Lunar Surface Innovation

CONSORTIUM

Extreme Environments Focus Group April Working Meeting

April 13, 2021

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JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Today's Agenda

- 2:30 - Introduction, Scope, and Products (Greenhagen - 5 min)
- 2:35 - Review of Environment Drivers (Subgroup Leads or Alternate - 5 min lightning talks)
- 3:00 - Transition to Breakout Zooms (5 min)
- 3:05 - Breakout Sessions (55 min)
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  - Non-Polar Specific Environments (Moderated by Stockstill-Cahill)
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- 4:30 - Adjourn

Winter/Spring Meeting Cycle

Topic: Identifying and Classifying Specific Lunar Surface Environments

- “Breaking Down the Lunar Environment Monolith”
- How do different environments stress technologies in different ways
- How do specific lunar environment differ from descriptions of the general lunar environment?
  - NASA Cross-Program Design Specification for Natural Environments (DSNE) Revision H
  - https://ntrs.nasa.gov/citations/20205007447

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Winter/Spring Meeting Cycle

Activities to Complete Before the LSIC Spring Meeting

	February	March	April
LSIC-EE Leadership	Topic & Products Developed; Compile Environments	Compile Environments	Draft Findings
Focus Group Meeting	Discuss and Gather Site Inputs	Review and Discuss Site Inputs	Supersized 2-hour Meeting with Breakout Sessions
Subgroup Meetings	Evaluation of Target Environments	Evaluation of Target Environments	Review and Rank Environments

We're finally here!

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Winter/Spring Meeting Cycle

What "Specific" Kinds of Environments?

- Any lunar surface environment that represents a challenge or requires a technical mitigation to allow surface sustained survival and operations

Polar Environments	Environmental Variations
Permanently Shadowed Regions (PSRs)	• PSRs with significant reflected illumination • PSRs without significant reflected illumination • PSRs with volatiles in the near-surface regolith • PSRs with desiccated near-surface regolith
Areas of High Illumination (>55% Illumination)	• Naturally high illumination • Mobility-enabled high illumination
Mixed Polar Environments	• Illuminated terrain with rover-accessible macro cold traps (10s to 100s+ meter PSRs) • Illuminated terrain with rover-accessible micro cold traps (1 - 10 meter PSRs) • Occasionally illuminated terrain with subsurface volatile stability • Polar pits or lava tubes (hypothetical)

Non-Polar Environments	Environmental Variations
Apollo-style Environments	• Maria • Highlands
Topographic Margins	• Crater features (rims, peaks, floor fractures) • Volcanic features (vents, domes, riles)
Lunar Pits & Lava Tubes	• Mare basalt features • Impact melt features
Surface Anomalies	• Irregular Mare Patches • Regolith Texture Anomalies (High/Low Dust, Pyroclastic, etc.) • Magnetic Anomalies

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Trailblazing Missions

Date (landing/launch)	Mission	Location	Type of Environments
December 2021	NPLP 1 / Astrobotic (Peregrine Mission One)	Lacus Mortis (near Pit)	Apollo-style + Lunar Pit (surface)
November 2021	NPLP 2 / Intuitive Machines (NOVA-C lander, IM-1)	Schroter's Valley	Apollo-style + Topographic Margin
January 2022	Smart Lander for Investigating Moon (SLIM) – JAXA	Marius Hills Pit	Apollo-style + Lunar Pit (surface)
December 2022	LSITP 1 / Masten (XL-1)	Polar	Mixed Polar
November 2022	PRIME-1 / Intuitive Machines (NOVA-C lander, IM-2)	Polar	Mixed Polar
2023	LSITP 2 / Firefly Aerospace (Blue Ghost)	Mare Crisium	Apollo-style
November 2023	VIPER / Astrobotic (Griffin lander)	Polar	Mixed Polar + PSR
December 2023	PRISM 1 / TBD	Reiner Gamma	Apollo-style + Surface Anomaly
May 2024	PRISM 2 / TBD	Schrodinger Basin (Farside)	Apollo-style + TBD
December 2024	Artemis 3 / TBD	Polar	Mixed Polar
December 2024	PRISM 3 / TBD	TBD	TBD
May 2025	PRISM 4 / TBD	TBD	TBD

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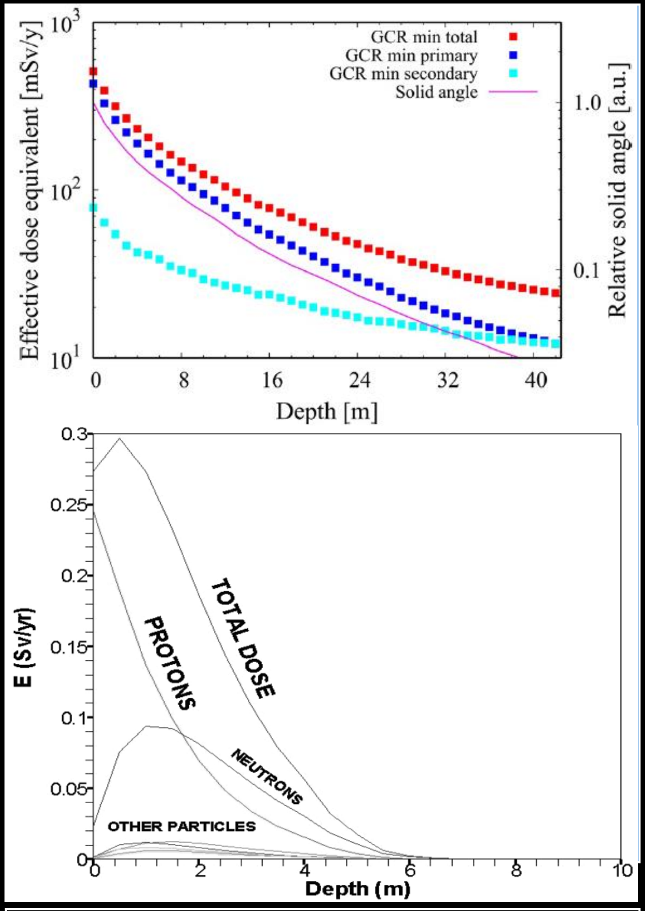
April 13th Working Meeting

- Provide brief backgrounds from the subgroups
- Break into two smaller groups to collect your opinions regarding the following:
    - The importance and urgency of exploring the different environments
    - Specific concerns and hurdles to technology development
    - Environmental impacts from exploration and habitation
    - Draw connections between different environments that could drive technology development

Radiation Environment

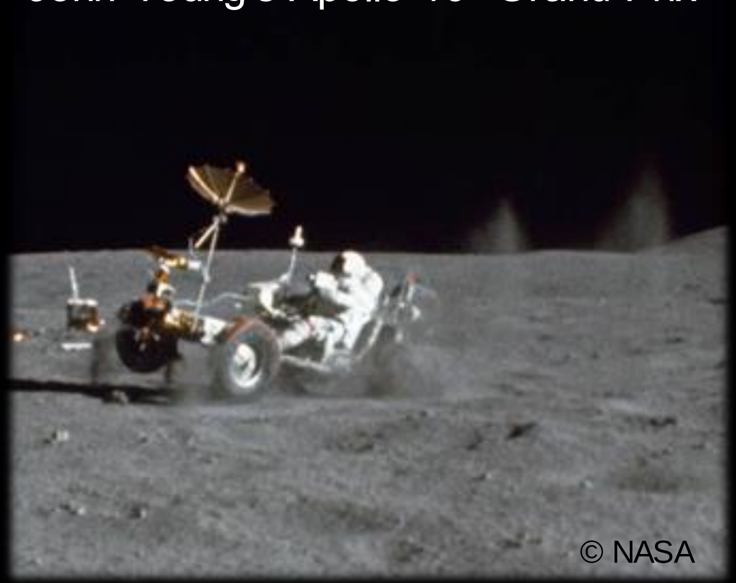


Lava tube doses
Top – total dose vs depth (Naito et al.)
Bottom – components of effective dose vs depth (de Angelis et al.)
references in subgroup's resources section

- *Available view of open sky dictates the amount of primary and secondary radiation in any location*
  - *Shielding provided by local topography (crater walls, pits, lava tubes, etc…) reduces dose from primary radiation but increases contributions from secondary radiation*
  - *DSNE provides little guidance on secondary radiation field beyond an estimate of albedo neutrons. Secondary radiation source of greatest uncertainty.*
- *Surface Variability: Topography and hydrogen content*
  - *Presence of hydrogen will moderate albedo neutron spectrum*
  - *Secondary radiation field will vary with elemental content (heavier elements will produce more albedo neutrons) and with thickness of local shielding.*
- *Additional considerations: Improving the information provided by the DSNE*
  - *Need better description of environment in shielded areas (both natural and man-made shielding)*
  - *Consideration of SEP events (magnitude, time evolution) for various mission scenarios (i.e – exploratory excursions far from base/shelter)*
- *Assessment Contributors:*
  - *Brenda Clyde (JHUAPL); Cheol Park (NASA LaRC)*

Regolith/Surface Interface

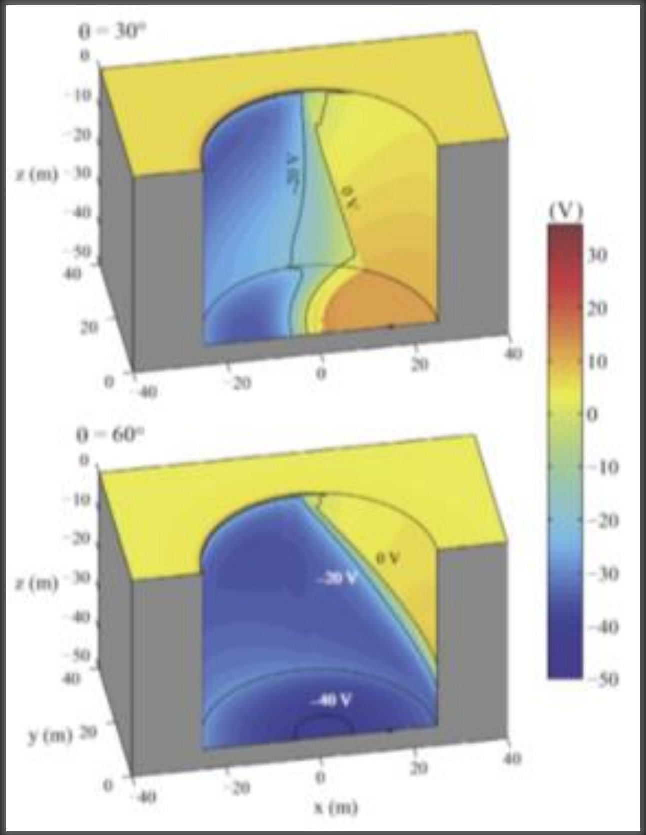
John Young's Apollo 16 "Grand Prix"



We need to use previous and future missions to better understand the properties of lunar regolith and its effect on our ability to survive and operate on the lunar surface.

- *More data and ground truth are needed to fully assess the regolith*
  - *Need robust initial missions to operate across a wider range of regolith properties*
- *Surface Variability: Potential for a range of geotechnical properties across the environments*
  - *Many similarities in the regolith and its interaction with technology*
  - *PSRs will have unique properties with potentially reactive volatiles*
  - *Many of these environments will have slope-related properties that will affect stability and mobility*
- *Additional considerations:*
  - *Volatiles outside traditional PSR*
  - *Features or advancements needed to operate in a variety of regolith properties*
  - *Mixed Polar Environments: best or worst of both worlds?*
- *Assessment Contributors:*
  - *Leslie Gertsch (Missouri S&T); Daoru Han (Missouri S&T); Walter Houston (Workforce 2.0); Laszlo Ketsay (USGS); Kevin Somervill (NASA LaRC); Paul van Susante (Michigan Tech)*

Space Weather / Plasma Environment

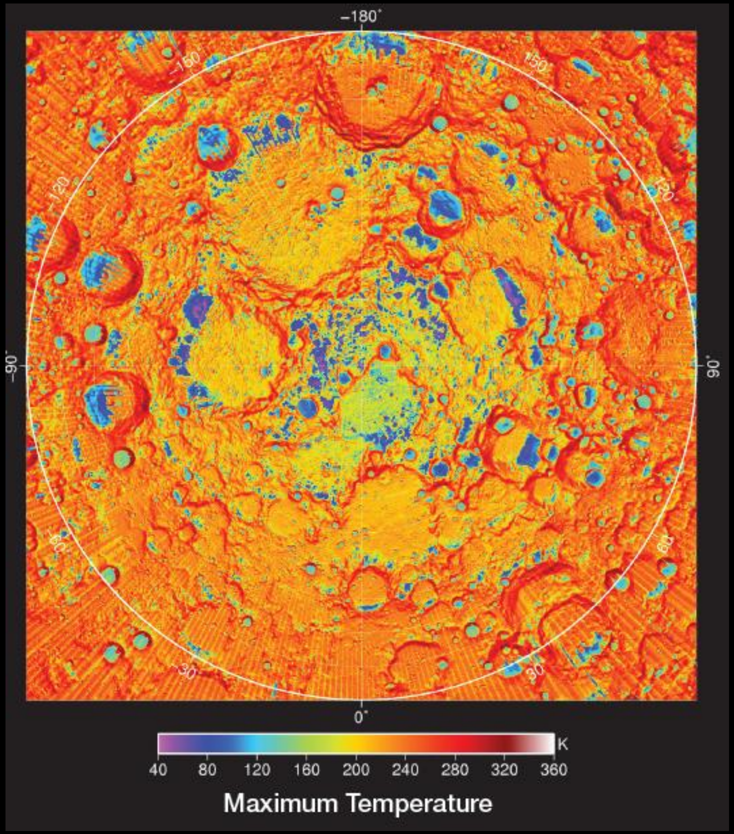


[1]Selected modeled lunar surface potentials as function of SZA; topographical feature mimics lava tube skylight or crater (e.g. diameters & depths 50 m to 100 m)

- *Surface potentials / surface charging driven by "large scale" & "small scale" variability*
  - *"Large scale" such as regular magnetotail passage, long time constant charging, …*
  - *"Small scale" such as topographic features, magnetic anomalies, …*
    - *Also statistical "tails" in environment distributions*
- *Surface variability (including human-modifications thereof) impacts resultant potentials (risk of ESD) & must be considered*
  - *Far side charging is extreme (~kV) but better predicted / understood*
  - *Day side and / or terminator charging dramatically impacted by surface features*
    - *All topographic features which create localized plasma instabilities (e.g. wakes), shaded regions, … necessitate specific study*
    - *Includes manmade structures (habitats, PV towers & vehicles)*
- *Additional considerations:*
  - *Dust modifies surface properties, and therefore potentials*
  - *High Voltage (solar arrays) impacts plasma (e.g. sheaths, particle trajectories, …)*
- *Assessment Contributors:*
  - *Daoru / Frank Han (MST); Michelle Donegan (APL); Jeff Gillis-Davis (WU, StL); Justin Likar (APL); Emily Willis (MSFC)*

[1]https://doi.org/10.1016/j.icarus.2015.07.011

Thermal & Illumination Environment

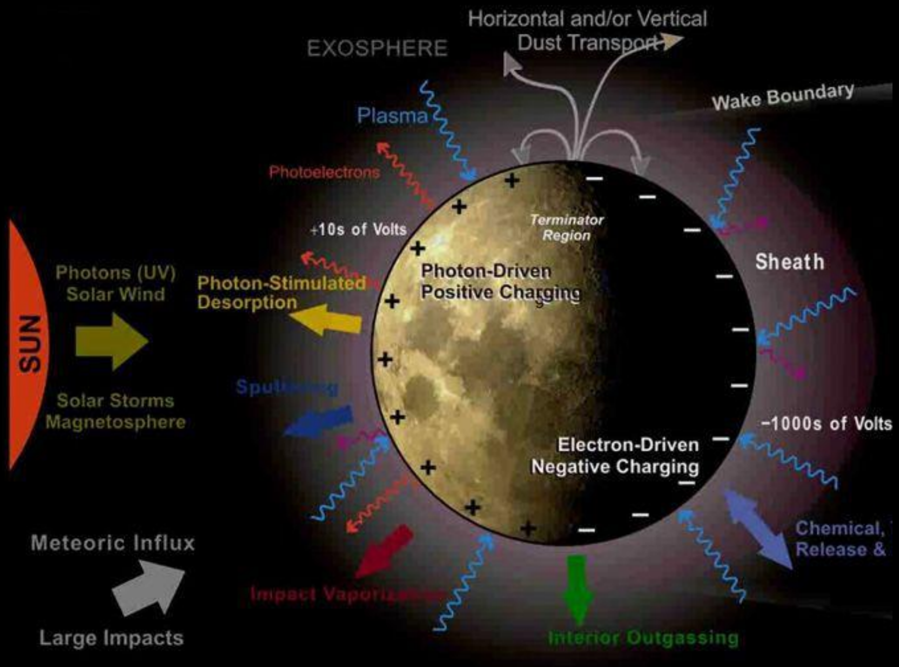


North Pole

Temperature Variation
Lunar Reconnaissance Orbiter
nasa.gov

- *Main environmental consideration for technology development*
  - *Low temperature: electronic performance in extreme cold environments*
  - *Brittle phase transitions of metals with abrupt changes in properties, the effects of combined low temperature and radiation*
  - *Thermal cycling: thermal performance and fatigue for 40 K - 400 K thermal cycling in every month*
- *Surface Variability:*
  - *Wide Temperature Range: 40 K – 400 K*
  - *Equator: 140 K – 400 K; 94 K (average minimum) – 392 K (average maximum); mean 215 K.*
  - *Polar (poleward of 85°): 50 K (average minimum) – 202 K (average maximum); mean 104 K; minimum 25 K in the floor of the Moon's Hermite Crater.*
  - *Heat flux (incident solar flux 0 - 1414 W/m2; planetary IR flux 0 – 1314 W/m2; and albedo 0.076 - 0.297)*
- *Additional considerations:*
  - *Thermophysical properties (Thermal conductivity~ 0.5 to 3.7 mW/m.K; specific heat~ 0.22 to 0.9 KJ/kg.K)*
  - *Surface Roughness*
- *Assessment Contributors:*
  - *Ahsan Choudhuri (UTEP);Daoru Han (MST); Md Mahamudur Rahman (UTEP); Mahadi Hasan (UTEP)*

Vacuum / Exosphere Environment



Caption: Air & Space, P. Spudis (2015) https://www.airspacemag.com/daily-planet/dust-cloud-around-moon-180955624/

- *Difficult to recreate accurate lunar vacuum terrestrially*
  - *Vacuum level on the lunar surface is on the order of 1E-12 Torr.*
  - *It is very challenging to achieve this level of vacuum in ground vacuum chambers, especially for device-scale chambers (i.e., large enough to test a device).*
  - *Vehicle or equipment outgassing considerations*
  - *"It is not anticipated that the tenuous atmosphere of neutral atoms and molecules near the lunar surface can affect the design and operations of lunar surface systems." DSNE 3.4.10 Lunar Neutral Atmosphere*
- *Surface Variability: Globally Low*
  - *Variation from Lunar day to night in atmospheric pressure readings*
  - *Surface pressure (night): 3 x 10-15 bar (2 x 10-12 torr)*
    - *Daytime surface measurements complicated by equipment outgassing*
  - *Expect local pressure to depend on temperature and cold traps*
- *Additional considerations*
  - *Human contributed impact of lunar pressure*
  - *Long term trending of Lunar atmospheric pressure changes*
- *Assessment Contributors:*
  - *Stephen Indyk (Honeybee Robotics); Daoru Han (Missouri S&T); Ahsan Choudhuri (University of Texas at El Paso); Bonnie Dunbar (Texas A&M University); Ben Greenhagen (Johns Hopkins Applied Physics Lab); Michael Poston (Southwest Research Institute); Melissa Roth (Off Planet Research); Paul van Susante (Michigan Tech);*

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Breakout Sessions

We are currently in breakout sessions. Each participant can select one of two breakout sessions:

- Polar Environments – Moderated by Ben Greenhagen

- Non-Polar Environments – Moderated by Karen Stockstill-Cahill

Main plenary session remains open for assistance

- Andrea Harman, ams573@alumni.psu.edu

Main plenary session will resume at ~4:05 pm EDT

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Post Breakout Discussions

Brief Recaps & Burning Questions

- Polar Environments – Ben Greenhagen
- Non-Polar Environments – Stockstill-Cahill

STMD Perspective

- *Kevin Somervill*

Next Steps (I)

Activities to Complete Before the LSIC Spring Meeting (May 11-12, 2021)

- Subgroups rank each specific environments by perceived technical challenges
  - *Expected to occur at April subgroup meetings*

- LSIC-EE Leadership integrates information pre-meeting activities, working meeting discussions, and subgroup rankings on Confluence

Activities to Complete After the LSIC Spring Meeting (May 11-12, 2021)

- Prioritize specific environments to focus on during LSIC Year 2
  - *Expected to occur around June focus group meeting*
  - *Likely a mixture of NASA priorities and community identified stressing environments*

- *Draft findings into white paper and present to focus group and subgroups*

May 2021 focus group meeting will be held jointly with Surface Power and Dust Mitigation in late May featuring VSATs

Next Steps (II)

Activities to Complete During LSIC Year 2 (May 2021 – April 2022) and beyond

- Dive deeper into (a few) prioritized environments / landing sites:
  - Identify observation and simulation (knowledge & prediction) capabilities and gaps
  - Identify specific, actionable technology capabilities and gaps
    - *Seek to coordinate this with release of NASA Strategic Technology Plans (STPs)*
  - Identify experimental testing and technology maturation (including facilities) capabilities and gaps

- Content could center on type of capabilities and gaps OR focus on prioritized environments / landing sites

- Format could be multi-month activities + working meeting or more traditional 6-hour workshop
  - Current working meeting format provides more opportunities for focus group members to participate
  - Workshop format is more conducive of cross-focus group coordination and collaboration

Thank you!

LSIC-EE activities like this are not possible without your participation!

Please continue to comment, reply, and like on Confluence.

- Specifically, take a look at the breakout session you did not attend today!

Please participate with the subgroup rankings later this month.

Reminder, next focus group meeting will be in late May (TBD) held jointly with SP and DM.

JOHNS HOPKINS
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