

Developing the Global Exploration Roadmap

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Global Exploration Roadmap

2013

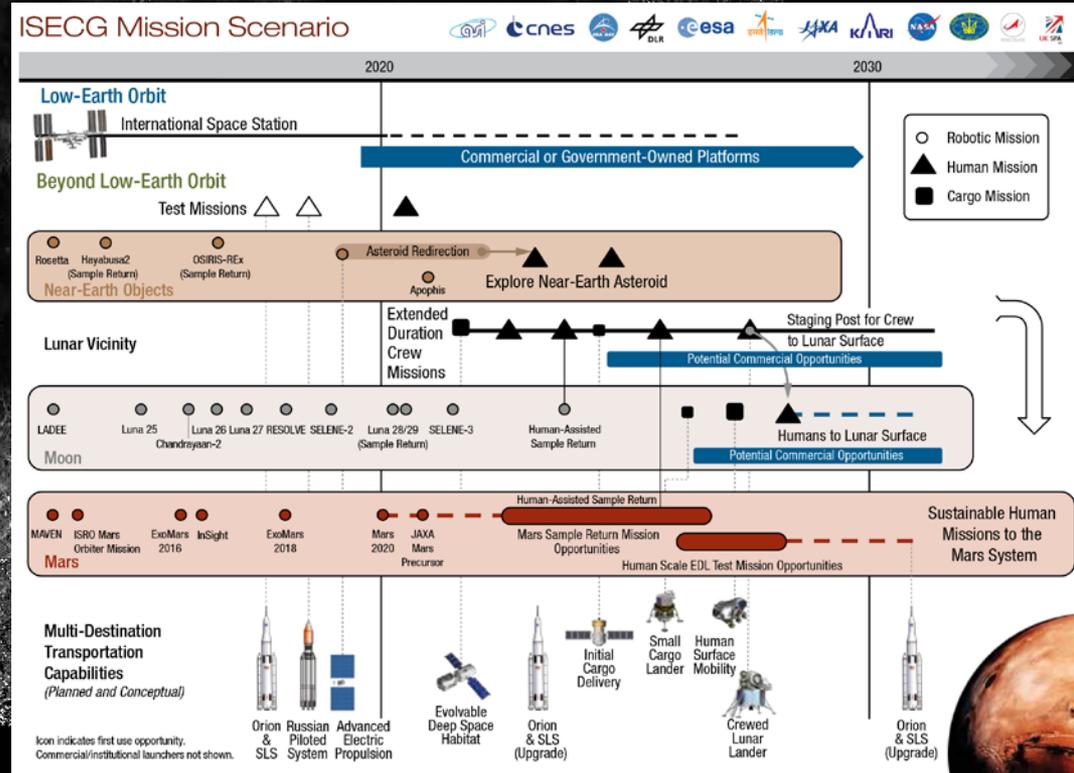
ISECG Mission Themes:

- NEA Exploration;
- Extended Duration Crew Missions;
- Humans to the Lunar Surface



Principles Driving the Mission Scenario:

- Affordability;
- Exploration Value;
- International Partnerships;
- Capability Evolution;
- Human/Robotic Partnership;
- Robustness (learn from Apollo).



Contributions to Mars Mission Readiness

NEA Mission

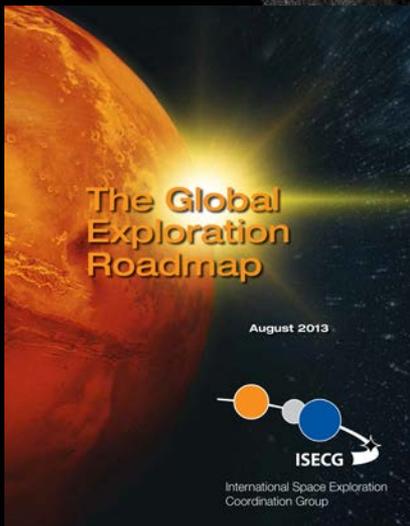
- Space Launch System;
- Solar Electric Propulsion System;
- Spacewalk, rendezvous, proximity operations, deep space navigation and communications.

Extended (Lunar Vicinity)

- Deep space exploration capabilities (crew transportation capabilities, life support systems) to reduce risk;
- Autonomous crew operation;
- Operations with reduced supply chain;
- Experience with complex deep space staging operations;
- Advance core technologies & radiation protection strategies for long duration missions;
- Interactive human and robotic operations;
- Solar electric propulsion on a crewed spacecraft.

Lunar Surface

- Staging operations with an Earth-return vehicle;
- Extended crew mobility and habitation systems;
- Advanced power systems;
- Characterize human health and performance, combining deep space and partial gravity environment exposure;
- Operations concepts and enhanced crew autonomy for surface exploration;
- Provide the opportunity for advancing concepts related to use of local resources.



The Moon

Proximity:

- “Ease” of access;
- Risk reduction.

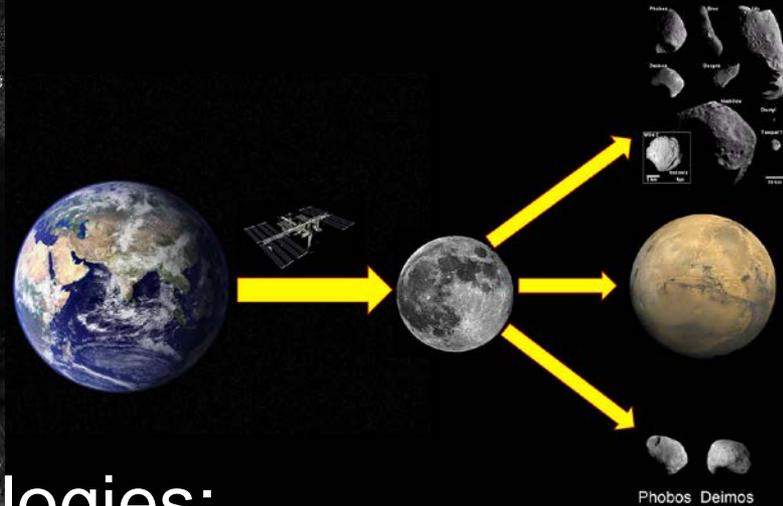
Harsh Environment:

- Test radiation shielding technologies;
- Reduced gravity (not microgravity);
- Dust.

Long-duration testbed.

ISRU:

- Learning to live off the land, off-planet.



Destination Moon

Use the Moon to create a sustained human space-faring capability, advancing exploration of the Solar System.

The Value of Exploring the Moon

- Open the gateway to the Solar System
- Pioneer development of new technologies
- Advance economic expansion
- Enable new scientific discoveries
- Promote international partnerships

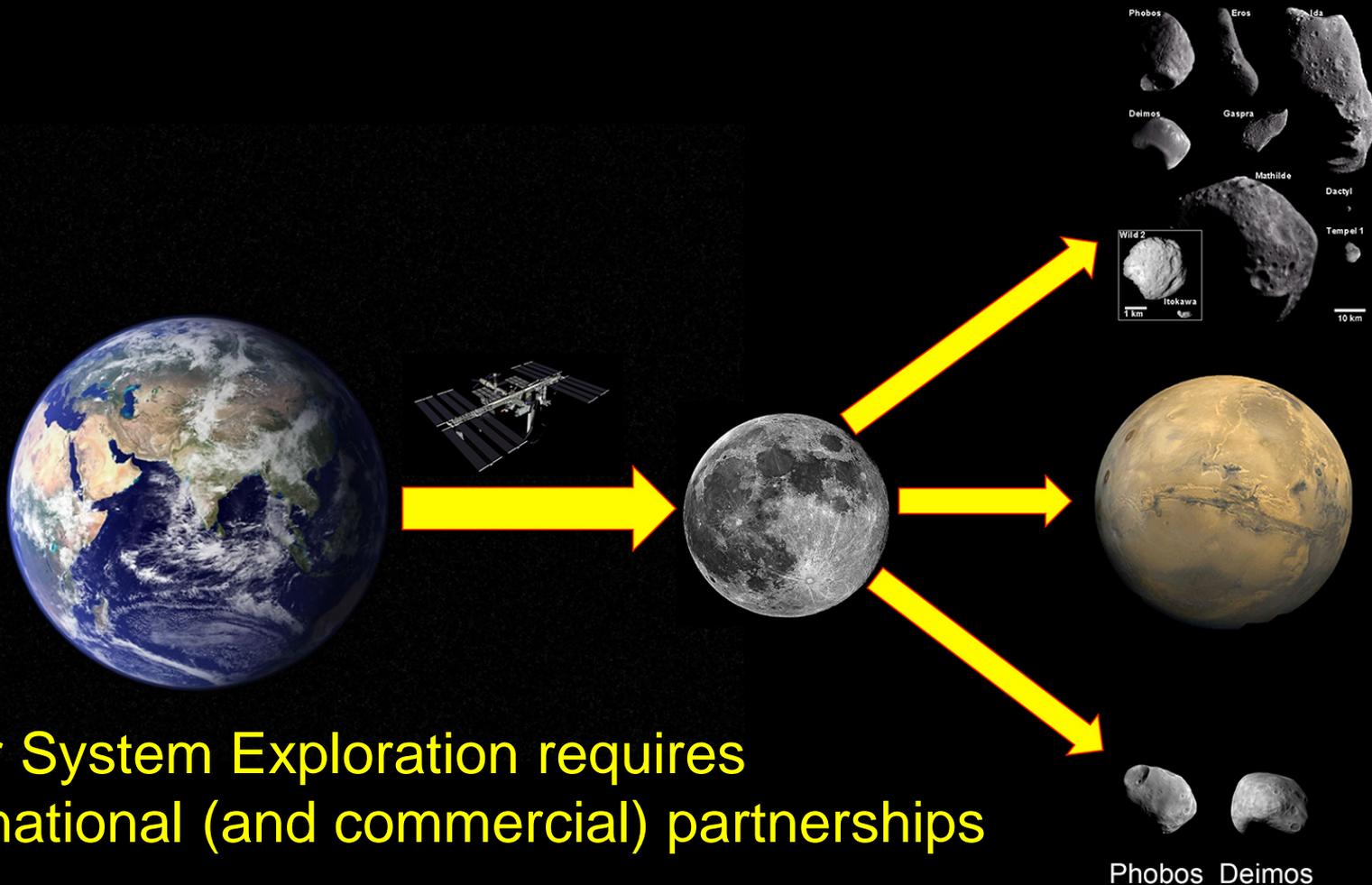
To the Moon and Beyond

- Sustainable investments
- Incremental units launched sequentially
- Operated collectively as an integrated system
- Technology spinoffs that improve life on Earth

The Moon is the most accessible destination for realizing commercial, exploration, and scientific objectives beyond low Earth orbit.

Important

The Moon is an enabling asset!



Solar System Exploration requires international (and commercial) partnerships

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Developing the GER



- **Map existing science and exploration documents to GER goals.**
- **Develop the Humans to the Lunar Surface Mission based on the MIT study finding of 2011 (Szajnfarber et al. *Space Policy* 27, 131-145):**
 - “We find that when international partners are considered endogenously, the argument for a “flexible path” approach is weakened substantially. This is because international contributions can make “Moon first” economically feasible”.

Humans to the Lunar Surface

GER Goals:

- Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).
- Characterizing human health and performance outside Earth's magnetosphere and in a reduced gravity environment.
- Conducting high priority science benefiting from human presence, including human-assisted lunar sample return.
- Advance knowledge base related to use of lunar resources.
- Explore landing sites of interest for extended durations.

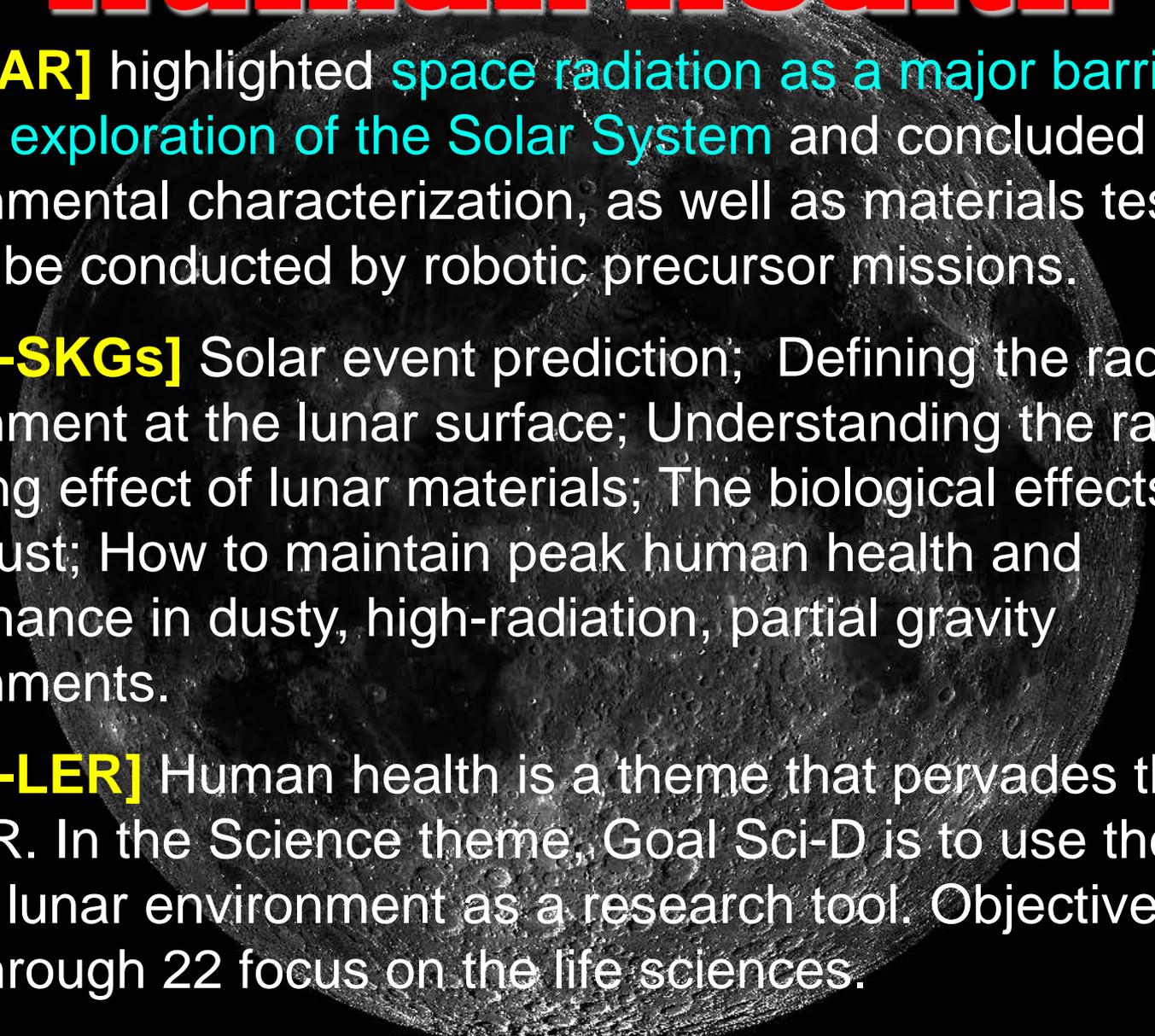


Humans to the Lunar Surface

Examples of International Documents used

- [1] Ehrenfreund et al. (2012) Toward a global space exploration program: A stepping stone approach. *Adv. Space Res.* 49, 2-48. [COSPAR]
- [2] LEAG (2012) Strategic Knowledge Gaps for the Moon First Human Exploration Scenario http://www.lpi.usra.edu/leag/GAP_SAT_03_09_12.pdf [LEAG-SKGs]
- [3] LEAG (2013) Lunar Exploration Roadmap http://www.lpi.usra.edu/leag/ler_draft.shtml [LEAG-LER]
- [4] NRC (2007) Scientific Context for the Exploration of the Moon <http://www.nap.edu/catalog/11954.html>; [SCEM]
- [5] Crawford et al. (2012) Back to the Moon: The scientific rationale for resuming lunar surface exploration. *Planet. Space Sci.* 74, 3-14. [SR]
- [6] Crawford (2010) Lunar Palaeoregolith Deposits as Recorders of the Galactic Environment of the Solar System and Implications for Astrobiology *Astrobiology* 10, 577-587. [ASTROBIO]

Human Health

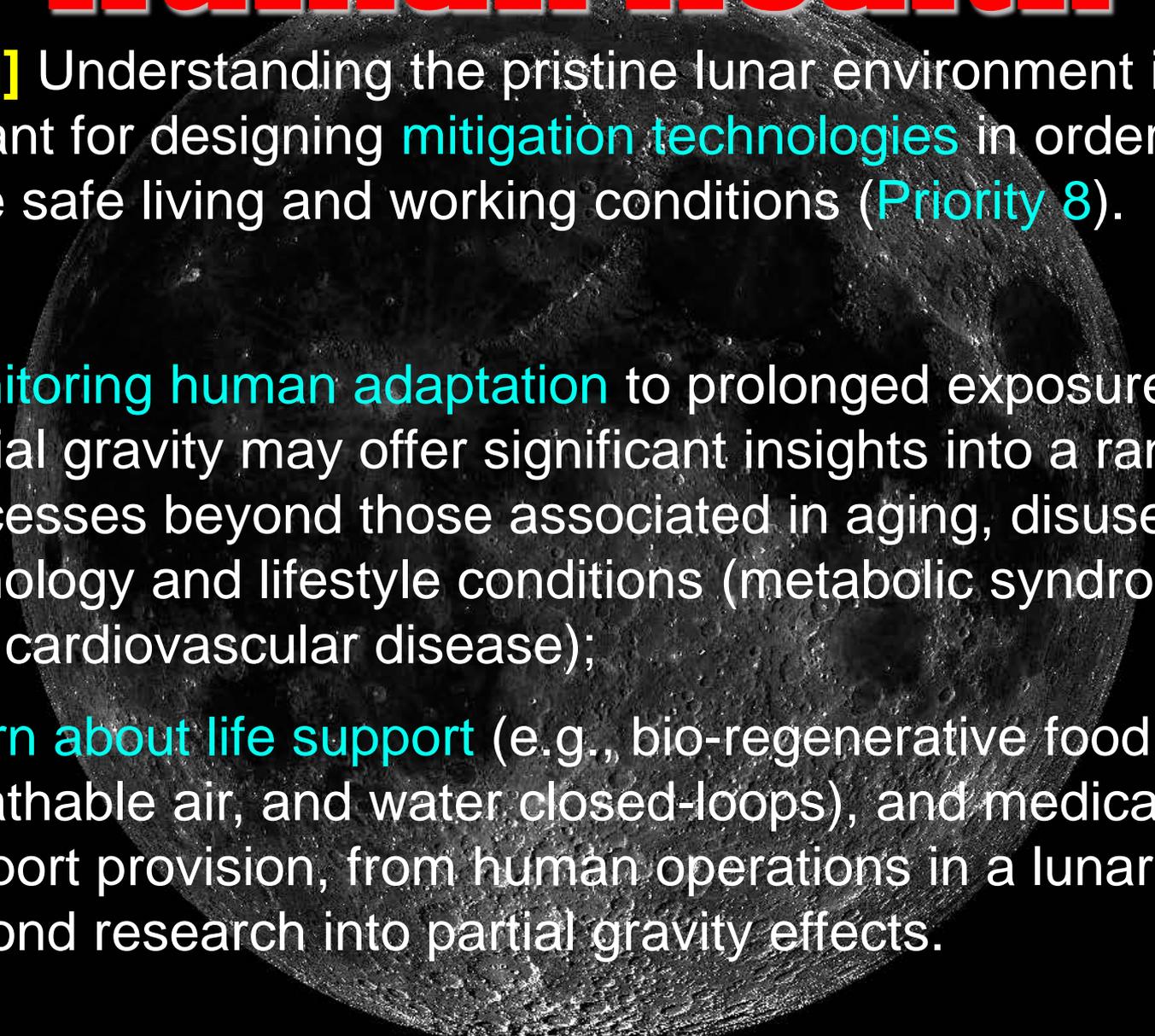


[COSPAR] highlighted space radiation as a major barrier to human exploration of the Solar System and concluded that environmental characterization, as well as materials testing should be conducted by robotic precursor missions.

[LEAG-SKGs] Solar event prediction; Defining the radiation environment at the lunar surface; Understanding the radiation shielding effect of lunar materials; The biological effects of lunar dust; How to maintain peak human health and performance in dusty, high-radiation, partial gravity environments.

[LEAG-LER] Human health is a theme that pervades through the LER. In the Science theme, Goal Sci-D is to use the unique lunar environment as a research tool. Objectives Sci-D-12 through 22 focus on the life sciences.

Human Health



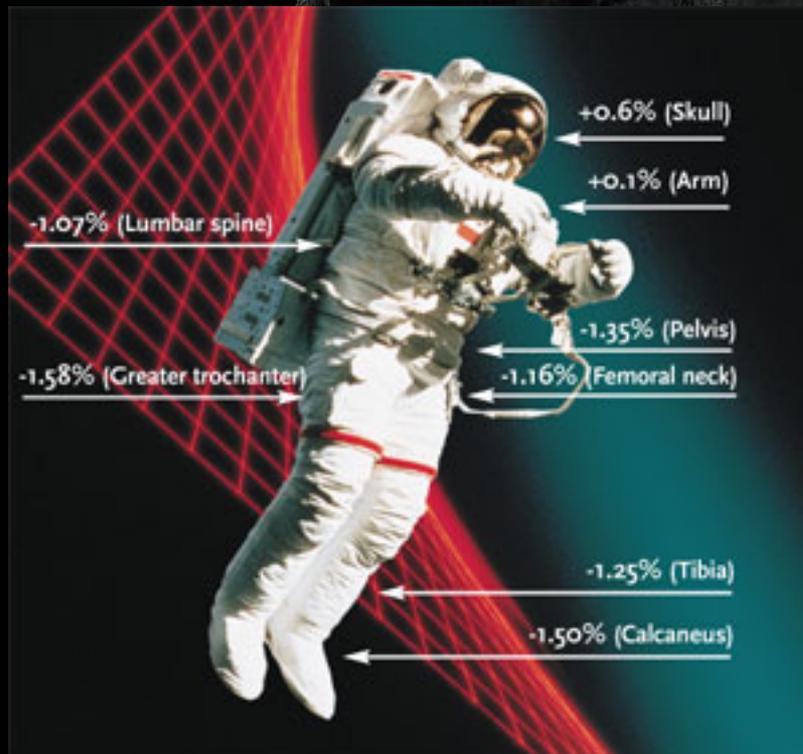
[SCEM] Understanding the pristine lunar environment is important for designing **mitigation technologies** in order to provide safe living and working conditions (**Priority 8**).

[SR]:

- 1) **Monitoring human adaptation** to prolonged exposure to partial gravity may offer significant insights into a range of processes beyond those associated in aging, disuse-pathology and lifestyle conditions (metabolic syndrome and cardiovascular disease);
- 2) **Learn about life support** (e.g., bio-regenerative food, breathable air, and water closed-loops), and medical support provision, from human operations in a lunar base beyond research into partial gravity effects.

Human Health

[ASTROBIO] Use of the Moon to understand the long-term effects of the space environment (e.g., the radiation, microgravity, psychological aspects) is required because our knowledge is not sufficient.

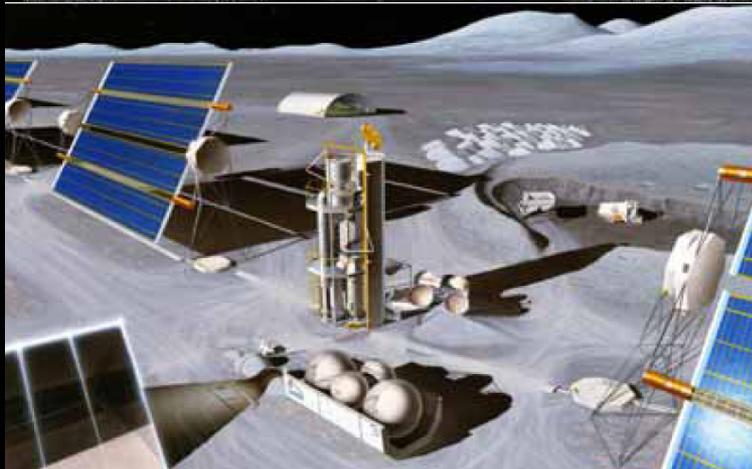


Lunar Resources

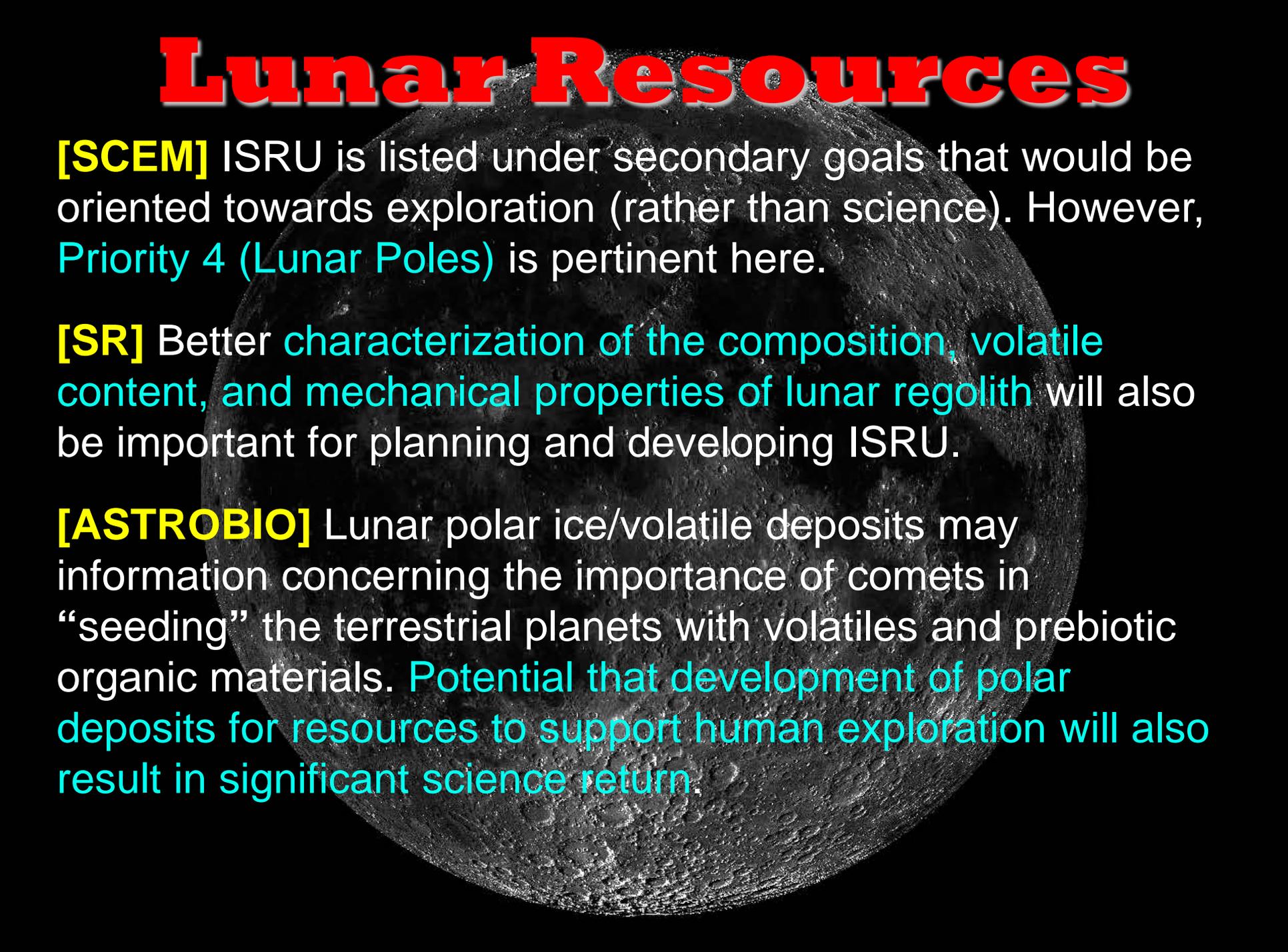
[COSPAR] listed technologies needed to prepare for human exploration of the Moon. These included **in situ resource utilization (ISRU)** and **energy production and storage**.

[LEAG-SKGs] Theme I is devoted to understanding the **lunar resource potential**.

[LEAG-LER] The LER includes a number of objectives throughout all three themes that are related to ISRU. ISRU is particularly critical in the **Feed Forward** and **Sustainability** themes.



Lunar Resources



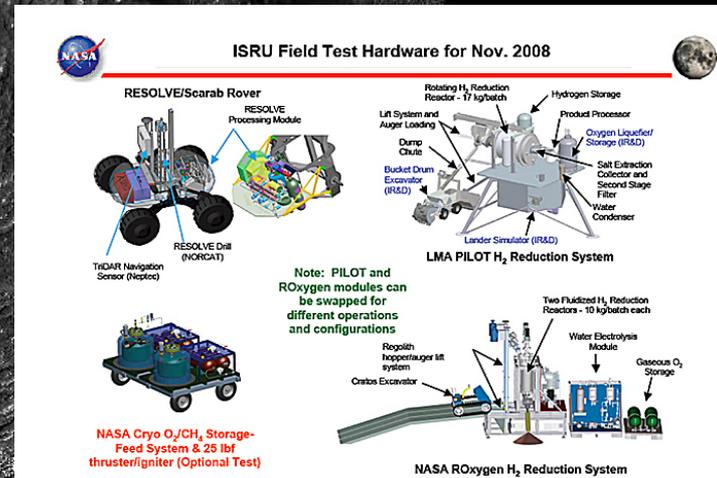
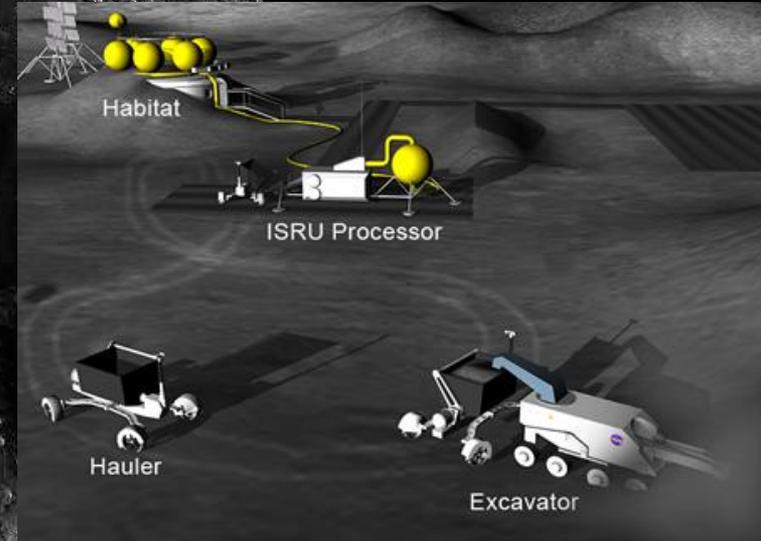
[SCEM] ISRU is listed under secondary goals that would be oriented towards exploration (rather than science). However, **Priority 4 (Lunar Poles)** is pertinent here.

[SR] Better characterization of the composition, volatile content, and mechanical properties of lunar regolith will also be important for planning and developing ISRU.

[ASTROBIO] Lunar polar ice/volatile deposits may information concerning the importance of comets in “seeding” the terrestrial planets with volatiles and prebiotic organic materials. **Potential that development of polar deposits for resources to support human exploration will also result in significant science return.**

Lunar Resources

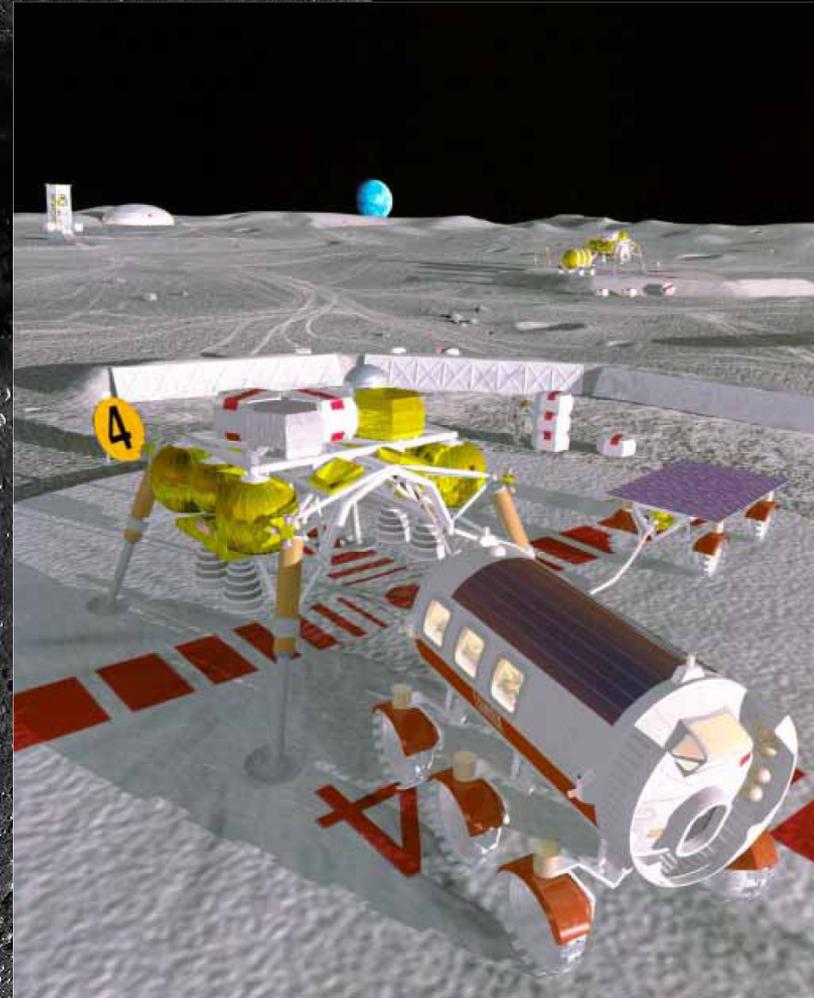
- In Situ Resource Utilization (ISRU) is the *game changer* – produce fuel and consumables on the lunar surface to enable human exploration of other airless bodies and Mars.
- Use the Moon to explore the Solar System due to the much reduced “gravity well” and presence of resources.
- Enables international cooperation and commercial participation (i.e., jobs!) in space exploration by starting at the Moon with the goal to go much further.



Lunar Resources

Resource Prospecting and Verification.

- **Ground truth is required to validate and characterize the polar and other resources:**
 - **Determine the form;**
 - **Measure the amount and location;**
 - **Characterize the local environment.**
- **Orbital missions are not sufficient.**



See www.lpi.usra.edu/leag for more details

Lunar Resources

(Implementing the LEAG LER)

Phase I: Lunar Resource Prospecting.

- Defining the composition, form, and extent of the resource;
- Characterizing the environment in which the resources are found;
- Defining the accessibility/extractability of the resources;
- Quantifying the geotechnical properties of the lunar regolith in the areas where resources are found;
- Being able to traverse several km and sample and determine lateral and vertical distribution on meter scales.
- Identifying resource-rich sites for targeting future missions.



Lunar Resources

(Implementing the LEAG LER)

Phase II: Lunar Resource Mining.

- Feedstock acquisition and handling;
- Resource extraction, refinement, transport, and storage;
- Usability of resources (e.g., fuel cell, small engine test, propellant depot test);
- Regolith handling and size sorting technologies (only for mineral-based resources);
- Operable life to give information on the longevity of systems and materials in the lunar environment;
- Dust mitigation strategies.



Lunar Resources

(Implementing the LEAG LER)

Phase III: Lunar Resource Production.

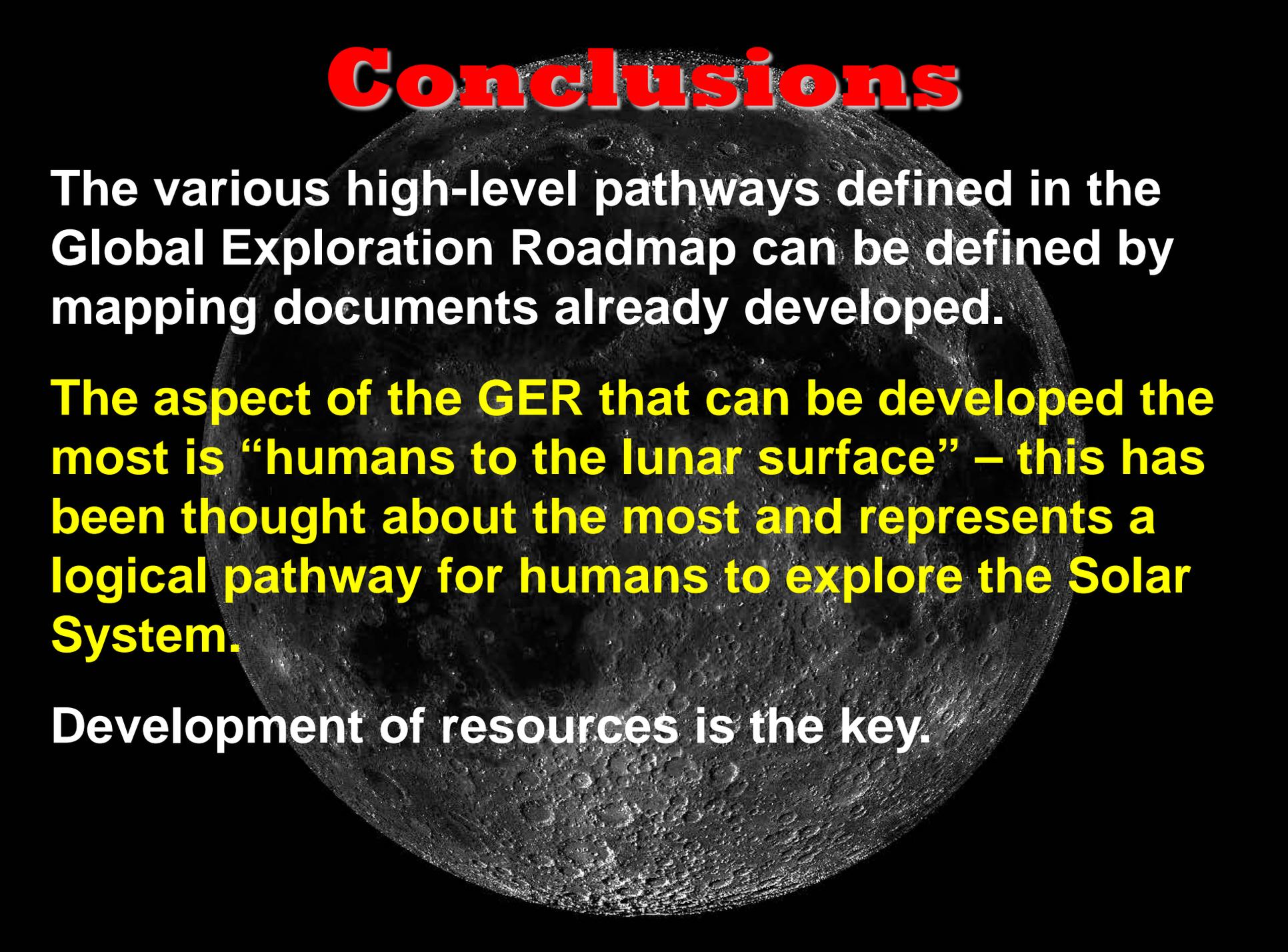
Based upon the results of Phase II a larger-scale (i.e., more appropriate scale) **continuous processing capability** would be deployed to the most appropriate site.

Greater quantities of resources will be produced and be used to undertake more **extensive demonstrations** such as life support, mobility technologies, and fuel for a robotic sample return.

An **automated full-scale production capability** would be established prior to the first extended human stay on the lunar surface.



Conclusions



The various high-level pathways defined in the Global Exploration Roadmap can be defined by mapping documents already developed.

The aspect of the GER that can be developed the most is “humans to the lunar surface” – this has been thought about the most and represents a logical pathway for humans to explore the Solar System.

Development of resources is the key.



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Developing the global exploration roadmap: An example using the humans to the lunar surface theme

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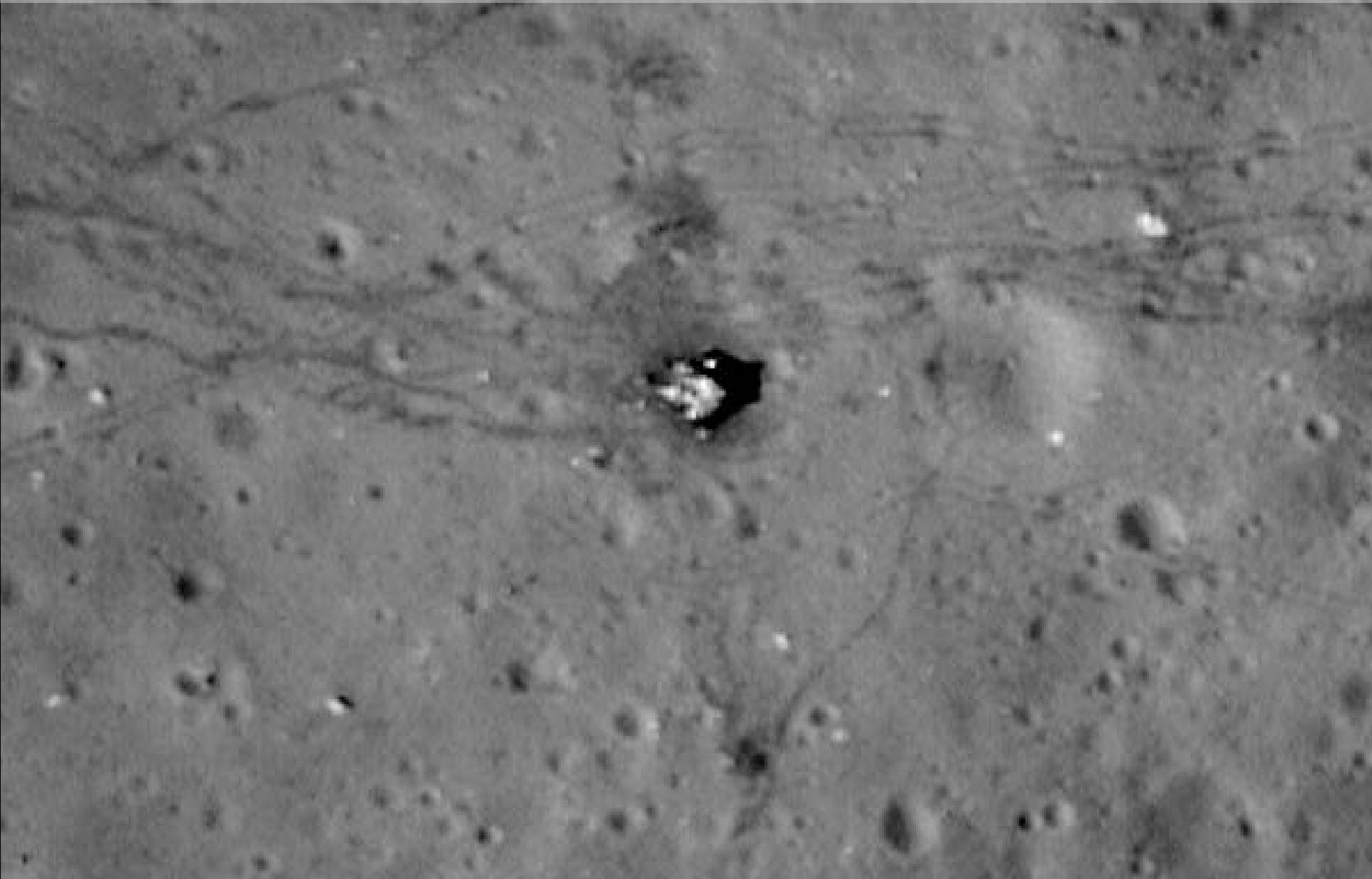
Global exploration roadmap

Test bed

ABSTRACT

The development of the Global Exploration Roadmap (GER) by 12 space agencies participating in the International Space Exploration Coordination Group broadly outlines a pathway to send humans beyond low Earth orbit for the first time since Apollo. Three themes have emerged: Exploration of a Near-Earth Asteroid, Extended Duration Crew Missions, and Humans to the Lunar Surface. The lack of detail within each of these themes could mean that realizing the goals of the GER would be significantly delayed. The purpose of this paper is to demonstrate that many of the details needed to fully define and evaluate these themes in terms of scientific rationale, economic viability, and technical feasibility already exist and need to be mapped to the GER. Here, we use the Humans to the Lunar Surface theme as an example to illustrate how this process could work. By mapping documents from a variety of international stakeholders, this process can be used to cement buy-in from the current partners and attract new ones to this effort.

WAITING FOR A RETURN VISIT...



APOLLO 17 LM CHALLENGER , 25 cm/pixel

2011

