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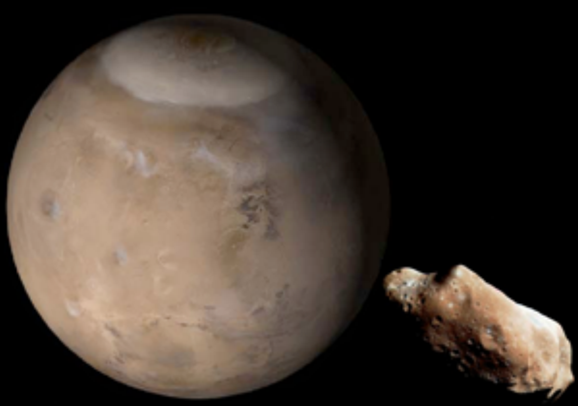
Lunar Exploration Analysis Group

Report to the Planetary Science Subcommittee

31 March 2015



LEAG Executive Committee

- Clive Neal – Chair
- Samuel Lawrence – Vice Chair
- James Carpenter
- Jasper Halekas
- Steve Mackwell
- Jeff Plescia
- Noah Petro
- Bob Richards
- Chip Shearer

Changes by the next PSS meeting as people rotate off.

Ex Officio

- Sarah Noble – SMD
- Ben Bussey – HEOMD
- Greg Schmidt - SSERVI

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Volatile Specific Action Team

This SAT is requested to assess recent discoveries related to detection of volatiles on the Moon, to suggest lunar polar regions of interest, and to suggest possible mission strategies where NASA and international / commercial partners could operate on the lunar surface in a cooperative manner to further understand the size, distribution, form, and resource potential of deposits of water ice and other volatiles.

- Synopsize the current understanding of the type, form and distribution of polar volatiles and the requirements and measurements needed to fully characterize the quantity, distribution, accessibility, and extractability of water ice and other volatiles.
- A candidate prioritized list and discussion of lunar polar regions of interest.

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Volatile Specific Action Team

Major Findings divided into orbital (7) and surface (8).

Report available at: http://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf

Thanks to Paul Lucey for chairing the V-SAT.

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Volatile Specific Action Team

Orbital Findings

- There are sufficient data to support near-term landing site selections.
- Mapping of subsurface hydrogen with sufficient precision and resolution to resolve many individual PSRs (<5 km after any required signal averaging) is the most important orbital measurement.
- Testable hypotheses for volatile distribution should be formulated with the goal of developing a model that exceeds the attainable spatial resolution of orbital neutron measurements.
- Missions that include early ISRU demonstrations should be aimed at sites with environmental conditions that are consistent with more extensive subsequent surface operations.
- LCROSS-like impact experiments should be encouraged.
- Continuing the LRO bistatic radar capability should be a priority.
- New orbital remote sensing can characterize the distribution of surface volatiles, provide some insight into buried volatiles and aid understanding the cycling of polar volatiles.

Volatile Specific Action Team

Surface Findings

- Small near term missions can provide critical data to resolve important unknowns regarding polar volatile science and resource utilization.
- Early characterization of the variation in volatile abundance at ISRU and scientifically relevant spatial scales would greatly benefit all future missions.
- The physical and chemical forms of abundant volatile elements are critical to understanding the resource and its origins.
- Successful exploitation of *in situ* resources requires knowledge of the physical (geotechnical) and thermal properties of polar regolith in addition to the volatile abundance.
- On-going development of polar rovers should include the ability to negotiate terrain and environmental conditions defined by measurement requirements.
- Polar missions should leverage persistent lighting at the lunar poles.
- Solar powered roving missions should take advantage of mobility to extend mission lifetime by “chasing the light”.
- In addition to ISRU goals, landed experiments should include measurements of current volatile flux to aid understanding volatile transport mechanism.

LEAG Activities

- Organizing proposal team for NVM II – draft outline complete.
- LEAG involvement in GER Science White Paper.
- LEAG involvement in SSERVI Exploration Forum.
- LEAG Town Hall meeting at LPSC 46 – 18 March.
- First LEAG-Next Gen "networking session" at LPSC: make connections between the young folks and the seasoned veterans. Two hour informal gathering with 90-100 people. This will become a regular LPSC event.

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LEAG Community News

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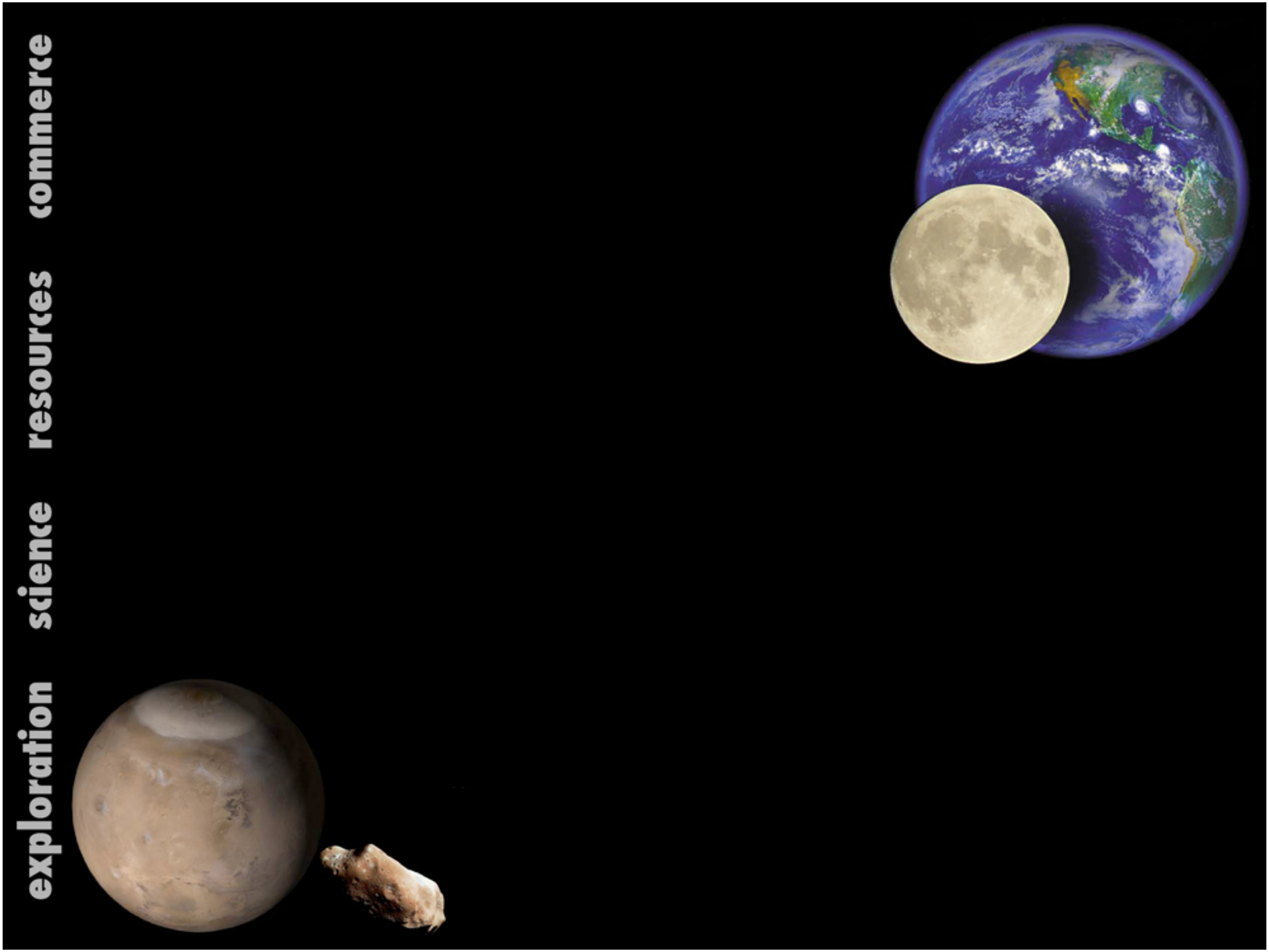
- LRO Icarus Special Issue (submissions due 30 June 2015. Contact Noah Petro (Noah.E.Petro@nasa.gov) for additional details.
- SSERVI Exploration Forum, 21-23 July 2015.
- New MicroCT capabilities at JSC coming soon.
- Deep community concern over the LRO budget and disregard for the Senior Review process.
- 5th International Workshop on Lunar Surface Applications (LSA 5) 14-17 April 2015, Cocoa Beach, FL http://lsaworkshops.com/
- LRO Education Team presents "Lunar Workshops for Educators" (NASA GSFC) 6-10, 13-17 July 2015. See http://lunar.gsfc.nasa.gov/lwe/index.html for more details.
- European Lunar Symposium 12-14 May 2015, Frascati, Italy. GER Science White Paper session 15 May 2015.

Future Initiatives/Activities

- International Lunar Workshop.
- Workshop on the Nature of the Lunar Mantle.
- NVM II.
- CubeSat opportunities and Lunar Catalyst involvement
- Next LEAG Meeting 20-22 October 2015 – LPI (probably)
- Potential SAT on Astronaut Training (under consideration).



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2014 LEAG Meeting Findings

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Astronaut Training.

The current program of geologic training for NASA astronauts, engineering, operations and management personnel is extremely valuable because it supports the development of a "exploration mindset" that will be essential to all future planetary exploration by:

- Providing a context for understanding planetary surface hardware design requirements should be designed and developed;
- Providing examples of the operations principles and practices that will be necessary for planetary surface exploration;
- Giving management experience in the astronaut training and hardware development necessary to produce significant returns from future planetary exploration.

Continuing the current management structure (NASA personnel) and training program (joint effort by NASA-USGS-academic institution), funded jointly by HEOMD and SMD, is strongly supported and endorsed by the 2014 LEAG meeting.

Questions for the PSD

- Will the next New Frontiers/Discovery calls allow a potential role for filling SKGs for specific destinations?
- With LRO being zeroed out, how can LEAG/PSS help PSD in keeping this mission (and Opportunity) going? LRO is still making important discoveries (see Science Nuggets) and we encourage PSD to ensure LRO continues if Congress does not cover the shortfall.
- Are there any guidelines or explicit procedures for approving project-paid travel? Do approvals really need to be done one-at-a-time?

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Science Nuggets

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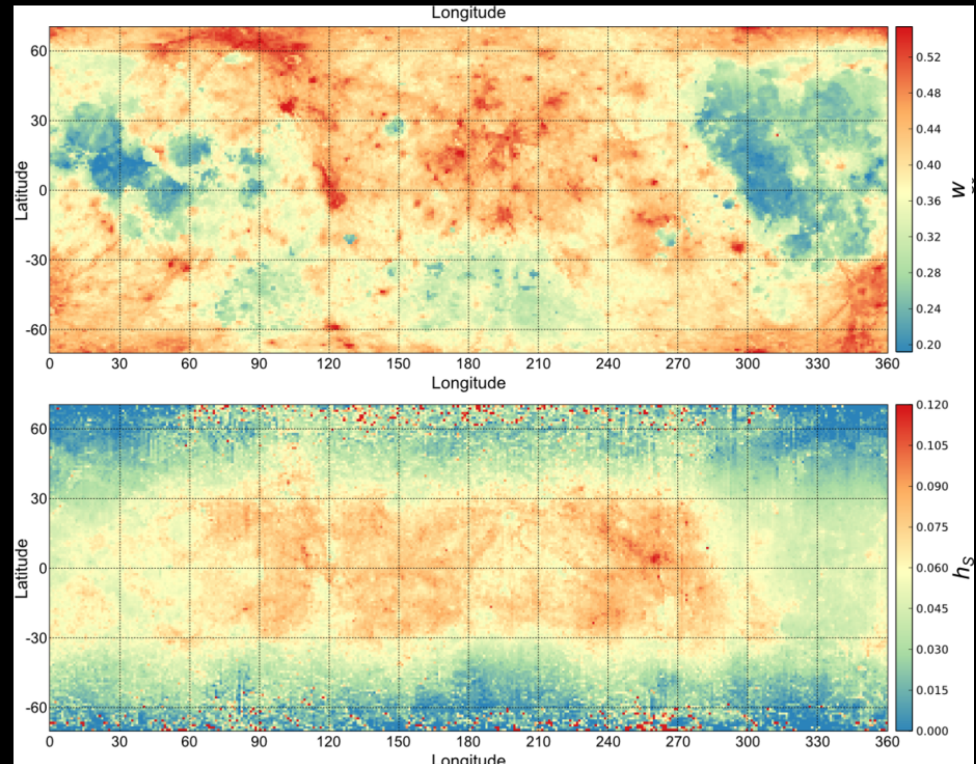
Probing the Surface In New Ways: First Global Maps of Hapke Parameters from LRO

- Hapke parameters have a physical meaning related to the interaction of light with the surface. The parameters vary based on the optical thickness and grain shape irregularity, albedo (*w*, top right),and grain size distribution (h_S, bottom right).
- LRO's stable orbit and the repeated global coverage (>50 times) by the LRO Wide Angle Camera (WAC) coupled with the high resolution LRO-generated topography enables the derivation of the Hapke parameters for nearly the entire Moon -- a first for any planetary body.
- Parameter maps highlight previously unobserved variations in certain parameters (right, bottom), which highlight physical differences in how the regolith is formed and evolves over geologic time.
- Observations closer to the poles lack adequate coverage and will be measured during LRO's second extended mission.

Bottom Line: we're learning how the regolith on airless bodies works in ways we've never been able to do before!



Two of the five derived parameter maps showing variations in surface albedo (*w*, top) and the scale of the opposition effect (h_s, bottom) which is related to the distribution of grain sizes in the regolith. Map is centered on the lunar farside and extends from 70º North to 70º South.

Sato, H., M. S. Robinson, B. Hapke, B. W. Denevi, and A. K. Boyd (2014), Resolved Hapke parameter maps of the Moon **J. Geophys. Res. Planets** *119*, 1775–1805, doi:10.1002/2013JE004580.

LRO Data Unravel the Mystery of Lunar Swirls

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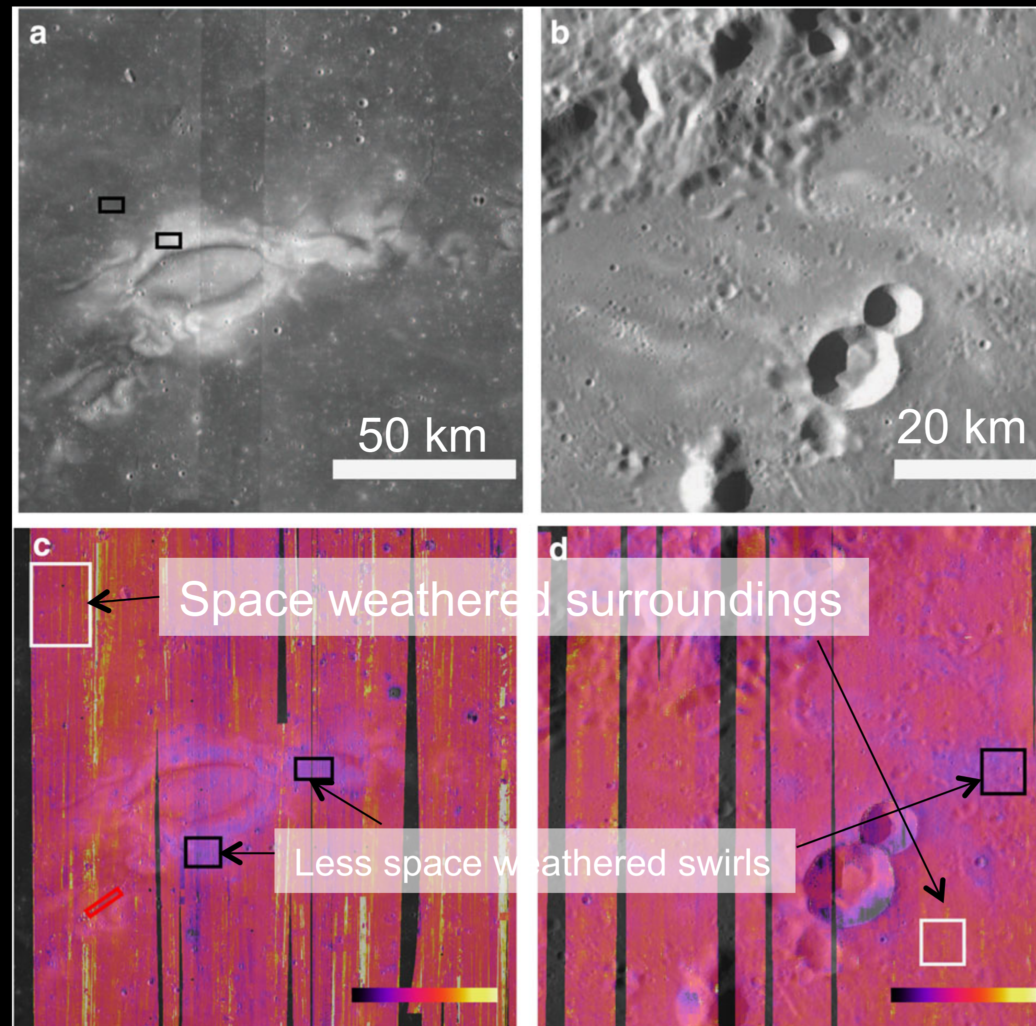
- Lunar swirls are unusually bright lunar features. Their origin has been debated since their identification in the 1960s
- LRO data are used to constrain their surface properties and explain their origin
- Swirls show no difference in surface texture, but do show differences in the amount of space weathering relative to their surroundings
- These data suggest that swirls are formed by the deflection of the solar wind by intense local magnetic fields that shield the surface from the darkening effects of the solar wind



LRO Data of lunar swirls (LROC image on top, Diviner composition maps on bottom). Left frames show the classic Reiner Gamma swirl on the nearside, right frames the Van de Graff swirl on the farside. Magenta features are optically immature, signifying less exposure to the solar wind.

Glotch, T. D. et al. Formation of lunar swirls by magnetic field standoff of the solar wind. *Nature Communications* 6:6189 doi: 10.1038/ncomms7189 (2015).

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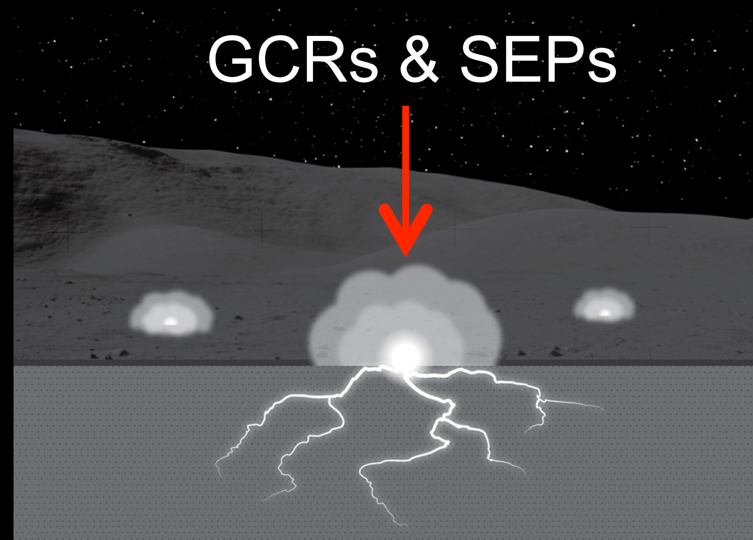
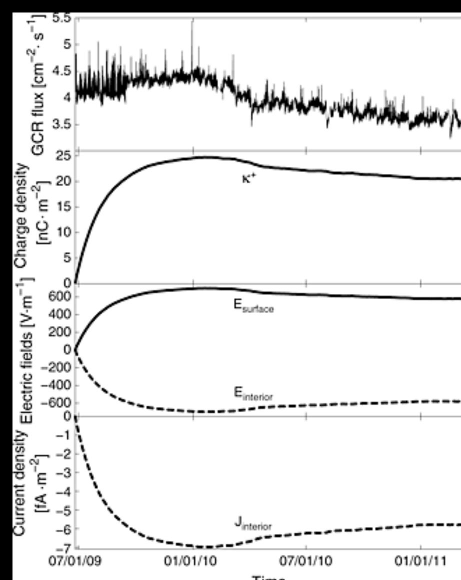
Electric Charging in Areas of Permanent Shadow on the Moon: Changing the Lunar Regolith

- Data from CRaTER on LRO was used to develop the first model predictions for dielectric charging of regolith on an airless body.
- Charged particles from GCRs and SEPs penetrate and charge the regolith.
- Areas of permanent shadow near the lunar poles are susceptible to enhanced charging because the regolith these areas are extremely cold (< 100 K – from Diviner data).
- Regular, high energy dielectric breakdown events may cause increased breakdown of the regolith within areas of permanent shadow



The above illustration shows a permanently shadowed region of the moon undergoing subsurface sparking (the "lightning bolts"), which ejects vaporized material from the surface. Subsurface sparking occurs at a depth of about one millimeter.



Model outputs using GCR fluxes measured by CRaTER (left, top). The charge density due to the accumulation of protons builds with accumulating GCR flux (second row). As the charged lay develops the surface (solid line) and interior (dashed) electric fields (third row). The divergent electric fields builds the interior current density, dissipating the charged layer (bottom row).

Jordan, A. P., T. J. Stubbs, J. K. Wilson, N. A. Schwadron, H. E. Spence, and C. J. Joyce (2014), *Deep dielectric charging of regolith within the Moon's permanently shadowed regions*, **J. Geophys. Res. Planets** *119*, doi: 10.1002/2014JE004648.

Sample Science/Sample Return Nuggets

Mercer C.M. et al. (2015) Refining lunar impact chronology through high spatial resolution $^{40}Ar/^{39}Ar$ dating of impact melts. *Science Advances* **1**:e1400050.

Results underscore the need to quantitatively resolve the ages of different melt generations from multiple samples to improve our current understanding of the lunar impact record, and to establish the absolute ages of important impact structures.

Hopkins M.D. & Mojzsis S.J. (2015) A protracted timeline for lunar bombardment from mineral chemistry, Ti thermometry and U–Pb geochronology of Apollo 14 melt breccia zircons. *Contributions to Mineralogy and Petrology* **169**: 30-47.

Three distinct age populations are defined. Results lend support to the idea that instead of a simple unimodal LHB scenario, or a monotonic decline in impacts, the Moon was battered by multiple cataclysms since ca. 4240 Ma.

Sample Science/Sample Return Nuggets

Boyet M. et al. (2015) Sm–Nd systematics of lunar ferroan anorthositic suite rocks: Constraints on lunar crust formation. *Geochimica et Cosmochmica Acta* **148**, 203-218.

Analysis of 5 FAN suite samples places constraints on the timing of the LMO and initial bulk composition.

Potts N.J. et al. (2015) Robotic traverse and sample return strategies for a lunar farside mission to the Schrödinger basin. *Advances in Space Research* **55**, 1241-1254.

Most of the highest priority objectives for lunar science and exploration (e.g., NRC, 2007) require sample return. Studies of the best places to conduct that work have identified Schrödinger basin as a geologically rich area, able to address a significant number of these scientific concepts.

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