NASA Lunar Science Institute
Lunar Exploration Advisory Group

Yvonne Pendleton, Director

14 September 2010

lunarscience.nasa.gov

NLSI Mission

- Carry out and support collaborative research in lunar science, investigating the Moon itself and using the Moon as a unique platform for other investigations
- Provide scientific and technical perspectives to NASA on its lunar research programs, including developing investigations for current and future space missions
- Support and catalyze the lunar science community and train the next generation of lunar science researchers
- Support education and public outreach by providing scientific content for K-14 education programs, and communicating directly with the public

NLSI: Scientific Breadth

For the NLSI, lunar science is broadly defined to include studies:

Of the Moon: Investigations on the nature and history of the Moon (including research on lunar samples) to learn about this specific object and thereby provide insights into the evolution of our solar system

On the Moon: Investigations of the effects of the lunar environment on terrestrial life and the equipment that supports lunar inhabitants, and the effects of robotic and human presence on the lunar environment

From the Moon: Use of the Moon as a platform for performing scientific investigations, including observations of the Earth and other celestial phenomena that are uniquely enabled by being on the lunar surface.

NASA LUNAR SCIENCE INSTITUTE

U.S. Teams

Understanding the Formation and Bombardment History of the Moon
PI: Bill Bottke, Southwest Research Institute

Impact Processes in the Origin and Evolution of the Moon: New Sample-driven Perspectives
PI: David Kring, USRA/LPI

Dynamic Response of the Environment At the Moon (DREAM)
PI: Bill Farrell, NASA Goddard Space Flight Center

Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS)
PI: Mihaly Horanyi, University of Colorado – Boulder

The Moon as Cornerstone to the Terrestrial Planets: The Formative Years
PI: Carle Pieters, Brown University

Scientific and Exploration Potential of the Lunar Poles
PI: Ben Bussey, Johns Hopkins University

Lunar University Network for Astrophysics Research (LUNAR): Exploring the Cosmos from the Moon
PI: Jack Burns, University of Colorado - Boulder

Major Scientific Findings

"Of the Moon"

- Differential charging from UV photons and/or energetic electron beams = charging, mobilization and transport of dust.

- Polar crater electrical environments = reduction in plasma creating large anomalous surface potentials. Objects within polar craters are not well-grounded to the plasma and cannot easily dissipate charge.

- Geochemical analysis of lunar samples allowed for bulk lunar chemical composition estimates and dating of lunar breccias.
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- New high resolution hydrodynamical simulations of the giant impact likely responsible for the Moon's origin.

- New models of moving resonances show depletion of the asteroid belt region during giant planet migration linked to production of LHB impactors.

- New rock type (Mg rich spinel) found on lunar farside; New South Pole-Aitken Basin impact melt characteristics determined

Major Scientific Findings (Cont'd)

"On the Moon"

• Anomalous radar signatures indicative of water ice correlated with crater illumination and Earth/Sun shadow time.

• Quantified thermal stability of water on lunar analog materials. Modeled several aspects of observed H2O and OH distribution.

• Conducted tests on mobility, excavation (quasi-static), penetrometer index testing, and geotechnical properties of GRC-1 & JSC1 lunar simulants.

"From the Moon"

• LRO imaging of Lunokhod 1 allowed the first lunar laser ranging data from the Russian rover in nearly 40 years.

• The Apollo lunar laser reflectors show a clear signature of signal degradation that is exacerbated at full moon.

Publications, Collaborations and Students

Training the Next Generation:

Number of Interns being trained by NLSI teams:	41	
Number of Undergraduates within NLSI:	24	
Number of Graduate students within NLSI:	46	
Number of Postdocs within NLSI:		17
Number of New Faculty:		2

Publications:

Number of published papers:		37
Number of papers in press or review:	39	
Conference papers/presentations:		235

Collaboration highlights:

- NLSI consists of ~180 Lunar scientists (co-Is and collaborators) across 50 different institutions.
- The CCLDAS, CLOE and LUNAR teams have established a joint interdisciplinary graduate seminar series at the Univ. of CO.
- Collaboration between JAXA and three NLSI teams created to compare Lunar Prospector and Kaguya datasets.
- Postdoc sharing to combine modeling theory and laboratory results
- International collaborations have begun to study polarimetry and its relationship to Earthshine (Netherlands, U.K.)

EDUCATION/PUBLIC OUTREACH ACTIVITIES

Formal Education

- ✓ K-12 Educator Workshops
- ✓ Lunar Geology
- On-line Course For Teachers
- ✓ HS Students Research
- ✓ Summer Camps
- ✓ Lunar Student Academy
- ✓ Lunar Crater Tactile Book
- ✓ "Cosmos in the Classroom"
- conferences with the ASP

Informal Education

- ✓ Library Travelling Exhibit
- ✓ Planetarium Shows
  "Max Goes to the Moon"

Public Outreach

- ✓ Intn'l Observe the Moon Night
- ✓ Public Lectures
- ✓ Public Events: Night Sky Network
- ✓ Popular Science Magazines
- ✓ Podcasts: 365 Days of Astronomy
- ✓ Videos: How We Went to the Moon
- ✓ Social Media: Twitter, Facebook, Vimeo, Youtube, 12-Second videos, etc.
- ✓ Websites: Mymoon.com

CITIZEN SCIENCE (Moon Zoo)

NLSI – COMMUNITY SUPPORT

NLSI supports the entire lunar science community through:

- NASA Lunar Science Forum (LSF)
- LEAG – Schmidt on executive council, provides roadmap support and conducts LEAG Town Hall meetings at LSF,

  Co-organizer of LEAG Volatiles Workshop June 2011
- Focus Groups – open to entire community
  - Dust/Volatiles
  - South Pole/Aitken Basin
  - Lunar Commerce
  - ALSEP Data Recovery
  - Lunar Biology/Astrobiology
  - Lunar Bombardment
- Support of student/next gen researcher community

TRAINING THE NEXT GENERATION

LunGradCon

Over 25 participants in the first all-graduate lunar scientist conference, held prior to the 2010 Lunar Science Forum. Supported/funded by NLSI Central, the conference was organized by graduate students within NLSI teams and open to ALL graduate students interested in lunar research.

NLSI Post-doc Program

Two post-doctoral research positions awarded in 2010 to the NLSI community with intention to increase the number of postdocs each year. Applications for NLSI postdocs are due once a year: March 1, 2011 through the ORAU website.

Next Generation Lunar Scientists & Engineers Community

Workshops for early career lunar scientists and engineers, (AGU 2009, LSF 09,10; LPSC 09,10).

NLSI participation in Executive Committee & help acquiring external funding.

CURRENT INTERNATIONAL AFFILIATE TEAMS

Canada , PI: Gordon “Oz” Osinski,
University of Western Ontario
Partnership signed July 2008
Analog field science, shock processes in meteorites, remote sensing

Korea , PI: Im Yong-Taek,
Korean Institute for Advanced Science & Technology (KAIST)
Partnership signed November 2008
Post-doc at NASA Ames, lunar mission design/ small satellites

United Kingdom, PI: Mahesh Anand,
Open University
Partnership signed January 2009
Lunar interior, geochronology, pan-Europena NLSI network

Kingdom of Saudi Arabia, PI: Haithem Altwaijry
King Abdulaziz City for Science and Technology (KACST)
Partnership signed in December 2009
Lunar ranging technology, NEO studies, radar imaging

Israel, PI: Shlomi Arnon
Ben-Gurion University at the Negev
Partnership signed in January 2010
Laser ranging and communications for the Moon, small satellites

Netherlands, PI: Wim van Westrenen
VU University Amsterdam
Partnership signed August 2010
Experimental lunar interior science, astronomy from the Moon

LUNAR SCIENCE FORUM

- Next Forum – July 19-21, 2011

2010 Forum

- 600+ registered attendees
- 210 Abstracts accepted
- 17 Countries Represented

Highlights included:

- Shoemaker Award presented to Don Wilhelms
- LCROSS and LRO; 8 Parallel Science Sessions
- Student Poster Session Award Winners
  - 3rd place: Laura Kruger (Colorado U.)
  - 2nd place: Matthew Siegler (UCLA)
  - 1st place: Tie; Elise Rumpf (U. of HI) and Paul Hayne (UCLA).

TOWARDS THE FUTURE

- Current Lunar assets (LRO, ARTEMIS) and soon to be launched (GRAIL, 2011 and LADEE, 2013), plus international missions, to provide robust data streams
- Next CAN to be released after Planetary Decadal Survey report released and NASA budget/plan resolved
- Depending upon NASA directions, possible expansion of the NLSI charter to include the study of asteroids
- Lunar Science Forum 2011 (July 19-21)
- Continued participation in LEAG

  -Co-organizer of LEAG Volatiles Workshop June 2011

NASA LUNAR SCIENCE INSTITUTE

Bringing Lunar Science to a new generation

… around the world

http://lunarscience.nasa.gov

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Backup Charts

NLSI US Team Details

Understanding the Formation and Bombardment History of the Moon

PI: Bill Bottke - Southwest Research Institute

- Modeling of the formation of the moon through a giant impact
- Observational constraints on the bombardment history
- Modeling of lunar impact rates throughout lunar history

Impact Processes in the Origin and Evolution of the Moon: New Sample-driven Perspectives

PI: David Kring, USRA/LPI

- Apollo sample analysis drives understanding of lunar formation and potential for basin-forming epochs and cataclysms
- Regolith formation and processing through sustained impacts

Dynamic Response of the Environment At the Moon (DREAM)

PI: Bill Farrell, NASA Goddard Space Flight Center

- Determining rates of release and loss of gases from lunar exosphere
- Modeling plasma interactions within the Lunar atmosphere
- Temperature, lighting and volatile transport in the lunar environment

Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS)

PI: Mihaly Horanyi, University of Colorado - Boulder

- Laboratory experiments on Lunar plasma, dust and E-fields
- Effects of solar radiation on the lunar atmosphere and dust transport
- Lunar dust material transport and effects on human and robotic exploration

NLSI Team Details (Cont'd)

The Moon as Cornerstone to the Terrestrial Planets: The Formative Years

PI: Carle Pieters, Brown University

- Evolution of the Lunar magma ocean
- Solid state mantle flow, interior structure dynamics and core properties
- Lunar crustal record through geochemical research

Scientific and Exploration Potential of the Lunar Poles

PI: Ben Bussey, Johns Hopkins University

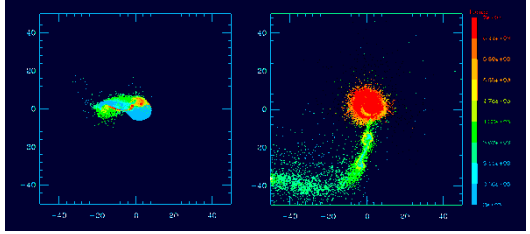
- Characterization of lunar pole geology, lighting and thermal conditions
- Civil engineering projects involving lunar regolith transport and utilization as well as instrument development for in-situ resource utilization

Lunar University Node for Astrophysics Research (LUNAR): Exploring the Cosmos from the Moon

PI: Jack Burns, University of Colorado - Boulder

- Using the moon as a platform for low frequency astrophysics and cosmology
- Lunar laser ranging for general relativity and gravity studies
- Heliophysics studies of solar particle acceleration using a low frequency radio array

Center for Lunar Origin and Evolution



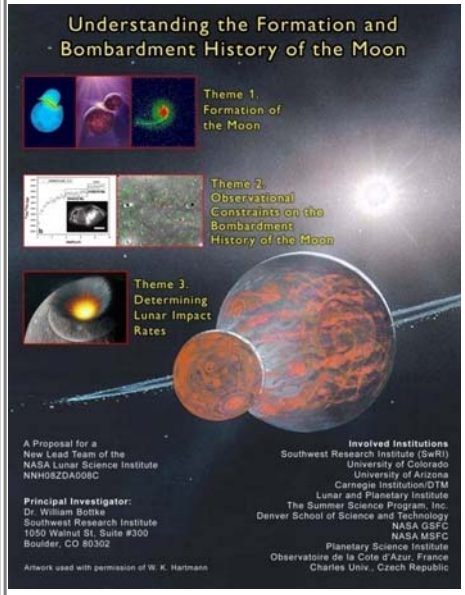
PI: W. Bottke, SwRI-Boulder

1. Major Scientific Results

1. New “late accretion” model of inner solar system used to determine largest impactors striking Earth/Moon after Moon-forming event and explain water in lunar mantle.
2. New “Late Heavy Bombardment” (LHB) model suggests terrestrial planets and Moon were hit hard by “extinct” asteroids that once resided between Mars and asteroid belt.
3. Models of moving resonances that sweep across and deplete the asteroid belt region during giant planet migration are linked to the production of LHB impactors.
4. New model suggests planetesimal-driven migration of inner solar system protoplanets is critical to understanding terrestrial planet formation and the Moon’s origin.
5. The highest resolution hydrodynamical simulations ever of the giant impact with the Earth believed responsible for the Moon's origin (see images above).
6. New model developed of the vertical structure of the proto-lunar disk that is in two-phase equilibrium containing both silicate melt and vapor.
7. High-resolution impact simulations used to model melt production, with the results used to interpret crater records and to simulate impact-induced differentiation.
8. U-Th-Pb depth-profiles completed on 11 terrestrial Hadean zircons . Their thermal histories suggest very energetic impact events on Earth 3.93-3.96 Gy ago.
9. Model suggests surfaces of Earth/Moon were “buried” by primitive micro-meteorites during the LHB. The Moon accreted $>10^{20}$ g of the comet-like particles.
10. New plots of crater size-frequency distributions within ancient lunar basins indicates the early lunar impactor population changed significantly between 4.4-3.7 Gy ago.

2. A Sample of CLOE Publications

1. Bottke, W.F., R.J Walker, J.M.D. Day, D. Nesvorny, L. Elkins-Tanton. 2010. Stochastic Late Accretion to the Earth, Moon, and Mars. *Science*, submitted.
2. Barr, A. C. and R. I. Citron, 2010. Scaling of Melt Production in Hypervelocity Impacts from High-Resolution Numerical Simulations, *Icarus*, submitted.
3. Mojzsis, S.J. and N. L. Cates, 2010. Early Earth Systems at the Hadean-Archean transition (4.0 - 3.7 Ga). *Chemie de Erde*, submitted.
4. Minton, D., and R. Malhotra. 2010. Secular resonance sweeping of the main asteroid belt during planet migration. *Astrophys. J.*, submitted.



CLOE themes include the Moon’s formation by giant impact and the potential of a lunar cataclysm 3.9 Gy ago

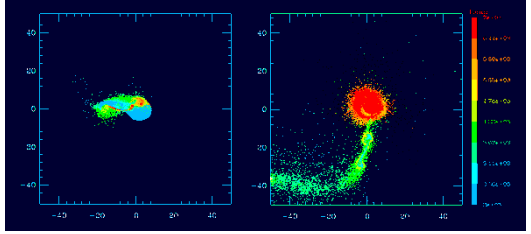
Publications

Publications: 2
Submitted: 6
Conference Abstracts: 15

Educating the Next Generation

Undergrad Students: 1
Graduate Students: 4
Postdocs: 4

Center for Lunar Origin and Evolution



PI: W. Bottke, SwRI-Boulder

3. Education and Public Outreach

1. *Role of Chaos in the Orbital Evolution of the Solar System*; Two-day student investigation conducted in partnership with the Summer Science Program (SSP). 72 high school students at 2 SSP locations. Led by: A. Barr, H. Levison, L. Dones. Activity will be repeated over next two years.
2. *Marvel Moon*; Module of activities for library children's programs completed by K. LaConte. Training of 30 librarians and informal science educators is scheduled for Sept. 3 and 4 at Harmony Library, Fort Collins, CO by K. LaConte and S. Shipp with presentations by B. Bottke and C. Chapman. Five additional live and virtual trainings will be held over the next two years.
3. *CLOE Website (http://cloe.boulder.swri.edu/)*; 12 Denver School of Science and Technology high school students designed and deployed initial site. Students in astronomy and computer classes at North High School of Denver, CO will expand and maintain the site in FY2011. Led by: K. LaConte.

4. Partnerships & Collaborations

1. *E/PO partnerships*: Summer Science Program, Inc., Denver School of Science and Technology, & North High School, Denver, CO
2. *Science*: Collaboration between SwRI dynamicists and U. Maryland/MIT geochemists/geophysicists led to submission of *Science* paper on how "late accretion" affected the Earth, Moon, and Mars.
3. *Science*: Collaboration with UK's "MoonZoo" project (w/Delia Santiago) .

CLOE activities at the Summer Science Program

CLOE uses the Moon to tell us about the primordial Earth and solar system formation (and vice versa!)

15 investigators and 7 collaborating institutions

NASA LUNAR SCIENCE INSTITUTE

CENTER FOR LUNAR SCIENCE AND EXPLORATION

vitally impacting the future – today

PI David A. Kring - USRA LPI, Houston

1. Major Scientific Objectives

a) Determine the chronology of the Moon's origin - Testing the Giant Impact Hypothesis
b) Determine the homogeneity/heterogeneity of the lunar interior - Testing the Giant Impact Hypothesis and Lunar Magma Ocean Hypothesis
c) Determine accretional vs. impact-derived siderophile element abundances – Testing the Lunar Magma Ocean Hypothesis vs. Late Impact Veneer origin of siderophiles
d) Determine the chemical composition and source of projectiles in the basin-forming epoch – Testing the mechanism that may have caused the lunar cataclysm
e) Determine the ages of impact events during the basin-forming epoch – A direct test of the Lunar Cataclysm Hypothesis (the highest NRC 2007 science priority)
f) Potentially determine the age of the South Pole-Aitken Basin – Anchoring the lunar chronology curve (the second highest NRS 2007 science priority)
g) Independently test the duration of the Lunar Cataclysm with basin geophysics
h) Inventory lunar basins and their relative ages
i) Determine Apollo site geology and contributions from basin impacts
j) Determine if the chemical composition of regolith-forming impactors has changed with time
k) Determine if cometary impactors have helped produce the regolith

2. Peer-Reviewed Publications

a) A. D. Brandon, T. J. Lapen, V. Debaille, B. L. Beard, K. Rankenburg, and C. Neal (2009) Re-evaluating the $^{142}Nd/^{144}Nd$ in lunar mare basalts with implications for the early evolution and bulk Sm/Nd of the Moon. *Geochimica et Cosmochimica Acta* 73, 6425–6445.
b) A. A. Nemchin, R. T. Pidgeon, D. Healy, M. L. Grange, M. J. Whitehouse, and J. Vaughn (2009) The comparative behavior of apatite-zircon U-Pb systems in Apollo 14 breccias: Implications for the thermal history of the Fra Mauro Formation. *Meteoritics and Planetary Science* 11, 1717–1734.
c) M. D. Norman, R. A. Duncan, and J. J. Huard (2010) Imbrium provenance for the Apollo 16 Descartes terrain: Argon ages and geochemistry of lunar breccias 67016 and 67455. *Geochimica et Cosmochimica Acta 74*, 763–783.
d) A. A. Nemchin, M. L. Grange, and R. T. Pidgeon (2010) Distribution of rare earth elements in lunar zircon. *American Mineralogist* 95, 273–283.
e) K. M. O'Sullivan, T. Kohout, K. G. Thaisen, and D. A. Kring, "Calibrating several key lunar stratigraphic units representing 4 billion years of lunar history within Schrödinger Basin," in *Recent Advances in Lunar Stratigraphy*, D.A. Williams and W. Ambrose (eds.), Geological Society of America Special Paper, Boulder, CO, in press.

Publications

Publications: 4
In Press:1
Conference Abstracts: 56
Policy White Papers: 2
Decadal Survey White Papers: 6
Presentations: ~50

Educating the Next Generation

Undergraduates: 4

Lunar Exploration Interns: 30 BS, MS & PhD

Postdocs: 8

Field Training and Research Program at Meteor Crater: 19 PhD and 5 MS participants

Lunar Consortium for Higher Ed: 12 member universities

3. Education and Public Outreach

a) High School Research Teams (http://www.lpi.usra.edu/nlsi/education/hsResearch/)
- Four teams of high school students and their instructors piloted projects in collaboration with NLSI scientists and Next-Gen mentors
- The team from San Antonio was selected to represent *all* STEM programs in the state and presented their lunar research to the Texas State Legislature

b) Traveling Library Exhibits (http://www.lpi.usra.edu/nlsi/education/exhibits/)
- Engaging the public in lunar science and exploration through library exhibits

4. Partnerships

1. NASA Johnson Space Center – Astromaterials Research & Exploration Science
2. Rice University
3. The University of Arizona
4. University of Houston
5. University of Maryland
6. University of Notre Dame

5. Collaborations

a) APL Team –
- Collaboration (with PI Bussey and others on APL LRO mini-RF team) to visit three lunar analogue sites (SP lava flow, Sunset Crater, and Meteor Crater (May 2010)

b) SwRI Team
- Sharing a postdoc (Simone Marchi)
- Collaboration (with Durda) on science illustration of impact bombardment (June 2010)

c) Univ. of Colorado, SwRI, and MIT-Brown Teams
- Students will be participating in impact cratering field training program

The Moon-

The Best and Most Accessible Place in the Solar System to Explore the Fundamental Principles of Our Origins

DREAM

Dynamic Response of the Environment At the Moon

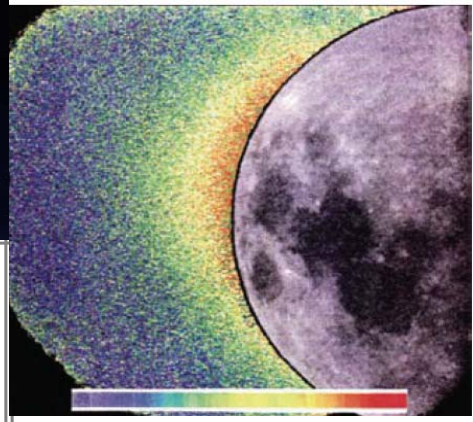
PI: W. Farrell, NASA/ GSFC

1. Major Scientific Results

1. Predicted the intensity and composition of Lunar Horizon Glow in support of the upcoming LADEE mission
2. Observed ejected sodium from the LCROSS impact using the ground-based 62" McMath-Pierce Telescope
3. Determined that polar craters are special electrical environments with the reduction in plasma creating large anomalous surface potentials
4. Discovered that the neutral sodium coma about the Moon is controlled by the solar wind
5. Found that objects within polar craters are not well-grounded to the plasma and cannot easily dissipate electric charge
6. Formed a joint Lunar Prospector/Kaguya team to understand the new dynamics of the lunar wake
7. Discovered that the surface potential changes abruptly and distinctly by ~10 V when the Moon crosses the bow shock of the Earth; this as detected by Apollo's Superthermal Ion Detector Experiment (SIDE)

2. Publications

1. Collier, M. R. and T. J. Stubbs (2009), J. Geophy. Res. 114, A01104
2. Sarantos, M., R. M. Killen, A. S. Sharma and J. A. Slavin (2010), *Icarus* 205, 364-374.
3. Killen, R.M., A.E.Potter, D.M. Hurley, C. Plymate, S. Naidu, (2010). *NOAO/NSO Newsletter*, 101,8.
4. Farrell, W. M. , T. J. Stubbs, J. S. Halekas, R. M. Killen, G. T. Delory, M. R. Collier, R. R. Vondrak (2010), J. Geophys. Res., 115, E03004, doi:10.1029/2009JE003464.
5. Stubbs, T. J., et al., *Planet. Space Sci.*, 58, 830, doi:10.1016/j.pss.2010.01.002.



Neutral Na Exoosphere
[Potter and Morgan, 1998]

Publications

Publications: 4
Submitted: 7
Conference Papers: 1

Educating the Next Generation

Undergrad Students: 2
Graduate Students: 2
Postdocs: 2
Interns: 3

DREAM

Dynamic Response of the Environment At the Moon

PI: W. Farrell, NASA/ GSFC

3. Education and Public Outreach

1. Maryland Day 2009 & 2010, UMD campus: Over 70000 people with a DREAM exhibit including an electrostatics demonstration
2. Home School Workshop , NASA/GSFC Visitor center: Work with local families on integrating space science in their curriculum
3. Moonfest, 2009, NASA/ARC: Celebrating the 40th anniversary of the lunar landing with a public science festival including a DREAM booth
4. DREAM E/PO team initiated Next Generation Lunar Scientist and Engineer (NGLSE) to provide new graduates mini-courses for maintained placement in the STEM pipeline
5. DREAM at: http://ssed.gsfc.nasa.gov/code695/dream/index.html

4. Partnerships & Collaborations

1. Strong collaborations with Japanese Space Agency (JAXA) on LP and Kaguya comparisons
2. NASA's Exploration Technology Development Program as the environmental arm of the dust program
3. NASA Engineering Safety Center (NESC) on lunar dust and charging hazards Please list any partnerships, international, academic institutions, government institutions, etc.

DREAM booth at Maryland Day

DREAM is a lunar environment modeling center

- **Maintains, advances, and integrates over 13 computational models of the lunar environment**
- **25 team members and 13 formal collaborators**
- **11 co-investigating and 6 collaborating institutions**

Colorado Center of Lunar Dust and Atmospheric (CCLDAS)

PI: M. Horanyi, University of Colorado, Boulder

CCLDAS

1. Major Scientific Results:

a) *Theory:* Successful modeling of the formation of photoelectron plasma sheaths, including the effects of realistic photoelectron energy distributions, and the emergence of electrostatic double-layers.

b) *Laboratory Experiments:* Demonstrated the role if differential charging due to exposure to UV photons and/or energetic electron beams leading to charging, mobilization and transport of dust.

c) *Space Hardware:* Completed demonstration units to measure the charge, mass, and velocity vector of slow-moving dust on the lunar surface. Completed testing of the EM version of LADEE/LDEX.

2. Publications:

a) J.E. Colwell, S.R. Robertson, M. Horanyi, A. Poppe, P. Wheeler, Lunar dust levitation, *J. Aerospace Engineering 22* , 2-9, 2009.

b) X. Wang, M. Horanyi, S. Robertson, Experiments on dust transport in plasma to investigate the origin of the lunar horizon glow*, J. Geophys. Res., 11*, Issue A5, CiteID A05103, 2009.

c) M. Horanyi, O. Havnes, G. E. Morfill, Complex Plasmas in the Solar System*, Complex (Dusty) Plasmas*, eds: V. Fortov and G.E. Morfill, CRC Press: Series in Plasma Physics, 2009.

d) D. James, V. Hoxie, M. Horanyi, Polyvinylidene Fluoride Dust Detector Response to Particle Impacts, *Rev. Sci. Instruments, 81*, 034501, 2010.

e) A. Poppe, M. Horanyi, Simulations of the Photoelectron Sheath and Dust Levitation on the Lunar Surface, *J. Gephys. Res.* , in press, 2010.

f) X. Wang, M. Horanyi, S. Robertson, Investigation of dust transport on the lunar surface in a laboratory plasma with an electron beam, *J. Geophys. Res.,*in press, 2010.

g) A. Poppe, B. Jacobsmeyer, D. James, M. Horanyi, Simulation of Polyvinylidene Fluoride Detector Response to Hypervelocity Particle Impact, *Nucl. Instr. Methods,* in press, 2010.

h) X. Wang, M. Horanyi, S. Robertson, Dust transport near electron beam impact and shadow boundaries , *Planetary and Space Science,* submitted, 2010.

i) E. Grun, M. Horanyi, and Z. Sternovsky, The Lunar Dust Environment*, Planetary and Space Scienc*e, submitted, 2010.

j) F. Postberg, E. Grun, M. Horanyi, S. Kempf, H. Kruger, R. Srama, Z. Sternovsky, and Mario Trieloff, Compositional Mapping of Moon Surfaces by Mass Spectrometry of Dust Ejecta, *Planetary and Space Science*, submitted, 2010.

k) A. Dove, G. Devaud, X. Wang, M. Crowder, A. Laitzke, C. Haley, Mitigation of lunar dust adhesion by surface modification**,** *Planetary and Space Science*, submitted, 2010.

Publications

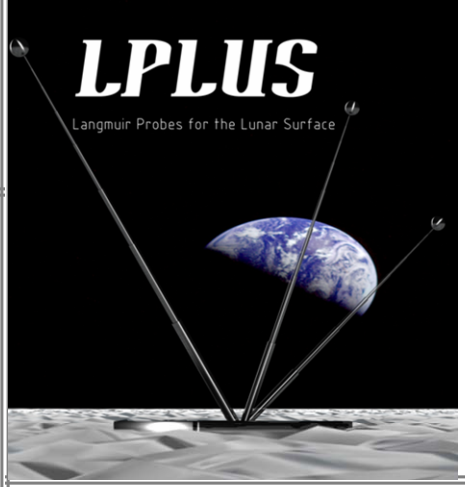
Published: 4
In Press: 3
In review: 4
Presentations: ~ 40

Educating the Next Generation

Undergraduates: 12
Graduate Students: 4
Postdocs: 2
NLSI New Faculty: 2

Colorado Center of Lunar Dust and Atmospheric (CCLDAS)

PI: M. Horanyi, University of Colorado, Boulder



3. Education and Public Outreach

a) "The Moon as a Field Station: The Science and the Exploration." Media Workshop April 30 – May 2, 2010. (Science Now, Physics Today, AP/Denver, Nova, National Geographic, Space News, Odyssey Magazine, + 3 free lance). Talks: J. Ashby, B. Bottke, J. Halekas, M. Horanyi, S. Mojzis, A. Stern, and B. Weiss

b) "Interdisciplinary Lunar Science Seminar", in collaboration with B. Bottke & J. Burns (15 grads).

c) Aerospace Senior Engineering Project: : "Langmuir Probes for the Lunar Surfaces (LPLUS)" (12 undergrads)

d) Weekly "journal club" style graduate seminar, including lunar and general dusty-plasma issues (http://www.colorado.edu/physics/phys7810_plasma/phys7810_plasma_sp10/)

e) Graduate plasma physics, the course now includes a segment on dusty plasmas relevant for the lunar surface (http://lasp.colorado.edu/~horanyi/5150/)

4. Partnerships

a) NASA Johnson Space Flight Center
b) Tech-X Corporation (Small Business)
c) Zybek Advanced Products (Small Business)
d) Max Planck Institute for Extraterrestrial Physics (Garching, Germany)
e) Max Planck Institute for Nuclear Physics (Heidelberg, Germany)
f) Katholieke Universiteit (Leuven, Belgium)

5. Collaborations

a) NLSI DREAM Team for modeling the lunar plasma environment and develop tools for improved interpretation of the Lunar Prospector measurements of the surface potential of the Moon.

b) NLSI LUNAR and CLOE Teams to direct an interdisciplinary graduate seminar at the University of Colorado.

C) NLSI DREAM and CLOE Teams for the presentations at the CCLDAS Media Workshop,

CCLDAS is focused on: **a)** experimental and theoretical investigations of dusty plasma processes; **b)** the development of new instrument concepts for future in situ dust and plasma measurements on the surface and in orbit about the Moon and other airless bodies in the solar system; and **c)** a complementary program of education and community development. CCLDAS is addressing basic physical and applied lunar science questions, including the long-term usability of mechanical and optical devices on the Moon. CCLDAS is supporting the development of the Lunar Dust Experiment (LDEX), an in situ impact dust detector to be flown on the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission scheduled to be launched in 2013.

NASA LUNAR SCIENCE INSTITUTE

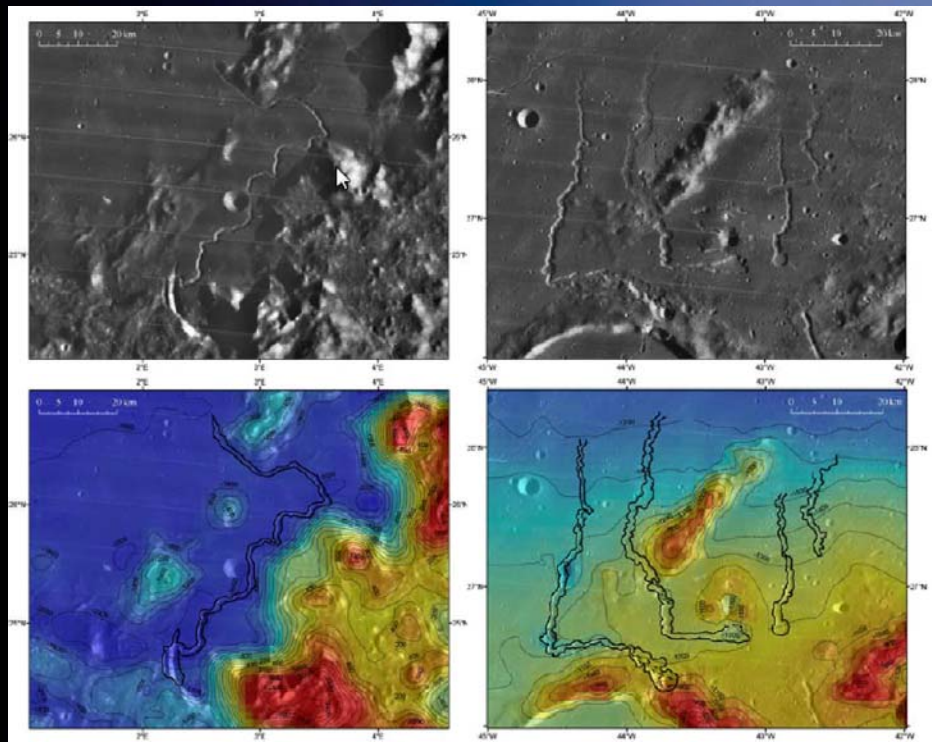
The Moon as Cornerstone to the Terrestrial Planets: The Formative Years

Evolution of the Lunar Magma Ocean
Post-magma Ocean Structure and Evolution
Deciphering the Crustal Record
Looking to the Future, Learning from the Past

PI: C. Pieters/Brown University
Inst. PI: M. Zuber/ MIT
+19 Co-investigators and 13 Collaborators from 8 institutions

NLSI Productivity 2009- spring 2010: Lunar Products

- Peer-Reviewed or submitted manuscripts:
  - Number of manuscripts: 28
  - Number with student-lead author: 5
- Extended Abstracts (e.g., LPSC):
  - Number of abstracts: 70
  - Number with student-lead author: 19
- Other (separate) Lunar Mission Activities
  - Number of Peer-reviewed manuscripts: 9
  - Number of extended abstracts: 61



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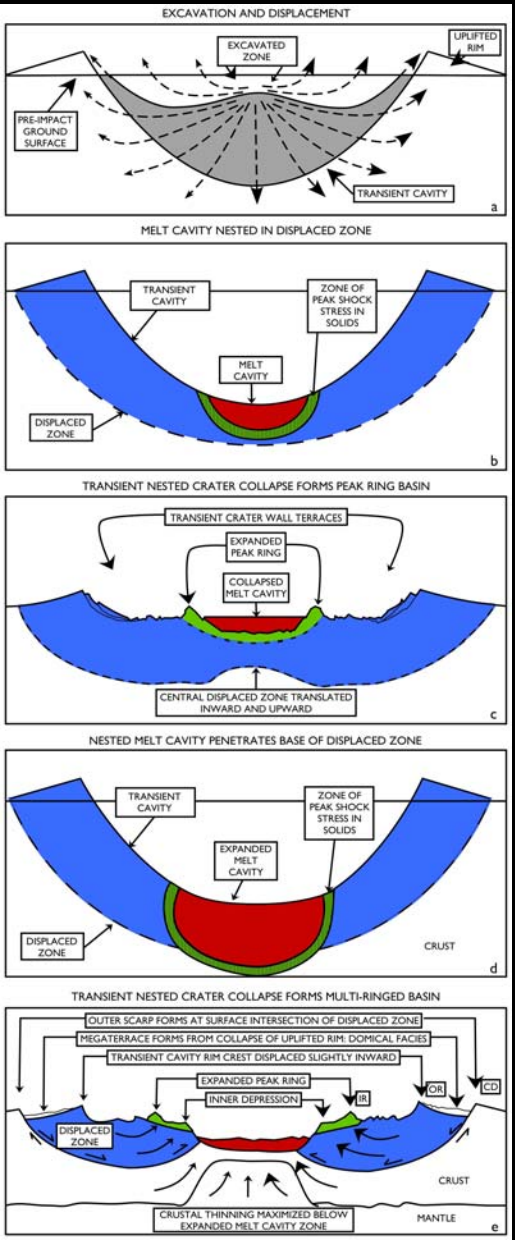


Example Recent Highlights

- A question of scale: transition from complex craters to basins [Head, GRL 2010]
- Basins as probes to the lower crust/mantle
  - New Rock type found on lunar farside (Mg-spinel dominated) [Pieters et al., JGR submitted, 2010]
  - SPA impact melt: pervasively noritic, but gabbroic center [Joint with SELENE optical team]
- Lunar interior water
  - Modeling water in the lunar mantle [Elkins-Tanton et al.]
  - Measuring water in lunar samples: apatites (several independent groups); volcanic glasses
- Lunar Swirls: New dust mobility model [Garrick-Bethell et al., Icarus 2010]

NASA LUNAR SCIENCE INSTITUTE

Scientific and Exploration Potential of the Lunar Poles

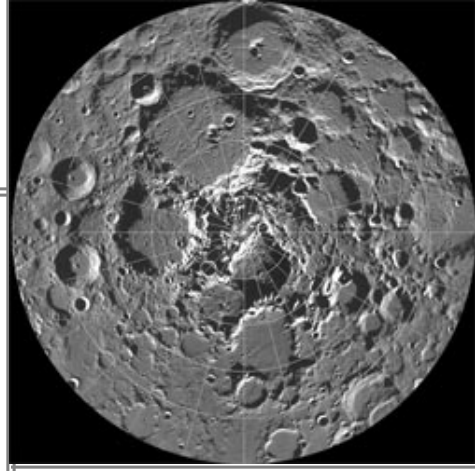
PI: Bussey, The Johns Hopkins University Applied Physics Laboratory

1. Major Scientific & Exploration Results

1. Identified craters with anomalous radar signatures indicative of the presence of water ice.
2. Identified the areas near both poles that receive the most illumination. Also mapped regions which are both Sun and Earth shadowed.
3. Quantitative determination of thermal stability of water on lunar analog materials. Successfully modeled several aspects of observed water and hydroxyl distribution on the Moon using thermal processes.
4. Conducted tests on mobility (inching & traditional), excavation (quasi-static), penetrometer index testing, geotechnical properties of GRC-1 & JSC1a lunar simulant (micromechanical, triaxial & penetrometer).
5. Distinction of layering of cinders, lava flows, ejecta, and covering sediments in GPR data, supporting the possibility that a lunar GPR could reveal useful information about the upper few meters of the subsurface, and thus about local geologic history.
6. Shown that the chiral molecules of photosynthesis produce measureable circular polarization signatures from both microbial communities and vegetation
7. Insight into the cratering processes where the regolith is a significant fraction of the target material
8. Studying the evolution of the vapor cloud resulting from the LCROSS impact. We have found that the diatomic hydrogen gas observed by LAMP is best fit by an isotropic cloud released with a temperature of 1000 K.

2. Publications

1. Spudis, P. D., et al. (2010), Initial results for the north pole of the Moon from Mini-SAR, Chandrayaan-1 mission, Geophys. Res. Lett., 37, L06204, doi:10.1029/2009GL042259
2. Bussey D.B.J.. et al. (2010), Illumination conditions at the south pole of the Moon derived using Kaguya topography Icarus, V208, 558-564.
3. Dyar, M.D., C.A. Hibbitts, T.M. Orlando (2010) Mechanisms for incorporation of hydrogen in and on terrestrial planetary surfaces, Icarus, 208, 425-437.
4. Oravec, H.A., et al. (2010), Design and characterization of GRC-1: A soil for lunar terramechanics testing in Earth-ambient conditions, J Terramechanics, doi:10.1016/j.jterra.2010.04.006

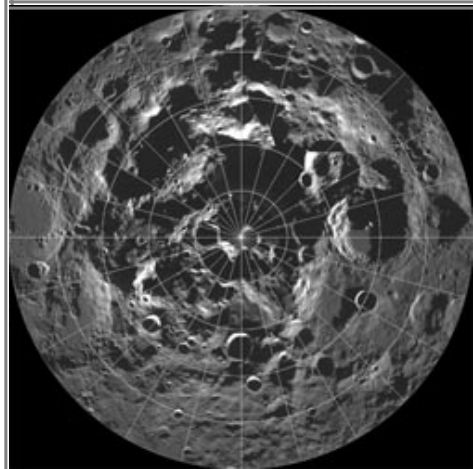


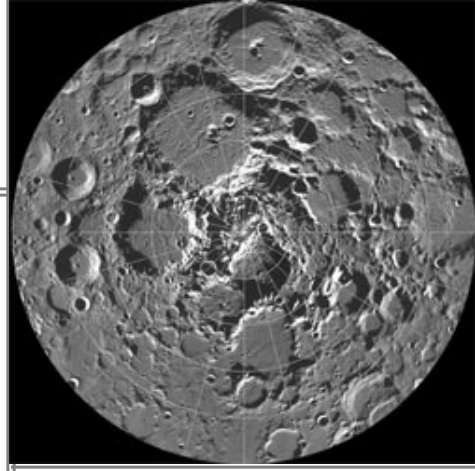
Publications

Publications: 5
In Press or Prep: 6
Conference Papers & Abstracts: 35

Educating the Next Generation

Undergraduates: 1
Graduate Students: 1
Interns: 1





3. Education and Public Outreach

1. Teacher workshop, Lunar Planetary Institute: “Unknown Moon”, 30 teachers present, July 12-17th, 2010.
2. Public Lunar Nights at Maryland Science Center, 237 visitors over 4 nights in July and August, 2 additional nights coming up, Sept 10 and 17, 2010.
3. Science on a Sphere exhibit and program, Maryland Science Center, shown on an ongoing rotating basis during daily live general public scheduled presentations.
4. Teacher workshop included discussions led by mini-RF scientist and engineer, hands on activities, and a first view of the science on sphere program, Maryland Science Center, 43 teachers in attendance, Aug 4, 2010.
5. Teacher presentation at Maryland MESA Advisors Workshop, approximately 50 teachers in attendance, Aug 5, 2010.
6. Student Planetary Investigators: Pilot test year, 4 high school teams, (approximately 50 students) working with science team to analyze mini-RF data, Sept-May, 2010.
7. Mini-RF podcasts: Two completed discuss science and engineering. Three upcoming will include data acquisition, significance of discoveries, and careers in space.
8. Permanent exhibit at Maryland Science Center, completion date Sept 30, 2010.

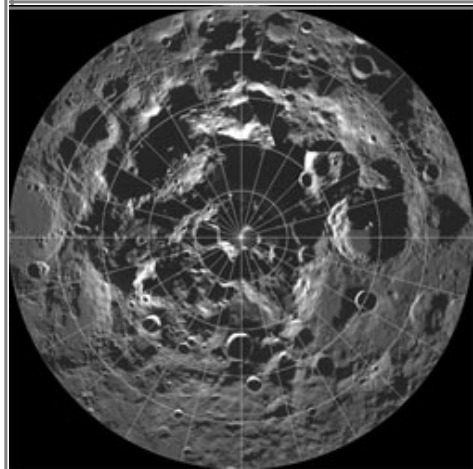
4. Partnerships

1. We are working with Thomas Germer, Optical Technology Division, National Institute of Standards and Technology on the use of precision polarimetry as a biosignature.
2. We work with scientists at the University of Hertfordshire, UK, on the use of circular polarization as a diagnostic of the presence of chirality, including Prof. James Hough, Dr. William Martin. Sparks is Visiting Professor at the University of Hertfordshire.
3. Arctic Region Supercomputing center
4. NASA Kennedy Space Center

5. Collaborations

1. Collaborating with JAXA scientists from the Kaguya lunar misision
2. Buffalo State College (SUNY) (outside of NLSI)
3. Kimberly Ennico of the LCROSS team is collaborating with Sparks and Meadows on analysis of LCROSS Earth observations providing new hands-on experience of Earth observing from space.
2. Sparks is collaborating with polarimetry experts Frans Snik, Cristoph Keller at the University of Utrecht, Netherlands, on instrumentation concepts for polarimetry observation.
3. McCullough is working with Ken Janes, University of Boston, on polarization observations of the Earthshine at Lowell Observatiory, Flagstaff.

Our team consists of over 30 scientists and engineers who are looking at a multitude of linked questions about the lunar poles



Lunar University Network for Astrophysics Research (LUNAR)
PI: Burns, University of Colorado at Boulder

1. Major Scientific Results

1. LRO's imaging of Lunokhod 1 allowed Tom Murphy of UCSD to get the first lunar laser ranging from the Russian rover in close to 40 years.
2. We have built a fast portable code to generate maps of highly red-shifted hydrogen.
3. Using data from Stereo A & B we have mapped the locations and strength of nearby low frequency radio transients.
4. The Apollo lunar laser reflectors show a clear signature of signal degradation that is exacerbated at full moon.

2. Publications

1. Datta, A., Bhatnagar, S., & Carilli, C. L. 2009, ApJ, 703, 1851
2. Hyman, S. D., Wijnands, R., Lazio, T. J. W., Pal, S. Starling, R., Kassim, N. E., & Ray, P. S. 2009, ApJ, 696, 280
3. Pritchard, J. R., & Loeb, A. 2008, Phys. Rev. D, 78, 103511
4. Visbal, E., Loeb, A., & Wyithe, S. 2009, Journal of Cosmology and Astro-Particle Physics, 10, 30
5. Wyithe, J. S. B., & Loeb, A. 2009, MNRAS, 397, 1926
6. Zeiger, B., & Darling, J. 2010, ApJ, 709, 386
7. Lazio, T. J. W., Carmichael, S., Clark, J., Elkins, E., Gudmundsen, P., Mott, Z., Szwajkowski, M., & Hennig, L. A. 2010, AJ, 139, 96
8. Harker G. J. A., Zaroubi S., Bernardi G., Brentjens M. A., de Bruyn A. G., Ciardi B., Jelić V., Koopmans L. V. E., Labropoulos P., Mellema G., Offringa A., Pandey V. N., Pawlik A. H., Schaye J., Thomas R. M., & Yatawatta S. 2010,, MNRAS, 405, 2492 (2010)

Publications

Publications: 12
In Press: 5
Conference Papers: 17

Educating the Next Generation

Undergraduates: 5
Graduate Students: 7
Postdocs: 2
Interns: 1

3. Education and Public Outreach

1. Cosmos in the Classroom at the 2010 ASP conference in Boulder, Colorado. 75 K-12 teachers participated these workshops.
2. Lunar Bagel Breakfast. This was a public event to watch and celebrate the impact of LCROSS in 2009.
3. We began working with High School robotics clubs to design and build a mini lunar rover that can deploy out low frequency arrays using aluminum foil.
4. We are writing and producing 2 planetarium shows. One for K-5 students and the other for the general public. We are in the early stages of scripting.
5. Many of our scientists have given public lectures and colloquia on lunar science.
6. Our team website is http://lunar.colorado.edu

4. Partnerships & Collaborations

1. We have strong partnerships with Godard Space Flight Center, Lockheed Martin Corp, Ball Aerospace & the Jet Propulsion Laboratory.

LUNAR

- Our main facilities are at University of Colorado, Harvard CFA, University of Maryland & GSFC

- Our expertise includes but not limited to: Astrophysics, Heliophysics, Gravitational Physics and Numerical modeling

- Collaborating institutions: GSFC, CFA, JPL, MIT, NRAO, UCLA, UCSD, U of Maryland, UNM, NRL, CASA

- 85 team member and 10 formal collaborators