It is one of the largest Copernican-aged craters and is located on the far side, is therefore a good candidate for a robotic sample return mission [7]. King has an extensive melt pond (~285km^2) located on the north rim of the crater that could be a convenient landing site.

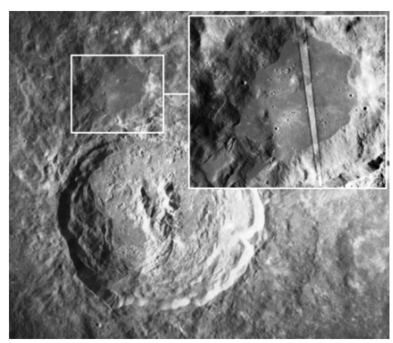


Figure 1 Melt pond on the northern rim of the King crater. AS16-M-1580, AS16-P-5000 and 4998.

Acknowledgements: This work is a part of the 2008 Lunar Exploration Summer Intern Program (at LPI).

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ADDRESSING INTERNATIONAL LUNAR SURFACE OPERATIONS. M. Lupisella[1], D. Eppler[2], L. Arnold[3], R. Landis[3], M. Gates[4], S. Hovland[5], B. Foing[6], J. Olds[7], D. DePasquale[7], R. Lewis[8], M. Hyatt[9], C. Conley[10], D. Mandl[11], S. Talabac[11], K. McNamara[12], M. A. Perino[13], L. Alkalai [14] C. Morrow[15], J. Burke[15]
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Introduction: The 9th International Lunar Exploration Working Group (ILEWG) "Sorrento Declaration" recommended "*establishing an informal Lunar Surface Operations Working Group under the ILEWG, which would aid in the definition of compatibility issues, such as interoperability for both initial robotic and later human missions*" [1]. It was apparent at the Sorrento meeting that many issues raised could benefit from an international effort that looked broadly and systematically at a wide range of surface operations considerations. We will present investigations regarding a systems engineering approach and Excel-based prototype analysis tool for lunar surface operations that incorporates international considerations – informed partly by preliminary issue areas and questions that we will also present – which were formulated after last year's Sorrento ILEWG meeting.

NASA has begun to examine lunar surface operations as part of lunar mission assessments and as the Lunar Surface Systems Project is being formed within the Constellation Program. Terrestrial analog activities [2], the NASA Lunar Architecture Team (now the Constellation Architecture Team), and other related efforts have been drivers for looking at surface operations – primarily from the perspective of surface EVA activities (including some science implications) and architectural implications. Some international considerations, such as communication standards, are also being explored. However, as international issues for lunar exploration continue to be examined in more detail, a more comprehensive integrated approach will be needed.

We will first touch on potential issue areas that have been considered, for example:

- *Safety* (e.g. international crew health standards)
- *Compatibility and Interoperability* (e.g. lunar surface element interfaces)
- *International Knowledge Management and Information Systems* (e.g. international lunar database)
- *Science Integration* (e.g. sample handling standards)
- *Earth-Moon Relationship* (e.g. crew autonomy)
- *Environmental Management* (e.g. contamination)
- *International Public Engagement*
- *Mars Feed Forward*

The above considerations have informed investigations for a systems engineering and integration software tool prototype, that integrates: (a) *lunar system elements,* (b) requirements, (c) *mission scenarios*, (d) *operational metrics* such as safety, operability, interoperability, maintainability, logistics, human factors, autonomy, work efficiency index, science, environmental management, Mars feed forward, and international factors, and (d) *system, technology and operational emphases alternatives*. This "operations systems engineering" approach allows for comprehensive integrated analyses, whereby operations metrics are evaluated against capabilities of individual elements, mission scenarios and system alternatives. This approach helps capture the combined effects of multiple factors together as a system, helping to develop operations requirements and a better understanding of overall operational system interdependencies.

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THE USE OF LUNAR LAVA TUBES AS EMERGENCY SHELTERS AND SUPPLY DEPOTS. A. A. Mardon[1] and C. A. Mardon[2], [1]Antarctic Institute of Canada (Post Office Box 1223, Station Main, Edmonton, Alberta, Canada T5J 2M4 Email aamardon@yahoo.ca), [2]NTC(Email Post Office Box 1223, Station Main, Edmonton, Alberta, Canada. T5J 2M4 Email: ccmardon@yahoo.ca)

The author proposes that where areas where Lunar Lava tubes are proposed to exist and human future surface activity will occur that caches and temporary emergency shelters could be created for use to store emergency supplies and rough shelter be provided. Robotic missions to lay supplies could put these supplies in place with inflatable structures to be used inside the micrometeorite shielded lava tubes. Entering and egress from such permanent structures could either be at entrances that are exposed and also a hole with ladder could be drilled to the lava tube from the surface. The supplies would not be as quickly degraded because there would be less thermal variation in the lava tube as compared to the surface. Lava tubes provide a viable alternative to use as structures on the Moon this is just one example of their potential versatile characteristics that could be used.

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JAPANESE 1ST MOON LANDER SELENE-2 AS SELENE FOLLOW-ON. Kohtaro Matsumoto[1], Tatsuaki Hashimoto[1], Takeshi Hoshino[1], Satoshi Tanaka[1], Masatsugu Otsuki[1], and Jun'ihiro Kawaguchi[1], [1]Space Exploration Center, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan, matsumoto.kohtaro@jaxa.jp

Introduction: JAXA plans the moon lander SELENE-2, as the SELENE follow-on lunar explorer. The system design study has been done as phase-A of SELENE-2.

SELENE: JAXA successfully launched SELENE orbiter in last Sep. 14 2007, with HDTV, 13 scientific sensors, and two small satellites. The major objectives of the SELENE mission are to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration. In addition to the many scientific results and academic papers, the repetative broadcasting of the 1st HDTV movies of the moon and rising earth over desolate gray lunar crators has promoted a better understanding on the detail of moon surface and status of earth in the space, with considerable public favor and popularity. The SELENE global lunar map had also made many 3D lunar pictures; those were never photographed and never drawn as the geographical image, such as the central hill of the Tycho crater. (Fig.1)

SELENE-2: From the SELENE's success as the 1st step of Japan's lunar exploration, the next step SELENE-2 is strongly expected to land on the surface and performs in-situ scientific observation, environment investigation, and research for future lunar utilization with human lunar activity. At the same time, it will demonstrate some key technologies for future lunar and planetary exploration. The SELENE follow-on moon lander is requested to be launched until mid of 2010s in the report of the lunar exploration WG of SAC (Space Activity Commission).

Phase-A study: Following the SAC report, phase-A study of SELENE-2 had been carried out by JAXA experts and by major space companies until this July. The lunar scientists team is organized to identify the most valuable lunar science for SELENE follow-on landers, SELENE-2 and SELENE-Xs. To accomplish the lunar landing exploration and lunar science, the primary technological missions identified in the early stage of this phase-A study are, (1)safe & precise landing, (2)lunar surface mobility, and (3)lunar night survival. (Fig.2)

Technical subjects: The landing site selection is major critical factor for safe & precise landing, landing sensors, and the lunar night survival. For the surface mobility, the major factors of the rover design are the lunar night survival and the travelling area size to carry the scientific in-site measurement, such as terrain observation, selection and picking samples, seismometer installation, and so on. The mission life length of SELENE-2 might be the largest design factor. The trade-off study is still open for the required energy source for lunar night survival, and/or survivability of lander, rover, or scientific instruments.

For the SELENE-2 system design, the maximum weight of the mission payloads, available on the lander, is the most important design parameter. To identify this payload weght, various SELENE-2 design cases were also examined, such as the rocket itself, selection of the transfer scenario to the moon, the lander configulation, and the development period.

Summary: In this paper, interium report of SELENE-2 phase-A study will be described, including the preliminary design of the lander itself. Also the present status of SELENE-2 international cooperation, such as ILN, will also be reported.

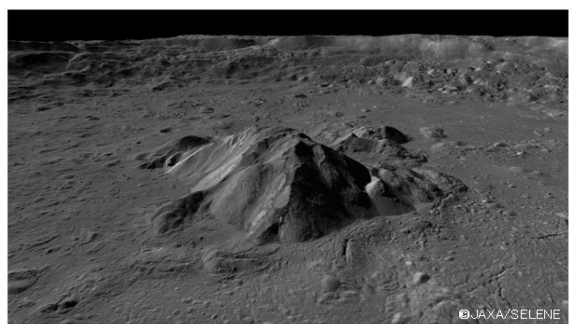

Fig.1 3D image of Central hill of Tycho crater
http://wms.selene.jaxa.jp/data/jpn/tc/012/tc_012_b_l.jpg


Fig.2 Artistic Image of SELENE-2
http://www.jspec.jaxa.jp/e/activity/selene2.html

SIMULATING LUNAR LANDING SITE ILLUMINATION WITH SYNTHETHIC DEMs. J. A. McGovern[1], David T. Blewett[1] , G. Wesley Patterson[1], and N. R. Lopez[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 USA (andy.mcgovern@jhuapl.edu).

Introduction: As part of the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project, the Applied Physics Laboratory was tasked with developing realistic lunar navigation, descent and landing simulations. A strong science rationale exists for landing near the poles, where it may be possible to exploit permanently shadowed craters containing resources helpful for long term habitation [1]. Obviously illumination near the poles will be drastically different from mid-latitude Apollo-era missions and may pose significant challenges for a piloted or automated landing. The primary goal of these simulations is to understand what sensors or pilots would see as they approach and land near the lunar South Pole along a given trajectory. Each simulation consists of three important components: a digital elevation model (DEM), a known illumination geometry, and an appropriate photometric function.

Surface Modeling: Surface modeling is accomplished by APL-developed tools that generate high-resolution synthetic digital elevation models (DEMs) for the Moon; detailed application of the tools is provided in reference[2]. The software can start with existing data, such as the Goldstone Radar DEM, and fill gaps with purely synthetic terrain, and realistic random terrain, that conforms to established size-frequency distributions for craters and rocks. Beyond providing an important component for simulating illuminated surfaces, these DEMs are also useful in characterizing landing hazards [2,3].

Illumination Geometry: The second component of the simulations is calculation of the illumination geometry. ALHAT trajectories are the primary input for illumination determination; these trajectories are essentially a listing of spacecraft states for the navigation and landing phases. Each state includes a time-stamp, and the spacecraft position and attitude in a Lunar body-fixed frame. Using the trajectory information, along with the latest NAIF ephemeris, illumination and viewing geometry can be calculated for each facet at each time step; and ray tracing is used to identify regions of terrain shadowing.

Photometric Function: The Lambert model is a convenient photometric model that works surprisingly well in many cases; in this model incidence angle is the only illumination variable. The Lambert model uses the cosine of the incidence angle which results in a value of 1 at the sub-solar point and zero at the terminator. A quick look at the Moon reveals that this model is insufficient as the brightness of the surface decreases only slightly from the sub-solar point out to the limb. A more appropriate photometric function is the Lunar-Lambert function [4]. The Lunar-Lambert function was developed empirically with the recognition that limb-darkening on planetary bodies with no atmosphere is remarkably insensitive to different surface albedo units. The function incorporates the full photometric geometry of incidence, emission, and phase angles to model limb-darkening as well as backward and forward scattering. Lookup tables of model parameters have been formulated from the Clementine Ultraviolet/Visible (UVVIS) camera basemap.

Simulation and Future Work: The Lunar-Lambert function is relatively simple to understand and use but has the drawback that each trajectory step within the simulation must be rendered anew since the viewing geometry is different for each step and each surface facet. This drawback can be mitigated by using a programmable graphics processing unit (GPU) to evaluate the photometric function for surface facets in parallel. Figure 1 shows some results from illumination and ray tracing of a synthetic DEM.

Future work will incorporate data from the Lunar Reconnaissance Orbiter (LRO) and simulate second-order illumination effects such as Earthshine and multipath reflections.

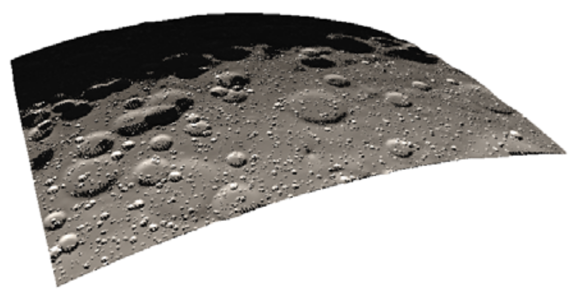

Fig.1. Illuminated and ray-traced synthetic lunar South Pole in early August of 2011.

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Moon Orbiter, Propulsion Issues. Gianmarco Mengaldo[1], Valerio Moro[2], Luca Rossettini[3], A. Bandera, F. Maggi [1] Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy, gianmarco.mengaldo@mail.polimi.it, [2] Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy, valerio.moro@mail.polimi.it, [3]Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy, luca.rossettini@polimi.it)

Introduction: In the recent years a renovated interest on Moon missions has been growing. The objective to send again men on the Moon, the commercial projects about space hotels and Moon tourism, and the necessity of acquiring more information about the Earth satellite are pushing the study and development of many new lunar missions. At academic level both NASA and ESA are helping student to design and realize an orbiter which should reach the Moon in the next four years: ESMO and ASMO missions.

In this scenario, the choice of the propulsion system become critical for the success of the mission. Both chemical and electrical propulsion systems compete for advantages and disadvantages; however, for short-term missions, chemical propulsion seems to be most reliable solution. Traditionally the choice for chemical propulsion system has been liquid propellant, but hybrid motors, still under development, seems to offer the best competitive solution for short and middle range space applications.

In this article a comparison between the two philosophies and a trade-off for a moon orbiter are proposed. It is then discussed the main characteristics, requirements and implementation of the propulsion system simulator, which has been of fundamental importance on the whole orbiter design.

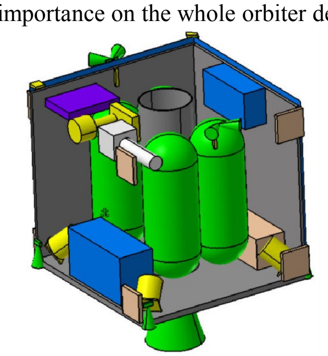

Fig. 1: Hybrid Propulsion Moon Orbiter, CatiA model produced by the ESMO Structure & Configuration team M_STRU_A1

Propulsion systems trade-off: Orbital maneuvers are usually performed using electric or chemical propulsion. The first one produces a very small thrust, usually in the order of mNewton, but with a very high specific impulse, usually in the order of thousands of seconds, while the other produces a much higher thrust but with low specific impulse. For a mission to the Moon, both the time and propellant mass variables, together with costs implications, are taking into consideration. On the chemical propulsion side, both hybrid and liquid propulsion are discussed: a solid fuel enriched with aluminum hydride and liquid oxidizer hybrid engine is compared with a commercial MMH-MON liquid bipropellant thruster.

Hybrid propulsion (Fig. 1) is known to be the best compromise between solid and liquid systems, joining advantages of both configurations: higher specific impulse compared to solid propellant, thrust control and re-ignition possibility, simpler architecture than liquid systems. The most critical disadvantage of hybrid propellant thruster is the lack of heritage: it has never flown before. On the other side the bipropellant liquid thruster system is very reliable, with a good heritage, but it implies more weight.

Propulsion simulation system: A propulsion simulation tool is proposed to monitor the state variable such as temperature, pressure and mass and predict their variation during mission operations.

The simulator replicates the engine and its main components working conditions (Fig. 2), giving maximum flexibility for the performances analysis of the chemical propulsion system in order to accomplish all the maneuvers required by the moon orbiter mission.

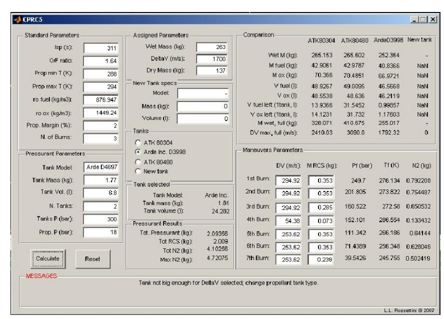

Fig. 2: Propulsion simulation tool graphical interface

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Unpressurized Cargo ORION a Launch Opportunities for Lunar Missions. M. B. Milam[1] and R. Lewis[2], [1]Affiliation NASA Goddard Space Flight Center Code 455 Greenbelt MD 20771 Bruce.Milam@nasa.gov, [2]Affiliation NASA Goddard Space Flight Center Code 401 Greenbelt MD 20771 Ruthan Lewis@nasa.gov

Introduction: Access to space cost and availability is and has been the primary problem for lunar missions. The Orion/Aires I launch vehicle can be used as a launch platform for lunar missions while the Orion is enrooted to the ISS. Studies at the GSFC indicate that a 50 kg payload can be placed in lunar orbit using this launch method. This capability is part of a new program similar to the Hitch Hiker program where excess space on the Space Shuttle was filled with scientific instruments, small free flying satellites and technology experiments. The approach is to launch the Orion with the Aires I and use one of three modes to accommodate science payloads, fixed pallet payloads, extractable or ejectable payloads. The fixed pallet mode is where the payload is permanently integrated with the Orion service module and stay in space for 6 months while the Orion is attached to the ISS. The extractable payload mode is one that is removed from the Orion with one of the ISS robotic arms and placed on the ISS for long durations. The third mode is to eject a free flying satellite out of the Orion Service Module that can stay in an ISS like orbit, boosted to a longer duration orbit or sent to lunar orbit. Possible payloads for the lunar case are scientific instruments, communication relays or lunar technology demonstrations.

Resources: The resources available to the payload change based of mission timeline. For example while attached to the Orion. The resources available are as follows:

Fixed Pallet Table I

Parameter	Capability
Orbit	LEO, 52°; ~350 km
Duration of Flight	180 days
Volume	≤2.92(m³(103 ft³)
Mass	25-250 kg
Power	≤1.0 kW
Data Rate	≤ 30 Mbps
Thermal	Passive/Active
Field of View	Zenith or Nadir
Payload sites	0ne-Four

For the free flyer the post ejection the parameters are mission specific based on specific spacecraft design. The next table shows what is possible with known technology at this time.

Free Flyer Table II

Parameter	Capability
Orbit	LEO to Lunar
Duration of Flight	Varies
Volume	≤2.92(m³(103 ft³)
Mass	50-200 kg
Power	1.5 kW
Data Rate	≤2.25 Mbps
Pointing Accuracy	TBD

Extractable Payload Table III*
(ISS Attached Payload)

Parameter	Capability
Orbit	LEO, 52°; ~350 km
Duration of Flight	Varies
Volume	≤2.92(m³(103 ft³)
Mass	450 kg
Power	1.25-3.0 kW
Data Rate	1.55 – 100 Mbps
Thermal	Passive
Field of View	Zenith or Nadir

*NASA/TP–2007–214768 "Overview of Attached Payload Accommodations and
Environments on the International Space Station"

Payload Volume: The payload volume for the fixed pallet case is shown in the table above. A more restricted case is the free flyer that, due to clearance issues is restricted to a cylinder 127 cm Dia. by 152.4 cm H or 114.3 cm Dia. by 203.2 cm H. The volumes are very generous. The parameters in the tables are based on studies of various missions to explore the use of excess performance on Orion. Free flying spacecraft when detached will have performance per the satellite design that may be different than the study values above.

Conclusion: The Orion has excess performance on at least 14 flights that can be used for lunar and other missions early in the Orion program. It is in the best interest of the Lunar Science community to take full advantage of this capability the new launch vehicle infrastructure brings to NASA. The point of contact for UPC-Orion is Bruce.Milam@nasa.gov.

SEISMIC MEASUREMENTS ON THE MOON: OBJECTIVES AND NETWORK ARCHITECTURES

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Rationale: The international effort for returning on the Moon will allow to adress several scientific objectives with seismic instruments, as well as information important for future crew safety issues, such as the meteoroid rates (meteoroid could damage any Moon base or vehicle) or evaluating the seismic hazards linked to moonquakes, especially near the South Pole where permanent Lunar bases are planned.

Meteoroitic hazards : The frequency and the size law of meteoroids impacting the Moon are still not known precisely (and therefore of the associated probability for affecting a future permanent basis on the Moon). Figure 1 provides such estimates for different models published in the literature, and shows that impacts of 10 mg @ 20 km/s are expected to occur at a rate approximately inversely proportional to the mass and with a flux of 10 to 300 impacts in 10 years per km^2 : this is therefore significant for future long term Lunar basis.

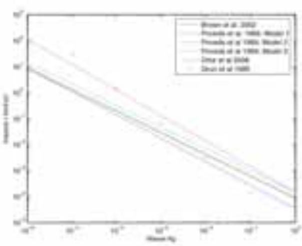

Figure 1 Frequency of the micro-impacts. Note the very large dispersion between the proposed models.

Very large uncertainties remains therefore in the estimation of these hazards, as most of the small impacts are not observed on the Earth, due to the shielding of the atmosphere and the lack of observable signals. A monitoring of these impacts can be done in the future by using a local network of short period micro-seismometers. Such seismometers with an instrument noise of 1-10 ng/Hz$^{1/2}$ will be efficient in detecting small impacts.

Moon internal structure and VBBs global network

The internal structure of the Moon remains unknown and solely the deployment of Very Broad Band seismometers will allow to solve key questions, such as the actual size of the Moon core, and the detailled structure of the mantle. In addition to this, the deployment of a VBB (Very Broadband) seismometer network will allow to have a quantitative evaluation of the seismic risk in the zones where to permament outpost are planned. It will in particular allow to monitor the risk linked to shallow Moonquakes.

Instrument : On the instrument point of view, IPGP in collaboration with CNES, the French Space Agency and ETHZ, is developping a Moon version of the Very Broadband seismic sensor (VBB) now selected to fly on the ESA ExoMars mission. The current specifications of SEIS seismometer allow, with a certain number of non-critical modifications, to make it operational on the Moon with even improved performance, as the mobile mass has been increased.

The maturity of the proposed instrument is good, with a TRL5 to be reached in November 2008 at the instrument PDR. We are currently funded by CNES on the track to increase the performances of the instrument in Moon configuration to level 10-20 times lower than Apollo's background noise, which might be close to the level of micro-seismic noise associated to the permament impacts on the Moon. In addition to this increase in signal to noise ratio, the use of a 24 bit acquisition electronics (we are also studying a 32 bit converter) will also considerably increase the signal dynamics with respect to Apollo data.

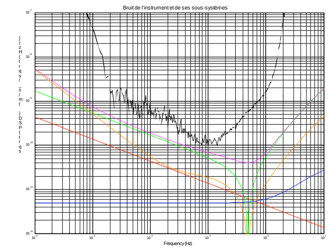

Figure 2 SEIS Moon Noise figure vs Apollo vertical Moon noise

As a result of this, this instrument has been proposed as baseline for the on-going PIDDP study for a LGIP (Lunar Geophysic Instrument package) , as well as for the ISAS/JAXA Selene 2 mission.

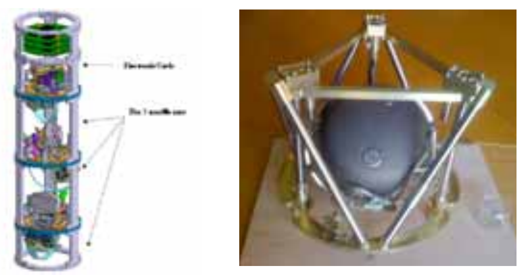

Fig 3. Two possible seismometer configurations (IPGP/MPS)

Possible network architectures and associated rationale.

The following table proposes some preliminary architecturesfor the deployment of seismometer network on the Moon.

Network Scale	Instrument	Rationale	Deployment type
Global	**VBB**	**Lunar structure and evolution** **Global seismic risk**	**Unmaned – Autonomous package deployed by Lander**
Regional	**VBB + SP network**	**Geologic Local structure (regolith depth …)** **Regional seismic risk** **- Meteorites rate (++)**	**Manned/Unmaned – Autonomous package**
Local scale	**SP network (3-4)**	**Local seismic risk** **Subsurface sounding** **Meteorites rate monitoring (+)**	**Manned (preferred)** **Small network**

Commonality with Mars exploration

The deployment of such networks on the Moon paves the way for future planetary networks, especially on Mars, which is expected to be the next step for human outpost in the Solar System. Most of the described technologies developed in the frame of the Moon exploration will therefore be re-usable "as is" for future Mars networks.

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ENABLING SUSTAINABLE HABITATION AT THE LUNAR BASE. C.A. Mitchell[1*], A.J. Both[2], C.M. Bourget[3], C.S. Brown[4], R.J. Ferl[5], T.J. Gianfagna[2], H.W. Janes[2], T.L. Lomax[4], G.D. Massa[1], O. Monje[6], R.C. Morrow[3], K.O. Orvis[1], A.L. Paul[5], H.W. Sederoff[4], G.W. Stutte[6] , R.M. Wheeler[6], N.C. Yorio[6] 1. Purdue University, 2. Rutgers University, 3. Orbital Technologies Corporation, (ORBITEC), 4. North Carolina State University, 5. University of Florida, 6. Kennedy Space Center / Dynamac Corporation, * cmitchel@purdue.edu

Introduction: Central to a sustainable human presence on the moon and Mars-forward technology development is a life-support system that will keep lunar-outpost crews safe, healthy, and psychologically stable. Any life-support system has numerous components, but a central and limiting feature is food. Currently, we are limited to what can be brought from Earth. The food component adds an enormous amount of costly launch mass, generates a large amount of packaging waste that requires disposal, and provides a diet deficient in fresh fruits and vegetables. Adding a plant component to any space diet will have numerous benefits including flavors, textures, aromas, nutrients, and anti-oxidants along with the psychological benefits that living plants and fresh food provide. The atmospheric revitalization that plants also provide will reduce the load on physico-chemical CO_2 removal. Furthermore, demonstrating plant growth in an off-Earth environment will advance life-support planning for future missions and validate that plants and plant-based activities relieve feelings of stress and isolation while living and working in the extreme environment of the lunar surface. While plant growth on the moon seems highly desirable, several scientific and technical issues need to be explored before it can be affordable in terms of equivalent systems mass (ESM), a roll-up metric including launch mass, volume, power-and-cooling energy, crew time, and mission duration. A multi-pronged approach is needed to lower the ESM obstacle to growing crops on the moon.

Approach: The main ESM obstacle for establishing a “salad machine” on the moon is the energy required for crop production. Whereas sunlight ultimately provides energy to drive photosynthesis on Earth, the process of lighting plants becomes much more complicated on the moon, where radiation and micrometeorite hazards make protection of outpost modules a priority. When available, lunar sunlight could be collected, concentrated, and transmitted to a protected plant-growth compartment in a module. During the protracted lunar night and/or during periods of dust occlusion, LED lighting also offers promise, either as a supplement to transmitted solar light or as a sole source of light for plant growth. LEDs are small, durable, long-lived, increasingly efficient, and heat can be removed separately from where light is generated, so they are ideal for plant growth off Earth. By selecting wavelengths and color ratios optimal for plant growth and by applying light uniquely to all photosynthetic surfaces of plants, large increases in energy-use efficiency are possible. Targeted lighting to specific zones of crops, such as tomato-fruit clusters and surrounding leaves, would stimulate fruit production without concomitant increases in inedible plant parts. Additionally, automated lighting that irradiates only leaves that are actively photosynthesizing will yield further savings of energy and crew time. Combining solar and LED-based sources into a hybrid plant-lighting system has potential for synergistic reductions in ESM for a lunar salad machine.

Operating the habitat at hypobaric pressures will minimize air leakage to the external lunar vacuum and reduce ESM for structural mass. Plants grow well at hypobaric pressures, with adjustment of CO_2 partial pressure, but related conditions must be optimized for the lunar-habitat environment, including heat transfer from lighting systems. Regolith is an *in situ* resource that may be used as a substrate and further reduce ESM for plant growth, but must be tested for hydraulic conductivity, porosity, ion-exchange capacity, toxicity, and release of volatile compounds.

Outdoors on Earth, plants gradually developed environmental and genetic limitations to what and how much they can produce. For life-support purposes on the moon and Mars, both limitations can be overcome through targeted R & D. By identifying combinations and levels of environmental factors that overcome limitations to plant productivity, optimization protocols can be developed that improve the quality and quantity of crop outputs with lower resource inputs. Altering a plant’s genetic makeup to produce needed compounds that are absent, increase the levels of desirable compounds that are present, or get rid of undesirable compounds are achievable goals for improving the nutritional content, safety, and health-related features of salad crops to support lunar-outpost crews. Genetically determined nutritional traits such as anti-oxidant content, flavor compounds, and lack of anti-metabolites are important targets for improving salad crops for the moon. Increasing stress tolerance, harvest index, and overall yield potential of crops to be grown within realistic, ESM-affordable growth environments are additional crop-improvement goals that will enable the move toward sustainable habitation at the lunar base.

WATER AND CHLORINE INDICATOR ON THE MOON WITH AKAGANEITE-LIKE COMPOSITION.

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Introduction: Water molecule on dry lunar surface is detected by infrared-spectra detected, though there is few terrestrial ocean water [1, 2, 3] with chlorine, metal, and light elements [2]. Purpose of the present paper is to elucidate water and chlorine reserved in materials.

Various water molecules: Two types of water molecules (liquid H_2O and crystalline OH) are considered to be different with sources and formation processes. Formation of "liquid water molecule" (H_2O) is vaporized molecules formed by meteoritic impacts to produce liquid (ocean) water by cooling process on the primordial Earth planet, though airless Moon has few liquid water molecule from lunar surface [2].

On the other hand, "crystalline water molecule" (OH) located to atomic positions which is formed at higher temperature and pressure conditions, can be formed easily by dynamic reaction of bombardments or so, though airless Moon is usually difficult to maintain such crystalline molecule (OH) on the lunar surface [2].

Therefore, crystalline water molecule (OH) is considered to be found on the Moon, especially on impact craters of the Polar Regions.

Water with chlorine as akaganeite on the Apollo lunar rocks: Micro-rosettes (flake) texture with meteoritic iron metals (Fe, Ni, Co) and crystalline water molecule (OH) with chlorine (Cl) as akaganeite (β-FeOOH) has been reported as "rusty rock" 66095of Apollo 16 [3], mainly by impact-produced aggregates by meteoritic elements to show sporadic distribution of the micro-texture with chlorine [3].

Micro-rosettes texture with chlorine of fallen fragments of meteorites on the Earth: Four meteorites of the Nio, Kuga, and Mihonoseki (in Japan) [4, 5, 6, 7] show similar micro-flake ("rosettes") texture with Fe, Ni, Co, Cl and O (in Akaganeite composition) mainly on "the melted fusion crusts and spherules formed in air of the Earth" [8] by the FE-ASEM (Field- Emission Analytical Scanning Electron Microcopy) analyses taken by author as follows:

1)The Nio chondritic meteorite: Meteoritic spherules and fragments formed at explosion in atmosphere by the Nio meteoritic shower found at the fallen sites of Niho, Yamaguchi, Japan reveal sporadic distribution of many micro-rosettes texture with chlorine, as shown in Fig.1.

2) The Kuga iron meteorite: The Kuga iron meteorite found in Kuga, Iwakuni, Yamaguchi, Japan has "fusion-crust" which includes Fe-Ni-Cl-bearing micro-rosettes texture formed from meteorite melting in atmosphere [8].

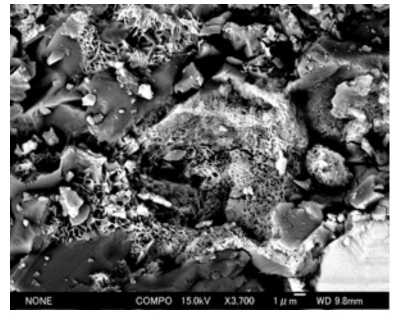

Fig.1. FE-SEM micrograph of Fe-Ni-Cl-O-rich flake texture with sporadic distribution of the Nio chondrite fallen in Yamaguchi, Japan.

3) The Mihonoseki chondritic meteorite: The Mihonoseki chondritic meteorite has been found after passing through wooden house in Mihonoseki, Shimane, Japan. Sporadic distribution of rosettes texture with 1μm in size can be found in spherules and fragments [8] of this sample.

Water and chlorine exploration on the Moon: The impact minerals of Akaganeite composition with Fe,Ni, Co, Cl and OH are considered to be found all lunar surfaces around impact craters, where Cl and OH ions are main ions for ocean-sea water composition (on the Earth).

Summary: The present study is summarized as follows: 1) Four meteorites of the Nio, Kuga, Mihonoseki and Carancas show micro-rosettes textures with Fe, Ni, Co and Cl-bearing elements with crystalline water phase as akaganeite-like composirtion. 2) The present comparative study suggests that lunar surfaces have crystalline hydroxyl (OH) and chlorine ions around impact craters or impact fragments.

Acknowledgements: Author thanks to Drs. T. Kato, T. Tanosaki, H. del Prado for discussion.

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European Architecture for Lunar Exploration. O. Mongrard[1], J. Schlutz[2] and B. Hufenbach[3], [1] ESA, The Netherlands, olivier.mongrard@esa.int, [2] Institute of Space Systems, Stuttgart Germany, schlutz@irs.uni-stuttgart.de [3] ESA, The Netherlands, bernhard.hufenbach@esa.int.

Introduction: In view of the evolving European and international context, ESA is analyzing and defining the potential role of Europe in an international space exploration programme through the study and development of long-term scenarios and supporting architecture for space exploration.

High-level objectives and requirements for the Exploration Architecture have been defined through consultation with representatives of the relevant stakeholder communities including industrialists, politicians and scientists. The analysis of the space exploration architecture has been performed in collaboration with European space industry. The reference architecture is defined as a strategic tool to identify European strategic interests and priorities, define technology roadmaps, and to inform discussions at an international level on future exploration architectures and associated needs and opportunities for international coordination and collaboration.

A phased approach has been derived for the Exploration Architecture, which ensures fulfillment of the requirements, while also incorporating the incremental build up of the architecture in terms of time, technology development, political and financial constraints.

Various trades and options have been studied within the study in order to derive a reference lunar architecture. The trades performed include the potential robotic lunar landing systems, the communication infrastructure, the crew transportation scenario to the surface (e.g. launcher class, staging location, and propulsion type) and the type of crew lunar surface operations (sorties, super-sorties, outpost or base).

A key conclusion from the Architecture study was that while current launcher capability are sufficient to support foreseen robotic missions, heavier launch vehicles are required for sustainable Human lunar missions. The proposed reference lunar transportation scenario is based on a medium lift launcher (50 tons to LEO) and lunar orbit rendezvous of the crew transportation system with a pre-deployed lunar lander such as to offers the necessary payload performance and flexibility to enable both orbital lunar missions as well as surface access.

A full Ariane 5 based lunar lander has been identified has a strategic element in an international lunar exploration architecture. It provides payload capability and flexibility for a multitude of robotic lunar missions, small element delivery and for human surface exploration support (e.g. logistics).

Moon-Mars synergies have also been highlighted during the course of the studies and will be described in particular with respect to the surface activities.

Based on the defined European reference architecture, potential collaboration scenarios for future exploration with international partners will be derived such as to create benefits to all actors (such as increased safety, re-use of common capabilities, cost reduction, additional exploration opportunities). The identification of synergies and interfaces with different international actors constitutes a first step toward the definition of an international reference architecture for space exploration.

DESIGN OF ROOT MODULES FOR A LUNAR SALAD MACHINE

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R.M. Wheeler, NASA, Kennedy Space Ceter, FL
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C.A. Mitchell, Purdue University,

Deployment of a small-scale plant growth system, or “salad machine” during a Lunar outpost mission provides an opportunity for testing bioregenerative subsystems for future missions to Mars. The production of even small amounts of fresh foods could improve the dietary diversity and supply bioavailable antioxidants to combat effects of radiation. A simple salad machine consists of a light cap and a root module. Designing and optimizing rooting modules for the plants will be key to avoiding plant stress and supplying physical support, nutrients, water, and O_2 to roots. An initial step will be to assess whether conventional hydroponic approaches are more efficient than soil-based systems that incorporate lunar regolith. Hydroponic systems typically require active pH control, replenished nutrient solutions, and recirculation. On the other hand, substrate-based root modules would require moisture sensing and control, and procedures for incorporating composted wastes and any missing nutrients. Key issues would include comparing plant yields, power use, system mass, and crew time for maintenance of the different systems, in addition to demonstrating the ability to sustain plant growth over successive generations. If regolith amendments prove cost effective, plant growing efforts would need to integrate closely with in situ resource utilization and waste recycling systems to accommodate long duration Lunar habitats and demonstrate Mars-forward concepts for growing plants.

Solar Thermal Power System for Oxygen Production from Lunar Regolith: Engineering System Development. Takashi Nakamura[1], Benjamin K. Smith[1], and Robert J. Gustafson[2] [1]Physical Sciences Inc. 2110 Omega Rd. Suite D, San Ramon, CA 94583 Phone: 925-743-1110; Fax: 925-743-1117; nakamura@psicorp.com [2]Orbital Technologies Corporation Space Center, 1212 Fourier Drive, Madison, WI 53717

ABSTRACT

This paper discusses the development of the solar thermal power system for oxygen production from lunar regolith. Physical Sciences Inc. (PSI), under the sponsorship of NASA/GRC and NASA/JSC, has been developing the engineering prototype of the solar thermal power system.

In this solar thermal system, as schematically shown in Figure 1, solar radiation is collected by the concentrator array which transfers the concentrated solar radiation to the optical waveguide (OW) transmission line made of low loss optical fibers. The OW transmission line directs the solar radiation to the thermal receiver for thermochemical processing of lunar regolith for oxygen production on the lunar surface. Key features of the proposed system are:

1. Highly concentrated solar radiation (~ 4×10^3) can be transmitted via the flexible OW transmission line directly to the thermal receiver for oxygen production from lunar regolith;
2. Power scale-up of the system can be achieved by incremental increase of the number of concentrator units;
3. The system can be autonomous, stationary or mobile, and easily transported and deployed on the lunar surface; and
4. The system can be applied to a variety of oxygen production processes.

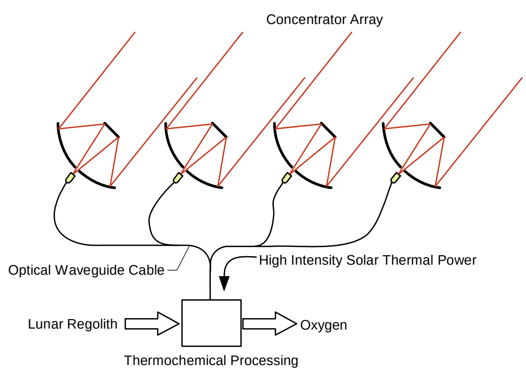

FIGURE 1. The optical waveguide solar thermal system for oxygen production from lunar regolith.

The OW solar thermal system was originally developed for lunar materials processing with NASA/JSC funding support during 1994~1996 (Figure 2). In the present program we are developing and engineering prototype system which is to be combined with the carbothermal oxygen production system being developed by Orbitec. The key components of the engineering prototype system are: (i) the primary solar concentrator array; (ii) the optical waveguide transmission line: and (iii) the power injection optics for the carbothermal reactor. We will discuss the current development status of each component and the performance of the integrated engineering sustem.

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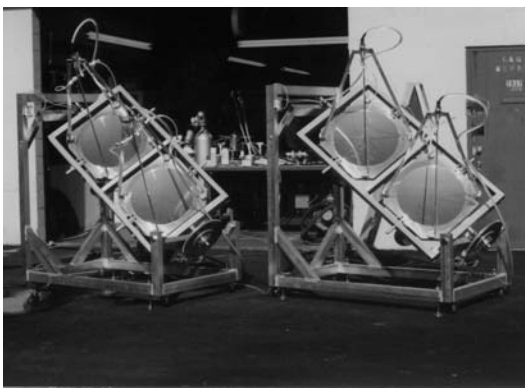

FIGURE 2. The Ground Test Model of the OW Solar Thermal Power System.

LEAG Annual Meeting
28-31 October, 2008
Cape Canaveral, FL

Executive Summary

Date Prepared: 12 October, 2008

Presenter’s Name: Clive R. Neal
Presenter’s Title:
Presenter’s Organization/Company: University of Notre Dame

Presentation Title

The Lunar Exploration Roadmap

Key Ideas

The request came to LEAG from the NASA Advisory Council to develop the Lunar Exploration Roadmap at the end of 2007. Throughout 2008 progress in developing this Roadmap has been made. The presentation reports on the Themes, Goals, Objectives and Investigations that have been proposed. It will also unveil the web portal for community input into this initial draft.

Supporting Information

OPTICAL AND LOW FREQUENCY RADIO OBSERVATORY ON THE MOON. H. Noda[1] , H. Hanada[1] , T. Iwata[2] , N. Kawano[1] , S. Sasaki[1] , H. Araki[1], and T. Imamura[2], [1] National Astronomical Observatory of Japan (2-12 Hoshigaoka, Mizusawa, Oshu, Iwate 023-0861, Japan, noda@miz.nao.ac.jp), [2] Institute of Space and Astronautical Science, Japan Aerospace ExplorationAgency (3-1-1 Yoshinodai,Sagamihara, Kanagawa 229-8510, Japan)

Introduction: One of the targets of the lunar exploration is to realize astronomical observatories on the Moon, because the Moon offers less-noisy environment for astronomical observation with high accuracy. We propose two experiments on the Moon to the Japanese post-SELENE landing mission. One is the ILOM (In-situ Lunar Orientation Measurement), which measures the rotation of the Moon to elucidate the inner structure of the Moon, and another is a low frequency radio antenna for the observation in the frequency range of 20-25 MHz.

Optical measurement: The ILOM is a selenodetic experiment to study lunar rotational dynamics by direct observations of the lunar physical and free librations from the lunar surface with an accuracy of 1 millisecond of arc in the post-SELENE mission [1]. An optical telescope is put on the lunar polar region so that it can track spiral trajectories of stars located near the lunar celestical pole. Year-long data will provide information on various components of the physical librations, and possibly those on the lunar free librations in order to investigate the lunar mantle and the liquid core. A photographic zenith tube (PZT) telescope, which is similar to ones used for the international latitude observations of the Earth, is applied. The ILOM optical telescope is small in size (20 cm diameter) so that it is also positioned as a precursor for the future larger telescopes.

If small dust particles levitate above the surface due to the electromagnetic forces or artifitial disturbances in landing, it is expected that these particle scatter the solar light and that the sky above the instrument becomes brighter [2]. This phenomenon, if it is detected, could affect the optical observation. However, it also provides us of the information of the lunar dust behavior.

Low frequency radio telescope: Astronomical radio observation in the low frequency, long wavelength region has been argued for more than two decades (e.g. [3]), but it has never been realized until now. In the next generation of the lunar exploration, many lunar landers are expected to land on the lunar surface, so that we can study the possibility of the low frequency radio antenna on the Moon. We propose a strategy as well as instrumentation for the future large astronomical facility on the Moon. As the first stage, a dipole antenna will be put on the lander, which will be an element of a very long baseline interferometer (VLBI) with Earth's ground antennas in 20-25 MHz. This array will be dedicated to study the source region of Jovian decameter emission. In the following stages, arrays of low frequency radio antennas in less than 10 MHz range will be put on the Moon for the astronomical study.

Attention should be paid to the result by the former mission that the lunar ionosphere is considered to exist ([4]). The existence of the lunar ionosphere could constrain the lowest frequency limit for the astronomical study. The radio science experiment on SELENE will provide us of the electron density profile of the lunar tenuous atomosphere ([5]). Also, it is noteworthy that the use of radio waves for communication purpose in the vicinity of the Moon should be appropreately regulated in terms of the frequency protection for the astronomical study.

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OPTIMIZING LUNAR SURFACE ACTIVITIES: LIDAR AND mSM AS SCIENTIFIC TOOLS? G. R. Osinski[1], T. Barfoot[2], N. Ghafoor[3], P. Jasiobedzki[3], J. Tripp[4], R. Richards[4], T. Haltigin[5], N. Banerjee[1], M. Izawa[1], S. Auclair[1], [1]Depts. of Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON, N6A 5B7 (gosinski@uwo.ca), [2]University of Toronto Institute for Aerospace Studies (UTIAS), Toronto, ON, M3H 5T6, [3]MDA Space Missions, 9445 Airport Road, Brampton, ON, L6S 4J3, [4]Optech Incorporated, 300 Interchange Way, Vaughan, ON, L4K 5Z8, [5]Dept. of Geography, McGill University, Montreal, QC

Introduction: LiDAR (LIght Detection And Ranging) has been used extensively during the past few years for on-orbit space shuttle inspection [1] and, more recently, for autonomous satellite rendezvous [2]. The use of LiDAR as a vision system for long-range rover navigation has also received considerable attention [3, 4] as it provides the capability to operate at night and within permanently shadowed regions [5]. Space-based LiDAR has many terrestrial applications (e.g., [6, 7]). LiDAR has been used extensively for atmospheric studies on Earth [8] and, now, with the Phoenix mission, for Mars [9]. This research is driven by the question: can LiDAR be used as a scientific tool for the rover-based geological exploration of planetary surfaces? Very few studies have addressed this question [10]. A complementary vision system in development for planetary exploration – suitable for both rover and astronaut mounted scenarios – is the Mobile Scene Modeler (mSM) developed by MDA, based on a stereo camera system. mSM autonomously generates rapid 3D models from sequences of stereo images obtained from a mobile stereo camera pair [11].

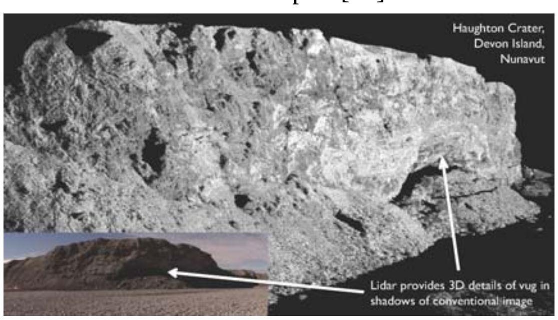

Figure 1. LiDAR scan and panoramic image (inset) of a site of impact-associated hydrothermal mineralization.

Hardware: We used an ILRIS3$_6$D-ER (Intelligent Laser Ranging and Imaging System on pan-tilt unit) LiDAR developed by Optech Inc. [12] with a range of up to 1 km. Two stereo camera systems were used – one in a rover-mounted configuration and another simulating astronaut handheld or robotic arm deployment. The former was a Bumblebee 2, manufactured by Canadian company Point Grey Research (PGR). This was an integrated fixed-baseline stereo camera with a motorized base to allow for panning and tilting.

Field tests: We conducted a series of field tests at the Haughton impact structure, Canadian High Arctic, in July 2008. Haughton is a well-preserved, well-exposed 23 km diameter, 39 Myr old meteorite impact structure [13]. This site represents an ideal space analogue environment with an unusually wide variety of geological features and microbiological attributes [14].

Results and Discussion: Several sites of geological interest within Haughton impact structure were imaged. This work shows that a key strength of LiDAR and mSM is in the 3-D record of a site(s), providing the ability for a geologist to virtually revisit sites, perform measurements, and view from multiple directions and angles; the latter is something that is not always possible in the field. A particular strength of LiDAR is the independence from ambient lighting conditions. Many of the outcrops surveyed during the field tests had shadowed zones; with conventional camera systems little or no useful data could be obtained without supplementary active illumination, which was not the case with the LiDAR, and implicitly active system. This is particularly relevant for the Moon because many high-priority scientific targets lie within the permanently shadowed zones of lunar impact craters [15]. Further applications will be discussed. Future work will address the specific scientific information that can be gleaned by LiDAR and mSM in a variety of lunar and Martian analogue environments.

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SCHRÖDINGER BASIN: A GEOLOGICALLY DIVERSE LANDING AREA. K. O'Sullivan[1], T. Kohout[2 3 4], A, Losiak[5], D. Kring[6], K. Thaisen[7] and S. Weider[8, 9]. [1]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN, USA. kosulli4@nd.edu, [2]Department of Physics, University of Helsinki, Finland, tomas.kohout@helsinki.fi, [3]Department of Applied Geophysics, Charles University in Prague, Czech Republic, [4]Institute of Geology, Academy of Sciences of the Czech Republic, Prague, Czech Republic, [5]Michigan State University, East Lansing, MI, USA, [6]Lunar and Planetary institute, Houston, TX, USA, [7]University of Tennessee, Knoxville, TN, USA, [8]The Joint UCL/Birkbeck Research School of Earth Sciences, London, UK, [9]The Rutherford Appleton Laboratory, Chilton, Oxfordshire, UK.

Introduction: The National Research Council's *The Scientific Context for Exploration of the Moon* report (NRC) outlines a set of prioritized objectives that should be accomplished with missions that return to the Moon [1]. The top priorities described by the NRC include dating basins and craters on the Moon in order to better understand the impact history of our solar system.

Schrödinger basin is the second youngest basin, therefore its absolute age would provide an important data point on the impact flux history curve. The basin also overlies two pre-Nectarian basins, South Pole Aitken (SPA) and Amundsen-Gainswindt (AG). SPA is the oldest known basin on the Moon, and accurately determining the age of the basin is the NRC's second highest priority. Schrödinger basin also presents a diverse and well-exposed set of geologically interesting features. Due to the location and geologic diversity of the basin, we feel that Schrödinger is an optimal landing site.

Geology: Schrödinger is located near the South Pole on the far side of the moon, and is approximately 300 km in diameter (figure 1). The inner peak ring is approximately 120 km in diameter and was created when materials underlying Schrödinger were uplifted just after impact [2]. Because Schrödinger is within the topographic rings of the SPA basin, SPA material could be uplifted and exposed as the inner peak ring of Schrödinger. The intersection of Schrödinger and AG basin is expressed as a set of landslides on the basin rim (figure 1), and AG materials could possibly outcrop in these areas.

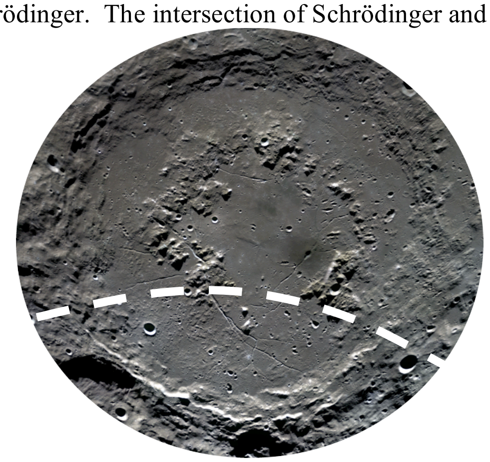

Figure 1: Schrödinger Basin. Dashed line indicates the rim of the Amundsen-Gainswindt basin.

Within the inner peak of Schrödinger are a variety of geologic features easily accessible for exploration. A pyroclastic volcano (dark albedo circular feature in figure 1) lies within the inner ring, and its material may have an upper mantle origin [3]. Several other volcanic outcrops occur within the inner peak ring, and are thought to have different origins than the pyroclastic volcano [3]. A number of fractures occur within the basin, and are thought to pre-date the basin formation [3]. These fractures can provide important information on the pre-existing structure of the Schrödinger area, as well as provide excellent outcrops at which to study the Schrödinger melt sheet. Many secondary craters are found within Schrödinger [3], and examining them may provide important insights into the processes that form them.

Conclusion: A Schrödinger landing site would provide opportunities to find, collect, and date Schrödinger, SPA, and AG impact material, providing key points on the impact flux curve. Additionally, various other accessible geologic features could address the NRC objectives (Table 1). Specific localities can be located and mapped with a precursor robotic mission as described in [3]. Due to the diversity of the basin, Schrödinger is an optimal landing site.

Table 1: Example of NRC objectives that can be addressed within Schrödinger basin.

Schrödinger impact material	1a, 1c, 3a, 3d, 6b
SPA impact material	1b, 3d, 6a
Date Amundsen-Gainswindt impact	1a, 1c, 3d
Various volcanic events	1d, 3a, 3d, 5a,b,c

*see [1] for numbering and further explanation of goals

Acknowledgements: This work is part of the 2008 Lunar Exploration Summer Intern program at LPI in Houston. We would like to thank the LPI staff for their support.

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CHARACTERIZING POTENTIAL LUNAR LANDING SITES USING SYNTHETHIC DEMs. G. Wesley Patterson[1], N. R. Lopez[1], David T. Blewett[1] , and J. A. McGovern[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 USA (wes.patterson@jhuapl.edu).

Introduction: In support of the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project, the Applied Physics Laboratory (APL) has developed software capable of generating realistic synthetic Digital Elevation Models (DEMs) of the lunar surface at scales pertinent to terrain relative navigation and hazard avoidance. These DEMs currently incorporate established relationships invoving crater morphology [1] and size/frequency distribution [e.g., 2-4], with work to incorporate realistic rock distributions [e.g., 5] ongoing. We are using these synthetic DEMs to develop tools for assessing how hazard detection is affected by illumination geometery [6] and the statistical probability of locating 'safe' landing zones [7].

Synthetically Derived Topography: The software package developed by APL can currently generate synthetic DEMs of cratered surfaces (at any prescribed resolution) that are purely or partially synthetic. Purely synthetic DEMs (Fig. 1) are useful as a first order approach to evaluating potential landing hazards and, given the the current lack of high resolution data, are typically necessary to represent the distribution of craters at diameters < 100s of meters. At lower spatial resolutions we have the capability of incorporating both Goldstone radar data [8] and Unified Lunar Control Network (ULCN) data [9] into otherwise synthetic DEMs to provide a realistic 'basemap' for the distribution of craters in a particular region.

Impact Crater Statistics: A key to producing realistic synthetic DEMs for the Moon is understanding how impact craters affect topography. To accurately represent the topographic expression of individual impact craters in our synthetic DEMs, we use established scaling relationships involving morphology and crater diameter [1]. For representing the population of craters, we use size-frequency distributions based on crater-counting statistics [e.g., 2-4]. Variations in these distributions are dependent on the age of the surface that is being examined.

Shackleton crater, near the lunar South Pole, has been established as the target location for the next manned mission to the Moon. Mapping of Shackleton has been used to suggest that it may be as young as ~1.1 Ga [10]. However, more recent analysis indicates the crater likely formed ~3.6 Ga [11]. Using incremental crater size-frequency distributions described by [2,3], we have generated DEMs with two end-member distributions for the potential crater size-frequency associated with Shackleton crater (Fig. 1). One represents an 'average mare' distribution (~3.2 to 3.5 Ga) and the other represents a 'highlands' distribution (~3.9 Ga). These DEMs illustrate the potential variability in the distribution of craters in and around Shackleton crater and provide data useful in characterizing landing hazards for future manned missions to the lunar South Pole.

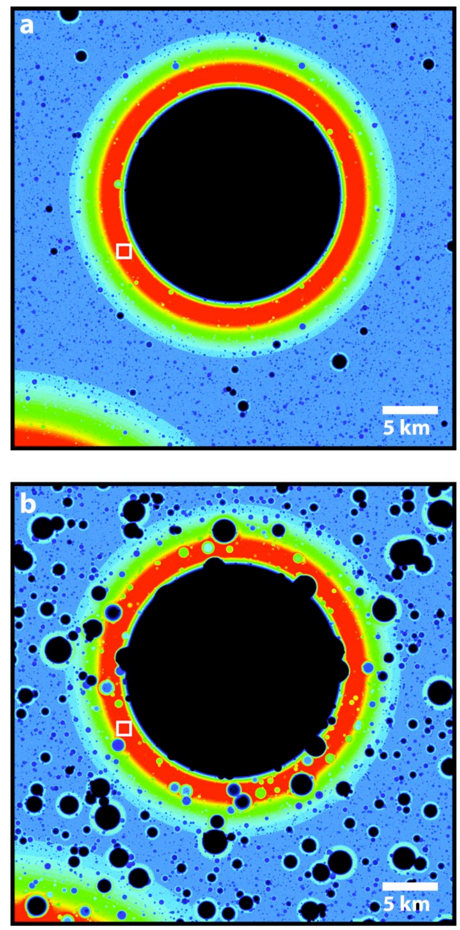

Fig. 1. Sample synthetic DEMs of the lunar South Pole surrounging Shackleton crater (center). (a) Cratered surface simulating an 'average mare' surface. (b) Cratered surface simulating a 'highland' surface. White box represents location where landing site statistics have been calculated [7].

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TELEMETRIC BIOLOGY: EVALUATING IN SITU RESOURCES FOR BIOLOGICAL PAYLOADS IN A LUNAR LANDER. Anna-Lisa Paul[1] and Robert J. Ferl[1,2], [1]University of Florida, Hort Sciences/Program in Plant Molecular and Cellular Biology, and [2]Biotechnology. Gainesville, FL 32611. alp@ufl.edu , robferl@ufl.edu.

Introduction: The concept of a biological payload for a lunar lander supports the conviction that we will need to effectively utilize local resources for support. Understanding challenges prior to mounting a long term mission will enhance the readiness level of returning humans for extended work on the moon.

Plants posses a set of characteristics that make them ideally suited to extraterrestrial biological payloads. As seeds, plants can lie dormant for years, and then be developmentally activated in favorable environment. There is also little difference in basic metabolic and genetic processes of both plants and humans, yet plants have evolved to adapt to their environment in situ, which has fostered a complex and dynamic mechanism to deal with environmental change unparalleled in higher eukaryotes. Plants can be easily bioengineered, and the mechanisms by which plants mount a response to a novel environment can be monitored telemetrically through the use of plants equipped with Fluorescent gene reporters.

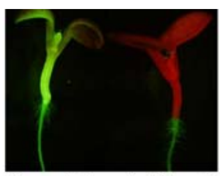

Figure 1. Two Arabidopsis GFP biosensors

The use of engineered Arabidopsis plants as biosensors has been widely used to assay the nature of stress responses. The incorporation of Green Fluorescence Protein (GFP) as a biosensor molecule makes it possible to evaluate patterns of gene expression telemetrically as processed fluorescence images (Fig. 1). The combination of biological engineering, high fidelity visual data collection and telemetry has created a means by which biologically relevant information can be obtained in a planetary lander in situ.

Tools and Analog Environments: A lander experiment of this nature is comprised of three components – biology, telemetric data collection and in situ resources. We have addressed the first two components with analog site studies by deploying the TAGES GFP imaging system within the Arthur Clarke Mars Greenhouse (ACMG) an autonomously operated greenhouse located within the Haughton Mars Project in the Canadian High Arctic [1]. Results demonstrate the applicability of the fundamental GFP biosensor technology for telemetric data collection from challenging deployment environments [2]. Thus, the basic efficacy of using plant biosensors in a capacity similar to deployment on a Lunar Lander has been demonstrated.

Evaluating local resources – regolith: It is not known how plants would fare in pure lunar regolith. Although plants have been exposed to lunar materials, it has always been in trace amounts due to its scarcity. [reviewed in [3]. A lander experiment capable of sampling surface material and depositing it into an internal growth chamber can evaluate the biological impact of regolith in lunar gravity and radiation environment.

As a first step, there are terrestrial analogs that can be evaluated to guide lander development. Additional to prepared simulants (e.g. JSC1a) are natural terrestrial analogs. The impact crater on Devon Island in the High Canadian Arctic contains geological features analogous to some lunar and martian impact sites [4].

Arabidopsis plants were grown in JSC1a Lunar simulant as well as in a variety of substrates from in and around Haughton Crater on Devon Island. All substrates were evaluated for their ability to support plant growth with and without mitigation. Figure 2 shows a small selection of the experiments conducted in native breccias and JSC1a with Arabidopsis. The results are

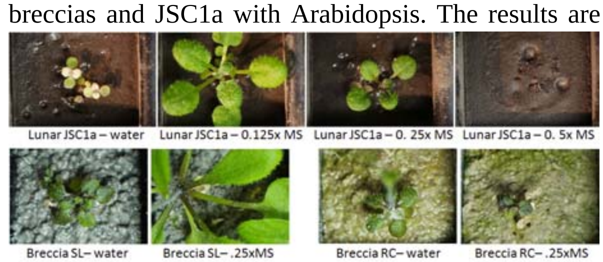

Figure 2. Growth tests with regolith simulants and analogs. All plants within each row are the same age, and photos taken to the same scale. The top row shows lunar simulant JSC1a; The second row compares two different sites from Devon Island.

preliminary, but show clearly that the native breccias and soils of Devon Island are complex and require a variety of mitigation steps to render them able to support plant growth. It is likely that the same would be true of native materials collected from any planetary surface. Telemetric data collection in the form of images can reveal the impact such substrates have on growth and habit, and well as reveal metabolic data in the form of GFP fluorescence of the biosensor gene.

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Global Space Exploration Until 2025 a European Perspective

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Space exploration is an emblematic domain of space activities where traditionally only established space powers have been active. But, following the evolution of the space context new actors are increasingly interested to be involved in those activities principally for international prestige reasons. An increasing number of actors are thus taking on ambitious plans with orbiters, robotic landers, sample return and human exploration missions. However, complementing national endeavours international cooperation has over the years become a central element of the strategy of most countries involved in space exploration since it is a demanding effort.

Human and robotic space exploration endeavours are embedded in a complex system of different "earthly" factors. These determinants will influence the decisions taken today for programmes which will be carried out in the future. It is therefore indispensable to be prepared for the on-going changes in the world which might affect the planning and the aspirations of space-faring countries. Europe's long-term exploration programme thus cannot be decoupled from emerging global trends and the plans of other major space-faring actors who shape the global environment for space exploration.

This presentation is intended as a first step in paving the way towards further reflection on the future position and role of Europe in space exploration. It provides a contribution to strategic policy-making by highlighting some of the variables influencing the evolution of the international system in which Europe will have to operate until 2025, as well as plans and ambitions for major and emerging space actors.

FUTURE ROBOTIC STUDY OF LUNAR BASINS: GOALS FOR GEOCHEMISTRY AND GEOPHYSICS.

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Geology and geochemistry of lunar basins: Various proposals have been made during the past decade for lunar landers and rovers. We present a summary of the scientific goals for geochemistry and geophysics and related technical requirements for future lunar lander missions, focused on the lunar maria, in order to contribute to the previous made and new proposals. Important questions that remain unresolved from our existing data are related to the origin and age of mare basalts, the solidification of the magma ocean, global variation in chemistry of mare basalts, and the positive gravity anomalies (mascons) and isostatic state of the basins.

Compositional studies: The chemistry and mineralogy of mare basalts represent those of the lunar mantle and are therefore of high interest to deduce the internal structure and evolution of the Moon. It has become clear from previous missions that strong lateral variations in chemistry of the mare basalts exist [1]. Radiometric dating will be useful to study the inhomogeneous distribution of elements in relation to time. Stable isotope analysis and radiometric dating will contribute to understanding of chemical evolution and global variation of the magma ocean, magma mixing processes, and thermal evolution. Detailed radiometric dating of impact melt and mare basalts for various basins will clarify the timescale of mare volcanism and the time gap between basin forming impact and volcanic activity (±500Myr [2]). Heat flow measurements are required to determine the role of radiogenic heat in mare volcanism at the Procellarum KREEP terrane and will provide information on the evolution and thermal state of the Moon as well.

Gravity and internal structure: Most circular basins coincide with regions of large positive gravity anomalies or mascons [3]. The current consensus is that mascons result from a mantle plug caused by isostatic adjustment after the basin forming impact and basin infill of dense mare basalts. Thickness of the mare basalts and depth of the crust-mantle boundary are significant inputs in the current models and have been determined only indirectly from combining gravity with topography and basin morphology. New subsurface images are required to complete our existing models.

Instruments for future missions: We now propose four types of instruments to make the investigations that are mentioned above.

Element analysis: We argued that spectroscopy of the surface is necessary for further understanding of lunar geochemistry. In situ robotic analysis however faces technical challenges. Most spectroscopic instruments that are currently used (e.g. XRF, XPS, electron microprobe) are large and significantly too heavy to serve as payload on a planetary mission. Recently however, spectrometer design has made major progression with the Raman/LIBS instrument that is currently developed for ESA's ExoMars mission.

Isotope analysis: Previous work on samples of lunar basalts has been done with Sm/Nd, Rb/Sr, U/Pb and tungsten isotopes. These methods provide a good coverage of isotope systems, but the number of sample locations is limited. In situ isotope analysis and radiometric dating for different basins is favorable, but faces technical difficulties. Current mass spectrometers are too heavy for payload on planetary missions and hence sample return followed by isotope analysis on Earth seems currently more realistic.

Subsurface imaging: Current subsurface images of the Moon result from the Apollo lunar sounder experiment (ALSE) and were made using ground penetrating radar. The depth range of this instrument type is however limited (2 km) and in order to investigate moho depth (below basins >20 km [4]), other techniques are thus required. Reflection seismology forms a good alternative. We propose a rover that places geophones around a basin and collect the signal that they record from moonquakes. In order to record active seismometry, the rover can place a seismic source as well, for example vibroseis instruments. It has been argued by Lognonné [5] that the meteorites may produce a sufficient amount of energy to function as a seismic source.

Heat flow measurements: We explained that heat flow measurements would contribute to the study of the thermal state of the Moon. Furthermore this will record geophysical properties of the regolith like electrical conductivity and permittivity. A package for heat flow measurement includes a penetrator that places the recording instruments at a depth of few meters within the regolith. A certain package is currently being developed for the ExoMars mission (i.e. HP^3). We suggest this package as a model for development of future lunar robotic instrumentation.

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Valuing Exploitation of Moon Resources using Real Options

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M.A. Perino, Thales Alenia Space SpA
G. Borriello, Aviospace SpA
C. Tuninetti, Rheinmetall SpA

Purpose of a successful and widely-accepted exploration programme should be not only advancement in planetary science but also development of terrestrial economy. Thus, use of space resources will be key in the development of an affordable exploration architecture.

Consumables and, in the longer term, propellants, will prove too costly if delivered from Earth, especially in case of the establishment of a surface base and of a permanent colonization of the Moon. Colonization will make a high level of autonomy for the crew somewhat mandatory. This makes an architecture based on cryogenic and "refuelable" propulsion a promising solution, in terms of projected profitability of investments in space.

A refuelable architecture would be also more appealing for private investments and tourism, lowering the transportation cost to the Moon and thus the average ticket for a futuristic tourism on the moon.

Investment strategies with high risks and uncertainty or irreversible corporate decisions coupled with managerial flexibility provide the best candidates for real options. Valuations of investments through real options were extremely hot during internet bubble, where the market environment was almost unknown. After the blast of the bubble, real options become a standard valuation method in a number of R&D-intensive industries, including oil and gas exploration and production, pharmaceutical research and development, e-commerce valuation, IT infrastructure investment, mergers and acquisitions.

And, last but not least, prioritization of venture capital investments that closely resemble prioritization of investments in space technologies.

Economic considerations on the exploitation of Moon resources and its impact on the architecture choices are developed using real-options calculations, and a comparison with the results achieved with traditional discounted cash-flow methods is presented.

AUTHORS:

Fabio Piccolo is an aeronautical and aerospace engineer. He works since 1997 in the Space sector first affiliated to Vitrociset company, then to Aero Sekur, and now to D'Appolonia. He is author of more than 10 papers presented in Space Conferences (mainly ESA sponsored) and has been chairman of the Descent and Landing System session at Arcachon conference in 2006, Currently he is in charge of D'Appolonia participation to ESA Exploration Architecture studies.

M.A. Perino is responsible of Advanced Studies at Thales Alenia Space, Infrastructures and Space Transportation division. In the 1990's she led the studies that brought to the definition of current ESA AURORA programme and is a reference person in the establishment of International Space University. In the last two years she led Thales Alenia Space participation to ESA Exploration Architecture studies, being the one of the two reference industrial contacts for ESA and coordinator of one of the research teams.

G. Borriello, former Marketing Executive at Alenia Spazio, and specialist in the field of system design and space transporation, is one of the components of Board of Directors at Aviospace, a consulting companies providing engineering support services to private and institutional space customers. He has been the reference person in an ASI-sponsored study aimed at the design of a Moon lander and, throughout the last year, the program manager of Rheinmetall Italy participation to ESA Exploration Architecture studies.

C. Tuninetti, Head of Space Programs at Rheinmetall Italy, has been during 2007/08 the responsible of Rheinmetall Italy participation to ESA Exploration Architecture studies. He is also responsible of many other space programs at Rheinmetall, including participation to VEGA ground segment, FLECS inflatable module project and Miosat (small satellite ASI program).

ROBOTIC EXPLORATION OF THE MOON: PRELUDE TO HUMAN SETTLEMENT AND ISRU EXPLOITATION.

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Introduction: As NASA prepares to return to the Moon, the role of robotic precursors needs to be defined. Robotic precursors play three roles: 1) provide data to enable landing and operations, 2) provide data necessary to settle the Moon and use it as a stepping stone for exploration, and 3) provide data to set the stage for advanced and complex human science activities. The specific objectives of those missions, their targets, payloads and operations are all different.

Raison d'être: This is not the song by the Japanese rock band *Dir en grey* or the American Ale brewed by Dogfish Head Brewery in Delaware. It is the reason NASA is returning to the Moon. Until it is defined and accepted by the agency and the nation, the precursor robotic missions, particularly as they relate to settlement, will be subjective interpretations.

Landing and Surface Operations Missions: To simply land on the surface, few new data lie in the critical path. At present, only geodetic control of high latitude sites would be considered enabling. LRO and the international missions will provide data sufficient to resolve this issue. Depending upon the stay times for the crew, the oxidation potential of lunar regolith fines may require *in situ* analysis. Such analysis requires a mission capable of collecting, sieving and processing samples. Data on the distribution of hazards (craters, rocks, slopes) is enhancing to mission safety and risk reduction, to develop statistics or if they are acquired for the actual outpost site. However, with our current understanding of lunar geologic processes and the technologies being developed by ALHAT, new data may not lie in the critical path.

Settlement Missions: The key to settlement of the Moon is the use of In Situ Resources to minimize the bonds to Earth. Such bonds will never be completely severed, but they can be reduced. It is the nuclear submarine that is perhaps the best analog to lunar settlement rather than Antarctic bases. A nuclear submarine produces its own power and water and recycles air and water; but it remains dependent upon a base for some materials (e.g., food and hardware).

The key to lunar settlement and using it as a stepping stone for continued exploration of the Moon and beyond is the production of fuel and life support volatiles. Hydrogen and oxygen are the two key elements. Oxygen makes up ~45% of lunar materials, it is globally distributed and can be obtained anywhere by any number of processes. Hydrogen, however, is concentrated at the poles, although whether it is in the form of elemental hydrogen or water-ice remains unknown.

Understanding the hydrogen form, concentration, and distribution thus is the key to exploiting lunar resources. To understand that will require missions to the surface having the ability to rove and analyze the regolith to depths of a few meters. Orbital data will never be able to definitively resolve the hydrogen story. The hydrogen may be more or less uniformly distributed over the polar regions or it may be sequestered in areas of permanent shadow. To resolve this, mission(s) that explore the illuminated and shadowed regions are required. The payload might consist of a neutron spectrometer to map the H distribution at high spatial resolution, a drill to acquire material from depth, volatile analysis (e.g., mass spectrometer) to determine the form of the H, and a ground penetrating radar to map its distribution if it is in the form of solid ice. This can be attacked piecemeal or with a comprehensive mission.

Once the volatile resources are located and mapped, an outpost site can be selected. The reason to wait until after such mapping, is that the economics of ISRU involve issues such as transportation between the outpost and the resource ore. Thus, a trade may need to be made between different outpost locations (because of their need for solar power) and the location of different ore bodies to minimize the overall costs.

Other commercial objectives may also have site-specific requirements. The extent to which they become the reason for the outpost may also drive its selection. Missions to assess these requirements might be necessary. However, until the commercial objectives are established, the requirements can not be defined.

Science: Robotic missions that explore different regions and which collect and analyze various data and samples can significantly enhance the potential of humans to conduct scientific exploration. Such missions would require mobility and the ability to collect samples from depth (few meters) and to operate for extended periods of time. They could explore the site and provide the basic information that would allow the humans to focus their attention on the key locations and make the measurements and collect the types of samples that are difficult or impossible for robotic systems.

Summary: Robotic missions are most critical to enable the exploitation of lunar resources. For other aspects, such as landing and nominal surface operations and science, they are enhancing, not enabling.

Automated Multi-Conditional Exploration Rover Series (AMCERS) — Low Cost Lunar Exploration
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Introduction: It is not possible for all human to land on lunar surface and even though, there are some points were human can't go. To fulfill all these needs, low cost moon rovers are being developed and propelled to lunar surface. Here I've taken a hypothetical situation of moon rover design and I so as to satisty the concept of low cost lunar explorationwhich is the **Automated Multi-Conditional Exploration Rover Series** (**AMCERS**). The mission objective is to locate the lunar outpost for the fore coming Deep Space Networking missions and bringing moon close to human.

Design approach: According to the concept, the rovers are designed as small as possible in order to minimize the total pay load. A series of three rovers, ALPHA, BETA and GAMMA are designed and fabricated so as to perform the exploration and research in lunar surface. The rovers are enclosed in a container of volume 0.2 m3 and the total weight inclusive of 3 rover series is subjected to 20kg. This container serves as the data communicator that transmit the data fron AMCERS to EARTH. After proper docking from the launch vehicle, the container (DATA COMMUNICATOR) is maneuvered to landed in a location of constant sunlit in lunar surface[1]. The rover is then driven out from the container in an automated way. With the help of GAMMA, the data communicator is automated for the orientation of its primary antenna (PHASED ARRAY) and the solar cells are directed towards constant sunlit. The container serves as the base and makes a communication loop (AMCERS←→container←→earth station).

AMCERS: Each rover is designed according to their specific payloads and respective mission objective. All the major system components i.e. the locomotive arrangement, real time imaging camera, electric drives etc. remains the same for all the AMCERS and they vary only with the payload and power source. ALPHA and BETA are powered by solar cells, provided with nanocomposite battery backup[2]. AMCERS GAMMA is powered by RTG. There is no directional constraint in the AMCERS locomotion, having all degrees of freedom. Each AMCERS is equipped with two long range high definition cameras and the payload includes,
ALPHA – Astrophotometer (Measurement and study of light level), BETA - MicroR Meter (Detection of Helium-3 presence),GAMMA – RADOM(Radiation Dose Monitor Experiment) [3]

The moon rover is made to survive at all condition i.e. varying temperature range (-233°C to 123°C), hazardous radiation prone area etc. Due to the low gravitational pull the traction should be maintained for this special type of wheels are designed.

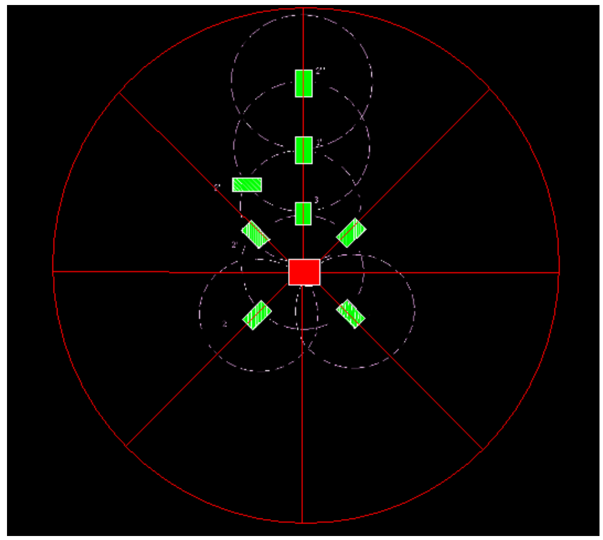

Figure2: AMCERS exploration range coverage.

The communication limit gives the range of the exploration area. The DATA CONTAINER is supposed to have a range of 20 km due to its high gain antenna. Each AMCERS is suppose to have a communication range of 15km. From the mode of path followed here, the exploration range can goes up to an area of **13,266.5 km²**.

CONCLUSION: The moon rover are designed to the given constrains. The entire span of the AMCERS will be about 2 years and can also be extended.So with this the low cost exploration of moon can be accomplished.

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Orbiting "Earth-Safe" Atomic Explosives for Defense Against Asteroids
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High Earth orbit is the best place to put a system of missiles carrying atomic explosives for destroying or deflecting incoming Asteroids or Comets. Ideally, two groups of these devices would be in both equatorial and polar orbits. From these two orbits, they can be launched in nearly any direction in less than 48 hours. To launch a response from the Earth's surface could take weeks or months.

Current designs for atomic weapons require the use of chemical explosives to initiate and enclose the preliminary chain reaction. Instead of explosives, the design for atomic explosives that would defend Earth would use the speed differential between an incoming Asteroid or Comet and the device. The device would use the speed differential or impact energy to assemble and detonate the device. The devices relatively fragile construction would not permit it to enter the Earth's atmosphere intact.

There are currently international treaties that wisely bar the orbiting of atomic weapons. Negotiations can be begun that would permit the orbiting of these "Earth-Safe" nuclear devices. Before launch, they would be inspected to verify that they lack chemical explosives and are incapable of being used against the Earth in an EMP, air-blast, or ground impact mode. In this article, I give a plausible example of an atomic explosive that is physically incapable of attacking targets on the Earth's surface.

Excavation of Habitat Trench by a Single Precision Kinetic Bombardment

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By the use of a special dispensing canister, a trench for burying a shielded habitation can be constructed before humans land. A canister containing kinetic impact devices (ball bearings) is placed on an orbital path that will intersect the desired trench site. Some time before impact the canister begins releasing the bearings. As it releases the bearings it will give them a measured shove so that they will be near their correct position in the matrix at impact. As the canister releases the bearings it also speeds up or slows down to spread the bearings along the path of the orbit. This will temporally separate the bearings so they will impact at different times. The impacts of the bearings will produce a progressive pattern or raster that will erode a trench into the surface.

A Study on Transnational Mission Crew Management

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ABSTRACT

With ever growing co-operation between international communities in the field of space science & technology, today's space operations often involve close co-working of people with different ethnical, professional and organizational backgrounds. The implications of cultural diversity for efficient collaboration between the personnel stress on four factors associated with challenges in interaction: Management, Compliance, Communication, and Competitiveness.

It is a widely accepted fact that cultural factors pose additional risk to the success of long-duration spaceflight (LDSF). Inadequate language competence will manifest itself in miscommunication during crew interactions and will ultimately lead to operational snag. Thus, goal is to suggest possible ways of reducing the risks and uncertainties associated with cultural and language factors.

Considering the potential cost of human error in operational settings, which may be due to cultural or language miscommunication, it is undisputable that measuring cognitive performance is a relevant challenge. The need for a robust remote assessment method for cognitive performance has been specifically ranked as a research priority for the preparation of exploration missions.

According to a recent study on astronaut's psychological analysis after a mission, the feeling of cultural isolation and interpersonal incidents during the mission were more common than psychological or negative incidents.

Yet, another established fact that a team's success in coping with a crisis situation largely depends on the team's composition, such as, national origin, gender, historical period of spaceflight, longest flight, and nationality status (minority or member of the majority of the crew).

In order to recompense above problems, a efficient Crew Resource Management (CRM) training program has to be designed and adopted to improve flight safety through better teamwork, good-communication, situational awareness and superior decision-making ability.

This study is intended for further help the employees working in international space program teams.

A Strategic Technological, Ethical and Socio-Legal Frame Work for a Sustainable Lunar Colonization

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ABSTRACT

Sooner or later, with vast technological prowess at our behest, our natural future course of action will be to expand Space Exploration and colonization. The first step towards realizing this dream would be establishing a Surface Base on Moon. Any further step towards this would involve number of strategic technical, ethical, socio-legal issues.

The technological challenges involve,

1) Crew safety, crew survivability, adequate provision to overcome contingencies, and in-situ resource utilization.

2) Extra-vehicular activity, Life Support, Dust mitigation and control, Human-Robotic Interactions, Power management and Habitat Design.

3) Space Traffic Management System for the Moon.

4) From debris creation to debris reduction.

5) Pursue technologies to remove or recycle debris.

6) Designing a robust, retrievable archive with storage in both Moon and Earth,

7) Defining archive contents essential for both immediate survival and longer-term recovery.

The ethical challenges involve,

1) Whether the in-situ resource exploitation will be only for carrying out further missions to other planets from Moon or for utilization on Earth.

2) Will the long term impact of pollution on Moon due to technologies employed for power generation and other logistics on Surfaces justifiable?

The socio-legal frame involves,

1) Given the choice of potential landing sites, where does one “drop” a spaceport that is accessible to all parties?

2) How is control of the spaceport handled: by joint declaration, straw votes, or what?

3) Human settlements in space, in particular the first few to be established, require advance political systems since they have to be internally politically administered

4). Focus on the criteria for the safe use of a nuclear reactor on the Moon.

5) Form an international body to seek out and implement debris reduction strategy – It must be non-political and non-military.

6) International legal regime.

7) Re-Engineer the Moon Treaty.

Much of this is not new and none of it would be easy. This paper elaborates the views of the authors on the above topics.

INTERNATIONAL LUNAR SCIENCE MISSION TO THE DESCARTES FORMATION.

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Introduction: Science deemed essential [1.] before extended human activity on the Moon calls for efficiencies already planned for LRO/LCROSS, GRAIL, LADEE, etc. We study the notion of a Station-Rover, redundant to a node in the International Lunar Network (ILN), to survey regolith and a relatively pristine exosphere in an area of long interest [2.] [3.].

Overview: Survey of South Pole–Aitken Basin is a higher priority, however equatorial sites feature insolation and geomagnetic sweep at highest incidence. Also, *Lunar Prospector* data [4.] indicates a lunar magnetic anomaly (LMA) centered near the north rim of ancient Descartes Crater, with albedo on the Descartes formation to the north. We propose traversal of likely surficial influence by this LMA, across the unique formation ~40 km, shy of Station 4 at Stone Mountain Cincos, and tentative scrutiny of artifacts of Apollo 16.

Our notional mission lands, establishing a fixed ILN node and science station within 2 km of the north rim of 2km *Descartes C* (~16.36° x 10.925°S), which is distinct on the ruined rim of Descartes to the southwest. From the south terminus of the albedo, science begins during a period of ILN calibration, the sampling of outgassing, heatflow and exosphere. As part of the LADEE [5.] “affordability option,” the ILN node becomes ground support in detection and characterization of electrostatically charged dust phenomena.

Maximum instrumentation of minimal weight is already proposed in the ILN paradigm [6.]. Doubling this in a rover adds redundancy in a distant robotic network. Descartes could be test ground for the wide distribution of ILN nodes to follow.

Beginning ~10 km east of the “center” of the Descartes LMA (strongest on the nearside) its affect on systems is tested by comparison of data as the rover is moved from node through Descartes Swirl, to Station 4, and gradually emerges from LMA influence.

Descartes formation defies easy explantion, whether or not it is radiant of Nectaris, and the region is apparently suited to dating every lunar epoch. [7.] suggested understanding Descartes may prove definitive to gradual fall off of bombardment or cataclysm.

After redundancy, our notional sensing mission might determine, and to what degree, the Descartes LMA protects the surface from relentless solar particles or lower energy cosmic rays under its “umbrella.”

Whether LMAs shield regolith from space weathering is a question that persists. One theory of origin for the Moon’s Swirl albedo and their associated LMAs holds them as recent, resulting from encounters with meteor swarms or comets [8.]. In noting some farside Swirl and coincident LMAs are antipodal to nearside basin-forming impacts [4.] attributes these to low optical maturity (OMAT) in regolith shielded by shock-fossilized paleomagnetism, long afterward shielding regolith below from the darkening of space weathering. Despite a demonstrated strength in some LMAs, sufficient to stand off solar wind, LMAs still seem insufficient to delay OMAT throughout ~4 Ba.

We would test one possible cause for the apparent longevity of low OMAT regolith under LMAs with improved understanding of electrostatic dust charging and ballistics. Positive electrostatic charging and levitation of microscopic dust, away from the Descartes Swirl, may continually expose the less optically mature, brighter regolith below. Upon subsequent negative charging, dust might be repelled from re-entering the area under the Descartes LMA (the polarization of which remains unchanged).

Regardless, improved understanding, leading perhaps to mitigation, of lunar dust is the highest priority ahead of extended human activity on the Moon.

Slow approach. At the end of our scenario are artifacts of Apollo 16. The examination of Surveyor 3 artifacts returned by Conrad and Bean showed the greater part of weathering from dust was set in motion by the arrival of the Apollo 12 LM descent stage. This is the reason future lunar archeology should begin with an approach from a distance and on the ground.

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BEYOND SPACE LAW: THE CULTURAL ASPECTS OF LUNAR COLONIZATION.

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Introduction: The envisioned return to the Moon and the associated planning for human settlement creates a novel cultural and ethical paradigm. Far different from the philosophy of the Apollo era—of which summary exploration was the only outcome—current planning has to be seen as a tentative colonization that has no point of comparison in human history. No previous colonization effort has ever targeted an object of such universal importance in each and every human culture, and at the same time, no other expansion of Man's horizon has ever been so unequal in terms of access. For this reason, While the topic of the legality, or the political and economical motivations of such activities is being explored [1]-[3], this cultural aspect has been mainly occulted. We strongly advocate that the planning of future uses of the Moon as a platform for human activities be executed with the most careful and respectful consideration for international and multi-cultural sensibilities and ethical standards.

The Cultural Moon: The importance of Earth's satellite in virtually all cultures is undeniable. From the dawn of history to modern times, our story is intimately linked to that of our planet's companion. All cultures, whether pre-Columbian, European, African, or Asian, have myths and legends that in overwhelming majority describe the Moon as a life-giving or life-preserving force. While western cultures have mainly ventured away from their poetic traditional foundations (Fig.1), Lunar themes resonated with their populations up until the turn of the 20th century (Fig.2).

Figure 1: The Greek Moon-goddess Selene accompanied by the Dioscuri, or Phosphoros (the Morning Star) and Hesperos (the Evening Star). Marble altar, Roman artwork, 2nd century CE. From Italy. Musée du Louvre, Paris.

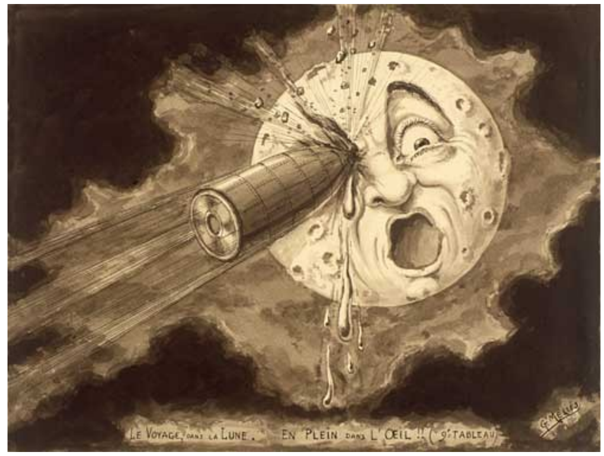

Figure 2: Illustration for a scene from Méliès feature movie "Le Voyage Dans La Lune" (1902)

Ethical Exploration and Settlement: Any attempt to build a settlement on the Moon will have to be respectfully planned to mitigate resentments that could arise from the perception of a minority taking possession of a universal body, at an international level—spacefairing vs. earthbound nations—and at national, social levels—use of a nation's resources for an uncertain common benefit. The utilization of Lunar resources and in particular any attempt to commercialize them—beyond services contracted by governments to enable exploration—should be carefully considered, as it is unlikely to be well received by a majority of the human community. Such commercialization would likely be regarded as benefiting a small minority while possibly desecrating a universal heritage. International collaboration has to be the main engine for this grand scheme in order to avoid the nationalistic tensions that are sure to arise if a unilateral—or uni-cultural—"conquest" of the Moon is launched. Beyond the legalities and the cost splitting that current space powers are discussing is a grander objective: a settlement of the Moon that—if not considered socially and culturally fair—will necessarily have to be regarded as acceptable by a majority of nations. With this objective in mind, it is of the utmost importance that any exploration plan be devised with cultural sensibilities in mind and in the framework of a wide international cooperation that includes non-spacefairing nations.

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Two Problems, One Solution – Microwave Sintering of Lunar Dust. R. R. Rieber[1] and M. A. Seibert[2], [1]Richard.R.Rieber@jpl.nasa.gov Mailstop 179-206, [2]Michael.A.Seibert@jpl.nasa.gov Mailstop 264-422; Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena, CA 91109

Introduction: The fine fraction lunar dust was a headache for Apollo astronauts and engineers and is creating havoc in many many new lunar exploration concepts. However, the harmful properties of lunar dust, such as small size, glass composition, large, abnormal surface area, coatings of nano-phase iron, among others, lead to a unique coupling of the dust with microwave radiation [1]. This coupling can be exploited for rapid sintering of lunar soil for use as a construction material that can be formed to take on an infinite number of shapes and sizes [1].

The most simple application of this technology is a microwave road-paver. This device will be able to create hard surfaces in the immediate area of astronauts for walkways, roadways, or landing pads. These hard surfaces will mitigate the effects of dust by limiting the exposure in the immediate area of habitats and minimizing the amount of dust kicked up by the descent engines of landing spacecraft.

Basics of Microwave Heating: The key to the microwave heating of lunar soil is the coupling of certain microwave frequencies to specific materials [2.3]. This will improve the efficiency of the device and expedite heating of the soil. Since lunar soil is composed of a variety of materials, a broadband microwave emitter must be used such as a magnetron or a traveling wave tube amplifier. This must be aimed into a tunable resonance chamber that can be autonomously adjusted to resonate the specific frequency that will couple with the material in the chamber [2,3].

R&D Roadmap: The various steps to designing, building, and testing a lunar regolith sintering device are laid out below.

Bench-top Sintering: The first step is to characterize the power, frequency, and duration requirements for sintering lunar dust. This will be done with soil simulants in a bench-top microwave heating instrument. Soil simulants have worse dielectric properties than lunar soil [1] and will provide worst-case figures.

Once initial characterization is complete, the chamber of the bench-top device can be swapped out for a prototype of the chamber to be used in the next step.

Static Sandbox Sintering: The second step is to create a device with a cavity open to the surface. The bench-top device previously described will need to be scaled-down and fitted into an instrument that will be able to sinter the surface of a simulated lunar surface (sandbox) while stationary to characterize the required duration for sintering a solid surface.

Translational Sandbox Sintering: Pending the success of the static sintering tests, the static device will be mounted on a simple mobility system. This system could be as simple as mounting the above device on rails and moving it by winch via a cable. This will allow experimentation with various forward progress rates.

Integration with Rover: The final step will be to redesign device and integrate it with a current lunar mobility system. The current plan is to integrate the device with JPL's ATHLETE rover and utilize the multiple degrees of freedom of the legs to enhance the placement and mobility of the device.

When this version of the device is complete, a multitude of tests and experiments can be performed to investigate mobility, transportability, progress rates, degrees of freedom, etc. This initial version could be utilized as the first flight version to further validate the system to prove it can be a relied upon method of construction.

Conclusion: Microwave sintering is a technology that has a great potential to provide both a method of construction along with the ability to mitigate the problems with lunar dust in the immediate area of a fixed lunar settlement. The concept relies on technology proven on Earth, however a large amount of research and development lie ahead in determining the fundamental requirements of the device and proving it is a viable technology for the lunar surface.

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A MULTI-PURPOSE ANALYSIS AND LOGISTICS DEVICE FOR LUNAR EXPLORATION.

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Introduction: This project studies the concept of a multi-purpose analysis device that may be used by astronauts on the lunar surface during extravehicular activities (EVAs). The device to be developed will be mobile and designed for compatibility with the astronauts' glove and space suit model. It must be robust and able to withstand the lunar environment. The purpose of this device is to provide the astronauts with scientific and logistical information. It would be known as MALIC: Mobile Analytical and Logistical Information Companion. MALIC, even though being developed for lunar use could also be adapted to any exploratory environment, such as the extreme regions of Earth.

Methodology: In order to complete this project, members of the scientific community will be surveyed to identify potential capabilities for the device. To foster the development of MALIC, prize competition and Space Act Agreement models will be reviewed and compared.

Expected Results: This project will conclude with a set of requirements for MALIC, as well as a roadmap for its development. This roadmap will be built around the selected model, which will either be a prize competition or a Space Act Agreement.

The underlying goal of this project is to further the involvement of private companies and individuals in the space industry, specifically in Man's return to the lunar surface.

Integrating a Modular Excavator as a Smart Tool into the Space Exploration Infrastructure using Small Satellite Systems Protocols. Gary Rodriguez[1] and Frederick Slane[2].

Abstract: *sys*RAND is developing an industrial-class excavator for planetary surface exploration and development. This device is a bucket ladder with heritage derived from projects originally from the Colorado School of Mines. The current device will be used extensively to study the physics of digging in simulated Lunar conditions. A successor design which is expected to be more robust and remotely serviceable is on the drawing board.

Technical capabilities developed in the Small Satellite community are being translated to other space applications. Concurrent with the excavator project, the company is developing hardware and software tools for the Air Force Research Laboratory's Satellite Data Model (SDM) and *Space Plug and Play Avionics* (SPA).

The Excavator control system is based upon a COTS industrial controller to be augmented by AFRL's Satellite Data Model plus SPA-E and SPA-U Plug 'n Play interfaces. The controls are further extended for real-time scientific data acquisition of environmental parameters such as plasma flux, magnetic and electrostatic field strengths, *etc*.

The excavator will employ a universal tool coupling which encourages the interchange of a wide variety of tools among a number of robotic arms and mobility turrets. This coupling will also connect the SPA-E (Ethernet derivative) from the vehicle to the excavator controller, which is consistent with NASA's extensive use of Ethernet throughout many of their architectures. The SPA-U (USB derivative) interface will be used for sensor interfaces and localized IO processing of excavator servo and sensor inputs along with sensors which are collecting scientific data on the ambient environment and the platform's interaction with it.

The goal for a fully operational system is autonomous and semi-autonomous operation, using a modest energy budget and minimal human supervision and intervention.

Applications include civil engineering and *in-situ* resource utilization in support of long-range logistical objectives. The excavator has been modeled at a production rate in the neighborhood of 1,000 kg / hr and will be integrated with a universal tool coupling, a robotic turret arm and a mobility platform.

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With Endpoints Defined, an ISRU Roadmap Takes Shape. Gary Rodriguez[1], Frederick Slane[2], Lee Johnson[3] and Richard Westfall[4].

Space Exploration is dominated by two realities: gravity and the rocket equation. Until one or both of these is somehow diminished in stature we will have to be clever if we are to afford extensive space exploration. Initial exploration identifies the coarse distribution of resources in a new frontier and is supported by the determined investment of a collection of enterprises (often through their governments). Follow-on exploration is required to locate specific feedstocks and is supported by the very activities which exploit and add value to the indigenous resources (usually through well-capitalized companies). Space exploration is sufficiently expensive that the cost of transport must be leveraged from the start, and since we've already conducted the initial exploration with the Apollo, Clementine and other Lunar orbital survey programs, adopting a follow-on exploration model would seem appropriate.

The *in-situ* Resource Utilization (ISRU) approach is to *live-off-the-land*, a concept familiar to those who have endured survival training in Boy Scouts or special ops. Many lessons were taught in these exercises, and success was enjoyed by those who could close the gap between their environment and an advantageous change to that environment with the least expenditure of energy.

A vigorous ISRU effort results in less *matériel* being launched into space, and a significant fraction of what does get launched are tools for manipulating the target environment. The ISRU work is of three distinct types: science, civil engineering and ISRU-manufacturing. Scientific sampling engages the smallest quantities of a planetary surface and civil engineering the largest. The highest complexity and added value are inherent to manufacturing and ore beneficiation.

The success of any vigorous Space Exploration program lies with the fabrication of products outside of Earth's gravity well. Such a place, rich with resources, energy and practical proximity to the Earth is the Moon. The Moon is well-positioned as a literal stepping-stone to Mars, Jupiter and beyond. It is on and near Luna that we can fashion products which have inherent mass and bulk from rocks, dirt and energy. Manufacturing the massy and bulky hardware and expendables from indigenous space resources eliminates launching production uphill from Earth's gravity well.

The exploitation technologies which are used to develop the Moon's resources should be sufficiently low-tech that early generations of Lunar ISRU factories can build them. This is where the rocket equation will yield to the logistics equation. Envisioned on a distant horizon, a shipyard can be built in a distributed fashion on the Lunar surface and in Lunar orbit, which will provide a focus for our near-term ISRU projects, and eventually (and inevitably) provide the largest fraction of the needs of Lunar habitation, development and exploration.

The pinnacle of this effort will be the ability of the CisLunar economy and infrastructure to construct and commission a series of flotillas to transport mankind in a robust way to Mars.

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GLOBAL TOPOGRAPHY AND GRAVITY FIELDS OF THE MOON BY KAGUYA(SELENE).

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Introduction: The Japanese lunar explorer KAGUYA (SELENE) was launched successfully on September 14th, 2007. The aim of KAGUYA is to investigate important issues in the lunar science such as the interior structure, the near/far side dichotomy and the origin of the Moon [1]. Two small spin-stabilized subsatellites, Rstar (OKINA) and Vstar (OUNA) were deployed in October for gravity measurement. Rstar and Vstar are spin-stabilized satellites of an octagonal shape with diameter 0.99m and mass 45kg [2]. Three satellites take different polar orbits around the Moon. Also, a laser altimeter (LALT) is on board the main orbiter of KAGUYA.

Gravity measurements: Using RSAT (a satellite-to-satellite Doppler tracking sub-system) and VRAD (artificial radio sources for VLBI), we can track the three satellites by new methods: 4-way Doppler tracking between the main satellite and Rstar for the farside gravity and multi-frequency differential VLBI tracking of Rstar and Vstar. The global lunar gravity field with unprecedented accuracy can be obtained. The 4-way Doppler tracking for the farside gravity started on November 5th 2007 during initial check out phase if KAGUYA. First, we estimated residuals of observed Doppler data from a prediction based on LP100K lunar gravity model. Over the nearside, the variation of the residuals is smaller than 5 mm/s. In contrast, the variation over the far side is as large as 30 mm/s, becausefar-side gravity anomalies were not accurately mapped previously [3]. We also confirmed the validity and accuracy of the multi-frequency differential VLBI tracking of Rstar and Vstar using VERA and international VLBI network [4].

From more than 6 month observation of 2-way and 4-way Doppler tracking, precise gravity field (free-air gravity anomaly SGM90d) including most of farside was obtained [3]. Although nearside gravity of KAGUYA would agree basically with previous LP100K gravity, on the farside our gravity field shows significant improvement from the previous model. In our new gravity model, many circular signatures corresponding to impact structures are identified. Some of the circular gravity anomalies in the free-air gravity apparently disappear in Bouguer anomaly map. This change implies that surface topography is a dominant source of free-air gravity anomalies and large impact structures are supported by lithosphere; difference of thermal history between nearside and farside can be discussed. A possible cryptomare candidate (a circular gravity anomaly without topographic signature) was also found on the farside.

Topography measurements: The objectives of LALT are (1) determination of lunar global figure, (2) internal structure and surface processes, (3) exploration of the lunar pole regions, and (4) reduction of lunar occultation data [5]. LALT transmits laser pulses whose time width is about 20 nanoseconds and pulse interval is 1 second. The beam divergence is 0.4 mrad and beam spot size on lunar surface is typically 40m when main orbiter altitude is 100km. Range accuracy is ±5m. The range data are transformed to the topography of the moon with the aid of position and attitude data of the main orbiter. By early April, more than 7000000 footprint data were obtained. The footprint spacing is 1.5 km (along-track) and 1 - 15 km (cross-track) in the equator region.

In the polar regions where previous CLEMENTINE altimeter did not cover, many topographic features that were difficult to see on the imagery from spacecraft or ground based radar images are discovered. Solar illumination condition was calculated: the region whose solar illumination rate is higher than 90% is very limited. Lunar mean radius is 1737.15±0.01 km and the COM-COF offset is 1.94 km based on the spherical harmonic model STM359_grid-02 from LALT topography. The amplitude of the power spectrum of STM359_grid-02 is larger than that of the previous model at spherical harmonics degree L>30 [6].

From the gravity and topography data, we obtain the distribution of the crustal thickness on the Moon. We also estimate the correlation between gravity and topography and localized admittance values. Gravity and topography observation of KAGUYA will continue until early 2009.

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Legal Aspects of Space Exploration

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After a long hiatus, space exploration has returned in recent years to the top of the political agenda of a growing number of countries. Following the changing geopolitics of space activities, new actors are getting involved in space exploration for international prestige reasons. But there are also actors targeting the economic and commercial potential of space activities even in the field of exploration.

Space exploration has to be conducted in a reliable legal framework. Actors – public and private – need the assurance that their activities are accepted by the others on the basis of agreed principles and norms. This presentation introduces the present legal framework for space exploration. It deals with the relevant binding legal instruments (i.e. the Outer Space Treaty of 1967 and the Moon Treaty of 1979), the so-called soft law, which are guidelines and standards, and international policy statements.

In analyzing these documents and the main principles and norms applicable to space exploration are highlighted. It shows that there does not exist a coherent legal framework for space exploration yet, taking into account the interests of all types of actors (i.a. also the scientific community). On this background, the presentation identifies needs for further developments of regulations in this field.

THE SCIENCE OF LAWS: APPLICATION TO LUNAR GOVERNANCE D.G. Schrunk[1]

Governments are necessary for the stability and effective operation of every social organization. When permanent human bases are established on the Moon, a lunar government will be needed to resolve disputes and facilitate the peaceful, productive, and responsible exploration and development of the Moon[2]. The legislative branch of the lunar government could employ the traditional legislative process that is now used by national Earth governments to create its body of laws[3]. However, the traditional process of lawmaking is seriously flawed and it often produces cumbersome, defective, and counterproductive laws[4,5,6]. This paper proposes that the future lunar government adopt the science of laws as the basis for the creation, evaluation, and disposition of laws[7,8,9]. The science of laws has the potential to create bodies of laws that will optimally serve the best interests of the people who live and work on the Moon[10].

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THE MOON'S SURFACE MAY BE A SELF-STERILIZING ENVIRONMENT FOR TERRESTRIAL MICROORGANISMS. Andrew C. Schuerger[1] and David J. Smith, [1] Dept. of Plant Pathology, University of Florida, Bldg. M6-1025, Kennedy Space Center, FL 32899; acschuerger@ifas.ufl.edu, [2] , Spaceport Technology Division, NASA, Mail Code KTE-3, Kennedy Space Center, FL 32899; david.j.smith-3@nasa.gov.

Introduction: Microbial surveys of robotic and crewed vehicles prior to launch have documented a wide diversity of microorganisms present on spacecraft surfaces [1,2,3]. Bioloads on vehicles have been estimated using traditional culture-based assays, and have yielded between 1 x 10^4 and 2 x 10^8 viable mesophilic bacterial species per vehicle [4,5]. Recovered microorganisms were composed of approximately 80% non-spore forming bacterial, 10% spore-forming bacterial, and 10% eukaryotic species [3,4,5].

Although a significant number of papers have appeared in the literature on the microbial diversity of spacecraft prior to launch [1,2,3,4], very little literature exists on how terrestrial microorganisms might survive the journey to the lunar surface, or how long they might survive on the Moon. One notable exception is the study by Mitchell and Ellis [6] that described the recovery of a single colony of *Streptococcus mitis* from foam insulation that was deeply embedded within the Surveyor III camera and recovered from the lunar surface by Apollo 12 astronauts. Based on this single report, the possible survival of at least one terrestrial microbe on the lunar surface for 2.5 years has been adopted by the astrobiology community as proven fact. However, in a paper by Knittel et al. [7], published at the same conference report as the Mitchell and Ellis paper [6], a second team of microbiologists were unable to recover viable terrestrial microorganisms from Surveyor III wire cabling.

The primary objective of the study was to expose a common spacecraft contaminant, *Bacillus subtilis*, to low-pressure and high temperature lunar conditions to predict if terrestrial microorganisms can persist on spacecraft surfaces on the Moon. A model for the inactivation of terrestrial microorganisms on the lunar surface has been developed.

Methods: The microbial bioloads of spacecraft from documented lunar spacecraft [1,2,3,4,5] were used to estimate the microbial bioload of 48 spacecraft to have landed or crashed on the Moon. Then based on published reports on the effects of ultra-high vacuum on microbial survival [see reviews 1,3,4], inactivation kinetics were modeled for *Bacillus subtilis*, non-spore forming eubacteria, and eukaryotic species.

A series of new lab experiments were conducted in high-temperature ovens and a Moon simulation chamber to investigate the survival rates of *B. subtilis* under temperatures up to 100 C and in combination with high levels of vacuum (1 x 10^{-6} mb).

Results: Although UV irradiation was not studied, it is the most biocidal factor for terrestrial microorganisms on external surfaces of spacecraft [1.2]. Based on published literature [see reviews 1,3], most, and perhaps all, terrestrial microorganisms on sun-exposed external surfaces would be inactivated within one lunar day after landing.

The viable microbial bioload for all spacecraft predicted to have landed on the lunar surface is 9.52 x 10^{12} spores, and the per-vehicle average (for 48 spacecraft) was 1.98 x 10^{11} viable microorganisms per vehicle. These estimates are several orders of magnitude higher than earlier published reports because the earlier reports under-sampled and under-estimated non-culturable, eukaryotic, archaea, and extremophilic species on spacecraft.

Inactivation kinetics for *B. subtilis* for low-pressure alone suggests that 0.5% of landed spore-forming bacteria may survive to the present day, if shielded from solar UV irradiation and insulated from high temperatures. In contrast, non-spore forming bacterial and fungal species are likely to lose up to two orders of magnitude of viability per lunar day from high vacuum effects alone.

Thermal stresses would accelerate the loss of viability for landed spores or cells. Results of interactive studies between low-pressure and high temperature suggest that these two factors interact synergistically and are likely to inactivate all microbial species adhered to spacecraft surfaces heated above 70 C, within one lunar day. It is predicated that between 50 and 66% of landed or crashed spacecraft surfaces reach at least 70 C during the lunar day.

Results suggest that the lunar surface is a self-sterilizing environment that will likely leave no microbial survivors on spacecraft surfaces within 2-3 years after landing. Implications for lunar astrobiology will be discussed.

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MULTISPECTRAL HAND LENS AND FIELD MICROSCOPE. R. G. Sellar[1], J. D. Farmer[2], M. S. Robinson[2], and J. I. Nuñez[2], [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109, glenn.sellar@jpl.nasa.gov), [2]Arizona State University, School of Earth and Space Exploration (PSF room 686, Tempe, Arizona 85287-1404).

Introduction: With recent support from NASA's Moon and Mars Analogue Mission Activities (MMAMA) program, we plan to perform field trials of a *Multispectral Microscopic Imager (MMI)* within the context of ESMD's Desert Research and Technology Studies (Desert RATS) lunar analogue mission activity. The MMI is intended as a basic tool for use by an astronaut or robotic rover for traverse characterization, documentation, and mapping the distributions of a broad variety of geological materials, including igneous and sedimentary materials (e.g. basaltic pyroclastics and their sedimentary derivatives, lavas, impact ejecta and soil/regolith materials, as well as weathering alteration surfaces of rocks, soil crusts, etc.). Color microscopic imaging and spectroscopy provides fundamental observations for interpreting the origin of rocks and soils, for inferring their secondary (post-depositional) alteration (diagenesis) and for interpreting paleoenvironments. Such observations are basic to an evaluation of the physical properties, health risks, and *in situ* resources for human exploration of the Moon.

Development of the MMI was achieved through the addition of spectrometric capabilities to the highly-successful Microscopic Imagers (MIs) currently in operation on the Mars Exploration Rovers (MERs). The MMI, with its multiple spectral bands and spectral range extending into the infrared, has a demonstrated capability to discriminate and resolve the spatial distributions of minerals and textures at the microscale [1], [2]. After initially demonstrating these capabilities (Fig. 1) in the laboratory we have fabricated a rugged and portable MMI instrument (Fig. 2) for use in supporting field-based research at analogue sites. A flight version of the MMI could be mounted on a tripod or accommodated on a crewed rover for use during EVAs or could be employed for sample screening and documenatation at a lunar base.

The MMI employs multi-wavelength light-emitting diodes (LEDs), a substrate-removed InGaAs focal-plane array, and *no moving parts* to provide a multispectral, microscale image of a sample in 21 spectral bands extending from visible wavelengths to 1.7 µm in the infrared. This provides 21-band visible-to-infrared reflectance spectra acquired from every pixel in the field-of-view. Such data sets provide highly-desirable contextual information for guiding sub-sampling of rocks and soils for sample return and/or detailed analysis with instruments onboard a rover or at a lunar base.

Figure 1. False-color composite image composed of three bands (525, 805, and 1300 nm displayed in blue, green, and red respectively) extracted from a multispectral data set; the field-of-view is 40 x 32 mm with a resolution of 62.5 µm per pixel.

Figure 2. Field version of the Multispectral Microscopic Imager shown in the JPL Mars Yard.

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Preparing for the Next Generation of Lunar Sample Return. Charles Shearer[1], Gary Lofgren[2], and Clive Neal[3]. [1]Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131 (cshearer@unm.edu). [2] KT, Johnson Space Center, Houston, TX. [3] Department of Civil and Geological Engineering, University of Notre Dame, IN 46556

Introduction: Sample return missions provide a unique perspective not offered by either orbital or surface missions – the opportunity to study the returned material in well equipped Earth labs. This unique perspective is based on scale (down to angstroms), precision, sample manipulation capability, and the ability to modify analytical experiments as logic and technology evolves [1]. The return of samples during the Apollo Program and subsequent analysis of samples over a period of almost 40 years illustrates these points. Now that we are planning on returning to the Moon, what lessons have we learned from the Apollo Program and ensuing lunar science that will shape our strategy for sampling and curation of lunar materials during the next generation of lunar exploration?

Sampling:

Sample Mass. The total mass of sample returned during the Apollo Program was approximately 381.7 kg. The Apollo 17 mission, which is our closest approximation to initial future human missions in terms of mobility, expected crew training, duration on surface, returned a mass of 110.5 kg. An analysis of sample capabilities for future lunar exploration conducted by CAPTEM concluded that a total mass capability of 250 to 300 kg is appropriate to accommodate all materials and associated containers from the lunar surface [2].

Placing Samples within Geologic Context. Compared to the Apollo Program, the geology, mineralogy, and geochemistry of the lunar surface will be far better documented during future lunar surface activities. The availability of such data will result in refined training techniques and surface planning activities and provide a better geologic and scientific context for sample collection. Samples will be selected within local-, regional-, and planetary-scale context making them scientifically more valuable. Providing precise ground truth will feedback into improving and refining orbital observations. Linking samples with local geophysical networks will increase the scientific value of both. Investments must be made in both state-of-the-art imaging capabilities that are transferable from training activities on Earth to surface activities on the Moon.

Sample Analysis on Surface. As demonstrated by Apollo, the training of astronauts to perform as scientists and geologists on the surface of the Moon is key to collection of important samples and placing them in the context of local geology. An important augmentation to human observations is the development of simple analytical tools that assist the astronaut in sample selection. Clearly, these tools need to be miniaturized, user friendly, safe, and provide rapid results. However, it is important that the astronaut not be over loaded with instrumentation that makes the surface analyses cumbersome and overly long: simplicity is the key. Therefore, investments must be made in the technology to perform relatively quick and simple analyses on the lunar surface, always keeping in mind the strategy behind sample selection.

Sample Contamination. The Apollo Program was extremely successful in reducing contamination levels during sample collection. There were, however, some mistakes. The choice of Indium for the seal material in the rocks boxes precluded the scientific use of that element. More damaging was the inadvertent Pb contamination of the core stems for the deep drill on A-15 during the manufacturing process. Such mistakes point to the need for close cooperation between the science and engineering communities during the design and manufacture of hardware – preserving sample pristinity must take precedence over standard engineering materials that might make acquiring samples relatively easy, but in doing so contaminate the sample.

Preservation of Sample. The procedures for the return of samples much be reevaluated in light of past experience and future needs such as return sample container weight. Understanding the extent and properties of volatile-rich material within permanently shadowed lunar polar regions is a near-term high priority exploration objective for both scientific and engineering / resource availability reasons. In addition, retaining volatiles that occur on grain surfaces in the lunar regolith and minimizing modification to minerals susceptible to phase changes or chemical alteration in a non-lunar environment is also critical. The design of new containers for the return of samples that contain volatiles is a top priority. Technologies for cold/cryogenic and organic-contamination-free collection-storage are necessary to enable the sampling of these types of samples. In addition, pressure, humidity, and temperature management are necessary to maintain sample integrity and minimize sample phase changes.

Curation:

Curation facility and Infrastructure needs. The mass of samples returned by Apollo will be exceeded within 1-2 years if 180-200 kg of lunar samples is returned per mission, and there are 2 lunar missions per year. Therefore, it is important to examine the current capacity and infrastructure available at the Lunar Sample Facility at the Johnson Space Center and the White Sands Test Facility.

Advanced curation of fragile or environmentally sensitive samples. As noted above, icy regolith, volatile-rich materials, and reactive-samples present new technological challenges for curation. New curation techniques must be developed for preliminary examination, preservation, contamination, and allocation. Perhaps the first step is to examine some of the uniquely collected and stored sample returned during the Apollo program [3].

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US SPACE POLICY FOR GLOBAL LEADERSHIP.

A. H. Sinclair

This presentation addresses the need for a "holistic" approach to Space Law in light of the current US Moon Exploration objectives. The mandate that created NASA was put into place by Eisenhower to redress the imbalance between military involvements for space and the peaceful usages of space for civil society interests. Various treaties have attempted to address the legal status of outer space. However the more current treaty initiatives at the UN around the recommendations of PAROS (Prevention of an Arms Race in Space) have reached something of an impasse. To date virtually all countries subscribe for PAROS with the sole exception of the US. One reason the US declines endorsement of these recommendations is that US space based systems are viewed as both vulnerable communications assets and as valuable military ones, therefore high ground availability for the defense of the national space assets precludes the exclusionary usage clauses within current PAROS recommendations.

There is in fact a very reasonable way around this divergence of interests, one that would enhance and optimize current space law. Such legislative expansion would not only be of great benefit to the lunar exploration program, but would also support US technological interests, US foreign policy objectives and a host of innovative near earth orbit implementations for global development. The answer to the problem could be found within US initiative for a comprehensive "active" or utilization based International Space Systems Treaty (ISST) Preparation and ratification of ISST would create an international platform that would not only compliment and empower the distinctive PAROS resolutions, but would also give further prospects for international participation into the strategic space based security essentials, thereby creating an international space security architecture, which is a valid objective for current US Space Policy , the ITAR directives and the prospects for collaborative international space research and development agendas.

What does this have to do with the Moon? ISST would support a general and wide-range of space-based implementations, hence the possibility of a taking up a "holistic" approach and a more democratic interpretation for space development. Within an ISST utilization platform the initiative for moon exploration would be phased in as an international or a global enterprise. One which would offer a formal working basis for the pooling of multiple expertise, the burgeoning commercial interests and all Space Agency resources at the international level

The next Space Shuttle could certainly be an International Space Shuttle, integrating the best possible features that would be readily available from combined resources. Such a shuttle would have standardized components and could be readily duplicated, perhaps giving rise to an entire fleet of compatible Shuttles with operating bases in US, Russia, China, India, Japan and elsewhere. More equipment would speed up the lunar program, as would more funding, more public and governmental support and so on

Within a comprehensive and utilization based space treaty, moon exploration could be undertaken as international moon exploration, giving the peoples of this world much hope for a hospitable and benign future world. Likewise the future moon base would be an international moon base sharing responsibility and the accruing collective benefit for the peoples of a world in crisis.

Finding a way to achieve a balance of interests for the various subscribing space agencies within ISST and addressing the manifold and complex space utilization and space exploration objectives is not an easy task. It is not an impossible one either. If we are to perpetuate Eisenhower's vision of NASA as being primarily a humanistic resource, the establishment of a genuine and rational treaty basis to address the prospect of formative and global space security structures becomes highly relevant. The task of empowering innovative near earth observation capacities, upholding essential space based communications and enabling tremendous and formally associated developmental potentials will take a leading role in a future world.

We must investigate space policy in an integrated, considered and appropriate way. Standing at the dawn of the Information Age looking towards the moon, we remember those preemptive words "One small step for man, one giant leap for mankind " This statement still holds true for us all today. US space policy should directly address the preparation of an International Space Systems Treaty and an associated utilization platform that comprehensively enables the valuable and inspiring aspects of space development, for both the earth and the moon, for both global security and global development, for the community of nations and for a newer and a kinder world.

POSSIBILITY OF A MOON BASED TERRESTRIAL DEFENCE SYSTEM FOR THE EARTH.

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Introduction: Though alien attacks are remote possibilities, collision of our mother earth with some comet, meteorite or asteroid remains a grave threat to our civilization. As per some theories, extinction of dinosaurs from earth was also due to these phenomena and hence such a possibility cannot be fully ignored. This paper looks into the possibility, advantages and challenges of utilizing moon as a base for safeguarding earth from such collision possibilities.

Challenges in Defence against collision of comets & asteroids: The first challenge is spotting the comets or asteroid which is really going to collide with earth at a safer distance and as early as possible so that proper action can be taken. Second challenge is to take action with no damage to our environment. Third challenge is to destroy the comet or asteroid at such a distance that the debris shall not cover our earth and shall not affect ourselves.

Possible role of moon as a base for a terrestrial defence system against comets & asteroids: The moon offers an optimal alternative to solve the above challenges. Its distance from earth is approx. 3,84,403 km. which is sufficient enough to spot a comet or asteroid which is going to strike us much earlier through a telescopic observatory established on moon. Observation from moon will be much clearer due to nil atmospheric effects. The absence of environment on moon can make the use of very high intensity Particle Beam Weapons (using hydrogen atom) or Laser Directed Energy Weapons quite possible to destroy the heavenly body completely at a much safer distance than it is possible to do it from earth. Even missile based systems can work better on moon due to low gravity (and hence fuel saving). Also, nuclear denotation near moon to kill an approaching comet is much safer. Possibility of the debris affecting us is much less if the moon based system is established and used. In fact a combination of PBWs, LDEWs and missiles can ensure safeguarding against all types of terrestrial threats. Also, operation from moon is not as difficult as it is from mars or any other satellite or planet.

Limitations of such a scheme: Though the scheme of safeguarding earth from moon based terrestrial defence system is quite attractive, some people may oppose it who wish to colonize moon and make it another place for mankind. The finding of vast amount of ice on moon provides a remote possibility of creation of suitable atmosphere there for creation of a new civilization. But even this approach does not rule out the role of moon for defence of earth completely. Some fine tuning can make both the possibilities work well together. Earth will still remain our base planet and safeguarding it our main priority. Once a civilization on moon comes up, we can look for a similar scheme to safeguard it as well.

Challenges ahead in realizing such system: First challenges are the political ones i.e. getting the world convinced. Then landing on earth and establishing such a base will be difficult as no one has performed such physical and long work on moon surface. The locking of moon's face with earth due to which we always see the same side of the moon is going to offer both an advantage and a challenge. Advantage is that we only have to establish a base on the opposite side of the one facing us to keep a watch and kill something truly going to be dangerous for us. But the challenge is that we do not know much about the opposite side. However, proper direction to missiles can always be given and hence the challenges can be met by putting base on our side as well. Possibility of alien bases on the moon poses a remote challenge though not proven. All three options like - Building complete system on earth and taking it to moon, taking components on moon and assemble them there or build components and system there itself using materials available there seem to have their own challenges, though middle option seems feasible.

Conclusion: Moon is a suitable base for a defence system against comets and asteroids aiming to collide with earth. However, there are a number of challenges ahead in realizing such a base.

Further studies required in this area: A study about what can be done and built on moon and what to be done on earth is needed. Moon has got a lot of resources but utilization of those resources is still quite a difficult challenge. Reliability of such a defence system is another issue. Maintenance of this system on moon may become a difficult and costly problem. Proper cost benefit analysis including reliable data received through further explorations of the moon can be helpful.

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RAPIDLY DEPLOYABLE BLAST BARRIERS FOR LUNAR SURFACE OPERATIONS. David J. Smith[1], Luke B. Roberson[1], Rob Mueller[1], and Phil Metzger[1], [1]NASA Kennedy Space Center, Mail Code: KT-E-3, Kennedy Space Center, Florida, 32899, USA, djsone@u.washington.edu or luke.b.roberson@nasa.gov

Introduction: Apollo landing footage shows rocket blast streaking from the Lunar Module engines as the spacecraft approached the lunar surface. This blast streak (or 'plume') was mainly composed of small particles (10-60 microns) of lunar dust estimated to be traveling at speeds between 1.0-2.5 kilometers per second. The plume also consisted of engine exhaust gases powerful enough to move rocks up to 15 cm in size. Samples of the Surveyor 3 spacecraft returned to Earth revealed substantial lunar plume damage from the Apollo 12 landing in close proximity. If spacecraft land repeatedly at a permanent Constellation Program lunar outpost, special precautions will have to be made to prevent the plume from eroding hardware or causing jams in critical surface equipment mechanisms.

Barrier Concepts: One possible blast solution is to use synthetic materials brought from Earth to build a mitigation barrier. The structure must be light-weight to reduce payload constraints and easy to deploy through robotic or astronaut surface operations. Our design concept for synthetic barriers focused primarily on two commercially available structures: inflatable barriers and textile fences.

Inflatable Barrier: The inflatable concept shown in Figure 1 offers semi-automated deployment (for reducing EVA construction time); flexibility (for use on rugged lunar terrain), packaging efficiency (for minimal volume transport to lunar surface), and durability (for plume impacts) [1,2]. All materials were suppliedby SPM S.p.A. (Brescia, Italy) and purchased through World Cup Supply (Vermont, USA). The systems were integrated and assemblyed by our team to model the basic architecture of blast barriers. Advanced materials and assembly techniques more appropriate for the lunar environment must be implemented for Phase II designs.

Inflatable Phase II Considerations: Weight reduction of our inflatable concept is a high priority (for reducing Earth-departure transportation cost). Our Phase II design will also explore pressurizing the barrier with a monopropellant generated gas. Any vacant spaces in the inflatable walls could then be injected with structural foam while the empty chamber space could be filled with compacted regolith to provide additional stability against strong blast forces [3]. To enhance lunar environment tolerance and prevent impact degradation, the intrinsic properties of the inflatable could consist of rigidizable materials (including Thin polymer film laminates and thermoplastic composite laminates) which become rigid when exposed to a specific external influence such as heat, cold, ultraviolet radiation, or the inflation gas itself [4].

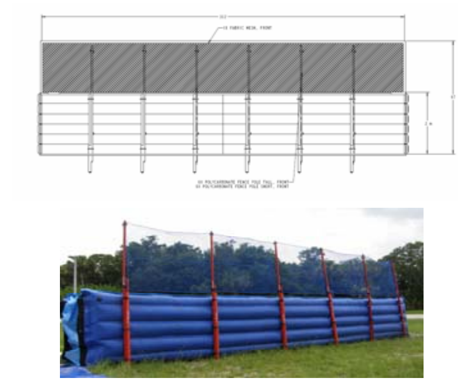

Figure 1: The KSC Phase I inflatable design stands 2.3 m tall and consists of two low pressure inflated walls, linked with a double zigzag tube chamber. The walls have loops for anchoring the structure with structural support poles (hollow, lightweight composites). These poles raise the height of the barrier with a fence extension. While only one section is depicted, multiple barrier sections can be linked, so the system may be made to any desired length or configuration.

Textile Fencing: Another vertical barrier concept that could prevent blast ejecta from impacting lunar architecture and equipment is textile fencing. Textiles can be made from commercial off-the-shelf materials such as Vectra or Kevlar and woven to impede particles ranging from micron-sized to larger gravel-sized impacts. Fabric should be attached (threaded or sewn) to poles made from advanced composites designed for flexibility during high velocity gas generation during ascent and landing. Securing fence poles deeply into the regolith will be essential to barrier performance. Apollo 15-17 demonstrated achievable depths for drilling in the lunar surface – soil which is characterized by a large increase in relative density proportional to increasing depth. Using manual techniques and specially modified drill core tubes, astronauts were able to successfully penetrate the cores 2-3 m – an acceptable depth for anchoring textile fence barriers [5].

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AN EXPERIMENTAL STUDY OF LUNAR RECONNAISSANCE BASE WITH THE ROBOTIC EMPLACEMENTS. Jayashree Sridhar, High school student,C-3 Icl Jubilee Apartments, No 16 Second Main Road, GandhiNagar, Adyar, Chennai-600020, Tamil Nadu, India.+91-24424969,+91-42115269, jayashree92@yahoo.co.in.

Introduction: The capabilities for humans to explore the moon have suffered from high projected costs of space-flight hardware development and production. An avenue for reducing these costs is proposed. Establishing a Permanent Moon Base with a robotic regolith harvesting system offers a safe, efficient approach to performing menial tasks required during exploration missions, such as site preparation and regolith collection. To evaluate the effectiveness of this strategy, cost assessments were performed and compared to estimates based on a more conventional lunar exploration scheme. The results indicate that an architecture emphasizing early production and utilization of lunar propellant has lower hardware development costs, lower cost uncertainties, and a reduction in human transportation costs of approximately fifty percent. Robotic systems launched ahead of manned missions can prepare the site and assure working on-site systems prior to crew arrival.

Reduction of Cost: Robotic infrastructure can be Economical in 3 ways:

1) They do not require life support systems, allowing greater payloads with lower development costs;

2) With smaller margins of safety, unmanned missions can use less expensive supplies;

3) It can deliver equipment from which following human explorers can use local resources.

Reduction of Risk:

1) Robotic precursor missions can test transportation vehicles before regular manned use, and help to develop the long-term missions to other planets.

2) Established in-situ supplies lower the risk that an accident leading to critical supply loss during transportation (e.g. Apollo 13) could strand astronauts.

3) Robotic systems reduces the risk to the health of astronauts at the moon base, by reducing the number of tasks that the astronauts must make to set up the base, by burying the base under regolith, to reduce radiation exposure to the astronauts.

Conclusions:

Maintenance of the lunar base will require constant support of the robotic system to minimize risks to astronauts while simultaneously harvesting in situ resources. The proposed modular, semi-autonomous approach lowers cost, increases power and mass efficiency, increases versatility, reduces radiation and dust exposure to humans.

Table shows the facilities that can be employed on the moon

LUNAR FACILITY	SOURCE OF INPUT	EXPECTED OUTPUT
Research Lab	Lunar soil	Research Products
Mining	Lunar soil	Slag, residuals, rocks, free iron natural gas,
Chemical Processing	Beneficiated soil, solid chemicals.	Organic wastes
Mechanical Processing	Organic waste, lunar oxygen, hydrogen, mixed lunar gases.	Material for lunar facility, repairs, replacements.
Biological Processing	Oxy gas, carbon-di-oxide and water	Food water and air residual.
Fuel Station	Ice ,Helium -3 , Hydrogen	LOX/LOH
Electricity	Solar Power	Highly Efficient and reduces the cost of the operation

Acknowledgements: This work evolved from my imagination about the future exploration and I have also referred several astronauts work for doing this paper. I would like to thank my family for giving me support and my school for encouraging me to do this project.

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[2] J. R. Gaier, the Effects of Lunar Dust on EVA Systems during the Apollo Missions.

[3] The Random Instrument for the Moon radiation environment onboard the Chandrayaan-I lunar space craft Dr. Giovanni De Angelis, ISS.

[4] Exploring the Moon & Mars.

Figure 1. Composition of Lunar Material

The Scientific Rationale and Technical Challenges of Drilling on the Moon and Mars C. R. Stoker, NASA Ames Research Center, M.S. 245-3, Moffett Field, CA 94035, carol.r.stoker@nasa.gov

Introduction: Drilling is a key science activity for both robotic precursor missions and human missions on both the moon and Mars. Drilling is needed to explore the third dimension to understand global processes on both bodies, and to answer many key questions. Furthermore, to get samples that are stratigraphically preserved, date from an epoch of interest, or are unaltered by surface weathering processes requires access to the subsurface.

Science Objectives: Science Objectives for the Moon that require drilling have been recently outlined [1] and include the study of regolith formation processes, sample a variety of basalts, study impact processes, characterize the lunar polar volatiles, and search for a record of the Hadean Earth. Life originated during this period and may have had multiple origin and extinction episodes.

Drilling and core sample analysis is also very important for addressing the key science questions on Mars. The highest level goal of the Mars exploration program is the search for life. The surface of Mars is hostile to the preservation of life signatures so the subsurface is most likely to hold the preserved record of biological activity on Mars. Should life survive on Mars to the present epoch, it might experience growth spurts during periods when orbital forcing increases the solar flux in the Northern plains regions resulting in ice in the near surface sediments melting to provide a liquid water niche for modern life. By drilling 5 m in the Mars Northern plains, a record of 10 M years of cycles of freezing and thawing may be accessed [2]. The growing evidence that liquid water occurs in the Martian subsurface, in some locations at relatively modest depths (100-500 m) [3], suggests searching for current life in Martain aquifers. This liquid water would also be readily accessible as a resource since it could be extracted by pumping.

Technical Capabilities: Modular, reconfigurable, autonomous and human-tended drilling systems are needed for use initially on Lunar and Mars robotic missions and ultimately by crewed missions. On the moon, the thickness of the regolith varies from ~5 to 15m so obtaining regolith samples through full depth is achievable with a 10-20 m drill, and such a system could also obtain bedrock samples and be used to emplace heat flow measurements. Similar depth of drilling on Mars could assess the preservation of biosignatures in sedimentary rocks and could assess whether liquid water occurs episodically in the Northern Plains. Automated fluidless drilling systems capable of supporting these objectives in robotic missions have been developed with NASA support for the Moon [4] and for Mars [5]. These systems use augering to bring cuttings to the surface, and depth is achieved by attaching segmented drill strings. Deep drilling (> 10s of meters) will require massive equipment if the same approach is used. An alternative low mass system is under development by my group for use in Mars ice-cemented material that uses side wall expansion anchors for downhole support and a drill head tethered to the surface so that additional depth of penetration requires only adding more cable.

A fluidless, low power, highly autonomous coring drill, capable of autonomous core ejection into a core clamp, and instruments for inspecting and documenting the core, subsampling, crushing, and performing in situ analysis for biosignatures was developed for the MARTE project and field tested to 6 m depth in a simulation of a Mars life search mission [5]. A drill system of this design could be landed on the moon or carried on a capable Lunar rover, although a relatively large mass drilling system is needed for this approach (50-100 kg, depending on depth).

Borehole logging tools have also been developed that can deteremine the presence and concentration of hydrogen, organic compounds, and biomarkers down hole, alleviating the need for sample retrieval to the surface.

Design issues to be addressed for a deep drill include operational simplicity, bit development and change-out strategies to respond to bit wear, the need to cut a range of materials, cuttings removal approach, systems for anchoring the drill string in the hole and providing weight on bit, and ensuring hole stability in unconsolidated regolith. While a fully automated or Earth-supervised shallow drill is feasible, deep drilling would benefit greatly by human tending the drill at crucial junctures. Astronaut field surveys are also needed to determine where to drill.

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Structural, Physical, and Compositional Analysis of Lunar Simulants and Regolith. K. Street, P. Greenberg, J. Gaier, NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135, Kenneth.W.Street@nasa.gov.

Introduction: Relative to the prior manned Apollo and unmanned robotic missions, planned Lunar initiatives are comparatively complex and longer in duration. Individual crew rotations are envisioned to span several months, and various surface systems must function in the Lunar environment for periods of years [1]. As a consequence, an increased understanding of the surface environment is required to engineer and test the associated materials, components, and systems necessary to sustain human habitation and surface operations.

One such environmental factor is the fine fraction of surface regolith, generally referred to as Dust. The problematic nature of this material is widely discussed, appearing early on in the crew logs of Apollo astronauts [2]. Subsequent analyses have described both the details and mechanisms of degradation resulting from dust deposition and interactions [3]. Anticipating the need for a variety of dust resistant technologies, both NASA and the private sector have initiated a number of programs aimed at meeting this objective. These efforts span a host of considerations, ranging from basic properties of materials, to complex mechanical, thermal, fluidic, and optical systems. Also being addressed are the fundamental aspects of the Lunar environment that influence the charging, transport, and deposition of fine particulates.

By definition, these initiatives must also consider the intrinsic properties of the dust itself. This includes physical attributes (e.g. size and shape distributions), as well as structure and composition. The bulk of existing knowledge obtained from Lunar returned samples pertains to the larger, super-micron fraction. Many properties are observed to correlate with particle size, so the extensibility of these measured properties to the smaller dust fraction remains largely unresolved.

Given the relatively small quantities of actual Lunar samples, the collective demands for testing the performance of flight components and systems must be largely accommodated through the use of regolith simulants. A number of simulant materials were derived in support of the Apollo program, and remain useful in many aspects. However, the increased demands of longer, more complex missions require simulants of higher fidelity. In turn, this situation drives the need for a more thorough characterization of Lunar regolith itself, particular for the smallest size fractions where many properties remain largely outstanding.

The effort described here concerns the analysis of existing simulant materials, with application to Lunar return samples. The interplay between these analyses fulfills the objective of ascertaining the critical properties of regolith itself, and the parallel objective of developing suitable stimulant materials for a variety of engineering applications. Presented here are measurements of the basic physical attributes, i.e. particle size distributions and general shape factors. Also discussed are structural and chemical properties, as determined through a variety of techniques, such as optical microscopy, SEM and TEM microscopy, Mossbauer Spectroscopy, X-ray diffraction, Raman micro-spectroscopy, inductively coupled argon plasma emission spectroscopy and energy dispersive X-ray fluorescence mapping. A comparative description of currently available stimulant materials is discussed, with implications for more detailed analyses, as well as the requirements for continued refinement of methods for simulant production.

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X-RAY DIFFRACTION IN THE FIELD AND LAB ON THE MOON G. Jeffrey Taylor[1], David Blake[2], Jeffrey Gillis-Davis[1], Steve J. Chipera[3], David Bish[4], Julia Hammer[5], Paul Lucey[1], David T. Vaniman[6], and Philippe Sarrizin[7] [1]Hawaii Inst. of Geophys. and Planetology, Univ. of Hawaii, Honolulu, HI 96822 (gjtaylor@higp.hawaii.edu); [2]NASA Ames Research Center, Moffett Field, CA 94035; [3]Chesapeake Energy Corporation, 6100 N Western Ave., Oklahoma City, OK 73118; [4]Dept. of Geological Sciences, Indiana University, Bloomington, IN 47405; [5]Dept. of Geol. and Geophys., Univ. of Hawaii, Honolulu, HI 96822; [6] Los Alamos National Laboratory, EES-6, MS D462, Los Alamos, NM 87545; [7] inXitu, Inc., 2551 Casey Avenue, Suite A, Mountain View, CA 94043.

Introduction: The CheMin X-Ray diffraction/X-Ray fluorescence (XRD/XRF) instrument has been chosen to fly on the 2009 MSL mission to Mars [1]. A similar instrument would add significant capability to lunar surface measurements on robotic missions and at a lunar outpost. We have measured the mineralogy of lunar soil samples a using newly developed field-portable version of the flight instrument, called *Terra* (sold commercially by inXitu, Inc.). The results indicate that Terra can determine the abundances of minerals and glass in lunar soil samples. Similar instruments could be used on robotic missions to the Moon, as an aid to human field work for resource exploration and scientific mapping, and for use as a screening device in a surface laboratory. Developoment of such highly automated instrumentation is called for in Objective 1A-5, Investigation 2 (*Provide sample analysis instruments and protocols on the Moon to analyze lunar samples before returning them to Earth*) in the LEAG Goals [2]. The LEAG document specifically notes: "Analytical instruments at a lunar base will allow us to choose the optimal samples to return to Earth, hence making the best use of cargo space and mass. It also allows astronauts to receive preliminary data on samples collected to help in planning additional field observations. Automation is required so that astronauts do not have to spend significant amounts of time analyzing rocks and soils."

Procedures. Apollo regolith samples with grain sizes of < 150 µm and weighing ~50 mg were placed inside the mini-CheMin sample holder and exposed for about 4 hours each. The resulting diffraction patterns were quantified using Rietveld refinement, a structurally based full-pattern fitting technique. This allowed us to determine the abundances of minerals present at levels greater than about 1 wt% and the abundance of silicate glass.

Results: To date we have measured phase abundances in 11 lunar regolith samples from Apollo 11, 12, 14, 16, and 17. We compare our results with those obtained by point-counting [3,4] using scanning electron microscopy in Fig. 1. Although the agreement is not perfect at this stage of our research, the results are promising. There is scatter, but in general our results are within 10% of those obtained by the elaborate and time-consuming point-counting procedure used by L. A. Taylor and his colleagues [3,4]. A linear fit to the data in Fig. 1 gives a slope of 1.09 and R^2 of 0.903. A more extensive dataset for lunar mineral and glass separates will greatly improve the results.

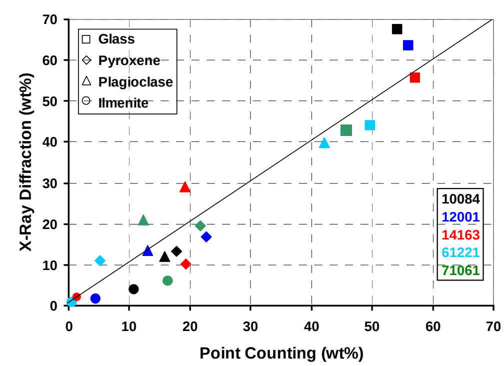

Fig. 1. Comparison of pointing counting using SEM (3,4) with our results using CheMin.

Implications : Terra is a robust instrument that would be extremely valuable for use in exploring the lunar surface. Instruments based on this design can be used on a rover making independent surveys of the surface (including highly automated surveys) or on a rover accompanying a human field party. Qualitative identification of all major phases in lunar soil samples can be achieved in 1-5 minutes of analysis time. Its ease of use would make it an ideal part of a lunar-surface laboratory suite designed to improve field studies and decrease sample-return mass, thus meeting an important LEAG objective. The instrument would take little astronaut time, requiring only ~5 minutes to prepare a sample sieved to <150 µm and load it into the instrument. The rest of the operation is fully automated.

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VAPOR BREADBOARD DEVELOPMENT, FIRST PYROLYSIS RESULTS. I. L. ten Kate[1,2], C. A. Malespin[3], D. P. Glavin[1], and the VAPoR team, [1] NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771, Inge.L.tenKate@NASA.gov, [2] Goddard Earth Science and Technology Center, University of Maryland Baltimore County, Baltimore, MD 21228, [3] Auburn University, Auburn, AL 36849, USA.

Introduction: The identification of lunar resources such as water is a fundamental component of the the NASA Vision for Space Exploration. *In situ* composition and isotopic analyses of the lunar regolith will be required to establish the abundance, origin, and distribution of water-ice and other volatiles at the lunar poles. Volatile Analysis by Pyrolysis of Regolith (VAPoR) on the Moon using pyrolysis mass spectrometry (pyr-MS) is one technique that should be considered. The VAPoR instrument concept study and development was recently selected for funding by the NASA Lunar Sortie Science Opportunities Program and the NASA Astrobiology Instrument Development Program. The VAPoR instrument suite is a miniature version of the Sample Analysis at Mars (SAM) [1] instrument suite currently being developed at NASA Goddard for the 2009 Mars Science Laboratory mission, and will include a sample manipulation system (SMS), vacuum pyrolysis unit, gas processing system, and mass spectrometer (quadrupole or time-of-flight, Fig. 1). The VAPoR suite has a lot of heritage from the SAM suite.

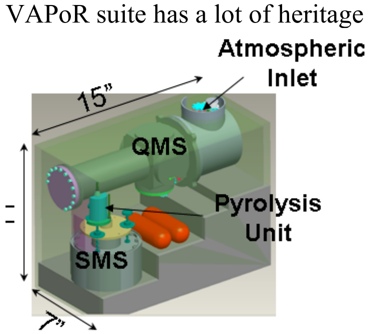

Figure 1. The VAPoR pyr-MS instrument, with the Atmospheric Inlet, the Sample Manipulation System (SMS), the Pyrolysis Unit and a Quadrupole Mass Spectrometer (QMS).

Science Objectives: The three major lunar science measurement objectives of the VAPoR instrument are (1) Measure the isotope ratios of carbon, hydrogen, oxygen, and nitrogen (CHON)-containing volatiles including water in polar regolith to establish their origin, (2) Understand the processes by which terrestrial organic compounds are dispersed and/or destroyed on the surface of the Moon to prepare for future human exploration and life detection on Mars, and (3) Measure the abundance of volatiles that can be released from lunar regolith for *in situ* resource utilization (ISRU) technology development.

Breadboard development: In order to test the different components of the VAPoR instrument package as well as to provide first calibration data a breadboard has been built (Fig. 2), consisting of a stainless steel vacuum chamber equiped with a modified Knudsen cell (K-cell), which serves as pyrolysis unit, and a residual gas analyzer (RGA, a commercial quadrupole mass spectrometer). The breadboard will evolve in time with the addition of flight hardware.

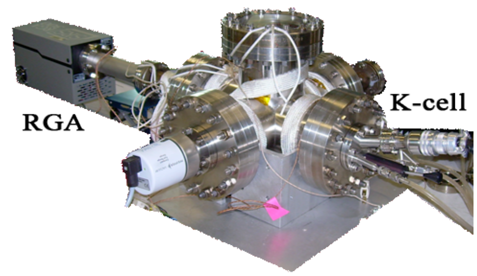

Figure 2. The VAPoR breadboard, equipped with the Residual Gas Analyzer (RGA) and the K-cell.

Experiments: A wide range of tests and experiments have been conducted in which different samples of ~50 mg have been pyrolised at rates of 5 °C per min to 1200 °C, while the RGA continuously recorded spectra of the evolving gases. The samples used in these experiments included the lunar simulants GSC1 [2] and JSC1A [3], Apollo 16 lunar regolith, and a Murchison meteorite sample.

Results: Preliminary results of JSC1A and Apollo 16 regolith are shown in Fig. 3. Further results from the different samples will be presented at the conference.

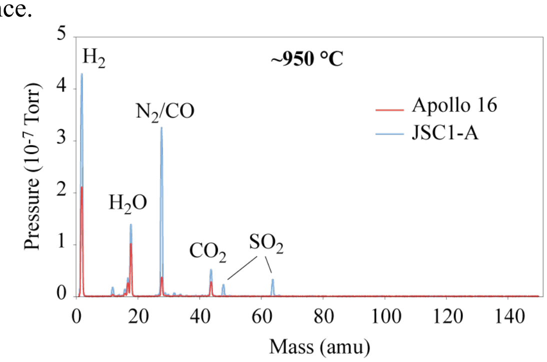

Figure 3: A pyrolysis spectrum of JSC1A (in blue) and Apollo 16 regolith (in red) at a temperature of 950 °C. SO_2 is found in the JSC1A sample, however not in the Apollo 16 sample.

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Geographic Information Systems: An Enabling Tool for Lunar Exploration. K.G. Thaisen[1], A. Losiak[2], T. Kohout[3], K. O'Sullivan[4], S. Weider[5], and D. Kring[6]. [1]University of Tennessee, 306 Earth & Planetary Sciences, 1412 Circle Dr., Knoxville TN 37996 (kthaisen@utk.edu),[2]Michigan State Univ. [3]Dept. of Physics, Univ. of Helsinki [4]Dept. of Civil Eng. & Geo. Sci., Univ. Notre Dame [5]UCL/Birkbeck School of Earth Sci., [6]Lunar & Planetary Institute.

Introduction: The Moon is rapidly becoming a hotbed of activity and the Japanese Kaguya [1] and Chinese Chang`e-1 [2] spacecraft will soon be joined by India's Chandrayaan [3] and the American Lunar Reconnaissance Orbiter [4]. Each of these missions will provide datasets with improved resolution which will be incorporated into the evaluation and planning of future landing sites for both robotic and human missions. These missions will provide volumes of data that will need to be correlated quickly and accurately. This can be performed within a Geographic Information System (GIS) platform. The ability to bring together and recognize the spatial relationships between multiple datasets provide mission planners and lunar scientists a powerful tool to understand the surface conditions seen on the Moon. Within a GIS, Apollo era data can be combined with current and future datasets in order to address the questions related to landing site assessment and lunar science.

A powerful attribute of a GIS is the ability to manipulate a digital elevation model (DEM). DEM's can be used to determine slope angles, aspects, and changes in elevation. Imagery draped over a DEM can provide a three-dimensional representation of the surface which may assist in early planning of possible landing sites and/or traverses across the lunar surface. Surface elevation information can then be combined with multi-spectral imagery, high-resolution surface imagery, surface roughness, and other datasets to quickly identify sites of interest for potential exploration or to rule out sites due to surface hazards. Topographic and lateral relationships can also be explored between the different datasets.

GIS and the past: It is important to remember that it has been nearly 40 years since NASA first went to the Moon. That is not to suggest that the Apollo-era data is obsolete; Lunar Orbiter and the Apollo metric and panoramic cameras images are frequently better than anything currently available and topographic and geological maps have already been generated for many parts of the Moon. However, many of these datasets are still in analog format and not quickly incorporated into the digital formats which are used by GIS. These datasets can be incorporated into a GIS, it just takes the time to digitize them and/or reference them properly to lunar coordinates and is often well worth the effort. Fig. 1 illustrates some of the basic features which can be done with an Apollo-era topographic map and imagery.

GIS and the Present: Geographic Information Systems are quickly becoming the tool of choice for mapping due to the ability to associate additional information with features on a map and to be able to query that information. Some of the information that was collected from recent missions like Clementine and Lunar Prospector is available in GIS formats and ready to be used. As new data becomes available from lunar orbiters, it can quickly be incorporated into existing maps or to generate new maps. This rapid incorporation of new datasets will help to focus attention to particular locations of interest and provide valuable insights for future landing site selections.

Serious consideration should be given to assigning an institute, or other organization, to be responsible for the cataloging and maintenance of all Lunar datasets. This would help ensure standardize products and reduce or eliminate errors caused by different groups using different datums, projections, or coordinate systems.

GIS and the future: When robotic and human missions return to the Moon and start doing detailed field work on the lunar surface, ground truth data will undoubtedly affect current maps and can be incorporated quickly to enable better decisions for future exploration. Once a location for a permanent outpost has been selected, extremely detailed maps will be produced of the immediate area to facilitate in construction, possible in-situ resource utilization, and logistics. A GIS can incorporate all this information and be updated quickly as things change on the ground and will be essential for continuity as multiple crews rotate in and out of the outpost.

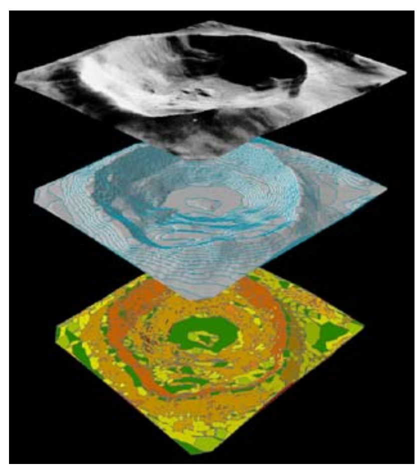

Figure 1. Lalande Crater (~22 km dia.), Top-Sub image of Lunar Orbiter IV 113-H3 draped on DEM generated from the NASA Lunar Topophotomap 77A4S1(50) Laland in ArcGIS, mid.- DEM with 100m contours, bot.-slopes (green<6°, yellow 6°-12°, orange 12°-25°, everything else >25°.

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Critical Strategies for Return to the Moon: Altair Dust Mitigation and Real Time Teleoperations Concepts

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Abstract

Natural, unimproved lunar terrain will present a direct challenge for the Altair lunar landers. They will produce energetic regolith debris during approach, touchdown and blast-off. We can expect severe ballistic debris effects over a radial range of 5-10km depending on terrain, approach trajectories and landing and lift-off modes.

Such effects can have serious implications and deadly consequences for lunar base buildup in the south polar region. It will not be possible to reliably place equipment or situate habitable lunar base components within this range. It will severely restrict crew activity in the region. While regolith shielding prescribed primarily for radiation protection in most habitat concepts explored to date would ameliorate debris effects, we cannot expect them to be in place during the first several sortie missions. Also, it is not considered efficient to have landing zones several km from base because of initial transportation infrastructure constraints.

For these reasons, it is desirable to quickly deploy systems that will ameliorate, curtail or eliminate debris production from repeated lunar landings and lift offs, especially in the region before sortie missions leading up to lunar settlement activities commence in earnest. Some system concepts and allied elements are presented.

As a crucial system of primary activities for astronaut crew, the lunar surface Cabin for Teleoperations(C-TOPS) is proposed as an integral part of the first Altair lunar lander mission. The main function of C-TOPS is to quickly provide the crew with an efficient and productive habitable volume and platform from which to command and control a variety of robots which are needed to build, operate and service the critical components of the initial operational capability(IOC) lunar base. This system concept provides an alternative in order to circumvent the >2.77 sec time delay associated with Earth-based lunar teleoperation systems and associated latency, especially for several tasks involving multiple, simultaneously moving components, equipment and crew during assembly operations. By relegating certain tasks, the C-TOPS system will also help to minimize EVAs, thereby enhancing astronaut safety at the settlement.

CHEMICAL REACTIVITY OF LUNAR DUST RELEVANT TO HUMANS. E. Tranfield[1], J. C. Rask[1], C. McCrossin[1], W.T. Wallace[2], K. R. Kuhlman[3], L. Taylor[4], A. S. Jeevarajan[2], R. Kerschmann[1], D. J. Loftus[1]. [1]Space Biosciences Division, NASA Ames Research Center, Moffett Field, CA 94035 (erin.tranfield@nasa.gov); [2]Habitability and Environmental Factors Division, NASA Lyndon B. Johnson Space Center, Houston, TX 77058; [3]Planetary Science Institute, Tucson, AZ 81719; [4]Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37996.

Introduction: Analysis of Apollo era samples has provided a wealth of data about the basic structure and composition of lunar regolith. Diligent study over the last three decades has shown that lunar regolith is a complex material, formed and modified by continuous micrometeorite impacts on the lunar surface. High velocity impacts cause localized vaporization of lunar regolith which quickly re-condenses on surrounding regolith resulting in agglutinates with high surface area, complicated shapes, and sharp jagged edges. The bulk composition of these materials is about 50% SiO_2, 15% Al_2O_3, 10% CaO, 10% MgO and 5-15% iron. The iron component consists of both iron oxide and metallic (fully reduced) iron, in nanoscale deposits ("nanophase iron") a form of iron not present in terrestrial minerals.

Based solely on mineral composition, we expect that lunar regolith will exhibit substantial chemical reactivity. On the Moon's surface the problem is even more complex, since lunar regolith is exposed to intense UV radiation, as well as three different sources of particle radiation. The highest fluence particle radiation is from the solar wind, which consists of low-energy (keV) protons and helium. Also of concern is solar particle event radiation, which consists of a spectrum of MeV-range protons. Lastly, Galactic Cosmic Radiation, which consists of higher energy protons (1GeV) and low fluences of heavy ions (HZE particles), may also have an effect on lunar regolith. Radiation effects undoubtedly alter the chemistry of lunar regolith especially on particle surfaces, and these effects will likely have significant implications for lunar dust (a fine fraction of lunar regolith) interactions with both biological systems and non-biological systems.

The Challenge: While the importance of Apollo era samples cannot be underestimated, it is now clear that specimens in the curation facility at NASA JSC have significant limitations. Some of the Apollo era samples became contaminated with oxygen and water from ambient air due to an imperfect vacuum in the specimen containers. Water and oxygen are expected to interact with surface radicals and other reactive sites on lunar dust, with the result that the chemical reactivity, as it existed on the lunar surface, has been lost. Even in the absence of contamination, the long duration of storage has likely resulted in changes in the surface chemistry of the lunar samples. Since the chemical reactivity of lunar dust may be the most important feature that determines its interaction with biological systems, toxicology experiments must include reactivation of lunar dust. The issue of chemical reactivity is also important for non-human biological systems, such as small rodents, cyanobacteria, and plants.

Strategies for "reactivating" lunar regolith may include exposure to hydrogen and helium plasmas, UV exposure, and proton bombardment (e.g. ion implantation). Work in these areas is ongoing at NASA and the Planetary Science Institute. A difficulty that we face is that critical measurements of the chemical reactivity of lunar dust were never carried out during the Apollo program. As such, it is not possible to compare the reactivation methods we are using with a known measure of the chemical reactivity of pristine lunar dust.

A Potential Solution: At ARC and JSC, we have been using a simple chemical assay to evaluate the chemical reactivity of lunar dust (1). The assay measures the potential for surface radicals on lunar dust to generate hydroxyl radicals upon exposure to water. The assay involves the conversion of terepthalate (non-fluorescent) to hydroxyterepthalate (fluorescent), in the presence of hydroxyl radicals. Hence, simple fluorescence detection systems can be used as an indicator of surface radicals on lunar dust. This assay provides us with a method for evaluating different techniques of lunar dust reactivation, as well as a method for characterizing the decay (passivation) of this reactivated state in a habitat like environment.

To fully validate our reactivation methods, we need to use pristine lunar dust to calibrate the terepthalate assay. To this end, we have designed an instrument, LunaChem, that can be delivered to the lunar surface as a secondary payload, so that an analysis of lunar dust can be performed using the terepthalate assay *in situ*. LunaChem includes a robotic arm for acquisition of lunar regolith, microfluidics for reagent dispensing, and optical components for measuring fluorescence. The results of *in situ* analysis of lunar dust chemical reactivity will clarify critical issues pertinent to lunar dust toxicology, and will provide fundamental understanding of the interaction of biological systems with lunar regolith.

(1) W.T. Wallace, L. Taylor, B. Cooper, and A.S. Jeevarajan, Earth Planet. Sci. Lett. (2008) submitted.

ESA's Lunar Robotics Challenge. G.Visentin[1], B.Foing[2], R. Walker[3], and A. Galvez[4] - [1,2,3,4]European Space Agency, [1,2,3]P.O.Box 299 2200AG Noordwijk The Netherlands, [4]8-10 rue Mario Nikis 75738 Paris Cedex 15 France

Abstract : As interest in exploration of the Moon soars among the world's space agencies, the European Space Agency (ESA), through it's General Studies Programme, has challenged university students to develop a robotic vehicle that is capable of overcoming difficult terrain comparable to that at the lunar poles.

This paper will present the outcome of the challenge, which takes place in week 43 (20-26th October) 2008, i.e. right before the 2008 ICEUM10/LEAG conference.

Background There is compelling scientific evidence that there is hydrogen rich ore into the cold dark craters located at the poles of the Moon. The question whether this ore contains water or not, still waits for a more definitive answer. It is clear that for answering this question one needs to go down into these cold, dark craters.

To this purpose, engineers have postulated the use of a wide variety of robotics means (e.g. walking/hopping/rolling rovers, cable ways, tethered tumbleweeds, harpoons) which despite their basic different working principles have in common one characteristic: lack of experimental proof of the concept.

The ESA Lunar Robotics Challenge (LRC), has been conceived as a means to spark interest in robotic exploration, stimulate the discovery of new innovative ideas and investigate, in a practical way, several of these concepts at the same time.

Participants: In the Lunar Robotics Challenge, eight teams of University students have each designed, manufactured, integrated and tested a robot, engineered to complete the task of:

1. descending into a terrestrial analogue of lunar crater,
2. performing soil and rocks sampling and
3. returning the collected samples back out of the crater.

The competition focussed on the challenges imposed by locomotion in the extremely harsh environment of crater lunar surfaces

ESA has selected the 8 teams after a European wide call.

The eight teams have been selected from reputable European robotics research institutions, in order to provide the most diverse robotics means to complete the above task.

Venue of the competition: The LRC venue has been chosen to fulfil the following requirements:

1. Be Representative of many technical aspects of the real mission.
2. Present a degree of difficulty high enough to allow learning, but not to high to discourage participants
3. Be outdoor and fairly remote: it has to be a "field" experience
4. Have a mild and stable climate, to avoid risk of re-scheduling event
5. Be reachable in an affordable way from European Space Agency
6. Be scenically representative of a Moon-like environment.

After a survey of possible locations, ESA selected an area within the Park of Teide in the island of Tenerife, Canary Islands, Spain.

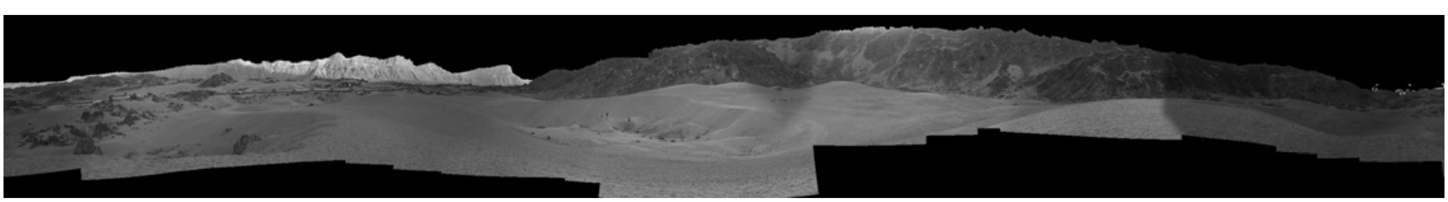

Figure 1: Panorama picture of the venue of the Lunar Robotics Challenge in full Moonlight

THE EUROPEAN STUDENT MOON ORBITER (ESMO): A SMALL MISSION FOR EDUCATION, OUTREACH AND LUNAR SCIENCE

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Abstract: The paper will present the programmatic and technical status of the ESMO project, provide a description of the payload and its measurements, the spacecraft and mission design, and how the project is structured to provide maximum education/outreach benefits to prepare the space science/exploration workforce of the future.

Introduction: The European Student Moon Orbiter (ESMO) is planned to be the first European student mission to the Moon. 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. In addition, ESMO has a powerful education outreach aspect and strong attraction for younger students studying in high schools across Europe, by lowering the entry-level for lunar exploration to attainable university project activities. ESMO also represents an opportunity for students to contribute to the scientific knowledge and future exploration of the Moon by returning new data and testing new technologies.

Mission objectives: The primary objectives of the ESMO mission are (1) to launch the first lunar spacecraft to be designed, built and operated by students across ESA Member and Cooperating States; (2) to place the spacecraft in a lunar orbit; (3) to acquire images of the Moon from a stable lunar orbit and transmit them back to Earth for education outreach purposes; (4) to transfer to a science orbit, and perform niche measurements of interest to lunar science and exploration.

Payload description: A miniaturised payload would perform measurements in order to achieve these objectives over a period of 6 months in lunar orbit. The core payload is a Narrow Angle Camera for optical imaging of specific locations on the lunar surface upon request from schools, and presently a nanosat subsatellite for global gravity field mapping to 10-20 mGal precision via accurate ranging of the subsatellite from the main spacecraft. Such a nanosat, called Lunette, would be deployed in a low altitude near-circular polar orbit at 100 km altitude. Alternative scientific payload under consideration includes a Biological Experiment (BioLEx) characterizing lunar environment effects on living cells, and a passive microwave radiometer measuring the temperature of the lunar regolith at a few metres below the surface. Furthermore, it is planned to demonstrate a lunar internet communications protocol in lunar in order to enable future data delay between lunar surface elements, orbiters and Earth ground stations.

Mission/system design: The 250 kg ESMO mini-spacecraft is designed to be launched into Geostationary Transfer Orbit (GTO) as a secondary payload in the 2012/2013 timeframe. The exact launch opportunity has yet to be established, although design work to date has assumed the use of the ASAP adaptor on the Ariane 5 or Soyuz launchers from Kourou. However, the design is adaptable to other launch vehicles. An on-board liquid bipropellant propulsion system will be used to transfer the spacecraft from its initial GTO to the operational lunar orbit via the Sun-Earth L1 Lagrange point over a period of 3 months. The spacecraft would then perform outreach and science operations in the operational lunar polar orbit for a period of 3-6 months.

Programmatics: ESMO is the third mission within ESA's Education Satellite Programme and builds upon the experience gained with SSETI Express (launched into LEO in 2005), the YES2 experiment (launched on the Foton-M3 mission into LEO in 2007) and ESEO (the European Student Earth Orbiter planned for launch into GTO in 2011). Some 200 students from 17 Universities in 10 countries are currently participating in the project, which has successfully completed a Phase A Feasibility Study and is proceeding into preliminary design activities in Phase B. The ESMO project has a high potential for international cooperation involving various elements that could be provided by international partners and their respective universities.

LUNAR ROVERS AND THERMAL WADIS BASED ON PROCESSED REGOLITH. R. S. Wegeng[1], J. C. Mankins[2], R. Balasubramaniam[3], K. Sacksteder[3], S. A. Gokoglu[3], G. B. Sanders[4] and L. A. Taylor[5], [1]Pacific Northwest National Laboratory, operated by the Battelle Memorial Institute (robert.wegeng@pnl.gov), [2]Artemis Innovation Management Solutions, [3]NASA Glenn Research Center, [4]NASA Johnson Space Center and [5]University of Tennessee.

Introduction: Mobile robotic systems, tele-operated from Earth such as the rovers Spirit and Opportunity, which have been operating on the surface of Mars for more than four years, could provide substantial scientific payloads for lunar science and exploration. However, the lunar environment and particularly the 27-day diurnal cycle of the Moon present a thermal challenge that is considerably more severe than on Mars. At equatorial regions, for example, temperatures range from a high of about 400 K to a low of about 100 K, too cold for most electronics, sensors and battery systems. Unless onboard radioisotope heating is included, robotic lunar rovers may be unable to survive the extreme cold of the lunar night.

Thermal Wadi Concept: We propose the development of an innovative science and exploration architecture for the lunar surface based on the establishment of distributed sources of heat and power – thermal wadis – that can support tele-operated rovers and stationary science platforms for periods of years. Thermal wadis can be assembled using minimal hardware from Earth plus a locally available resource, lunar regolith, which can be processed to yield suitable thermal-mass materials for energy storage.[1]

The basic concept for a thermal wadi consists of a thermal mass plus an energy reflector that can be configured to either reflect solar energy onto the thermal mass during periods of sunlight or reflect infrared energy back to the thermal mass during periods of darkness. As depicted in Figure 1, solar energy is absorbed and stored within the thermal mass during periods of sunshine and is used to provide temperature control for rovers and other assets during periods of darkness.[2]

Standard Rover Concept: Thermal wadis will enable the establishment of a class of compact rovers having standard equipment for the functions of power, mobility, navigation and communications plus standard interfaces for instrument packages. Multiple rovers would be associated with each thermal wadi, allowing a wide variety of instruments and lunar science objectives to be fulfilled.

Networks of Thermal Wadis: We contemplate the establishment of multiple thermal wadis, placed tens or hundreds of kilometers apart, based on the development and landing of wadi assembly modules on the lunar surface. In principle, each thermal wadi would be capable of providing heat (and perhaps power) for multiple lunar rovers, tele-operated from Earth by teams of researchers and engaging multiple countries. Figure 2 illustrates one notional network of thermal wadis in the vicinity of the South Pole of the Moon. In the figure, the bold red circles identify notional exploration perimeters, with one thermal wadi at the center of each, overlapping areas of interest based on data from the Clementine and Lunar Prospector spacecraft suggesting the possible presence of water-ice and other volatiles. For this figure, the exploration perimeters are based on radii of 48 kilometers – the distance that a rover could travel over a time period of about 80 hours (about 1/8th of a lunar diurnal cycle) – and enclose an area of over 7,000 square kilometers each.

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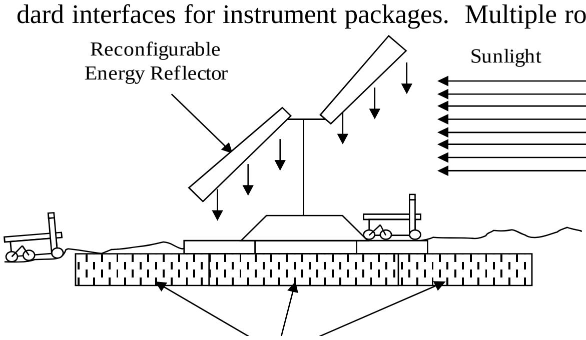

Figure 1 – Thermal Wadi Concept

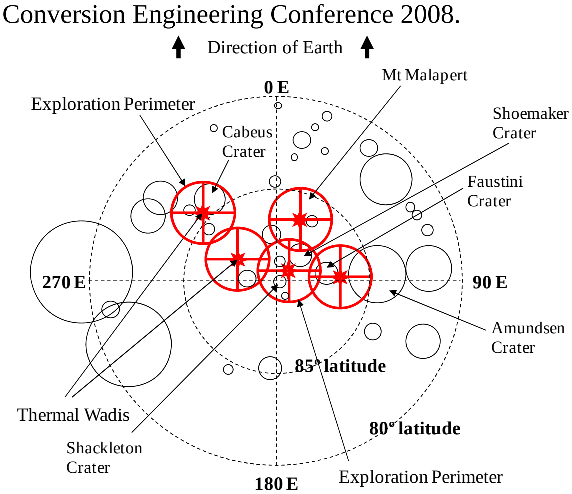

Figure 2 – Notional South Pole Network of Thermal Wadis

GLOBAL LUNAR GEOPHYSICAL AND EXOSPHERIC SCIENCE NETWORK. J. D. Weinberg[1], C. R. Neal[2] and G. T. Delory[3]. [1]Ball Aerospace & Technologies Corp., PO Box 1062, Boulder, CO 80306-1062, jweinber@ball.com. [2]University of Notre Dame, Department of Civil Engineering & Geological Science, 156 Fitzpatrick Hall, Notre Dame, IN 46556, neal.1@nd.edu. [3]Space Sciences Laboratory, University of California, Berkeley, CA 94720, gdelory@ssl.berkeley.edu.

Summary: Scientific knowledge of the structure and composition of the lunar interior may be greatly advanced with a network of small, long-lived (> 6 yrs) robotic geophysical probes, globally deployed at strategic locations on the surface of the Moon. Similarly, much can be learned about dynamic plasmas and the exosphere from the lunar surface, akin to lunar weather, through long term globally distributed measurements. Together, these investigations can help characterize the overall lunar environment, by measuring both seismic activity and the changing space environment. In addition to the wealth of scientific information they would provide, these precursor measurements would be invaluable for understanding phenomena that could potentially pose hazards to human exploration, settlement and commercial development. Thus, these investigations directly address two fundamental questions of the LEAG: *(2-4) What are the needs and advantages of robotic missions for advancing lunar science and how can they benefit human exploration? (3-3) What types of precursor lunar surface experiments are highest priority for space settlement and commercial development?*

Seismology: The Lunar interior serves as a time capsule providing clues to its initial composition, differentiation, crustal formation and possible ancient magnetic dynamo. The best, and in some cases the only way to determine the composition and structure of the deep crust, mantle and core is to conduct geophysical measurements [1]. The NRC report, *The Scientific Context for Exploration of the Moon – Interim Report*, finds that “Long-duration geophysical stations … implemented at multiple (six or more) sites are required to provide comprehensive subsurface information” [2].

Shallow moonquakes are the largest of the lunar seismic events. The Apollo missions recorded 28 events, with seven of them greater than a [Richter] magnitude of 5 [3-6]. While they appear to be associated with boundaries between dissimilar surface features [6], the exact origin of shallow moonquakes is still unclear. Strong moonquakes may pose a potential hazard to lunar exploration as well as any permanent lunar habitat or science installations. Thus, the investigation of shallow moonquakes is not only important for understanding basic scientific questions, but also has direct relevance to supporting exploration initiatives.

Exosphere: The existence of a lunar atmosphere was long suspected but unproven until the first Apollo measurements. The Moon is a solid body immersed in the space environment, consisting of incoming solar plasma and illumination, solar energetic particles (SEP) from solar coronal mass ejections (CME), terrestrial plasma in the Earth’s geomagnetic tail, and meteoric influx. Given all of these environmental forces acting on the lunar surface, there should exist a host of sputtered materials around the Moon. However, the details of the composition, distribution, and temporal variability of the lunar exosphere are still largely unknown; *in-situ* observations from a contamination-free platform are essential in order to answer these fundamental questions.

These environmental forces also create various electrical currents at the surface of the moon. One consequence of this is the possibility that individual dust grains may become highly charged and be repelled upwards by the equally charged lunar surface. This could explain Lunar Horizon Glow (LHG), first detected by Surveyor. Correlation of these measurements with the terminator strongly suggests that variations in the lunar surface potential and the electrical charging of individual dust grains are key factors in the physical mechanisms producing dust motion.

Dust transport, be it through human or robotic activity, or a natural occurrence, poses a significant problem and possible hazard for both human exploration and commercial development. Beyond the suspicion that dust is lofted above the surface, however, very little is known about the mechanisms or properties of the lofted dust. Such a phenomenon, once characterized, would constitute the discovery of lunar “dust storms”, and demonstrate how dust is transported and entrained around and on the lunar surface. This knowledge would be of great utility for both human exploration and scientific understanding.

References: **[1]** *The Scientific Context for Exploration of the Moon: Final Report, N.R.C.*, 2007. **[2]** *The Scientific Context for Exploration of the Moon: Interim Report, N.R.C.*, 2006. **[3]** Oberst J. & Nakamura Y., *Lunar Bases & Space Activities* **2**, 231-233, Lunar & Planetary Institute, Houston, 1992. **[4]** Nakamura Y., et al., *Proc. Lunar Planet. Sci. Conf.* **10th**, 2299-2309, 1979. **[5]** Nakamura Y., *Proc. Lunar Planet. Sci. Conf.* **11th**, 1847-1853, 1980. **[6]** Oberst J., *J. Geophys. Res.* **92**, 1397-1405, 1987.

DETERMINING TECHNOLOGY PRIORITIES TO ENHANCE LUNAR SURFACE SCIENCE MISSION PRODUCTIVITY.

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Introduction: The Exploration Technology Development Program (ETDP) of the ESMD (NASA Exploration Systems Mission Directorate) has supported the evolution of a capability intended to systematize and quantify the relative priorities of advanced capabilities needed for lunar science in concert with human return to the moon. The product is a quantified list of sensitivities (percent change in mission productivity with respect to potential percent change in advanced capability). These sensitivities would then be folded with estimated achievable technology improvements to determine achievable mission improvement. Initial application of this approach is in support of the OSEWG (Optimizing Science and Exploration Working Group) surface science scenarios; a joint effort of the NASA Directorate Integration Office of ESMD and the NASA Science Mission Directorate.

Mission Scenarios: This study based its analyses on a hypothetical 14-day mission to the lunar surface, in which a specific set of experiments is to be accomplished at each of 5 localities (each of which is about 3 km across) among four geographical sites. Shackleton Crater, Shoemaker Crater, Sverdrup Crater, and de Gerlache Crater. Each of the 5 localities has 7 science activity sites, for a total of 35 places where the astronauts and robots stop to conduct experiments. This initial study examined two mission architectures. One consists of four astronauts and two small, pressurized rovers (SPRs), and the other consists of four astronauts and two unpressurized rovers (UPRs).

Assumptions, Constraints, and Productivity: The assumptions and constraints are in the full paper, and in Reference (1). Mission productivity is the value of the activities performed (number times relative importance) divided by the marginal cost of completing those activities. The experiments to be conducted at each locality consist of the following activities: collecting rocks and regolith, digging shallow trenches, hammering a “drive tube” into the soil, drilling soil and rock cores, and raking. All of the data for the total number of samples to be collected, the average mass of each sample, and the amount of time required to perform the experiments, are given in the full paper.

Initial Results: Our HURON optimization tool (2) was used to recommend the temporal schedule for astronauts working with each of the two kinds of rovers, it was found that the operational cost of the SPR scenario is about twice that of the UPR scenario, but that the value provided by the SPR scenario is about 14 times that of the UPR scenario. Thus, in our study’s model, the SPR delivers about 7 times the productivity of the UPR. Importantly, neither scenario fills the 14 days that were envisioned for the mission. (See section on Further Work for additional activities which have been added.).

Technology Impact: For the mission configuration and associated assumptions and constraints described above, we compute the relative impact (Fig. 1) as:

$$\text{Impact} = \frac{\Delta\ \text{productivity/productivity}}{\Delta\ \text{performance parameter/performance parameter}} \qquad (1)$$

Activity Name	Agent Type	Units	Nominal Value	Impact in two UPR case	Impact in two SPR case
Drive UPR	eva astronaut	km/hr	10	100.0	n/a
Drive SPR	astronaut	km/hr	10	n/a	100.0
DriveTube	eva astronaut	hr	0.25	12.9	44.1
Regolith	eva astronaut	hr	0.25	12.9	44.1
Rock	eva astronaut	hr	0.25	12.9	44.1
Trench	eva astronaut	hr	0.25	12.9	44.1
Rake	teleop	hr	0.4	6.5	22.2
DrillCore	teleop	hr	2.5	5.8	19.8
RockCore	teleop	hr	1.5	3.5	11.9
DrillCore	eva astronaut	hr	1.75	n/a	n/a
DriveTube	teleop	hr	0.4	n/a	n/a
Rake	eva astronaut	hr	0.25	n/a	n/a
Regolith	teleop	hr	0.3	n/a	n/a
Rock	teleop	hr	0.75	n/a	n/a
RockCore	eva astronaut	hr	1	n/a	n/a
Trench	teleop	hr	0.6	n/a	n/a

Figure 1. Estimated impact of changes in capability performance. Yellow rows do not have impact because analysis precluded those agents performing those activities in the scenarios included.

Further Work: In consultation with the SMD science community and the Constellation Architecture Team, we explicitly added as activities time for documentation; other experiments (microscopic imaging, ground penetrating radar, lidar imaging etc.); margins for unexpected events; and astronaut free time. These analyses are now underway, and the results are reported in the full paper. We are relating the sensitivities of functional parameters which appear in the model (e.g. rock acquisition time) to their various constituent individual technologies (e.g. sample identification, mobility to sample, sample acquisition; sample analysis and preservation.

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[1] Human-Robot Lunar Exploration: Pressurized vs. Unpressurized Rovers”, C.R. Weisbin, J. Mrozinski, H. Hua, K. Shelton, J.H. Smith, A. Elfes, W. Lincoln, V. Adumitroaie, R. Silberg}, 19th International Conference on System Engineering, August 19-21,2008,University of Nevada, Las Vegas, USA.

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A Proposal for "The [Insert Sponsor Here] L2 Cup" William White, 5330 Main Street #205 Downers Grove IL 60515

Proposal: The L2 Cup would be a crewed spacecraft race modeled on offshore sailing races such as the Rolex Fastnet Race or the Volvo Ocean Race blended with certain financial aspects of the America's Cup. The proposal is directed at private groups such as Space Adventures, Ltd. that could take a leadership role in organizing an event to facilitate commercial and international synergy on the following objectives:

> *LEAG Question 3-1:* What opportunities are afforded within the current architecture for commercial on ramps and how can these be facilitated?
>
> *ILEWG Question 3-2:* What are the logical architectures and open implementation to allow effective integration of international elements?

Race Course: The proposed L2 Cup Race would begin in LEO and upon race start the competing spacecraft would proceed to EML-2 where they would perform a mandatory loiter within a specified distance from EML-2. Thereafter, the spacecraft would return to LEO where they would finish the race. The winner would be determined by comparing total elapsed time from the start signal until a successful return to LEO, subject to time adjustments for navigational accuracy or other mission requirements.

Base line competitor: A baseline L2 Cup competitor would consist of one Soyuz spacecraft, one Fregat tug, and two Proton Block D propulsion modules. The configuration upgrades the well-publicized Soyuz lunar circumnavigation mission (lunar free return trajectory) currently marketed by Space Adventures, Ltd. This proposal would seek to encourage deployment of comparable systems by spacefaring (and potentially spacefaring) nations such as China, the European Union and the United States as well as Japan and India, all of which possess the technology base needed to build a configuration functionally equivalent to the Soyuz plus Proton Block DM base-line configuration.

Projected costs: A Soyuz based EML-2 mission would appear to cost somewhere between $300 million dollars and $500 million dollars, extrapolating from the $100 million dollar price suggested for the free return mission currently marketed by Space Adventures, Ltd.

Revenue sources: The L2 Cup proposal contemplates funding packages that blend revenue from paying adventurer/tourist crew members with revenue from media, marketing and sponsorship funding and investment from venture capitalists seeking to share in the prize package awarded to the winner of the first L2 Cup. National governments might also choose to subsidize competitors for purposes of national prestige.

Prize package: The winner of the first L2 Cup would be awarded ownership of media, marketing and merchandizing rights associated with the second L2 Cup. Thereafter the winner of the second L2 Cup would be awarded such rights for third L2 Cup and so on. The America's Cup sailing event currently uses a similar system of financial incentives potentially creating a self-sustaining recursive economic bootstrap. Media, marketing and merchandizing rights associated with the event would be distinguished from sponsorship and marketing of individual teams.

Foster national pride: Greater media, marketing and sponsorship interest could be achieved by requiring competing vessels "to be substantially constructed within the country in which the Challenger resides" in a manner analogous with the America's Cup Deed of Gift. The precise definition of "substantially constructed" should be calibrated to encourage entries from as many nations as possible while preserving the national character of each entry. Ideally, the L2 Cup would eventually join the World Cup (soccer) as a source of citizen enthusiasm and national pride.

Supporting lunar exploration objectives: The L2 Cup would facilitate LEAG and ILEWG objectives by:

1. Encouraging the development of redundant systems of spacecraft capable of lunar orbit while funding such development with non-traditional, non-taxpayer based sources; and,

2. Offer synergy with ESA concepts that place greater emphasis on LaGrange Point lunar mission architectures as a supplement to current NASA lunar mission architectures.

ASTROBIOLOGY AND EXPOSURE EXPERIMENTS FROM THE LUNAR SURFACE. D. E. Wills[1,2] and B. Foing[2], [1]H. H. Wills Physics Laboratory, Tyndall Avenue, Bristol BS8 1TL [2]ESA/ESTEC, SRE-S, Postbus 229, 2200AG Noordwijk, Netherlands. dwills@rssd.esa.int, bernard.foing@esa.int

Introduction: In recent years, much experimentation has been directed at assessing how prebiotic organic molecules and micro-organisms are able to survive in the space environment. Such investigations serve to provide us with insight into the origin, propagation and evolution of life and its building blocks within the Solar system, all of which are central issues in the field of astrobiology. In these investigations, samples of organic compounds or dormant forms of life are exposed to the space environment for various lengths of time. The effects are subsequently assessed in the laboratory. Experiments of this type have flown in Low Earth Orbits (LEO's) on the ESA facilities BIOPAN and STONE on the Russian Foton spacecraft, and EXPOSE on the ISS [1]. In LEO exposure experiments the impact of the space vacuum, solar UV radiation, extreme temperature, microgravity, and a certain degree of ionizing cosmic radiation can be studied. However, the crucial next step is to conduct studies outside of the protective shield of our Earth's magnetosphere, such that the full flux of cosmic radiation in the interplanetary medium can be included in the investigations. Until this is done, no complete picture of the effect of the interplanetary space environment on organics and micro-organisms can be achieved. The lunar surface opens new opportunities for investigations outside of the magnetosphere and is thus an appropriate environment for the next generation of exposure experiments.

We propose exposure experiments that can be conducted from the lunar surface. The results of these experiments may be used in conjunction with those obtained from LEO exposure experiments so as to assess the survivability of life across two interplanetary environments. Exposure experiments of this type are precursors for investigations on the Martian surface, a necessary preliminary step for future human missions to Mars.

Proposed Experimental Arrangement: A simple experimental set-up mimics the experiment hardware of EXPOSE on the ISS. Samples of organic compounds or micro-organisms are accommodated in multiple vented or sealed cells situated in sample carriers. These carriers are secured into larger trays, and the trays are exposed on the lunar surface for varying lengths of time. Sensor equipment to monitor the environment to which the samples are exposed includes radiometers, UV sensors, temperature and pressure sensors as well as radiation dosimeters [2]. At the conclusion of the experiment, the organics samples are analysed by way of UV/Vis and Infrared spectroscopy. Survival of micro-organisms is assessed using CFU techniques or Live/Dead Staining.

Further Astrobiological Investigations from the Lunar Surface: The Moon provides an excellent non-biological testing ground for research into spacecraft contamination. Knowledge about the types of micro-organisms that are able to withstand current spacecraft sterilisation techniques and how they interact with a planetary environment is crucial for assessing planetary protection constraints.

The fifth and sixth goals of NASA's Astrobiology roadmap are to 'Understand the evolutionary mechanisms and environmental limits of life', and to 'Understand the principles that will shape the future of life, both on Earth and beyond [3]. Aside from simple exposure experiments, fulfilment of these goals calls for investigations into the evolution and adaptation capacities of micro-organisms in the interplanetary environment, for it is only in the context of multiple generations that the long term effects of life in extreme environments will start to emerge. The Moon is at present the only possible location for long-term biological studies under interplanetary space conditions [4]. From the lunar surface, adaptations of microbial communities by genetic mutations and natural selection can be investigated.

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PERCUSSIVE DIGGING TOOL FOR LUNAR EXCAVATION AND MINING APPLICATIONS.
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Introduction: The extraction of top surface and also of highly compacted material on the lunar surface is critical to the success of long term utilization of resources for the production of oxygen, water and other consumables needed for propulsion and life support systems as well as for other 'civil' engineering applications such as building berms, roads, trenches etc. The ISRU will become even more critical if the lunar polar craters are found to contain water ice. Apollo data clearly indicates highly compacted soil at shallow depths [1] on the lunar surface, for which there is no existing experience in effective excavation under the vacuum and partial gravity environment there.

Percussive Digging Tool: 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 system which has inherit advantages (over electromechanical systems) that include ability to generate larger forces, small size, simplicity, robustness etc. Another advantage that terrestrial earth moving machines have includes their large weight reaching hundreds of tons and more. This will not be possible on the Moon, which with its lower gravity of 1/6th that of the earth's, would require similarly capable excavation systems to be 6 times heavier. The solution to this problem is to use percussive/vibratory approach [2]. A scoop with a percussive actuator can dig deeper and faster with force that is at least 25 times lower than corresponding non-percussive scoop. This directly translates into 25 times lighter excavator and in turn money saved by not launching heavier systems. Apart from much higher efficiencies, percussive and vibratory system 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/ploughs 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 particles and soil and in turn forces and power required to move the regolith. There are many other applications where transfer of regolith takes place. Note also that the impulse magnitude and frequency can be tuned relative to soil strength to improve efficiency even further.

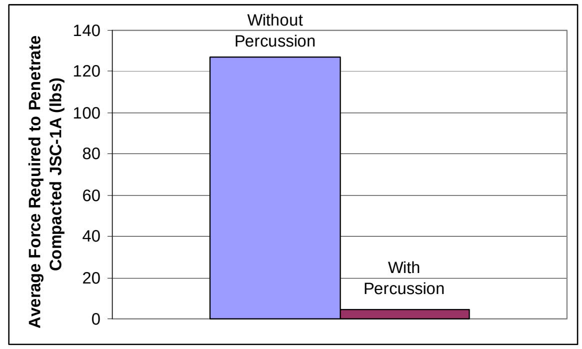

Figure 1. Preliminary test shows that percussion dramatically reduces the reaction loads necessary to penetrate compacted JSC-1a.

Honeybee has developed a percussive shovel for use on the military's Man-Transportable Robotic Systems such as iRobot's PackBot and Foster Miller Talon. Due to their light weight, these robots can provide only limited reaction force for digging and hence lessons learned from using these platforms can be directly applicable to the Moon, where lunar gravity leads to the reduction of the system weight as compared with that on Earth by 1/6th. The mass of the Talon is 60kg while that of the PackBot is 30kg.

Honeybee's digging tool design is a novel approach ideally suited for lunar applications to defeat compacted regolith. By using the impact energy imparted by a reciprocating hammer transferred through the scoop to defeat the target material, the need for large reaction loads from the vehicle is minimized. As with all space-flight systems, mass is at a premium. A system which does not rely solely on the vehicle's weight and traction to react against forces required to break-up and penetrate the soil will provide a distinct advantage over other such systems, especially in a microgravity environment such as the moon.

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HEAT FLOW PROBE DEPLOYMENT IN LUNAR REGOLITH SIMULANT USING A PERCUSSIVE PENETROMETER. K. Zacny[1], P. Fink[1], B. Milam[2], S. Nagihara[3], and P. Taylor[2]. [1]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com); [2]NASA Goddard Space Flight Center; [3]Texas Tech University

Introduction: Measuring internal heat flow (i.e., heat flow that originates deep within the interior of the Moon) is important since it tells us about the origin of the Moon and its compositon. If we know the age of the Moon, then the heat flow will reveal if it had a hot or cold origin. In addition, heat flow will reveal information on the bulk structure and composition of the Moon relative to heat producing elements (radioactive ^{40}K, ^{232}Th , ^{235}Uand ^{238}U) and the extent of crustal differentiation.

The shallow subsurface temperature of the Moon is strongly influenced by the diurnal, annual, and other fluctuations of the insolation. Therefore, the best way to measure the internal heat flow is to insert a probe to a depth beyond the reach of the surface fluctuation. Such depth is considered to be 5 to 7 m [1,2].

Apollo astronauts deployed heat flow probes by drilling with a 400 Watt rotary-percusive drill, a fiberglass casing to a depth of ~2.4 meters and inserting a heat flow probe into it. The biggest problem encountered by Apollo 15 astronauts was caused by poorly designed auger flutes. With redesigned bore stems, Apollo 16 and 17 had little problem in reaching the required depth.

Proposed Deployment Method: Although the rotary-percussive approach has been proven, it is possible to make the heat flow probe deployment simpler by using a pure percussive approach. The percussive penetrometer uses high frequency and low energy impacts to penetrate the regolith. When a rod is inserted into regolith, the resistance to insertion comes from two sources: displacing or crushing regolith ahead of the probe and regolith sliding against the rod as it is being inserted. (The latter is referred to as sleeve friction.) The combination of high frequency and low energy percussive impacting reduces both resistance forces. The regolith ahead of the pointed tip of a penetrometer gets displaced, packed, and crushed due to the vibration; this allows the cone to penetrate deeper. Simultaneously, the regolith rubbing against the penetrometer surface continuously vibrates and reduces the sleeve friction; this makes insertion of the penetrometer much easier.

This method of heat probe deployment is simpler than drilling. The penetrometer head can be made lighter since no rotation is required. In addition, each penetrometer section can form the heat flow probe itself. The connection of consecutive probes is also easier; since there is no rotation, there is no need for sliprings. The lack of an auger (screw profile) also makes data interpretation easier.

Laboratory and Field Tests: Several different penetrometer designs were built and tested. Each design consisted of three parts: the rotary percussive actuator for creating the hammering penetrating force, the detachable cone that was hammered into the lunar regolith simulant, and the connecting rod that held the detachable cone to the rotary percussive hammer. Tests were carried out by penetrating into columns of compacted (1.9 g/cc) lunar regolith simulant, JSC-1A to a depth of 0.9 meters and GSC-1 to a depth of 9 m.

Initial laboratory testing using JSC-1A yielded promising results (see Figure 1). All penetrometer designs were able to deploy down to nearly one meter in 1-3 minutes (depending on the design). Subsequent testing and analysis resulted in a final cone size of 25-mm at the base with a 30° point angle, and a final rod outer diameter of 21.3-mm with an inner diameter of 15.8-mm (to house wires, instruments, etc.).

With satisfactory results from the initial testing, a full scale test setup near Goddard Space Flight Center was built (see Figure 2). This setup used a ten meter tall section of pipe with an inner diameter of 18 inches filled with GSC-1 regolith simulant. Several one meter long rods were connected together to form a long penetrating string. A depth of 9 meters was achieved in a few minutes and greater penetration depth is possible with an addition of extra rods.

Figure1. Percussive actuator with a rod penetrating compacted JSC-1A.

Figure 2. 10 meter testing column, filled with GSC-1.

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ROTARY PERCUSSIVE DRILLING IN A VACUUM CHAMBER: A TEST BED FOR LUNAR AND MARS DRILLING.

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Introduction: There is a strong interest for drilling on extraterrestrial bodies. The applications for subsurface access on Mars are sampling water-ice in the regions of Phoenix Lander or assessing mineral potential of regolith on the Moon.

Honeybee Robotics developed a rotary-percussive test bed and a matching vacuum chamber for conducting drilling tests to a depth of 1 meter. Tests will investigate drilling telemetry as well as conduct scientific observations (e.g. volatile loss during drilling).

Rotary-Percussive Drill: The rotary percussive drill, shown in Figure 1, consists of 3 main components: the drill head, drill stand with a Z-axis lead screw, and drill string (auger) and bit. The drill head consists of two motors geared together to provide rotational motion to the drill string as well as a separate actuator for providing a percussive energy to the drill bit. This particular architecture enables varying rotary speed and percussive frequency independently of each other. The drill head also consists of an embedded slip ring assembly for transferring electrical power and data from the actuators or sensors (such as a thermocouple) inside a drill string to a data acquisition system laptop. In addition, an inline load cell system allows for accurate measurement of the Weight on Bit (WOB, or vertical drill force).

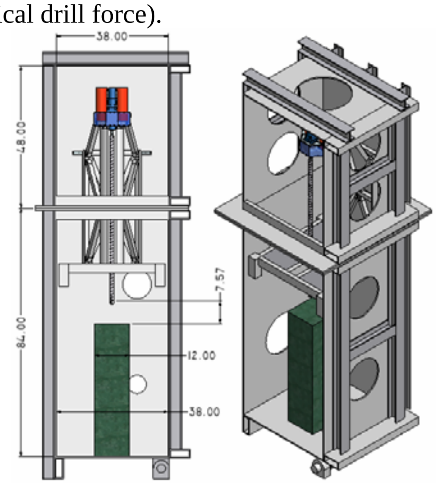

Figure 1. Vacuum chamber will house a rotary-percussive drill. Testing of planetary drills in relevant atmospheres is one of the most important aspects of any drill development.

Vacuum Chamber: Testing of planetary drills in relevant atmospheres is one of the most important aspects of any drill development [1, 2]. A matching vacuum chamber is being fabricated (Figure 1). This vacuum chamber is 11 feet tall, 38 inches wide and 38 inches deep. It consists of two chambers (the bottom one being 84 inches tall and the upper one being 48 inches tall) which can be operated individually.

Preliminary Tests: Preliminary testing has been conducted in lunar regolith simulants to assess the performance of various drill bits. Experiments were conducted in 10wt% water bound and frozen lunar regolith simulant. It was found that drilled holes in the sample were extremely smooth with no amount of hole collapse

A comparison of the performance of the PDC and WC bits at 60 RPM and a similar bit temperature of approximately -10°C shows that the PDC bit is more efficient (specific energy 169 MJ/m^3 vs. 212 MJ/m^3), but requires a higher WOB. Additional data is shown in Figure 4.

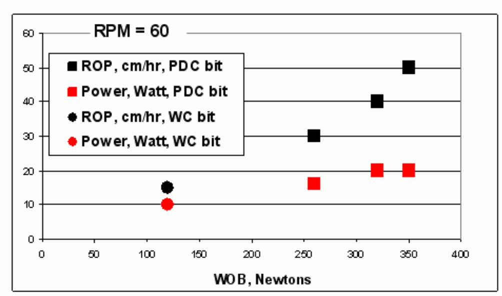

Figure 4. Power and rate of penetration for PDC and WC bits at 60 RPM and a bit temperature of -10° C.

Future tests: the future work will include investigation of drilling efficiencies in various formations (e.g.t JSC-1A) and various rocks. The regolith will be compacted with water saturated to different levels and cooled to different temperatures to determine the effect of these parameters on drilling efficiencies. The loss of volatiles (if applicable) and bit temperatures will be monitored. Different drill bits and auger designs will be tested. Vacuum tests will be done at pressures below and above the triple point of water to mimic conditions that exist in the northern region of Mars (pressure above the triple point of water) and the southern region of Mars and the Moon (pressures below the triple point of water or hard vacuum).

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GEOTECHNICAL PROPERTY TOOL ON NASA AMES K-10 ROVER. K. Zacny[1], J. Wilson[1], A. Ashley[1], C. Santoro[1], M. Sudano[1], S. Lee[2], L. Kobayashi[2], T. Fong[2], M. Deans[2]. [1]Honeybee Robotics Spacecraft Mechanism Corporation (zacny@honeybeerobotics.com), [2]NASA Ames Research Center.

Introduction: Geological examination of the near subsurface will increase understanding of the formation and history of a planet or moon and, by extension, the history of the solar system. Soil physical properties are used to help interpret surface geologic processes and to constrain the origins and formation processes of the soils. In addition, regolith geotechnical properties are extremely important to planning mining and construction activities on the Moon or even Mars. Lack of knowledge of Martian soil, for example, resulted in the Mars Exploration Rover Opportunity being stuck for nearly five weeks (Figure 1).

To enable future robotic geotechnical measurements, Honeybee Robotics designed and build a Percussive Dynamic Cone Penetrometer for NASA Ames' K-10 rover.

Percussive Dynamic Cone penetrometer

The penetrometer is a stand alone device that requires limited to no human intervention to operate. It consists of a percussive actuator and a rod with a sharp 60 degree cone at the end. The penetrometer is driven into the soil under constant load and the penetration, converted to California Bearing Ratio, gives an indication of soil trafficability. The CBR scale is from 1 to 100, with 1 being very soft and 100 being very hard soil.

The PDCP is essentially a battery-operated percussive actuator attached to a linear slide. A rod and cone, which interact with the soil, are attached to the output of the percussive actuator. The percussive actuator moves up and down the slide via a motorized chain drive, which is responsible for deploying the penetrometer rod and cone into the soil and removing it after a test is complete. The penetrometer maintains a constant "weight-on-bit" applied to the cone as it penetrates into the soil. Since the applied load is constant, the rate of penetration of the cone can vary depending on the properties of the soil. The rate of penetration is then converted into number of hammer blows (or energy expended) per soil layer, which in turn can be converted into a CBR value. The resulting data from a PDCP test is CBR versus depth at a given location.

The PDCP is capable of penetrating up to 15 cm into soil below the K10 rover wheel base plane. Typically, it takes less than 60 seconds to penetrate to 15 cm in hard soils with less than 10 lbs of WOB. The PDCP weighs approximately 32 lbs, which includes the rod and cone, percussive actuator, deployment system, mounting structure, electronics and cabling, and its own battery.

Over the past few decades a number of correlations between the California Bearing Ratio and other soil properties have been developed. These include Bearing Capacity, Dynamic Modulus, and Modulus of Subgrade Reaction.

Figure 2. Percussive Dynamic Cone Penetrometer.

Figure 3. Nasa Ames K-10 rover.

K10 Mobile Platform

The K10 rovers are autonomous mobile robots designed to satisfy three

goals: (1) movement at human walking speeds; (2) low time-to-repair using commercial off-the-shelf parts wherever possible; and (3) the ability to operate in both high-friction indoor (concrete floors) and moderate natural outdoor (30 deg slope, hard-pack dirt) environments.

The NASA Ames Intelligent Robotics Group currently operates two K10's which are used for applications including human-robot interaction studies and multi-robot Lunar relevant site survey (resource mapping).

K10 has four-wheel drive and all-wheel steering with a passive rocker suspension, which allows it to traverse moderately rough natural terrain at speeds up to 90 cm/s. Hot-swappable Lithium-ion batteries provide the necessary power to run the drive system's motors and avionics. K10 weighs 80kg and can carry an additional 40kg payload. The current payload includes but is not limited to: an Optech LIDAR, stereo cameras, ground penetrating radar, a microscopic imager, HYDRA Neutron Spectrometer, Chemin, and a HoneyBee Penetrometer. The K10 rovers use NASA Coupled Layer Architecture for Robotic Autonomy software architecture running under a Linux operating system.

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