Strategic Knowledge Gaps:

Planning for Safe, Effective, and Efficient Human Exploration of the Solar System

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Planetary Protection Subcommittee

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Background and Context

Science Enables Exploration

Exploration Enables Science

Background and Context

NASA has recently created the Joint Robotic Precursor Activities (JRPA) effort.

- It is a joint effort between the Advanced Exploration Systems Division within Human Exploration and Operations, and the Planetary Science Division of the Science Mission Directorate.
- These precursor activities will strive to characterize the engineering boundary conditions of representative exploration environments, identify hazards, and assess resources.
- These activities will provide knowledge to inform the selection of future destinations, support the development of exploration systems, and reduce the risk associated with human exploration.

Background and Context: JRPA

- A small Research and Analysis effort will be supported with the goal of turning the data gathered by JRPA instruments, as well as the data of other SMD instruments and missions, into strategic knowledge in support of human spaceflight planning and systems development.

- Many of these research and analysis activities will be jointly conducted with SMD to maximize the mutual benefit to both science and exploration objectives, as was done with the highly successful Lunar Reconnaissance Orbiter mission.

- JRPA will also maintain a small study effort to plan for future precursor activities to further enable and reduce the risk associated with human exploration."

Informing Exploration Planning: Strategic Knowledge Gaps

- **To inform mission/system planning and design *and* near-term Agency investments**
  - Human Spaceflight Architecture Team (HAT) Destination Leads were asked to identify the data or information needed that would reduce risk, increase effectiveness, and aid in planning and design
  - The data can be obtained on Earth, in space, by analog, experimentation, or direct measurement
- **For some destinations, the needed knowledge is well identified**
  - Analysis Groups, such as LEAG and MEPAG, have identified pertinent investigations/measurements needed to acquire the requisite knowledge regarding the Moon and Mars
  - Significant advances in filling the knowledge gaps have been made (examples: LRO and MRO, and soon, MSL)
  - NASA will establish traceability of the SKGs to its currently planned robotic missions, utilization of ISS, and known opportunities for Research and Analysis efforts, and exploitation of existing ground based assets.

Informing Exploration Planning: Strategic Knowledge Gaps

- **Based on this draft version of the Strategic Knowledge Gaps…**
  - NASA is engaging the external Science and Exploration communities to vet and refine the SKGs.
    - Lunar Exploration Analysis Group (complete)
    - Small Bodies Assessment Group (started)
    - Mars Exploration Program Analysis Group (draft results)
  - NASA will establish traceability of the SKGs to its currently planned robotic missions, utilization of ISS, and known opportunities for Research and Analysis efforts, and exploitation of existing ground based assets.

Common Themes and Some Observations

- **There are common themes across destinations (not in priority order)**
  - The three R's for enabling human missions
    - Radiation
    - Regolith
    - Reliability
  - Geotechnical properties (Moon, NEAs, Mars)
  - Volatiles (i.e., for science, resources, and safety) (Moon, NEAs, Mars)
  - Propulsion-induced ejecta (Moon, NEAs, Mars)
  - In-Situ Resource Utilization (ISRU)/Prospecting (Moon, NEAs, Mars)
  - Operations/Operability (all destinations, including transit)
  - Plasma Environment (Moon, NEAs)
  - Human health and performance (all destinations, including transit)
- **Some Observations**
  - The required information is measurable and attainable
  - These measurements do not require "exquisite science" instruments but could be obtained from them
  - Filling the SKGs requires a well-balanced research portfolio
    - Remote sensing measurements, in-situ measurements, ground-based assets, and research & analysis (R&A)
    - Includes science, technology, and operational experience

Testing Relevancy Descriptions

Venue	Description
● (red)	**Preferred Location**: Denotes a preferred testing venue or location for gaining required knowledge. Venue provides the best location to obtain knowledge, including actual or flight-like conditions, environments, or constraints for testing operational approaches and mission hardware.
●	**Highly Relevant**: Venue provides highly relevant location to obtain knowledge, including flight-like conditions, environments, or constraints for testing operational approaches and mission hardware. This venue can serve as a good testing location with less difficulty and/or cost than anticipated for the preferred location.
⊙	**Somewhat Relevant:** Venue can provide some relevant testing or knowledge gain (including basic analytical research and computational analysis). Conditions are expected to be not flight-like or of sufficient fidelity to derive adequate testing or operational performance data.
○	**Not Relevant:** Venue is not considered to be an adequate location for testing or knowledge gain.

National Aeronautics and Space Administration

Mars Human Precursor Measurements (MEPAG Goal IV)

John Baker
Bret Drake

Background

- Teams have been evaluating precursor measurement requirements within NASA with support from the community since the early 1990s.
- Some payloads have already flown on Mars science missions to understand more about the planet surface and a lot has been learned.
- A number of science missions have also flown and are about to fly to gather additional relevant information
- The Mars Exploration Program Analysis Group (MEPAG) consists of NASA, academia and industry and is an open public forum where discussions are held.
- A recent update of the human precursor requirements (referred to as Goal IV) was performed in 2010

MEPAG Goal IV Measurement Summary

Measurement Type	Description	Complexity/Mass	Orbital/Surface	Risk
Atmospheric	Drives EDL design and risk	High/High	Both	High
Biohazards	Risk to crew on surface and to public	High/TBD	Surface	High
ISRU	Map resources (C, H, O, etc.)	Low/Low	Orbital	Medium
Radiation	Surface and orbital GCRs & SPE	Low/Low	Both	High (modified by HAT)
Toxic Dust	Detect cancerous and corrosive substances	Medium/High?	Surface	Medium
Atmospheric Electricity	Detect atmospheric lightning	Low/TBD	Both?	Medium
Forward Planetary Protection	Identify “special regions” to avoid terrestrial contamination.	Unknown		Medium
Dust effects on Systems	Surface dust characteristics	Low/Low	Surface	Low
Trafficability	Assess landing site hazards	Low/High	Orbital	Low

Mars Strategic Knowledge Gaps – MEPAG Goal IV

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	LEO Testing	Beyond-LEO Missions (Robotic & Human)	Robotic Precursor Missions to the Mars surface	Comments[1]
Atmospheric aspects that affect aerocapture, EDL and launch from the Mars surface	⊙	○	○	○	⊙	○	○	○	🔴	Observations directly support engineering design and also assist in numerical model validation.
Biohazards identification	⊙	○	○	○	○	●	○	●	🔴	Determine if the Martian environments to be contacted by humans are free of biohazards that may have adverse effects on crew, and on other terrestrial species if uncontained Martian material is returned to Earth.
ISRU resources	⊙	○	○	○	●	●	○	○	●	Characterization of potential key resources, such as water and oxygen for crew support and fuel manufacture

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

[1] See backup for additional details.

Mars Strategic Knowledge Gaps – MEPAG Goal IV

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	LEO Testing	Mars Orbit	Robotic Precursor Missions to the Mars surface	Comments[1]
Radiation measurements	⦿	○	○	○	○	○	○	●	🔴	Characterize the ionizing environment at the surface, including energetic charged particles and secondary neutrons. (modified by HAT)
Toxic Dust	⦿	○	○	○	○	○	○	○	🔴	Determine the possible toxic effects of Martian dust on humans.
Atmospheric electricity	⦿	○	○	○	○	○	○	○	🔴	Assess atmospheric electricity conditions that may affect human and mechanical systems.
Forward Planetary Protection	🔴	○	○	○	○	○	○	○	🔴	Determine the Martian environmental niches' vulnerability to terrestrial biological contamination
Trafficability	○	○	○	○	●	○	○	●	🔴	Includes surface load bearing strength *(addition by HAT)*

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⦿ Not Relevant ○

[1] See backup for additional details.

BACKUP

MEPAG Goal IV – Atmospheric Measurements

Investigation	Measurements	Rationale	Priority
Atmospheric (1A) Determine the aspects of the atmospheric state that affect aerocapture, EDL and launch from the surface of Mars. This includes the variability on diurnal, seasonal and inter-annual scales from ground to >80 km in both ambient and various dust storm conditions. The observations are to directly support engineering design and also to assist in numerical model validation, especially the confidence level of the tail of dispersions (>99%).	Make long-term (> 5 martian year) observations of the **global atmospheric temperature** field (both the climatology and the weather variability) at all local times from the surface to an altitude >80 km with a vertical resolution ≤ 5 km as well as observations with a horizontal resolution of ≤ 10 km Occasional temperature or **vertical density profiles** with resolutions < 1 km between the surface and 20 km are also necessary. Make global measurements of the **vertical profile of aerosols** (dust and water ice) at all local times between the surface and >60 km with a vertical resolution ≤ 5 km. These observations should include the optical properties, particle sizes and number densities. Monitor **surface pressure** in diverse locales over multiple martian years to characterize the seasonal cycle, the diurnal cycle (including tidal phenomena) and to quantify the weather perturbations (especially due to dust storms). Globally monitor the **dust and aerosol activity**, especially large dust events, to create a long term dust activity climatology (> 10 martian years).	Reduce the risk of loss of crew and loss of mission primarily by reducing the risk during EDL, aerocapture and ascent from Mars. *Note: The large uncertainties will also result in much larger and costlier systems as well.*	High

MEPAG Goal IV - Biohazards

Investigation	Measurements	Rationale	Priority
<u>Biohazard (1B)</u> Determine if the martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that may have adverse effects on the crew who may be directly exposed while on Mars, and on other terrestrial species if uncontained martian material is returned to Earth. Note that determining that a landing site and associated operational scenario is sufficiently safe is not the same as proving that life does not exist anywhere on Mars.	Determine if **<u>extant life</u>** is widely present in the martian near-surface regolith, and if the air-borne dust is a mechanism for its transport. If life is present, assess whether it is a biohazard. For both assessments, a preliminary description of the required measurements is the tests described in the MSR Draft Test Protocol (Rummel et al., 2002). - *This test protocol would need to be regularly updated in the future in response to instrumentation advances and better understandings of Mars and of life itself.* Determine the **<u>distribution of martian special regions</u>** (see also Investigation IV-2E below), as these may be "oases" for martian life. If there is a desire for a human mission to approach one of these potential oases, either the mission would need to be designed with special protections, or the potential hazard would need to be assessed in advance.	Reduce the risk associated with back planetary protection to acceptable, as-yet undefined, standards as they pertain to: 1) the human flight crew, 2) the general public, and 3) terrestrial species in general.	High

MEPAG Goal IV – In-Situ Resource Utilization (ISRU)

Investigation	Measurements	Rationale	Priority
ISRU (2A) Characterize potential key resources to support ISRU for eventual human missions	**Orbital Measurements** 1) Hydrated minerals – high spatial resolution maps of mineral composition and abundance. 2) Subsurface ice – high spatial resolution maps (~100 m/pixel) of subsurface ice depth and concentration within approximately the upper 3 meters of the surface. *3) Atmospheric H-bearing trace gases* b. Higher spatial resolution maps (TBD resolution) of H-bearing trace gases. c. Assessment of the temporal (annual, seasonal, daily) variability of these gases. **In-Situ Measurements** 1) Verification of mineral/ice volume abundance and physical properties within approximately the upper 3 meters of the surface. Measurement of the energy required to excavate/drill the H-bearing material 2) Measurement of the energy required to extract water from the H-bearing material.	Reduce the overall mission cost by reducing the amount of ascent fuel, water and oxygen that a crew would need on the surface to live.	Med

MEPAG Goal IV - Radiation

Investigation	Measurements	Rationale	Priority
Radiation (2B) Characterize the ionizing radiation environment at the martian surface, distinguishing contributions from the energetic charged particles that penetrate the atmosphere, secondary neutrons produced in the atmosphere, and secondary charged particles and neutrons produced in the regolith.	1) Identify **charged particles** from hydrogen to iron by species and energy from 10 to 100 MeV/nuc, and by species above 100 MeV/nuc. 2) Measurement of **neutrons** with directionality. Energy range from $\leq$10 keV to $\geq$100 MeV. **3)** **Simultaneous with surface** measurements, a detector should be placed **in orbit** to measure energy spectra in Solar Energetic Particle events.	Risks to astronauts from radiation in space have been characterized for decades. Outside the shielding affects of the Earth's magnetic field and atmosphere, the ever-present flux of Galactic Cosmic Rays (GCRs) poses a long term cancer risk.	Med

Note: Risk of Exposure Induced Death (REID) limits exposure considerably making this one of the top risks for flight crews during long duration space flight. As such, the priority should be high, not medium as indicated by the MEPAG Goal IV committee.

MEPAG Goal IV – Toxic Dust

Investigation	Measurements	Rationale	Priority
Toxic Dust on Mars (2C) Determine the possible toxic effects of martian dust on humans.	1) Assay for chemicals with known toxic effect on humans. Of particular importance are oxidizing species (e.g., CrVI, i.e. hexavalent chromium) associated with dust-sized particles. May require a sample returned to Earth as previous assays haven't been conclusive enough to retire risk. 2) Fully characterize soluble ion distributions, reactions that occur upon humidification and released volatiles from a surface sample and sample of regolith from a depth as large as might be affected by human surface operations. Previous robotic assays (Phoenix) haven't been conclusive enough to significantly mitigate this risk. 3) Analyze the shapes of martian dust grains with a grain size distribution (1 to 500 microns) sufficient to assess their possible impact on human soft tissue (especially eyes and lungs). 4) Determine the electrical conductivity of the ground, measuring at least 10-13 S/m or more, at a resolution DS of 10% of the local ambient value 5) Determine the charge on individual dust grains equal to a value of 10-17 C or greater, for grains with a radius between 1-100 mm 6) Combine the characterization of atmospheric electricity with surface meteorological and dust measurements to correlate electric forces and their causative meteorological source for more than 1 martian year, both in dust devils and large dust storms (i.e., may be combined with objective 1A. c.)	Detect risks to astronauts from cancer causing compounds.	Med

MEPAG Goal IV – Atmospheric Electricity

Investigation	Measurements	Rationale	Priority
<u>Atmospheric Electricity(2D)</u> Assess atmospheric electricity conditions that may affect Mars takeoff, ascent, on-orbit insertion and human occupation.	1) Measure the magnitude and dynamics of any quasi-DC electric fields that may be present in the atmosphere as a result of dust transport or other processes, with a dynamic range of 5 V/m-80 kV/m, with a resolution DV=1V, over a bandwidth of DC-10 Hz (measurement rate = 20 Hz) 2) Determine if higher frequency (AC) electric fields are present between the surface and the ionosphere, over a dynamic range of 10 uV/m – 10 V/m, over the frequency band 10 Hz-200 MHz. Power levels in this band should be measured at a minimum rate of 20 Hz and also include time domain sampling capability. 3) Determine the electrical conductivity of the Martian atmosphere, covering a range of at least 10-15 to 10-10 S/m, at a resolution DS= 10% of the local ambient value. 4) Determine the electrical conductivity of the ground, measuring at least 10-13 S/m or more, at a resolution DS of 10% of the local ambient value 5) Determine the charge on individual dust grains equal to a value of 10-17 C or greater, for grains with a radius between 1-100 mm 6) Combine the characterization of atmospheric electricity with surface meteorological and dust measurements to correlate electric forces and their causative meteorological source for more than 1 martian year, both in dust devils and large dust storms (i.e., may be combined with objective 1A. c.)	Atmospheric electricity has posed a hazard to aircraft and space launch systems on Earth, and may also do so on Mars. Among many notable incidents was the lightning strike that hit the Apollo 12 mission during the ascent phase, causing a reset of the flight computer. In the case of Apollo 12 the strike was likely triggered by the presence of the vehicle itself, combined with its electrically conducting exhaust plume that provided a low resistance path to ground.	Med

MEPAG Goal IV – Forward Planetary Protection

Investigation	Measurements	Rationale	Priority
<u>Forward Planetary Protection (2E)</u> Determine the martian environmental niches that would meet the definition (as it is maintained by COSPAR) of "special region*" to determine the vulnerability to terrestrial biological contamination, and the rates and scales of the martian processes that would allow for the potential transport of viable terrestrial organisms to these special regions.	1) Map the distribution of naturally occurring surface special regions as defined by COSPAR (see note below). One key investigation strategy is change detection. 2) Characterize the survivability at the Martian surface of terrestrial organisms that might be delivered as part of a human landed campaign, including their response to oxidation, desiccation, and radiation. 3) Map the distribution of trace gases, as an important clue to the potential distribution and character of subsurface special regions that cannot be directly observed either from the surface or from orbit. 4) Determine the distribution of near-surface ice that could become an <u>induced special region</u> via a human mission. Orbital and landed measurements may be required to characterize such properties as thermal conductivity, structure, composition (soil probes, heat flow, electromagnetics, GPR).		Med

****Note: A Special Region is defined as "a region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high potential for the existence of extant Martian life. As of 2010, no Special Regions had definitively been identified.***

Strategic Knowledge Gaps for Human Mission to Near-Earth Asteroids (NEAs)

NEA Destination Leads:
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Near-Earth Asteroid Working Group (NEAWG) Members:

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Renee Weber
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NEA Testing and Knowledge Gain Venues

Venue	Description
Research and Analysis	Includes basic analytical research and computational analysis including high-fidelity computer simulations along with basic laboratory testing of subsystems and systems in a relevant simulated environment or facility. Low to mid-TRL (1-6) technology testing.
Earth-based Observation	Data obtained by Earth-based observatories and radar facilities.
LEO-based Observation	Data obtained by LEO-based observatories.
Non-LEO Space-based Observation	Data obtained by non-LEO space-based observatories, such as an IR survey/characterization telescope in a heliocentric orbit (e.g., Venus-trailing) or other locations.
Earth-based Analog Testing	Tests conducted in remote locations on the Earth that provide similar environments expected on planetary surfaces (NBL, NEEMO, PLRP, D-RAT, parabolic micro-g airplane flights, drop towers, etc.)
ISS/ISTAR Testing	Includes human and robotic testing conducted at the ISS in LEO. Microgravity testing of operational approaches and gravity sensitive systems. Mid to high-TRL (6-9) technology testing.
Earth Orbit Testing	Includes human and robotic testing conducted in LEO (but not at ISS), as well as testing conducted in Near-Earth space beyond LEO. Mid to high-TRL (6-9) technology testing.
Beyond LEO Missions (Robotic & Human)	Beyond LEO Missions of adequate duration to obtain critical system performance and operational data necessary for performance validation. The required number of missions and required duration are system dependent consistent with the level of risk mitigation required for that specific system.
NEA Robotic Precursor Missions to the Human Target	Robotic precursor missions (both scientific and engineering/operations focused) to the same NEA target as for the human mission. (Information gathered from robotic precursor missions to NEAs in general is highly valuable, but due to current lack of knowledge about NEAs and the variety of different target characteristics a mission to the target of interested is required.)

NEA Strategic Knowledge Gaps – Characterization (1 of 2)

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	Earth Orbit Testing	Beyond-LEO Missions (Robotic & Human)	NEA Robotic Precursor Missions to the Human Target	Comments
Target Orbital Position: Orbit Condition Code (OCC)	○	●[1,2]	●[1]	🔴	○	○	○	○	🔴	Robotic precursor secures target orbit – OCC=0 (TBD, 0-2) prior to NEA precursor mission is required.
Spin Mode (rotation rate and tumble)	○	⊙[1,2]	⊙[1]	●	○	○	○	○	🔴	
System Type (i.e., binary or ternary)	○	⊙[2]	⊙	⊙	○	○	○	○	🔴	
Activity/ Debris Field	⊙	⊙	⊙	●	⊙	⊙	⊙	○	🔴	Required "ground truth" in-situ measurement.
Near-Surface Mechanical Stability, Surface Morphology & Compaction	⊙	⊙[2]	○	○	⊙[3]	⊙	⊙	○	🔴	Required "ground truth" in-situ measurement.

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

[1] LEO space-based observations have greater limitations on target visibility, viewing geometry, and follow-up observations.

[2] Earth-based radar is highly relevant but has limited target accessibility.

[3] Parabolic micro-g airplane flights and drop towers.

NEA Strategic Knowledge Gaps – Characterization (2 of 2)

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	Earth Orbit Testing	Beyond-LEO Missions (Robotic & Human)	NEA Robotic Precursor Missions to the Human Target	Comments
Regolith Mechanics/ Geotechnical Properties (adhesion, abrasion & electrostatics)	⦿	○	○	○	⦿	⦿	⦿	○	🔴	
Mineralogical/ Chemical Composition	⦿	⦿	⦿	⦿	○	○	○	○	🔴	Measurement of destination NEA to identify potentially hazardous compounds
Gravitational Field	⦿	○	○	○	○	○	○	○	🔴	Rendezvous measurement required for sufficient gravitational field characterization.
Electrostatic/ Plasma field environment	⦿	○	○	○	⦿	⦿	⦿	⦿	🔴	
Thermal Properties	⦿	○	⦿	⦿	⦿	⦿	⦿	○	🔴	Infrared survey telescope provides some thermal information

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⦿ Not Relevant ○

NEA Strategic Knowledge Gaps – Destination Operations

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	Earth Orbit Testing	Beyond-LEO Missions (Robotic & Human)	NEA Robotic Precursor Missions to the Human Target	Comments
Surface Anchoring	⊙	○	○	○	⊙	⊙	⊙	○	🔴	Gravity field and regolith properties are critical factors that can only be properly characterized at the NEA.
Crew Translation, restraint, worksite stabilization	⊙	○	○	○	⊙	●	⊙[1]	○	🔴	Gravity field and regolith properties are critical factors that can only be properly characterized at the NEA.
Effects of propulsive stationkeeping on surface ejecta	⊙	○	○	○	○	●	⊙[1]	○	🔴	Gravity field and regolith properties are critical factors that can only be properly characterized at the NEA.

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

[1] ISS/ISTAR testing assumed to be more cost effective than a dedicated LEO free-flyer (e.g. commercial/international habitat). If not, both are highly relevant.

NEA Strategic Knowledge Gaps – Transit Operations (1 of 2)

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	Earth Orbit Testing	Beyond-LEO Missions (Robotic & Human)	NEA Robotic Precursor Missions to the Human Target	Comments
Acute and long-term physiological effects from space radiation	⊙	○	○	○	○	⊙	⊙	🔴[1]	●	Long duration human missions outside of Earth's magnetosphere are preferred location (e.g., Earth-Moon L1).
Behavioral health support: psychological & sociological issues	⊙	○	○	○	●	🔴	●[2]	●[1]	○	
Physiological challenges of long-term microgravity environment	⊙	○	○	○	○	🔴	●[2]	●	○	In-space missions only
Human factors and group interactions	⊙	○	○	○	●	🔴	●[2]	●[1]	○	

Preferred Testing Location 🔴 Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

[1] Human missions of sufficient duration only where radiation protection is deemed adequate prior to flight.

[2] ISS/ISTAR testing assumed to be more cost effective than a dedicated LEO free-flyer (e.g., commercial/international habitat). If not, LEO testing could be preferred.

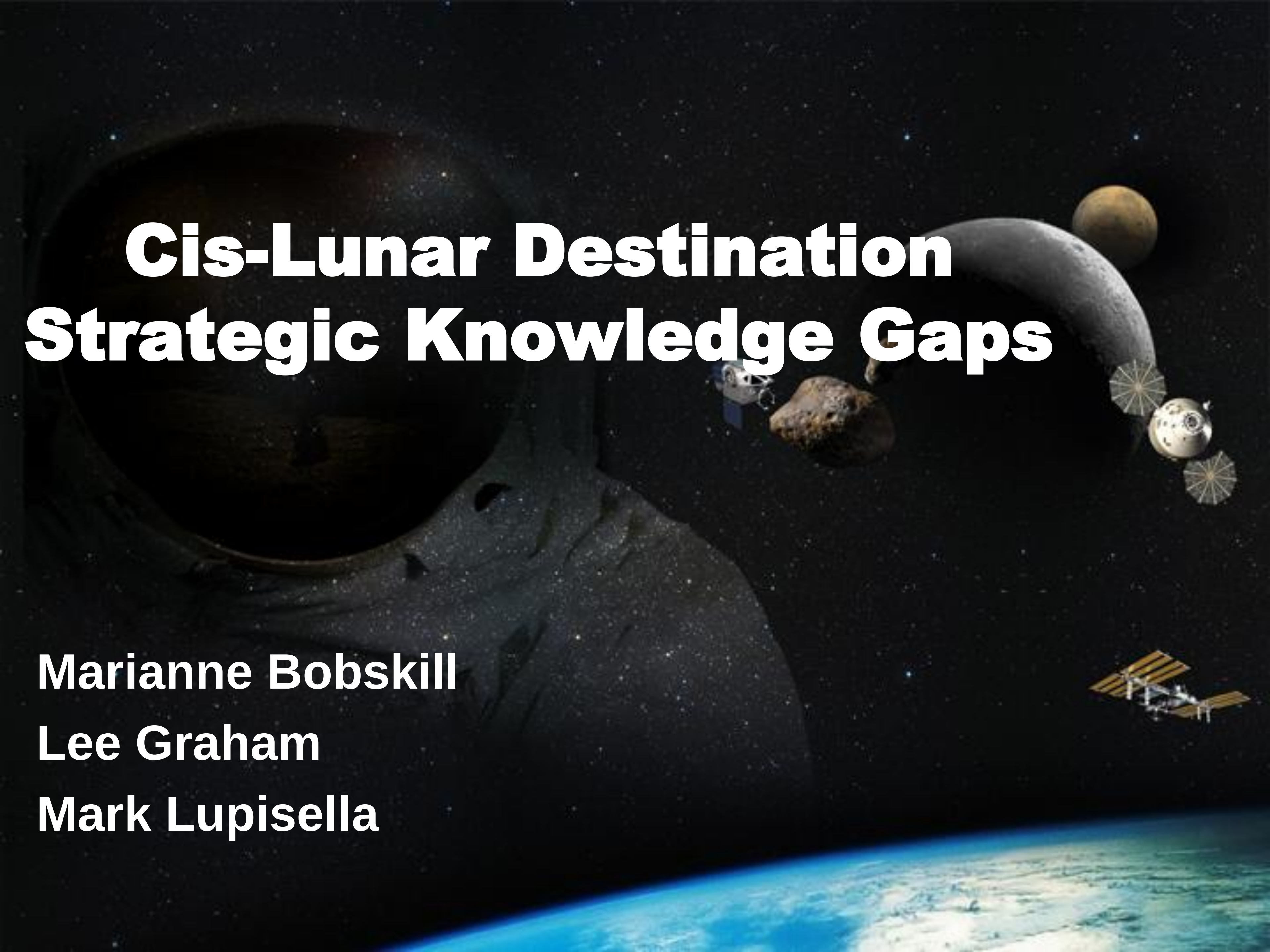
NEA Strategic Knowledge Gaps – Transit Operations (2 of 2)

Strategic Knowledge Gap	Research and Analysis	Earth-based Observation	LEO Space-based Observation	Non-LEO Space-based Observation	Earth-based Analog Testing	ISS / ISTAR Testing	Earth Orbit Testing	Beyond-LEO Missions (Robotic & Human)	NEA Robotic Precursor Missions to the Human Target	Comments
Life support system reliability	⦿	○	○	○	●	● (red)	●[1]	●[2]	○	
Medical support	⦿	○	○	○	●	● (red)	●[1]	●[2]	○	
Logistics and waste management	⦿	○	○	○	●	● (red)	●[1]	●[2]	○	
Subsystem serviceability and sparing	⦿	○	○	○	●	● (red)	●[1]	●[2]	○	
Other common long duration mission gaps – integrate with other destinations)										Need to work through as a group with other destinations

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⦿ Not Relevant ○

[1] ISS/ISTAR testing assumed to be more cost effective than a dedicated LEO free-flyer (e.g., commercial/international habitat). If not, LEO testing could be preferred

[2] Human missions of sufficient duration only.


Cis-Lunar Destination
Strategic Knowledge Gaps
Marianne Bobskill
Lee Graham
Mark Lupisella

Cis-Lunar Strategic Knowledge Gaps

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	GEO	EML1 / EML2*	Comments
GEO environment – particularly system charging and radiation.	⦿	⦿	○	○	● (red)	○	For Earth-based testing, test internal charging mitigation strategies (e.g., UV light exposure). Possibly test surface charging, but actual levels to use and variables associated with orientation (including spacecraft configuration) are unknown.
EML1 / EML2 radiation and gravitational field	⦿	⦿	○	○	○	● (red)	Actual gravity gradient measurements at EML1 / L2 could provide model updates, influencing spacecraft propulsion and control. Earth-based radiation measurements support design of appropriate radiation mitigation approaches.
System Reliability	⦿	⦿	●	●	● (red)	● (red)	Test new systems in new locations for very long durations. Supports reductions in crew maintenance time, crew housekeeping, logistics, propellant need and, possibly, number and size of launch vehicles. ISS and LEO can provide adequate testing venues for a variety of system reliability needs, but the actual environments at the cis-lunar locations are the preferred testing stressors.

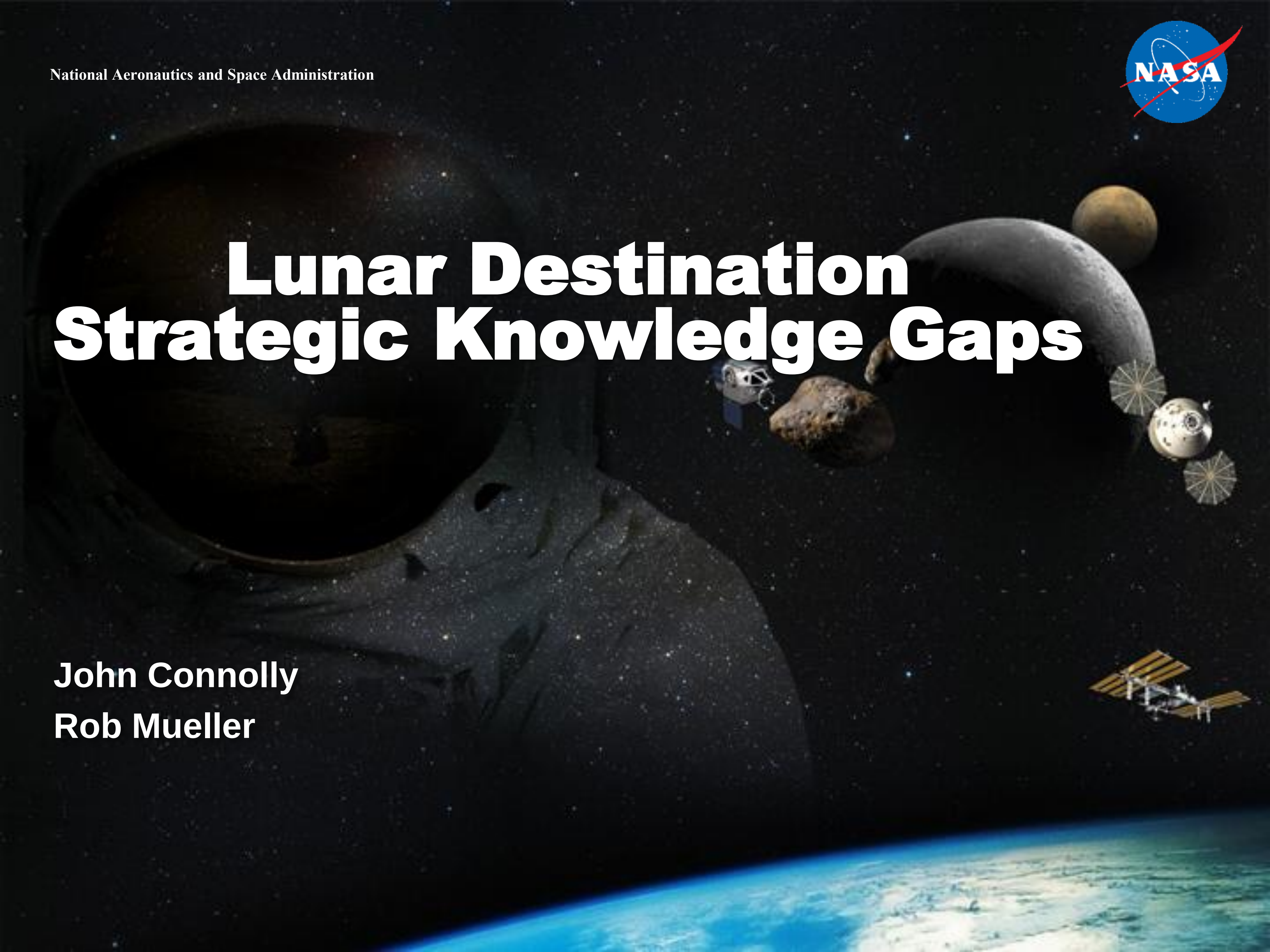
EML= Earth-Moon Libration Point

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⦿ Not Relevant ○

National Aeronautics and Space Administration

Lunar Destination Strategic Knowledge Gaps

John Connolly
Rob Mueller



Strategic Knowledge Gaps - Lunar

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Quality/quantity of water and volatiles in Lunar Mare Regolith -1	⊙	● (red)	○	○	○	Measure volatiles returned in pristine Apollo samples (samples still stored in lunar vacuum and refrigerated)
Quality/quantity of water and volatiles in lunar cold traps regolith and elsewhere -2	⊙	○	○	○	● (red)	Required “ground truth” in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data
Descent engine blast ejecta velocity, departure angle and entrainment mechanism -1	●	● (red)	○	○	○	Laboratory modeling with plume and entrained simulant
Descent engine blast ejecta velocity, departure angle and entrainment mechanism -2	●	○	○	○	● (red)	Metric camera measurement of actual landing conditions and in-situ measurements of witness plates

Preferred Testing Location ● (red)   Highly Relevant ●   Somewhat Relevant ⊙   Not Relevant ○

Strategic Knowledge Gaps - Lunar

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Radiation environment at lunar surface -1	● (preferred)	○	○	○	○	Model primary and secondary radiation components; confirm secondary models using national labs and lunar soil or simulant
Radiation environment at lunar surface -2	⊙	○	○	○	● (preferred)	Direct measurement primary and albedo/ secondary radiation on the lunar surface over a solar cycle
Radiation shielding effect of lunar materials -1	● (preferred)	○	○	○	○	Model and measure the radiation shielding properties of lunar soil samples and/or simulant
Radiation shielding effect of lunar materials -2	⊙	○	○	○	● (preferred)	Direct measurements of the radiation shielding properties of lunar soil – cover detectors with different depths of regolith
Lunar Mass Concentrations (Gravitational anomalies)	⊙	○	○	○	● (preferred) **GRAIL Soon!**	Lunar Mascons will affect the accuracy of navigation and precision landing

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps - Lunar

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Biological effects of lunar dust -1	⊙	● (red)	○	○	○ (green)	Measure reactivity of archived Apollo samples/lunar regolith simulant. Measurements of the most pristine samples could yield the best data
Biological effects of lunar dust -2	●	○	○	○	● (red)	Chemical assay to test in-situ reactivity of lunar dust
Lunar ISRU production efficiency - 1	● (red)	○	○	○	○	Determine the likely efficiency of ISRU processes using lunar simulants in relevant environments
Lunar ISRU production efficiency - 2	⊙	○	○	○	● (red)	Measure the actual efficiency of ISRU processes in the lunar environment

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps - Lunar

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Lander propellant scavenging	⊙	○	○	○	● (red)	Determine the efficiency of extracting residual oxygen from tanks in lunar landers. Variables include propellant settling in 1/6g, and LOX-He separation
Lunar surface trafficability - Predicted	● (red)	⊙	○	○	○	Geo-technical testing in high fidelity regolith simulants
Lunar surface trafficability – Real Time Sensing	●	○	○	○	● (red)	Geo-technical in-situ measurements using robotic missions
Lunar Topography Data	⊙	○	○	○	● (red) Done. LRO	Acquire complete topography map of moon at 0.5 m (or better) resolution and preferably in 3D
Solar Illumination Mapping	● (red)	○	○	○	● (red) Done. LRO	Combined elevation-illumination models to map solar energy incidence over time

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps – Lunar
Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Map and characterize the broad features of polar cold traps	⊙	○	○	○	● (red)	• Learn the extent, settings, physical properties, and locations of permanently dark cold traps near the lunar poles. • Understand the thermal environment of these areas, including the effects of this thermal regime on lunar regolith and geotechnical properties. • Understand the temporal history of lunar cold traps. • Survey potential lunar polar landing sites for detailed study and subsequent resource extraction experiments.

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps – Lunar
Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Detailed characterization of polar cold traps and nearby sunlit areas	⊙	○	○	○	● (red)	•Composition and phase of trapped volatiles •Lateral and vertical distribution •Environmental factors
Resource processing	⊙	●	○	○	● (red)	Produce and store small quantities of hydrogen and oxygen from lunar regolith by melting ice. • Demonstrate disposal of heated regolith after processing. • Process at high temperature to test techniques for extracting metals (e.g., Fe, Al) from regolith.

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps – Lunar
Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Characterize the geotechnical properties of the shadowed regolith	⦿	○	○	○	🔴	Physical and electrical properties, including shear strength, angle of repose, and electrical conductivity.
Techniques for excavation of lunar resources	⦿	●	○	○	🔴	•Create trenches 1 meter deep. • Load excavated regolith onto a conveyor belt. • Load excavated materials into resource extraction apparatus • Crush rock fragments • Sieve regolith materials into size fractions

Preferred Testing Location 🔴   Highly Relevant ●   Somewhat Relevant ⦿   Not Relevant ○

Strategic Knowledge Gaps – Lunar

Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Demonstrate surface power and energy storage systems	⊙	●	○	○	● (red)	Demonstration of capability to enable the thermal survival of robotic precursor systems through significant durations of darkness
Test radiation shielding technologies	●	● (red)	⊙	○	●	Essential for protecting astronauts on the lunar surface from galactic cosmic rays (GCR) and solar energetic particle (SEP) events.
Test micrometeorite protection technologies	●	● (red)	⊙	○	●	Needed to prevent damage caused by micrometeorite impacts

Preferred Testing Location ● (red)   Highly Relevant ●   Somewhat Relevant ⊙   Not Relevant ○

Strategic Knowledge Gaps – Lunar
Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
Solar event prediction	● (red)	○	⊙	⊙	●	Establish space weather modeling, forecasting and monitoring capabilities To warn transit/surface crews of potentially hazardous solar events. The goal of these systems should be to provide as early a warning as possible of dangers.

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○

Strategic Knowledge Gaps – Lunar
Source: LEAG (EXPO-SAT) 4-10-2010

Strategic Knowledge Gap	Research and Analysis	Earth-based Testing	ISS / ISTAR	LEO	Robotic Lunar Missions	Comments/ Narrative
How to maintain peak human health and performance in dusty, high-radiation, partial gravity environments:	●	● (red)	⊙	⊙	○	Research the fundamental biological and physiological effects of the integrated lunar environment on biological systems In partial gravity environments, the effects of the mixed-type radiation spectrum, and the consequences of exposure to anhydrous lunar dust, enabling the design and development of countermeasures.

Preferred Testing Location ● (red) Highly Relevant ● Somewhat Relevant ⊙ Not Relevant ○