National Aeronautics and Space Administration

EXPLORE SCIENCE

Planetary Decadal – Human Exploration Chapter

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Science Mission Directorate

Joint Sci/HEO NAC meeting
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The National Academies of
SCIENCES · ENGINEERING · MEDICINE
ORIGINS, WORLDS, AND LIFE
A Decadal Strategy for Planetary Science & Astrobiology
2023–2032

What is a “decadal”

Every 10 years each of the SMD divisions requests the National Academy to do a study of what science should be prioritized over the next decade.

This is our most important guiding document, trumps LEAG docs or any other community generated guidance.

This is the Planetary Science Division’s 3rd :

- New Frontiers in the Solar System (2003-2013)
- Visions and Voyages (2013-2022)
- Origins Worlds and Life (2022-2032)

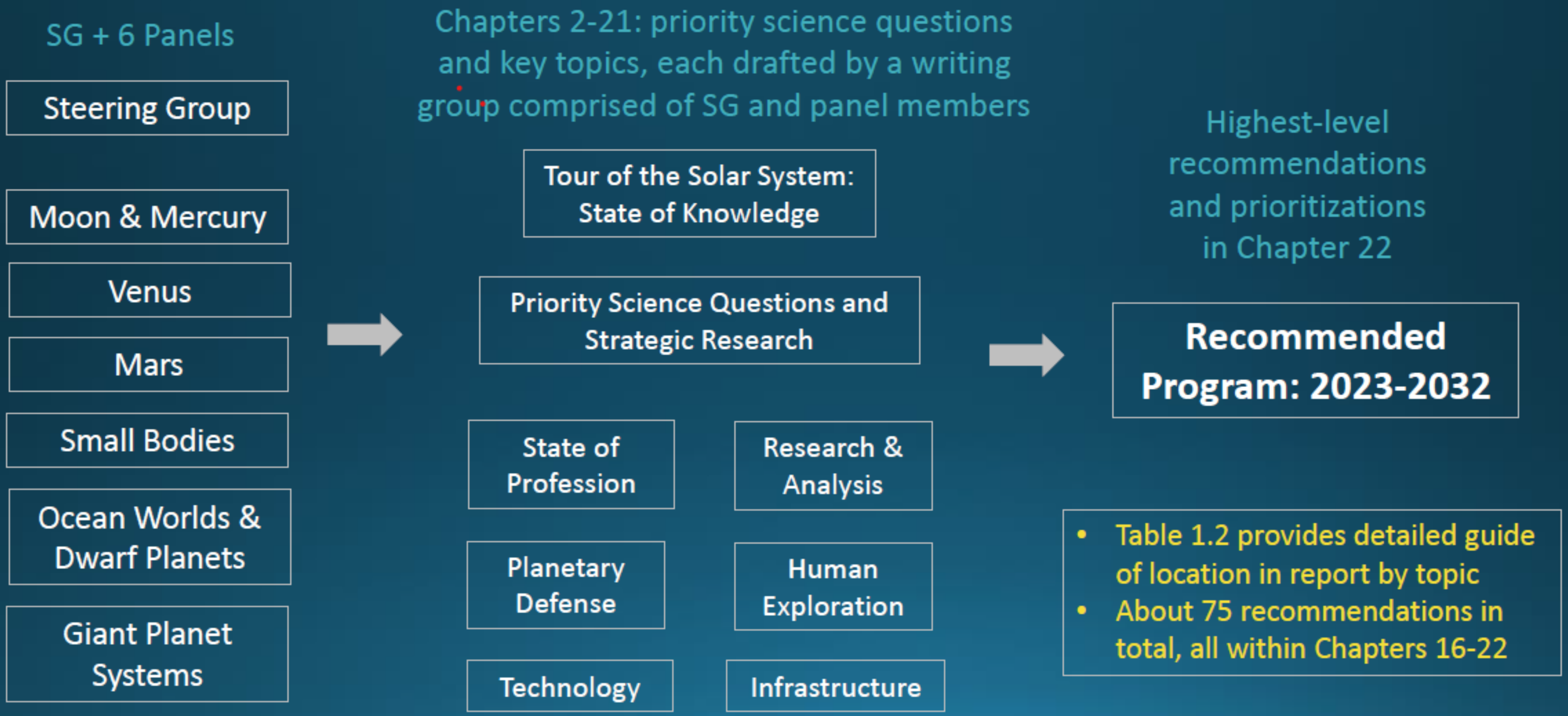
It is a ~3 yr process

Starts with mission studies, soliciting white papers from the community

Subcommittees meet regularly for ~1.5 yrs, invite presentations Q&A from HQ, community

For the first time Human Exploration and Planetary Defense were included in the doc

Survey and Report Organization



Panels (chairs and vice chairs listed first)

Moon and Mercury	Venus	Mars	Small Bodies	Ocean Worlds & Dwarf Planets	Giant Planet Systems
Tim Grove, NAS	Paul Byrne	Vicky Hamilton	Nancy Chabot	Alex Hayes	Jonathan Lunine, NAS
Brett Denevi	Larry Esposito	Bethany Ehlmann	Carol Raymond	Francis Nimmo, NAS	Amy Simon
James Day	Giada Arney	Will Brinckerhoff	Paul Abell	Morgan Cable	Frances Bagenal, NAS
Alex Evans	Amanda Brecht	Tracy Gregg	Bill Bottke	Alfonso Davila	Richard Dissly
Sarah Fagents	Thomas Cravens	Jasper Halekas	Megan Bruck Syal	Glen Fountain	Leigh Fletcher
Bill Farrell	Kandis Jessup	Jack Holt	Harold Connolly	Chris German	Tristan Guillot
Caleb Fassett	James Kasting, NAS	Joel Hurowitz	Tom Jones	Chris Glein	Matthew Hedman
Jennifer Heldmann	Scott King	Bruce Jakosky	Stefanie Milam	Candice Hansen	Ravit Helled
Toshi Hirabayashi	Bernard Marty	Michael Manga, NAS	Ed Rivera-Valentin	Emily Martin	Kathleen Mandt
James Keane	Thomas Navarro	Hap McSween, NAS	Dan Scheeres, NAE	Marc Neveu	Alyssa Rhoden
Francis McCubbin	Joseph O'Rourke	Claire Newman	Rhonda Stroud	Carol Paty	Paul Schenk
Miki Nakajima	Jennifer Rocca	Miguel San Martin, NAE	Myriam Telus	Lynnae Quick	Michael Wong
Mark Saunders	Alison Santos	Kirsten Siebach	Audrey Thirouin	Jason Soderblom	
Sonia Tikoo-Schantz	Jennifer Whitten	Amy Williams	Chad Trujillo	Krista Soderlund	
		Robin Wordsworth	Ben Weiss		

Each Panel vice chair was also a member of Steering Group

*Human Exploration writing group led by Jen Heldmann and John Grunsfeld

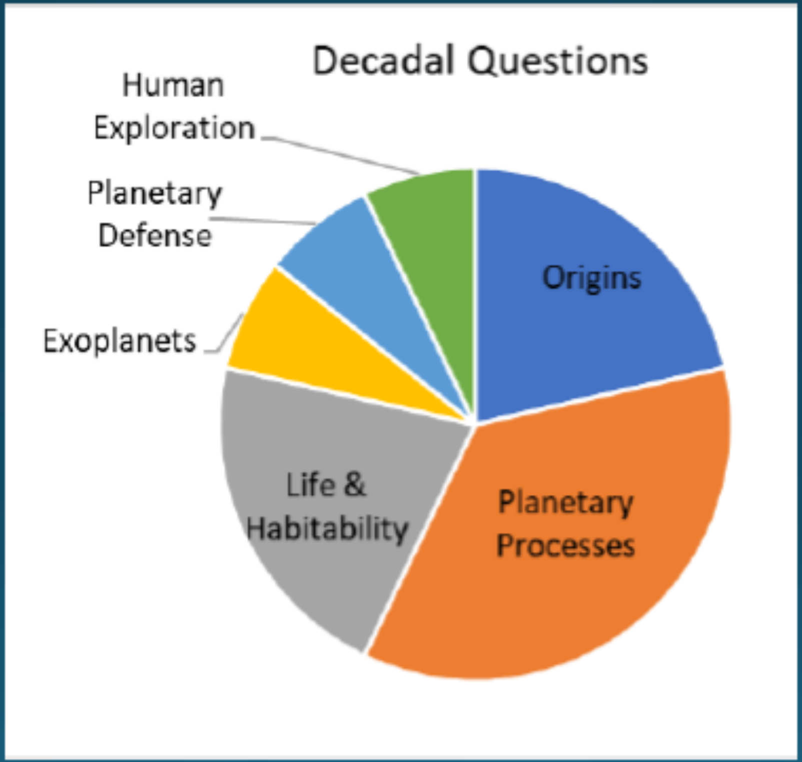
Decadal Process

- > 500 white papers received (summer 2020)
- 153 Panel and 23 steering group meetings (fall 2020 to fall 2021)
  - > 300 presentations by external speakers in open sessions
- Key Milestones:
  - Review of white papers and Planetary Mission Concept Study reports (Fall 2020)
  - Identification of priority science questions (Fall 2020)
  - Definition of 9 additional mission concepts & new study completion (Fall 2020 – Winter 2021)
  - Prioritization of mission concepts for TRACE (Spring 2021)
  - Report chapters developed by writing groups (Spring – Fall 2021)
  - Review of TRACE results (Summer 2021)
  - Prioritizations and high-level recommendations (Summer – Fall 2021)
  - Draft report to Academies and external review (November – December 2021)
  - Response to reviews and final report approval (January – March 2022)

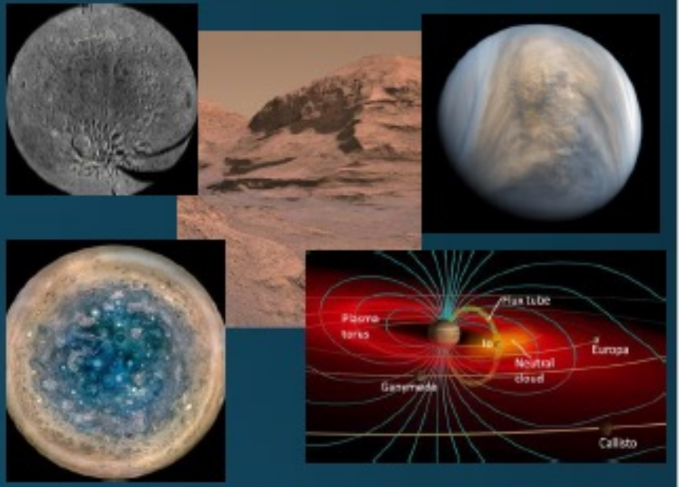
Priority Science Question Development

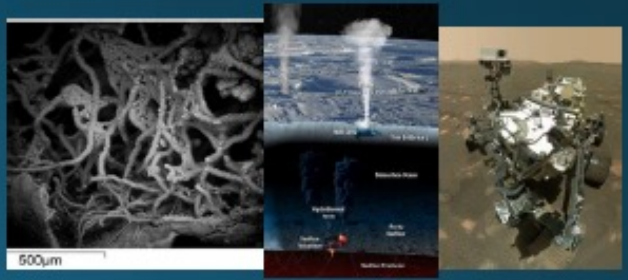
"Report should … be organized according to the significant, overarching questions in planetary science, astrobiology, and planetary defense"

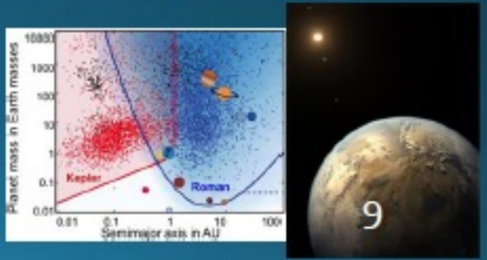
- First Steering Group (SG) task was to identity the most compelling, overarching questions
- Defined 12 Priority Science Questions and 2 related topics (Human Exploration + Planetary Defense)
- Plot shows distribution by topic



Themes	Priority Science Question Topic and Scope
A) Origins	**Q1. Evolution of the protoplanetary disk** What were the initial conditions in the Solar System? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. Accretion in the outer solar system How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. Origin of Earth and inner solar system bodies How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer Solar System materials incorporated?
B) Worlds & Processes	**Q4. Impacts and dynamics** How has the population of Solar System bodies changed through time, and how has bombardment varied across the Solar System? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
	Q7. Giant planet structure and evolution What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. Circumplanetary systems What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
C) Life & Habitability	**Q9. Insights from Terrestrial Life** What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. Dynamic Habitability Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
	Q11. Search for life elsewhere Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?
All Themes	**Q12. Exoplanets** What does our planetary system and its circumplanetary systems of satellites and rings reveal about exoplanetary systems, and what can circumstellar disks and exoplanetary systems teach us about the solar system?







Twelve Science Question Chapters

Key Takeaways:

Crucial role of sample return and in situ analyses

Dearth of knowledge of the ice giant systems

Importance of primordial processes to compositional reservoirs, planetary building blocks and primitive bodies, and early solar system dynamical evolution

Complex interplay of internal and external processes that affect planetary bodies

Varied evolutionary paths of the terrestrial planets

Central question of how life on Earth emerged and evolved, and the compelling rationale to study habitable environments at Mars and ice ocean worlds

Desire to make substantive progress in this decade in understanding whether life existed (or exists elsewhere in the solar system)

Human Exploration

- Human exploration is aspirational and inspirational, and NASA's Moon-to-Mars plans hold the promise of broad benefits to the nation and the world
- A robust science program provides the motivating rationale for sustainable human exploration

The advancement of high priority lunar science objectives should be a key requirement of the Artemis human exploration program

PSD should execute a strategic program to accomplish planetary science objectives for the Moon, with an organizational structure that aligns responsibility, authority, and accountability. This structure should give SMD the responsibility and authority for integrating the Artemis science requirements with human exploration capabilities.

Why are humans useful for lunar science? (modified fromTable 19.1)

Human Expertise	Science Objective
Astronauts can be well-equipped to conduct sorties and sample and return intact cores deeper (>1 m) than easily accomplished by robotic missions.	Determine the origin, composition, and history of ice deposits
	Establish internal heat flow and determine near-surface stratigraphy using geophysical probes and cores
Astronauts can collect more and better geologic samples than static robotic missions by virtue of their ability to more rapidly assess geologic context to select the optimal samples, conduct traverses to allow for increased sample diversity, and to return larger sample quantities. Astronauts could also retrieve samples robotically cached.	Establish the impact flux through time in the inner solar system, the nature of impactors, and whether there was a late heavy bombardment
	Probe of volcanic, tectonic and magmatic processes, including the formation of planetary dichotomy/asymmetry
	Determine the timing and characteristics of the giant impact that produced the Earth-Moon system
Astronauts can efficiently deploy stations over a wide area to make measurements of modern properties, can conduct in situ tests to determine optimal layouts pre-deployment, and can conduct tests using an initial layout and re-deploy as necessary post-testing.	Measure interactions of atmospheres and exospheres with the space environment
	Determine interior structure and history of the magnetic field

Science Themes for Lunar Exploration (BOX 22.2)

The central goal of a science-driven program of lunar discovery and exploration is to reveal the history of major events and processes that have shaped the Earth–Moon system and the solar system.

The committee prioritizes three overarching Science Themes:

Science Theme 1: **Uncover the lunar record of solar system origin and early history.** The Moon’s composition, structure, and ancient surface preserve a record of early events: from the giant impact that produced the Earth−Moon system to ongoing bombardment as life on Earth emerged and evolved.

Science Theme 2: **Understand the geologic processes that shaped the early Earth that are best preserved on the Moon**. The Moon retains a record of processes that set the evolutionary paths of rocky worlds, including volcanism, magnetism, tectonism, and impacts.

Science Theme 3: **Reveal inner solar system volatile origin and delivery processes.** The Moon hosts water and other volatiles in its interior, across its surface, and in ice deposits at its poles, providing a record that may help constrain the origins of Earth’s oceans and the building blocks for life, as well as ongoing volatile delivery processes.

Human Exploration Recommendations

19-1: Conducting decadal-level science should be a central requirement of the overall human exploration program.

19-2: NASA should engage with the science community to 1) define scientific goals for its human exploration programs at the early stages of program planning; and 2) ensure scientific expertise in field geology, planetary science, and astrobiology in its astronaut teams.

19-3: PSD should develop a strategic lunar program that includes human exploration as an additional option to robotic missions to achieve decadal-level science goals at the Moon.

19-4: NASA should adopt an organizational approach in which SMD has the responsibility and authority for the development of Artemis lunar science requirements that are integrated with human exploration capabilities. NASA should consider establishing a joint program office at the Associate Administrator level for the purpose of developing Artemis program-level requirements across SMD, ESDMD, SpaceOps, and other Directorates as appropriate.

19-5: PSD should have the authority and responsibility for integrating science priorities into the human exploration plans for Mars.

19-6: NASA should develop a strategy to utilize opportunities to fly science payloads on commercial test flights and crewed missions to the Moon and Mars as such opportunities arise.

Human Exploration Recommendations

22-8: The development of the goals and measurement requirements for missions addressing both science and human exploration interests should be developed to meet the objectives of both communities.

22-10: NASA should continue to support commercial innovation in lunar exploration. Following demonstrated success in reaching the lunar surface, NASA should develop a plan to maximize science return from CLPS by, for example, allowing investigators to propose instrument suites coupled to specific landing sites. NASA should evaluate the future prospects for commercial delivery systems within other mission programs and consider extending approaches and lessons learned from CLPS to other destinations, e.g., Mars and asteroids.

22-11: PSD should execute a strategic program to accomplish planetary science objectives for the Moon, with an organizational structure that aligns responsibility, authority, and accountability.

22-12: The advancement of high priority lunar science objectives, as defined by PSD based on inputs from this report and groups representing the scientific community, should be a key requirement of the Artemis human exploration program. Design and implementation of an integrated plan responsive to both NASA's human exploration and science directorates, with separately appropriated funding lines, presents management challenges; however, overcoming these is strongly justified by the value of human-scientific and human-robotic partnerships to the agency and the nation.

22-13: Endurance-A should be implemented as a strategic medium-class mission as the highest priority of the Lunar Discovery and Exploration Program. Endurance-A would utilize CLPS to deliver the rover to the Moon, a long-range traverse to collect a substantial mass of high-value samples, and astronauts to return them to Earth.

LDEP strategic mission

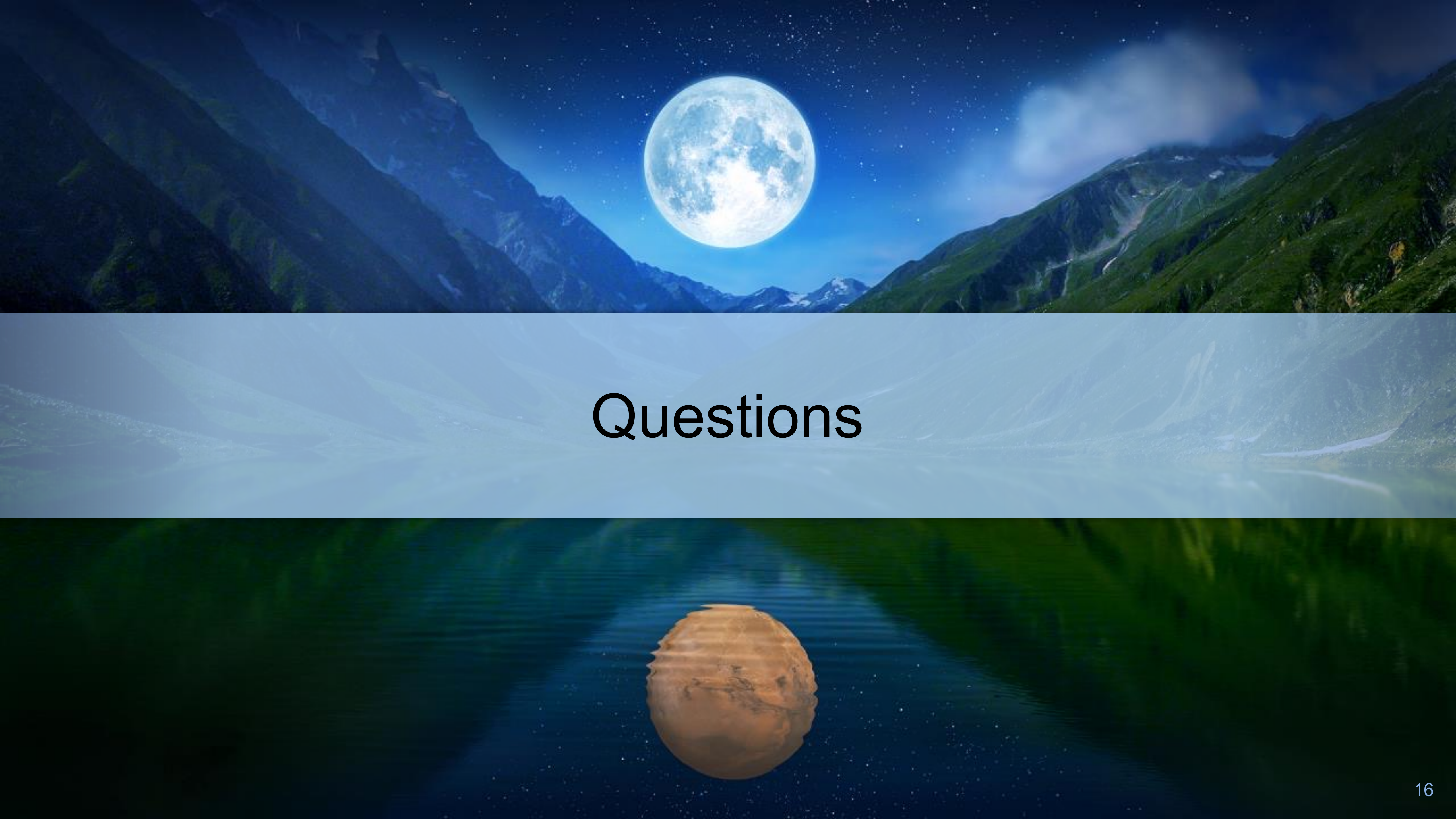
The committee prioritizes the Endurance-A lunar rover mission to address the highest priority lunar science, revolutionizing our understanding of the Moon and the history of the early solar system recorded in the most ancient lunar impact basin. The mission would:

- Utilize CLPS for delivery to the lunar surface
- Collect ~100 kg of samples in a ~10^3 km traverse across diverse terrains in the South Pole Aiken basin
- Deliver the samples for return to Earth by astronauts

Coordination with Artemis provides an outstanding opportunity to expand the partnership between NASA's human and scientific efforts at the Moon

- The result would be flagship-level science at a fraction of the cost to PSD

Endurance-A should be implemented as a strategic medium-class mission as LDEP's highest priority



Questions