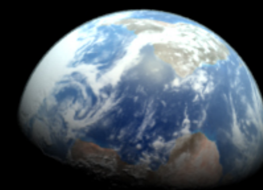
Lunar Exploration Analysis Group

Lunar Human Exploration Strategic Knowledge Gap Special Action Team Review

September 2016



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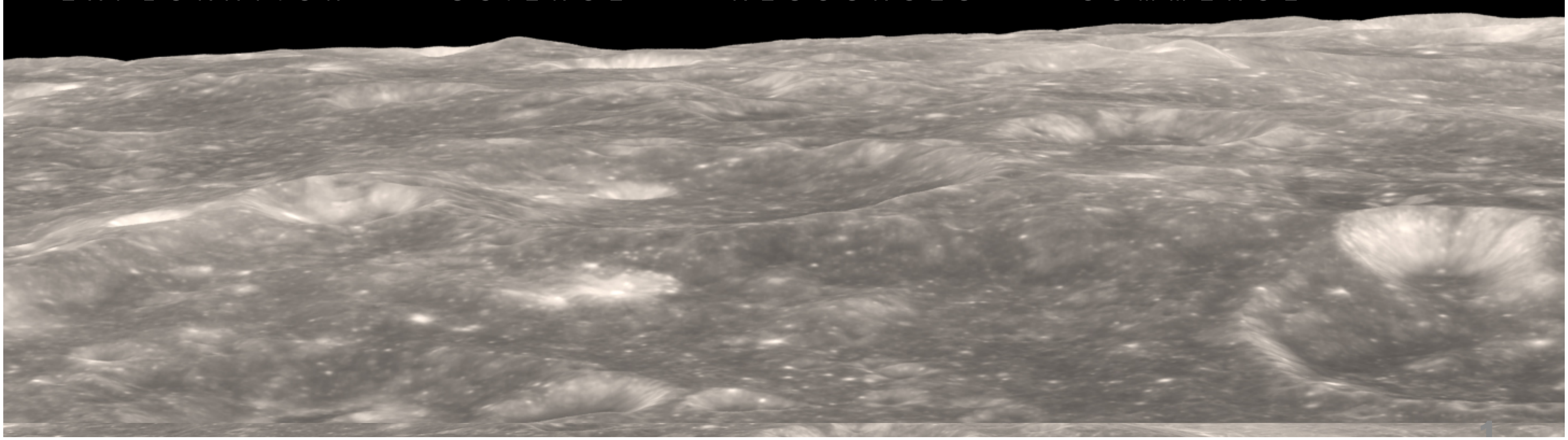


Contents of LEAG GAP REVIEW-SAT 2016 Document

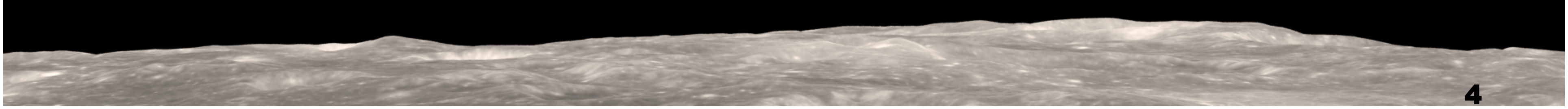
LEAG GAP REVIEW-SAT 2016 Charter 1

The Lunar Exploration Analysis Group (LEAG) has been tasked by the Human Exploration and Operations Mission Directorate (HEOMD) to establish a Specific Action Team (SAT) to review and provide findings related to NASA's Strategic Knowledge Gaps (SKGs) identified by NASA's Human Spaceflight Architecture Team's destination leads and the previous LEAG GAP-SAT 1 and 2.

LEAG GAP REVIEW-SAT 2016 Charter 2

This analysis should:

- Review the SKGs previously identified by NASA's Human Spaceflight Architecture Team and LEAG GAP-SAT 1 and 2 within the context of new lunar observations and specific human mission scenarios.
- Identify which of these SKGs have been fully or partially retired.
- Identify new SKGs that are a result of new lunar observations.
- Review quantitative description of measurements that are required to fill knowledge gaps, the fidelity of the measurements needed, and if relevant, provide examples of existing instruments capable of making the measurements.
- Review the SKGs in the context of implementing lunar mission scenarios.
- Identify the gaps in those knowledge / data sets that would need to be filled in order to implement the specific mission scenarios.
- Consider the knowledge /data gaps that exist in order to determine the viability of exploiting the resource in an effective manner.
- Identify specific robotic precursor instruments and missions that could fill these gaps and thereby enable or enhance future human missions.
- The results of this analysis should be considered a living document that will be updated as SKGs are retired and new SKGs are identified.



Membership GAP-Review SAT

SAT Members:

Chip Shearer, Chair: University of New Mexico
Dean Eppler, NASA-JSC
William Farrell, Theme 2 Lead, NASA GSFC
John Gruener, Theme 3 Lead, NASA-JSC
Sam Lawrence, Theme 1 Lead, Arizona State University and NASA-JSC
Neal Pellis, USRA
Paul Spudis, Lunar and Planetary Institute
Julie Stopar, Lunar and Planetary Institute
Ryan Zeigler, NASA-JSC

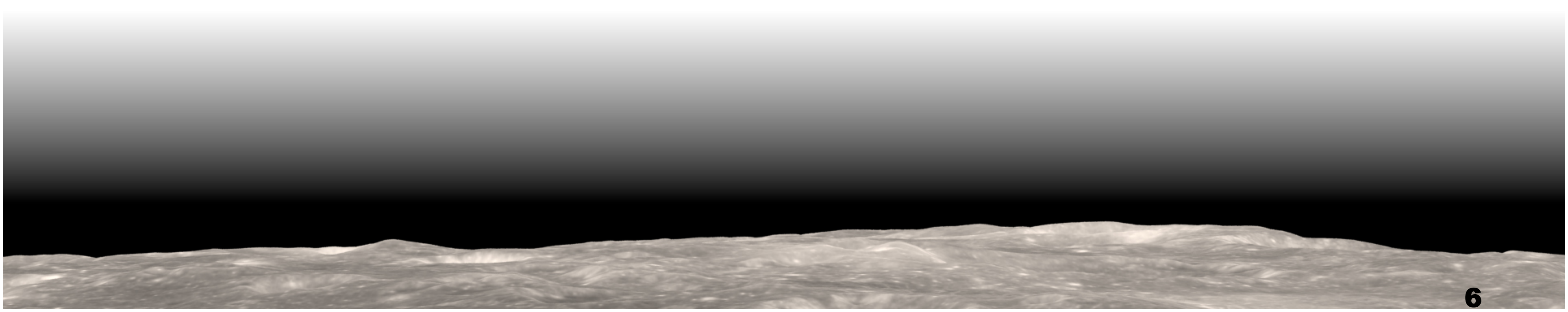
Ex Officio Members:

Ben Bussey, NASA Headquarters
Clive Neal, University of Notre Dame

Organization of SAT activities

Schedule of GAP Review-SAT:

- Finalize charter January 25, 2016.
- Finalize Membership February 16, 2016
- Telecon week of February 16, 2016 to April 1, 2016.
- Review progress at LPSC
- An initial "draft" set of findings reviewed by SAT in June 2016.
- A draft set of findings delivered to NASA in July 2016.
- A final set of findings delivered to NASA in August 2016.
- Report in the form of powerpoint charts and excel spreadsheet will be placed on LEAG and NASA websites in September 2016.



History of the Lunar SKG process

- The initial LEAG GAP-SAT 1 and 2 analyses used the "Moon First SKGs" initially identified by the Human Space Flight Architecture Team (HAT). The LEAG analysis resulted in numerous changes to the HAT SKGs to reflect the then-current state of the art.
- HAT-SKGs were reordered and characterized by themes and categories. For example: Themes: I. Understand the lunar resource potential, II. Understand the lunar environment and its effect on human life, and III. Understand how to work and live on the lunar surface.
- Although specific SKGs are dependent upon the architecture and goals of the "Moon First Scenario", we examined in detail SKGs tied to resource exploration and utilization (ISRU). This was prompted by ISRU being a "game changer" in how humans explore the Solar System by creating an infrastructure that enables a sustainable human presence and enduring commercial opportunities in cislunar space.
- Several HAT-SKGs were subdivided for clarity.
- The current LEAG analysis "GAP-Review SAT" used the SKGs identified by the GAP-SAT 1 and 2 as a starting point, identified SKGs that were retired by new missions and observations, and identified new SKGs based on results from recent lunar missions (e.g., LRO).

Strategic Knowledge Gaps Identified by GAP-SAT 2012

SKG Themes	SKG Categories	Examples of SKGs
I. Understand the lunar resource potential.	A. Solar Resources	I-A Solar illumination mapping
	B. Regolith Resources 1	I-B Regolith volatiles, Apollo samples
	C. Regolith Resources 2	I-C Regolith volatiles, in situ
	D. Polar Resources	I-D Extent, magnitude and age of cold traps
	E. Pyroclastic Deposit Resources	I-E Pyroclastic deposit volatiles, in situ
	F. Lunar ISRU production efficiency 1	I-F ISRU production efficiency, Earth testing
	G. Lunar ISRU production efficiency 2	I-G ISRU production efficiency, Moon testing
II. Understand the lunar environment and its effects on human life.	A. Solar Activity	II-A Solar Event Prediction
	B. Radiation at the lunar surface	II-B Radiation shielding effect of lunar materials
	C. Biological impact of dust	II-C Biological effects of lunar dust. Earth-based testing
	D. Maintaining peak human health	II-D Maintain peak human health and performance in dusty, high-radiation, partial gravity environments
III. Understand how to work and live on the lunar surface.	A. Resource production	III-A Excavation of lunar resources
	B. Geodetic grid & navigation	III-B Lunar Geodetic Control
	C. Surface trafficability	III-C Trafficability: Modeling
	D. Dust and Blast Ejecta	III-D Lunar Dust Remediation
	E. Plasma environment and charging	III-E Plasma Environment and charging
	F. Energy production and storage	III-F Propellant scavenging
	G. Radiation shielding	III-G Radiation shielding technology
	H. Micrometeorite shielding	III-H Micrometeorite shielding technology
	I. Lunar mass contribution and distribution	III-I Lunar mass contribution
	J. Habatat, life support and mobility	III-J Semi-closed life support

Definitions

Enabling or Enhancing a Moon First Scenario: Results from the ongoing Lunar Reconnaissance Orbiter mission (LRO) conclusively demonstrate that there are no strategic knowledge gaps (SKG) inhibiting the flight of Apollo-style mission or limited-duration human tended outposts (duration ≤1 lunar day). However, in the context of a "Moon First Scenario" which develops assets and capabilities for human activity within the Earth-Moon system (EMS) and beyond EMS to NEA and Mars, there are numerous SKG that are required to be filled to enable and enhance more mature human exploration of the Moon and beyond. Enabling and Enhancing are used to fill these "Moon First Scenario" SKG.

Enabling: SKGs that prevent the possibility of carrying out a "Moon First Scenario" due to safety, reliability, operational, and resource utilization issues.

Enhancing: SKGs that inhibit the science-exploration value and effectiveness of the "Moon First Scenario".

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Categories:

I-B Regolith 1:Quality/quantity/distribution/form of H species and other volatiles in mare and highlands regolith. Apollo heritage.

I-C Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith.

I-C Regolith 3: Preservation of volatile and organic components during robotic and human sampling, handling, storage, and curation.

I-D Polar Resources 3: Geotechnical characteristics of cold traps.

I-D Polar Resources 4: Physiography and accessibility of cold traps.

I-D Polar Resources 5: Charging and plasma environment within and near PSR.

I-D Polar Resources 6: Composition, Form, and Distribution of Polar Volatiles

I-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H_2O deposits towards PSR retention.

I-E: Composition/volume/distribution/form of pyroclastic/dark mantle deposits and characteristics of associated volatiles.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I- B. Regolith 1:Quality/quantity/distribution/form of H species and other volatiles in mare and highlands regolith. Apollo heritage.

Narrative: Measure volatiles and organics returned in "pristine" Apollo samples (core vacuum sample containers 69001, 73001). Measure the extent of disruption of volatiles during handling and processing. Enables prospecting for lunar resources and ISRU. Feeds forward to robotic and human analysis and sampling of lunar regolith and NEA-Mars regoliths. Relevant to Planetary Science Decadal survey.

Enabling or Enhancing: Enhancing

Measurements or Missions Needed to Retire: Need permission to proceed, and a well-defined technical strategy for opening the samples, and funding to do so. Measurement at precision and accuracy of current state of the art for cosmochemical analysis.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Category: I-C. Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith (requires robotic precursor missions).

Narrative: Further orbital missions may be used to better define the distribution and evolution of volatile deposits outside of PBRs. Robotic in situ measurements of volatiles and organics on the lunar surface and eventual sample return of "pristine" samples. Enables prospecting for lunar resources and ISRU. Feeds forward to NEA-Mars. Relevant to Planetary Science Decadal survey.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: Orbital mission to understand the distribution, form, and evolution of H-species deposits outside of the PSRs. These measurements may be analogous to an improved M^3 instrument. Need landed surface mission. Multiple measurements of undisturbed soil at depth at meter and decameter scales (laterally) and 0-2m depth. Need to measure abundance of solar wind gases or H species at the 10 ppm level. Need capability for multiple analyses at different locales and subsurface depths. Notional instruments include neutron spectrometer and a mass spectrometer, heat source for samples, and GCMS (concentrations and species).

Notes: Required for stay times > 28 days. Enables enduring commercial opportunities in cis-lunar space. Dramatically reduces costs and increases capabilities of missions to other destinations beyond cislunar economic activity zone.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-C Regolith 3: Preservation of volatile and organic components during robotic and human sampling, handling, storage, and curation.

Narrative: The volatile record that is preserved in lunar regolith is very fragile and could be easily disturbed during sampling-analysis by robotic and human exploration of volatile polar and non-polar deposits. Methodologies and technologies must be developed to access, handle, contain, and curate these valuable samples to minimize volatile loss and contamination.

Enabling or Enhancing: Enabling for short-duration (≤ 28 days) lunar missions and long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: Ground-based applied science research and technology development. Requires creation and analysis of appropriate simulant materials and studies. Comparison of in-situ and new returned samples would definitively address this SKG - sample return from a mare surface.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-D Polar Resources 3. Geotechnical Characteristics of Cold Traps.

Narrative: Landed missions to understand regolith densities with depth, cohesiveness, grain sizes, slopes, blockiness, association and effects of entrained volatiles.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. May be enabling if trafficability is an issue. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: Can be addressed partially through remote sensing, additional observations, and data analysis. Requires ground truth at the 10 meter scale (laterally) over 1-5 km baselines. Must determine trafficability, compressibility, rolling resistance, bulk density variations, and grain sizes. These properties need to be verified through in-situ observations. Minimal information will be provided by rover tracks. A scoop with a variety of end effectors could be an interesting assessment tool. In-situ GPR measurements would also have value to characterize subsurface properties. LRO is providing relevant data at the 10-20m scale, particularly LOLA observations for South Pole during Extended Science Missions. Data at the meter scale requires landed rover mission. Some information on surface roughness could be obtained at the 1m scale with an imaging radar.

Open Science-Exploration SKGs

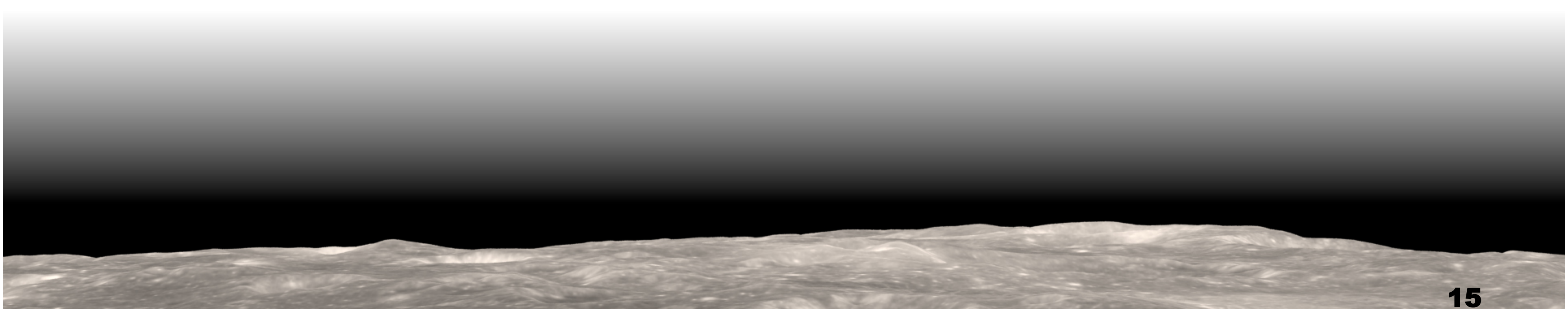
SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-D Polar Resources 4: Physiography and accessibility of cold traps (robotic and human).

Narrative: Needs landed missions to understand slopes, elevations, block fields, cohesiveness of soils, trafficability.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. May be enabling if trafficability is an issue. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: Landed surface exploration missions. Can be addressed partially through remote sensing, additional observations, and data analysis.



Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-D Polar Resources 5: Charging and plasma environment within and near PSR.

Narrative: Landed missions to understand the charge reservoirs (plasma or ground) in the low conductivity environment. Limited plasma flow into PSRs may create poor electrical dissipation for tribocharging objects like drills, rovers, etc. The electrical 'ground' or reference point is not identified. Examine ion entry into PSRs as sputtering loss process.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: The electrical "ground" or reference point is not identified. Examine ion entry into PSRs as sputtering loss process. Moving a rover in and out of shadowed region provides ground-truth. Use wire in shadowed and sunlit region to check whether current gets induced. Implications for astronaut safety and long-term maintenance.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-D Polar Resources 6: Composition, Form, and Distribution of Polar Volatiles

Narrative: Water and possibly other exotic volatile species are present in lunar polar regions; must determine the form, concentration (including mineralogical, elemental, molecular, isotopic make-up of volatiles), and distribution of these species and how they vary from depths 0-3 m over distances of 10-100m scales. Required "ground truth" in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions Needed to Retire: Requires ground truth at the 10 meter scale (laterally) over 1-5 km baselines. Landed surface mission. Surface mobility is absolutely essential to be able to provide ground truth to orbital sensor datasets and characterize the regolith concentrations laterally at the 10s of meter scale over baselines of at 1-5 km. Two desirable instruments: (1) Gas Analyzer/ICPMS: Heat the soil, measure and determine the different species for H+ and OH contained within; similar conceptually to Viking GCMS experiments. (2) Neutron Spectrometer: bulk H/OH measurements to the 1-5 ppm level, including the subsurface to at least 2 meters depth. (3) UV/VIS/NIR spectrometer to assess presence of OH- (4) Multi-frequency GPR to assess subsurface distribution.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H_2O deposits towards PSR retention.

Narrative: Survey surface-correlated OH at >65 degrees through orbital mapping; correlate with exospheric measurements, and use results to determine the temporal and spatial distribution of water and other volatile species in lunar surface-bound exosphere.

Enabling or Enhancing: Enhancing

Measurements or Missions Needed to Retire: More orbital measurements (resolved imaging spectrometer capable of detecting OH and H2O over long temporal baselines) and long-lived ALSEP-style instrument packages required to close this gap.

Open Science-Exploration SKGs

SKG Theme: Theme 1 Understanding the Lunar Resource Potential.

SKG Category: I-E. Composition/volume/distribution/form of pyroclastic/dark mantle deposits and characteristics of associated volatiles.

Narrative: Need to understand the volatile contents of RDMDs, as well as their depth and distribution in order to fully assay resource potential and develop useful processing technologies. Understanding the amount and form of solar-wind implanted volatile species in pyroclastics may inform other SKGs.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon

Measurements or Missions Needed to Retire: Either sample return from RDMD (e.g., Aristarchus) or in-situ measurements. GPR could provide information on depth of mantling deposits.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Categories:

II-A-1 Solar activity/solar event prediction
II-A-2 Solar energetic particle storm-time warning system

II-B-1 Radiation environment at the lunar surface (Model)
II-B-2 Radiation environment at the lunar surface (Measurement)
II-B-3 Radiation shielding effects of lunar material (Model)
II-B-4 Radiation shielding effects of lunar material (Measurement)

II-C-1 Biological effects of lunar dust (Earth testing)
II-C-2 Biological effects of lunar dust (In situ testing)

II-D-1 Radiation and humans
II-D-2 Virus and humans
II-D-3 Dust and humans
II-D-4 Robot and computer compatibility

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-A-1 Solar activity/solar event prediction

Narrative: Define active regions on the Sun that are sources of potential SEP events over a solar rotation. Knowing the location and intensity of these solar active regions can be used to provide a space weather 'watch' information.

Enabling or Enhancing: Enabling for all missions.

Measurements or Missions needed to retire: Joint SMD Heliophysics and HEOMD mission to send a dedicated monitoring spacecraft to Earth-Moon L5. Have onboard A) EUV imaging telescope to identify active regions. B) White light coronagraph to identify Earth-directed CMEs. This monitoring spacecraft acts as a sentinel to establish locations and intensity of active regions on the sun. The active region may not launch a mission-altering SEP, but is a possible source. Knowing the locations provides explorers with advance notice that conditions could change. Observations of these active regions provides an analogous 'watch' condition of severe weather.

Open Science-Exploration SKGs

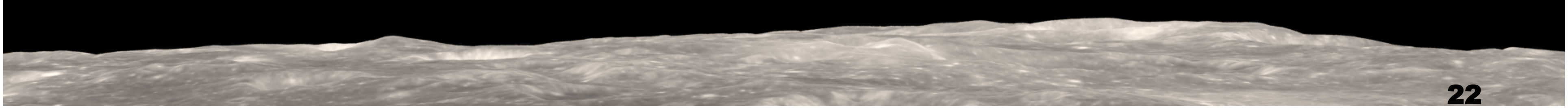
SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-A-2 Solar energetic particle (SEP) storm-time warning system

Narrative: Provide an immediate alert system for an impending SEP event (i.e., a warning system)

Enabling or Enhancing: Enabling for all missions.

Measurements or Missions needed to retire: Landed suprathermal ion and electron detection to provide SEP warning to explorers. On lunar surface to examine any secondary radiation effects. If an active region is magnetically connected to the Earth-moon system, and does flare, explorers only have minutes before the most energetic solar particles can arrive. A warning system is thus needed so the explorers can seek shelter. As a hazard alert system, the IDPU would contain algorithms to identify the early stages of the radiation hazard based on the precursor information. SEP information can also be obtained from orbital spacecraft, but there is latency in getting needed info to boots-on-ground.



Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-B-1 Radiation environment at the lunar surface (Model)

Narrative: Model primary and secondary radiation components; confirm secondary models by measuring the affect of appropriate, comprehensive radiation sources at terrestrial laboratories (e.g. Brookhaven) on detectors and lunar soil/simulant. The SKG is partially closed.

Enabling or Enhancing: Enhancing for all missions.

Measurements or Missions needed to retire: The LRO CRaTER team is currently modeling secondary radiation effects from incidence GCRs (Looper at al., 2013, Space Weather, 11, p142). However, the modeling is tied to continued LRO funding and has value independent of any one mission. Much of the work done to date involves correlation between GCR fluxes and sunspot number. However, operational models are not physics-based. Additional work is needed to develop physics-based models that derive Linear Energy Transfer from GCR modulation.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-B-2 Radiation environment at the lunar surface (Measurement)

Narrative: Directly measure primary and albedo/secondary radiation on the lunar surface for Galactic Cosmic Rays and solar-derived radiation sources; measured over a minimum of one solar cycle. This SKG is partially closed.

Enabling or Enhancing: Enabling for all missions

Measurements or Missions needed to retire: Place a Linear Energy Transfer (LET) spectrometer system on the surface. Measures the energy deposited in a material of given thickness during the particles passage. LRO/CRaTER is an example of this type of instrument, but added development can enhance the capability to include the destructive neutrons. LRO/CRaTER has developed albedo maps for secondary protons (Wilson et al, 2012, JGR, 117, E00H23; Spence et al., Space weather 11 643, 2013) which represent the kind of product to be created. The next generation CRaTER is suggested to also monitor secondary neutrons. Such measurements can be obtained from low-altitude orbit.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-B-3 Radiation shielding effects of lunar material (Model)

Narrative: Model and measure the radiation shielding properties of lunar soil samples and/or simulant. This SKG is partially closed.

Enabling or Enhancing: Enhancing for all missions.

Measurements or Missions needed to retire: The LRO CRaTER team is currently modeling shielding effects from high energy GCR, focusing on the effect of hydrated layers. However, the modeling is tied to continued LRO funding and has value independent of any one mission.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-B-4 Radiation shielding effects of lunar material (Measurement)

Narrative: Landed robotic missions should directly measure radiation shielding properties of lunar soil by covering detector arrays with variable depths and densities of regolith; detector arrays must have sufficient sensitivity and variation in particle energy to cover both the expected population of solar-derived radiation and Galactic Cosmic Rays.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: LET spectrometer with Thin/Thick Silicon detectors between predesignated material like Tissue Equivalent Plastic (TEP), lunar regolith, even microbiotic material. Zeitlin et al. (Space Weather, 11, 284, 2013) have quantified the effects of shielding on the lunar surface based on CRaTER observations. Reexamine data from Apollo 17 neutron probe.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-C-2 Biological Effects of Lunar Dust (In Situ testing)

Narrative: Test reactivity dust in the lunar environment.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: In situ obtain: A) Particle size distribution and dust shape morphology studies of the smallest particulates, from varied sample sites. B) In situ grain-clump adhesion strength and clump size distributions. C) Passivation experiment to determine grain reactivity as transported from intrinsic environment into normal atmosphere. If the reacting agent is chemical, then reactivity tests, including the effects of water on the passivity, should be performed. If the agent is physical, then detailed microscopic examination of the finest grains found in situ should be made. Small grain electrostatics/cohesion may be tested in the plasma/electrical environment to determine if they adhere to form larger less invasive grains, and such a test can only be performed in the actual environmental setting.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-1 How to maintain peak human health and performance: Radiation and Humans

Narrative: Obtain data on A) Acute and late nervous system effects from radiation exposure, B) Acute radiation syndromes from SEPs , C) Radiation carcinogenesis

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Robotic precursor program can contribute LET Spectrometer (II-B-2) which provides environmental information that feeds forward to address tissue damage either by experiment or model. In addition to the HRP research in progress, there will need to be a robust research program conducted in transit and planetary environments to assess toxicity, mutagenicity, factors that determine susceptibility as well as tolerance to radiation, and the role of duration of exposure to radiation in maintaining human health.

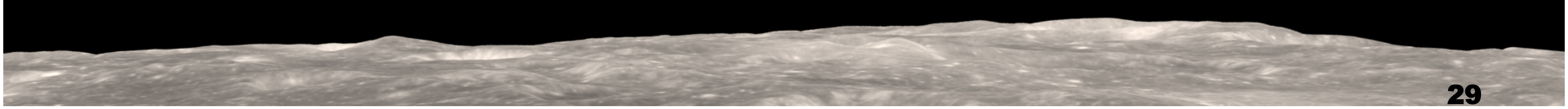
Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-2 How to maintain peak human health and performance: Virus and Humans

Narrative: Obtain observations of alteration in host-microorganism interactions. Decreased immunities and/or increased virulence needs to be examined in situ. The prospect of problems is most likely going to be with radiation of latent viruses in humans. It is the latent virus that is reactive during space flight that could be a problem, since those associated with communicable diseases can be pre-screened before flight. It is unknown if virus reactivation is via decline in human immunity or an effect of the space environment, e.g., microgravity, radiation, etc.

Enabling or Enhancing: Enhancing for a 28 day mission, enabling for a long stay.
Measurements or Missions needed to retire: Develop an automated system to monitor cells with viruses (initially latent). System would assess production of free virus by cells in vitro. Such a system may be telemetrically operated and the data returned in real time. Also, the system can be designed to be self-sterilizing so as not to introduce viable organisms to the planetary environment.



Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-2 How to maintain peak human health and performance: Virus and Humans

Narrative: Obtain observations of alteration in host-microorganism interactions. Decreased immunities and/or increased virulence needs to be examined in situ. The prospect of problems is most likely going to be with radiation of latent viruses in humans. It is the latent virus that is reactive during space flight that could be a problem, since those associated with communicable diseases can be pre-screened before flight. It is unknown if virus reactivation is via decline in human immunity or an effect of the space environment, e.g., microgravity, radiation, etc.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.
Measurements or Missions needed to retire: Develop an automated system to monitor cells with viruses (initially latent). System would assess production of free virus by cells in vitro. Such a system may be telemetrically operated and the data returned in real time. Also, the system can be designed to be self-sterilizing so as not to introduce viable organisms to the planetary environment.

Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-2 How to maintain peak human health and performance: Virus and Humans

Narrative: Obtain observations of alteration in host-microorganism interactions. Decreased immunities and/or increased virulence needs to be examined in situ. The prospect of problems is most likely going to be with radiation of latent viruses in humans. It is the latent virus that is reactive during space flight that could be a problem, since those associated with communicable diseases can be pre-screened before flight. It is unknown if virus reactivation is via decline in human immunity or an effect of the space environment, e.g., microgravity, radiation, etc.

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Open Science-Exploration SKGs

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-3 How to maintain peak human health and performance: Dust and Humans

Narrative: Understand and quantify the biological consequences of exposure to dust and volatiles. The effect of dusts on human health has an extensive history in mining and manufacturing. The exposures are basically three types 1) inhaled, 2) ingested, and 3) surface contact. The biology of dusts is determined by 1) composition, 2) particle size, 3) structure (crystalline or amorphous), and 4) dose and duration of exposure. The effect of lunar dust on humans is based on anecdotal experience. Based on the Apollo missions, it is likely at its worst, an irritant. Using regolith simulants of the Moon in rats, the permissible exposures an currently set at 1.0 to 1.2 mg/m^3. The simulants are usually quartz and/or TiO_2.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.
Measurements or Missions needed to retire: Robotic precursor program can contribute particle size distribution instruments and passivation experiment.

Open Science-Exploration SKGs

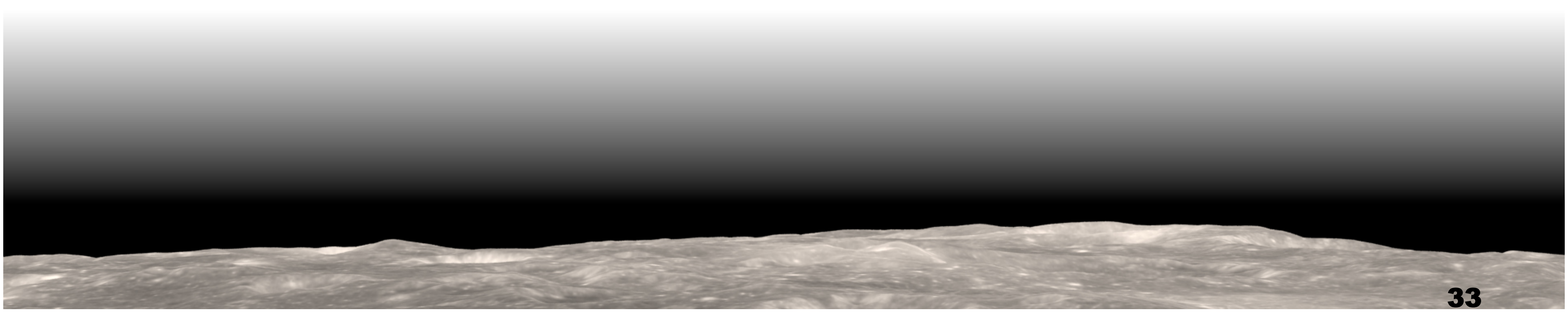
SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: II-D-4 How to maintain peak human health and performance: Robot and Computer Compatibility

Narrative: Obtain insight on inadequate design of human/robotic integration and inadequate human/computer interactions

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Adaptable systems should be tested in robotic precursor program. HRP developing systems but they could be tested as part of precursor robotic mission.



Open Science-Exploration SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Categories:

III-A-1 Technologies for excavation of lunar resources

III-A-2 Technologies for transporting lunar resources

III-A-3 Technologies for comminution of lunar resources

III-A-4 Technologies for beneficiation of lunar resources

III-B-1 Lunar geodetic control

III-B-2 Lunar topography control

III-B-3 Autonomous surface navigation

III-B-4 Autonomous Landing and Hazard Avoidance

III-C-1 Lunar surface trafficability – modeling

III-C-2 Lunar surface trafficability - in situ measurements

III-D-1 Lunar dust remediation

III-D-2 Regolith adhesion to human systems and associated mechanical degradation

III-D-4 Descent / ascent engine blast ejecta - in situ measurements

III-E Near-surface plasma environment and nature of differential electrical charging

Open Science-Exploration SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Categories:

III-F-1 Energy storage - non polar missions
III-F-2 Energy storage - polar missions
III-F-3 Power generation - non polar missions
III-F-4 Power generation - polar missions
III-F-5 Lander propellant scavenging
III-G Test radiation shielding technologies
III-H Test micrometeorite protection technologies
III-J-1 Fixed habitat
III-J-2 Mobile habitat
III-J-3 Semi-closed life support
III-J-4 Human mobility

Open Technology SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-A-1, Technologies for excavation of lunar resources.

Narrative: Collect raw materials; create trenches, roads, berms, etc.; enables ISRU, surface trafficability, and ejecta plume mitigation.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, and at different resource deposits (e.g., polar ice-bearing regolith, regional pyroclastic deposits), testing resource excavation techniques, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-A-2, Technologies for transporting lunar resources.

Narrative: Load, excavate, transport, process, and dispose of regolith; enables ISRU, surface trafficability, and ejecta plume mitigation.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing transport techniques of lunar resources, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-A-3, Technologies for comminution of lunar resources.

Narrative: Crush, grind regolith; understand effects of comminution; enhances ISRU process efficiency.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing the comminution of lunar resources, are required to retire this gap.

Open Technology SKGs

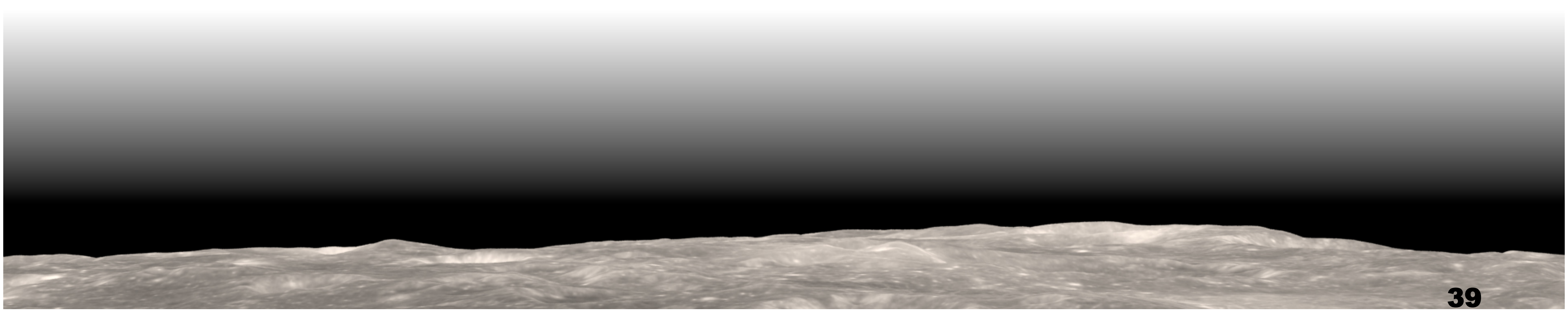
SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-A-4, Technologies for beneficiation of lunar resources.

Narrative: Sort regolith by material properties (e.g., particle size, density, mineralogy); some techniques utilize gravity and magnetic separation; enhances ISRU process efficiency.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Experiments on the lunar surface, at both polar and non-polar locations, testing the beneficiation of lunar resources, are required to retire this gap.



Open Science-Exploration SKGs

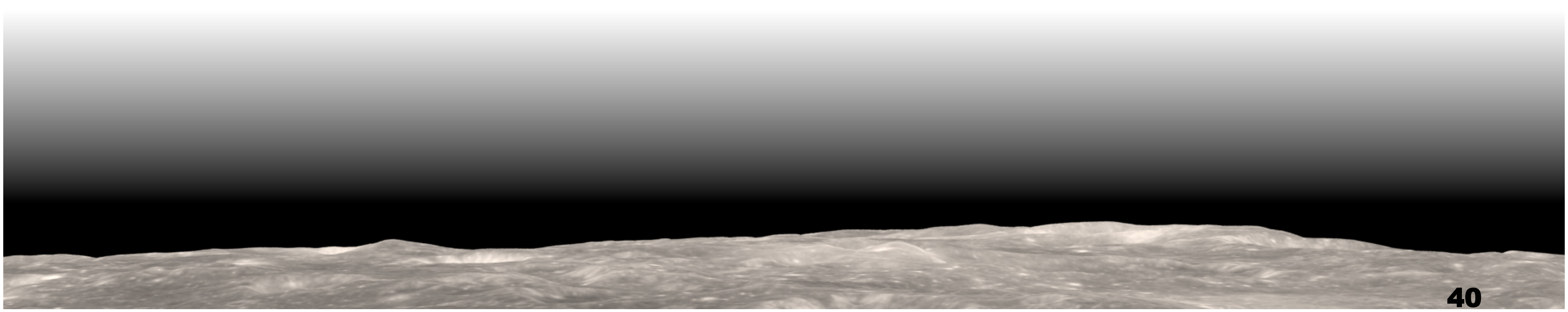
SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-B-1, Lunar geodetic control.

Narrative: Combine SELENE, ULCN2005, LRO LOLA, and LRO WAC GLD100 topographic products to produce a definitive lunar geodetic grid to facilitate future exploration planning.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: No additional measurements or missions are needed to retire this exploration science gap. Sufficient data exists from the LRO mission to retire this gap. However, the effort to create this geodetic grid has not been funded. Adequate funding would retire this exploration science gap.



Open Science-Exploration SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-B-2, Lunar topography data.

Narrative: LRO data (LOLA and LROC WAC) has produced substantial improvements in lunar topography, providing two independent global topographic datasets with ~200 m/pixel resolution, which enables many exploration missions. An LRO extended mission of at least 5 years duration (i.e., to 2017) could enable collection of a definitive global DTM with 1-2 m/pixel resolution using the LROC Narrow Angle Cameras.

Enabling or Enhancing: Enhancing for all missions.

Measurements or Missions needed to retire: Possibly, continued LRO extended missions until fuel runs out. Constructing a global 1-2 m/pixel DTM would require a large amount of computer processing and software capabilities not presently available, but additional research may enable creation of this dataset. This is “enhancing” because regional stereo observations exist or can be collected for numerous high-priority exploration destinations.

Open Technology SKGs

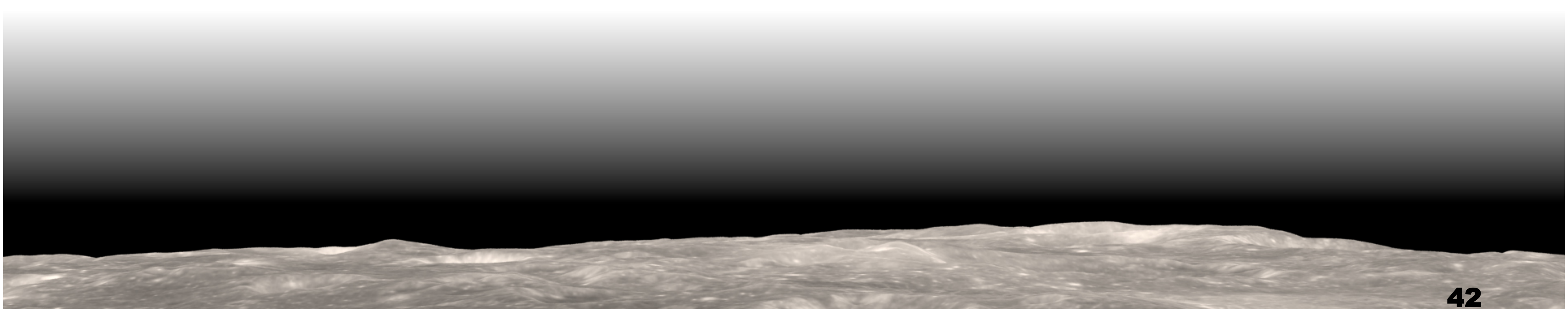
SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-B-3, Autonomous surface navigation.

Narrative: Ability to remotely traverse over long distances enables a) pre-positioning of assets, and b) robust robotic precursor missions. Requires sliding autonomy and localized hazard avoidance technology (e.g., DARPA Grand Challenge). Significant development work can be performed on Earth prior to lunar surface deployment.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing autonomous surface navigation, are required to retire this gap. **A l**unar GPS **c**onstellation may be required.



Open Technology SKGs

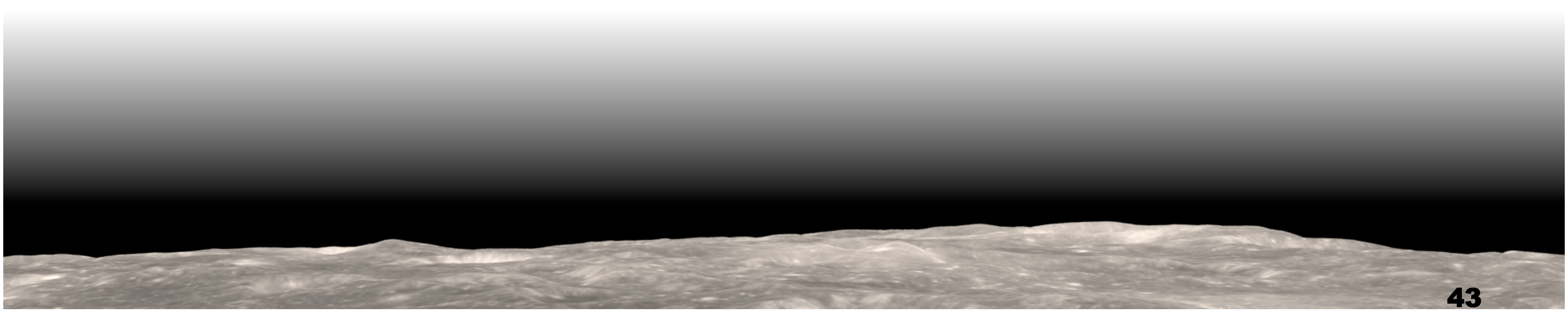
SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-B-4, Autonomous Landing and Hazard Avoidance.

Narrative: Autonomous landing capability for robotic missions similar to that demonstrated by Chang'e-3 lander.

Enabling or Enhancing: Enhancing for all missions.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing autonomous landing and hazard avoidance, are required to retire this gap.



Open Science-Exploration SKGs

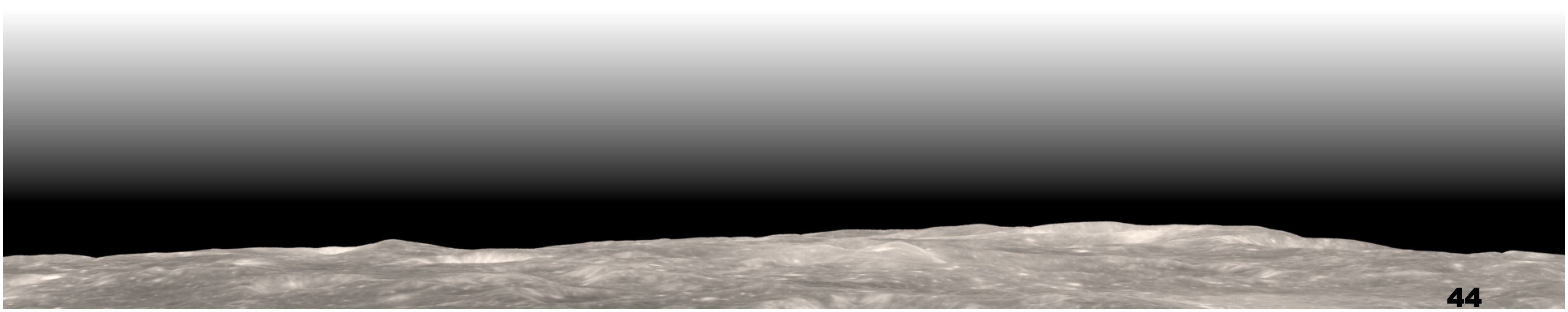
SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-C-1, Lunar surface trafficability - modeling.

Narrative: Production of relevant lunar soil simulants. Geo-technical testing (especially trafficability) of prototype or test hardware in high fidelity regolith simulants. Not required for Apollo-zone exploration, but important for unexplored areas like regional pyroclastic deposits, the lunar poles, and melt sheets of large impact craters.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Over 20 different lunar simulants exist, world wide. Terrestrial testing in relevant lunar conditions, using multiple lunar simulants is required to retire this gap.



Open Science-Exploration SKGs

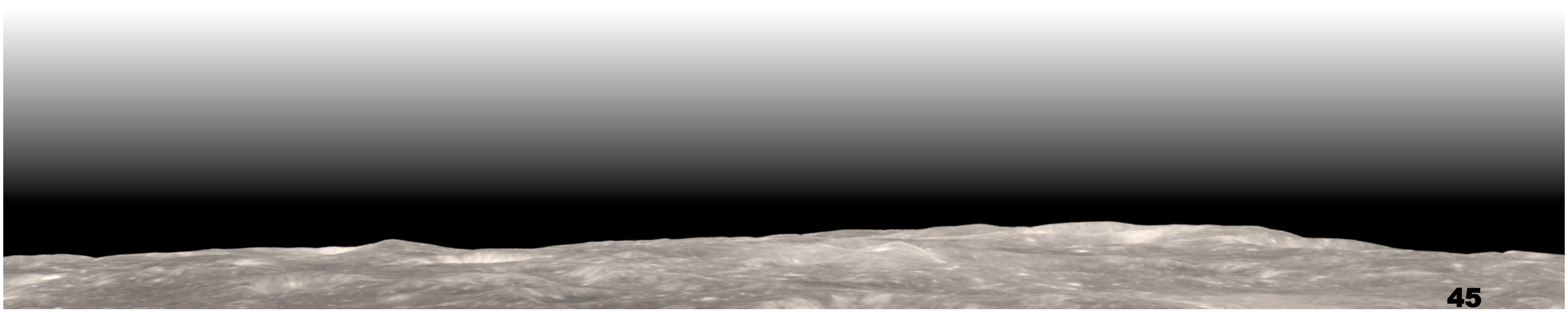
SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-C-2, Lunar surface trafficability - in situ measurements.

Narrative: Characterization of geotechnical properties and hardware performance during regolith interactions on unvisited terrains of the lunar surface.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, measuring geotechnical properties of the lunar regolith and conducting trafficability experiments in polar, pyroclastic, and young impact melt terrains, are required to retire this gap.



Open Science-Exploration SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-D-1, Lunar dust remediation.

Narrative: Test conceptual mitigation strategies for hardware interactions with lunar fines, such as hardware encapsulation and microwave sintering of lunar regolith to reduce dust prevalence.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing dust remediation techniques, are required to retire this gap.

Open Science-Exploration SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-D-2, Regolith adhesion to human systems and associated mechanical degradation.

Narrative: In situ grain charging and attractive forces, and cohesive forces under appropriate plasma conditions to account for electrical dissipation. Analysis of wear on joints and bearings, especially on space suits.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, testing techniques to counter regolith adhesion, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-D-4, Descent / ascent engine blast ejecta velocity, departure angle and entrainment mechanism - in situ measurements.

Narrative: Multiple landings at the same location on the lunar surface may scour or damage systems and equipment already emplaced at that location. Ejected regolith velocity, departure angles, and energy in engine plume exhaust need to be measured in situ to better understand mitigation strategies, such as landing pads/berms, and separation distances between landing zones and operational zones.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, equipped with LIDAR-type instruments to measure velocity and direction of blast ejecta, are required to retire this gap.

Open Science-Exploration SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-E, Determining near-surface plasma environment and nature of differential electrical charging at multiple lunar localities (includes PSRs).

Narrative: The lunar near-surface electrical field and plasma environment is poorly known due to lack of direct, long term observations. Significant questions remain as to the degree of charging of hardware on the lunar surface, particularly night-side of the lunar terminator. Also, surface and surface-placed objects may undergo large changes in potentials during passages of solar storms. Direct observation is required in order to understand the variations of the electrical 'ground' defined by the plasma currents to an object placed on the surface. In PSRs, the lack of an obvious charge reservoir (i.e., low conductivity surface and obstructed plasma) suggests the possibility of poor electrical dissipation for tribocharging objects like drills, and rover tires.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, at both polar and non-polar locations, measuring the near-surface plasma environment, are required to retire this gap.

Open Technology SKGs

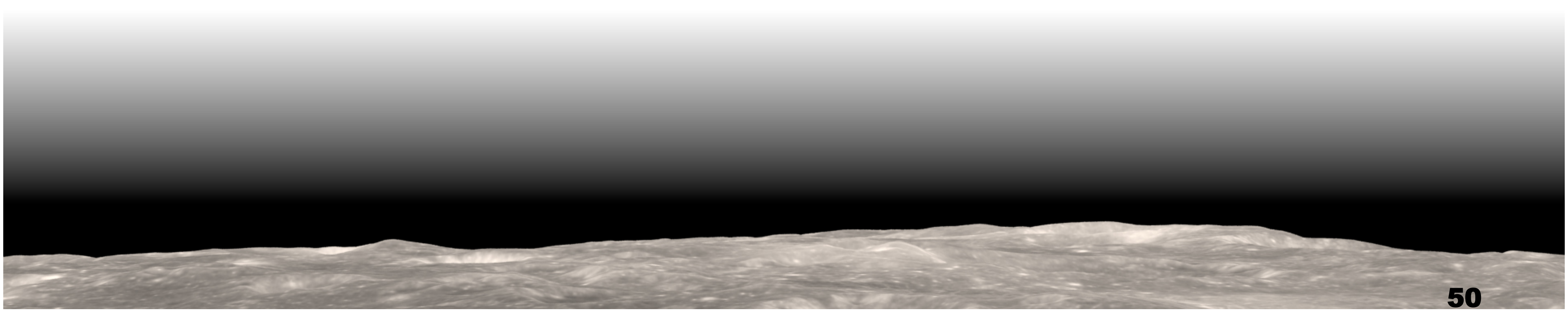
SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-F-1, Energy storage - non polar missions.

Narrative: Non-polar regions experience 14 Earth-days without sunlight; needs for entire lunar night in the 100s to 1000s kW-hrs; batteries will be prohibitively heavy.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to non-polar locations on the lunar surface, using energy storage systems, are required to retire this gap.



Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-F-2, Energy storage - polar missions.

Narrative: Polar missions may be positioned in areas with extended solar availability; blackouts may extend to 3-5 days requiring 100s of kW-hours; batteries will be prohibitively expensive.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to polar locations on the lunar surface, using energy storage systems, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-F-3, Power generation - non polar missions.

Narrative: Non-polar missions will require 10s to 100s of kW via deployable solar arrays or nuclear power systems on the lunar surface. Of particular concern is providing power through the lunar night.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to non-polar locations on the lunar surface, using power generation systems, are required to retire this gap.

Open Technology SKGs

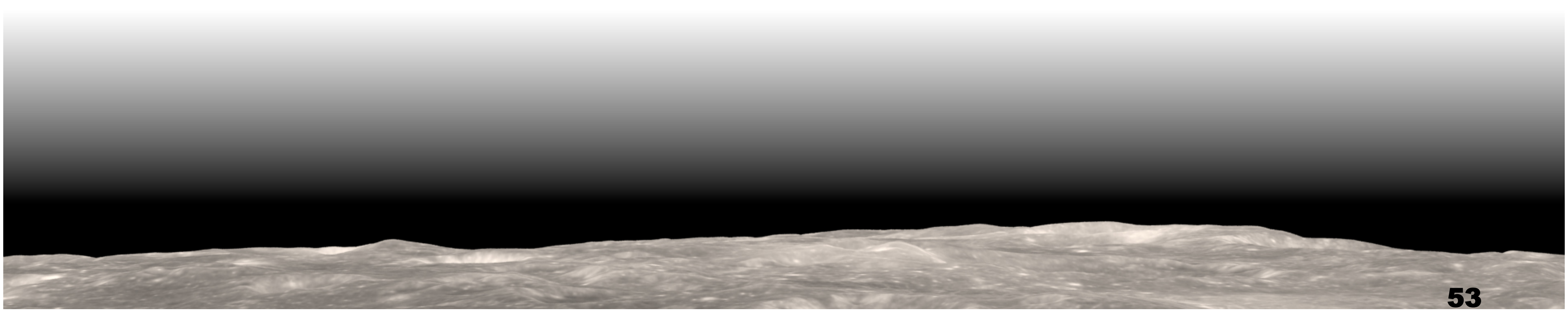
SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-F-4, Power generation - polar missions.

Narrative: Low grazing angles of sun light at the lunar poles requires solar arrays with rotational tracking, preferably on a high mast, or nuclear power systems on the lunar surface.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to polar locations on the lunar surface, using power generation systems, are required to retire this gap.



Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-F-5, Lander propellant scavenging.

Narrative: Determine the efficiency of extracting residual oxygen from tanks in lunar landers. Variables include propellant settling in 1/6g, and LOX-He separation.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, testing propellant scavenging techniques, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-G, Test radiation shielding technologies.

Narrative: Protecting human crews beyond the magnetic fields of the Earth from space radiation is critical. In addition to Earth-based testing, could be further accomplished during lunar robotic missions.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions beyond low earth orbit (LEO), in cis-lunar space or on the lunar surface, testing radiation shielding technologies and operational approaches, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3 Understand how to work and live on the lunar surface

SKG Category: III-H, Test micrometeorite protection technologies.

Narrative: Need to develop experimental data for the range of micrometeorite impactors and impact energies expected in the lunar environment. Data to be used for the development of improved hydrodynamic codes for impact shielding, which can in turn be tested in terrestrial gun facilities. Testing these technologies could be done during lunar robotic missions.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, measuring micrometeorite impacts on instrumented sensors, are required to retire this gap.

Open Technology SKGs

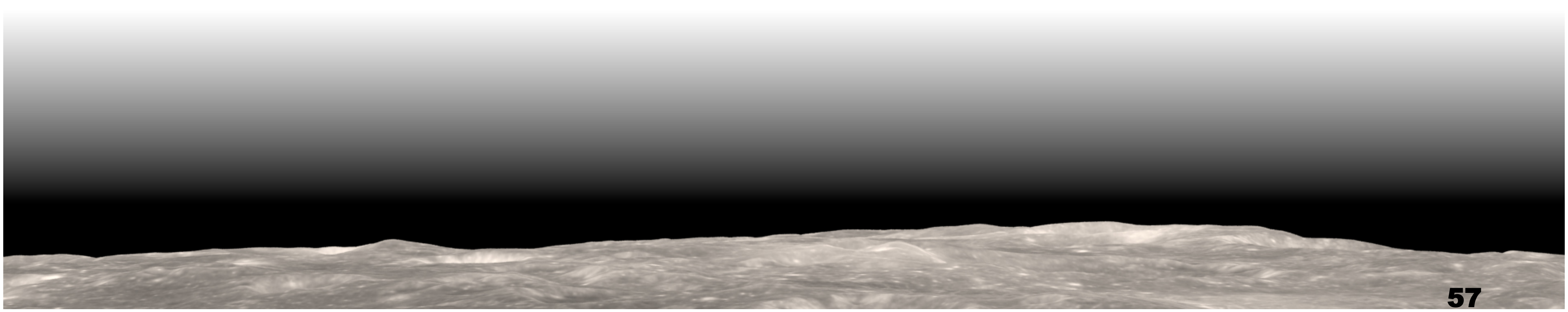
SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-J-1, Fixed habitat.

Narrative: Human explorers and workers on the Moon will require pressurized habitats to live in while on the lunar surface. For short duration missions, human crew may be able to live in their lander vehicles similar to the Apollo missions.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, using fixed habitats, are required to retire this gap.



Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-J-2, Mobile habitat.

Narrative: The Apollo J-missions clearly showed the benefits of mobility when it comes to human exploration of a planetary surface. Pressurized rovers used as short-duration field camps, or larger mobile habitats for longer duration exploration of a large region of the Moon may provide an exploration architecture that is not necessarily fixed to one point on the lunar surface.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, using mobility systems and mobile habitats, are required to retire this gap.

Open Technology SKGs

SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-J-3, Semi-closed life support.

Narrative: While initial, short-term missions to the Moon may get by with open life support systems, the Earth-moon distance will make the logistics of this type of system unsustainable for long periods of time. The ISS has incorporated aspects of closed life support systems, and extending their use to the Moon seems to make sense.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, using closed or regenerative life support systems, are required to retire this gap.

Open Technology SKGs

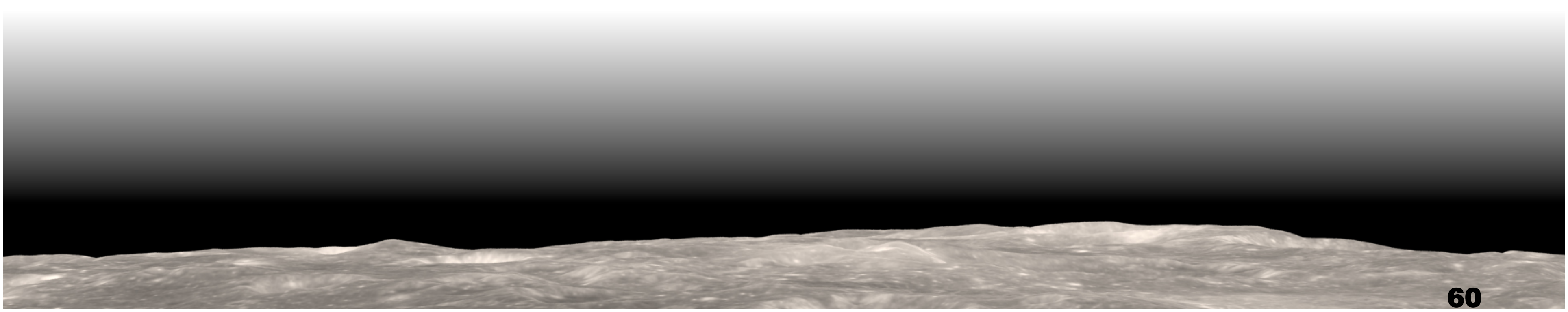
SKG Theme: Theme 3, Understand how to work and live on the lunar surface

SKG Category: III-J-4, Human mobility.

Narrative: Human crews on the Moon need spacesuits to explore and work out on the lunar surface. Also, the Apollo J-missions clearly showed the benefits of mobility when it comes to human exploration of a planetary surface. Unpressurized rovers like the Apollo LRV, or one-person Segway-like vehicles could be used for local transportation, while pressurized rovers could provide for longer multi-day traverses.

Enabling or Enhancing: Enabling for all human missions to the Moon.

Measurements or Missions needed to retire: Missions to the lunar surface, using multiple types of human mobility systems, are required to retire this gap.



Findings 1

- Recent missions (e.g. LRO, GRAIL, LADDIE) produced data that was used to retire several of the SKGs defined by HAT and the 2011-2012 LEAG GAP-SAT analyses.

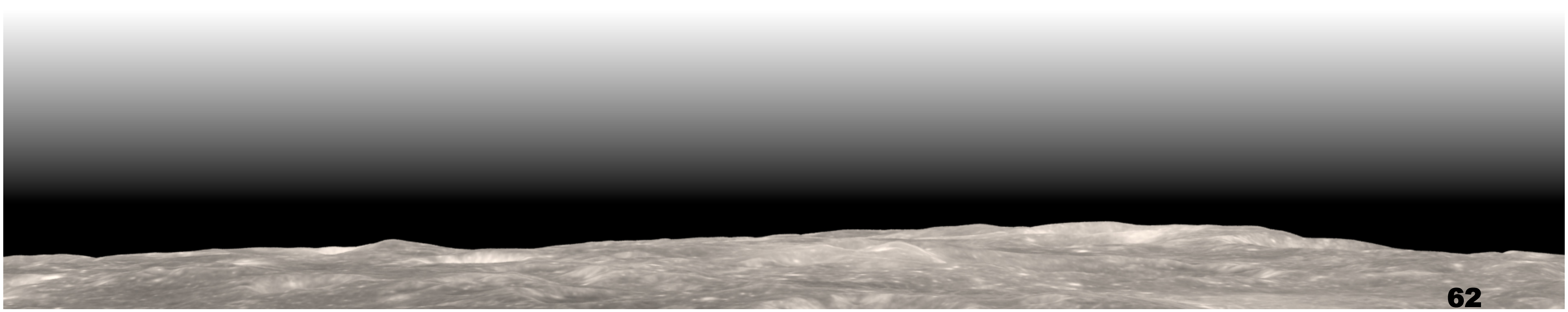
- Thanks to these missions, there are no strategic knowledge gaps (SKG) that would inhibit the flight of any human mission (e.g., sortie or human-tended surface facility) <28 days duration.

- However, there are several SKGs that should be addressed that would increase human safety not only at the Moon, but also in LEO, cis-Lunar space, and beyond the Moon. This includes the development of infrastructure to monitor solar activity (e.g. solar storms). The Apollo astronauts were very lucky missing the August 1972 solar storm/SEP event.

Findings 2

- In the context of a "Moon First Scenario" which develops assets and capabilities for human activity within the Earth-Moon system (EMS) and beyond EMS to near-Earth asteroids and Mars, there are numerous SKGs that would enable and enhance more mature human exploration capabilities for the Moon and beyond.

- Future programmatic, competed (Discovery, New Frontiers) and international missions to the Moon should be examined for potential NASA contributions for retiring SKGs. This could take the form of contributed instruments to international missions and "credit" or contributed instruments toward NASA competed missions. Additionally, NASA's R&A programs should be encouraged to support work that closes SKGs. SSERVI is a good example of such a program.



Retired SKGs Theme 1

SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Category: 1-A Solar illumination mapping

Narrative: Combined elevation-illumination models to map solar energy incidence over time. Data is in hand but R&A resources are required to reduce and leverage the data. LRO extended mission enables detailed multi-temporal mapping of lunar poles. Detailed mapping enables polar exploration mission site selection.

Enabling or Enhancing: Enabling

Retired Narrative: Measurements obtained by LRO during 1st and 2nd extended science missions have enabled the creation of illumination models.

Retired SKGs Theme 1

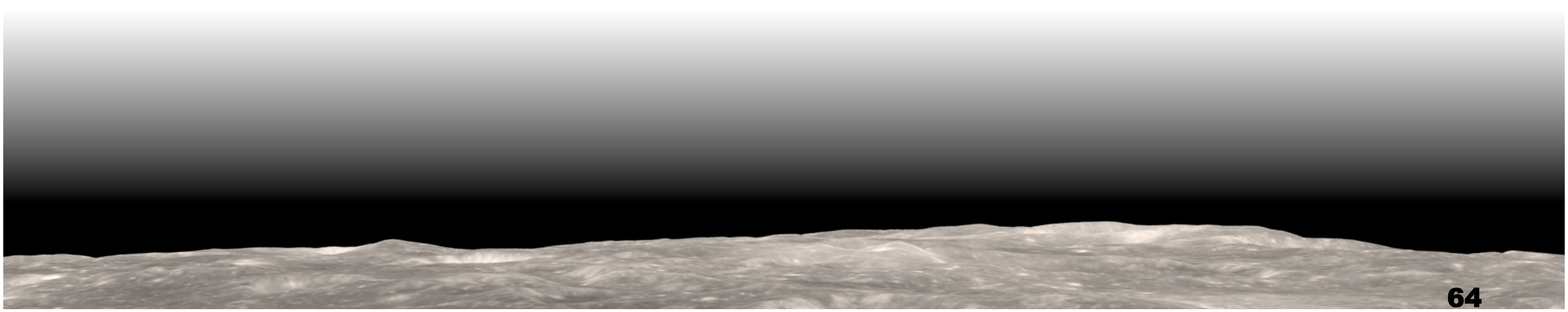
SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Category: SKG 1-D-Polar Resources 1: Extent of cold traps.

Narrative: DIVINER maps show temperature distributions, model stability and evolution of spin axis, mapping of old topographic lows.

Enabling or Enhancing: Enabling

Retired Narrative: LRO Observations have satisfied objective. However, continued Diviner observations in proposed 3rd extended mission will improve spatial coverage of polar regions by increasing signal to noise ratio.



Retired SKGs Theme 1

SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Category: SKG 1-D-Polar Resources 2: Correlation of cold traps and permanent darkness (PSR).

Narrative: Use LRO data to understand thermal environments of partly illuminated areas near poles.

Enabling or Enhancing: Enabling

Retired Narrative: LRO Observations have created measurement baselines.

Retired SKGs Theme 1

SKG Theme: Theme 1 Understanding the Lunar Resource Potential

SKG Category: SKG I-D-Polar Resources 8: Earth visibility from PSR, timing and extent.

Narrative: Understand if the Earth is sometimes visible from portions of PSR.

Enabling or Enhancing: Enabling

Retired Narrative: LRO Observations have created measurement baselines.

Retired SKGs Theme 2

SKG Theme: Theme 2 Understand the lunar environment & effects on human life.

SKG Category: SKG II-C-1 Biological effects of lunar dust (Earth-based testing)

Narrative: Understanding the effect of lunar dust on human health is critical for keeping humans safe on the surface of the Moon.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Retired Narrative: Extensive testing has been done on rats using a large amount of lunar sample by the Space and Life sciences group at the JSC. These results have been written up and published, and guidelines for safe levels of exposure have been set. Perhaps, one might argue that because they had to grind up the sample to get enough respirable material, or because the samples had been slightly pacified during their time on Earth more work is needed. However, this is covered under II-C-2.

Retired SKGs Theme 3

SKG Theme: Theme 3 Understand how to work and live on the lunar surface.

SKG Category: III-D-3 Descent / ascent engine blast ejecta velocity, departure angle and entrainment mechanism – modeling.

Narrative: Laboratory modeling with plume and entrained simulant. Measurements of the extent of high velocity sandblasting of Surveyor 3.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Retired Narrative: Phil Metzger's work at NASA-KSC and UCF, and the Morpheus lander tests at JSC and KSC fully addressed this strategic knowledge gap. This exploration technology gap can be retired.

Retired SKGs Theme 1

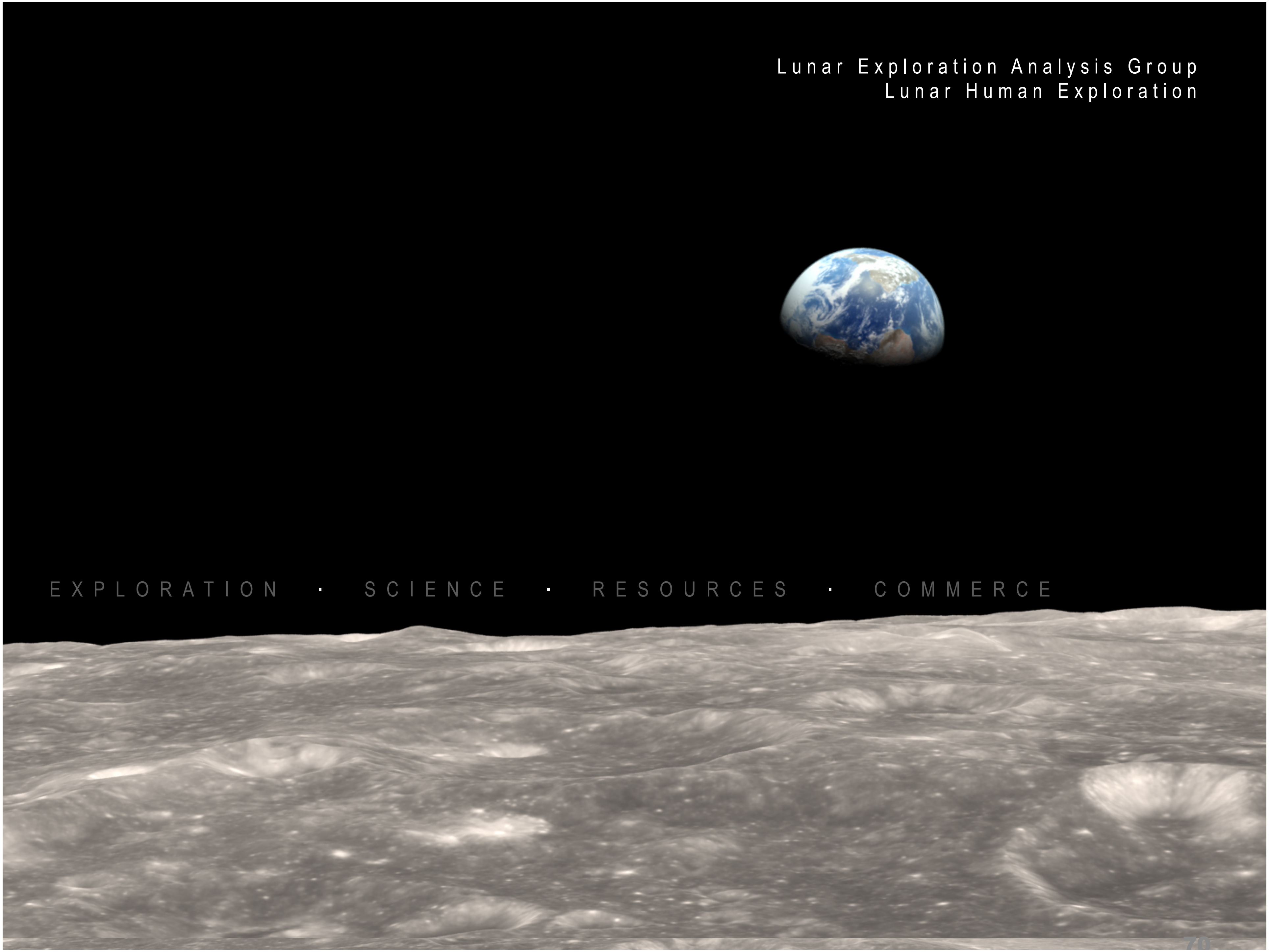
SKG Theme: Theme 3 Understand how to work and live on the lunar surface.

SKG Category: III-I Lunar mass concentration and distributions (i.e., gravitational anomalies).

Narrative: Understanding of the lunar gravity field affects the accuracy of navigation predictions, the ability to do precision landing and the stability of spacecraft left in orbit for long periods w/o active orbit maintenance (e.g, the stability of the Apollo 15 ejected sub-satellite (months) to similar hardware on Apollo 16 (2 weeks). The SELENE, LRO, and GRAIL missions have significantly improved our experience with stable orbits.

Enabling or Enhancing: Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.

Retired Narrative: NASA's GRAIL mission fully addressed this strategic knowledge gap. This exploration science gap can be retired.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