National Aeronautics and Space Administration

2024 Moon to Mars Architecture

white paper

Priority Science Objectives Enabled through NASA's Moon to Mars Architecture

Introduction

Crewed lunar exploration, beginning with the Artemis campaign, provides NASA an opportunity to significantly advance humanity's understanding of the origin and evolution of the Moon, the characteristics of cislunar environments, and their impacts on biological systems. **NASA has implemented an objective-based approach to address high-priority and high-impact science questions.**

The agency documented this approach in NASA's Moon to Mars Strategy and Objectives Development document[1] and the objectives in the Moon to Mars Objectives document.[2] The National Academies' decadal reports,[3] which establish science priorities for NASA's Science Mission Directorate, were the source material for the Moon to Mars science objectives and further break down those objectives into strategic investigations and are summarized in Appendix C of the Mars Strategy and Objectives Development document.[1]

Collectively, these documents establish what NASA wants to achieve in exploring the Moon and Mars and why it's important. NASA's Moon to Mars Architecture, as defined in the agency's Architecture Definition Document,[4] outlines how NASA will achieve these aims.

Realizing these ambitions requires a multi-disciplinary approach that integrates the scientific community; NASA's mission directorates, centers, and technical authorities; international partners; academic institutions; and commercial entities. **United under the architecture framework, NASA and its partners can realize a safe and sustained campaign of robotic and human exploration that reveals the secrets of the universe for the benefit of all.**

Science Implementation Strategy

In response to decadal recommendations, NASA's Science Mission Directorate is developing its Implementation Plan for a NASA Integrated Lunar Science Strategy in the Artemis Era.[5] The document — currently in draft — provides a snapshot of how NASA intends to implement the science strategy outlined in the recent decadal survey in planetary science: *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032* (OWL).[6] While this initial implementation plan focuses on planetary science, the Science Mission Directorate plans to produce an additional document that includes science strategies drawn from SMD directorate-specific science disciplines' decadal surveys and associated Moon to Mars Objectives, as well as Human Research Program goals and objectives.

This white paper focuses on the current implementation plan for the OWL strategy. It overviews how NASA will integrate science discipline areas with architectural elements as they come online.

Science Implementation Challenges

The OWL, Moon to Mars Strategy and Objectives Development document, the National Academies' *The Scientific Context for Exploration of the Moon*,[7] the Lunar Exploration Analysis Group's *Advancing Science of the Moon*,[8] and other community documents identify six primary lunar science challenges shown in **Table 1**. Three are architecture-dependent; three will require the incremental buildup of knowledge over time through investigations across varied lunar surface destinations.

Table 1: *Six primary lunar science challenges. (NASA)*

	Lunar Science Challenges	Associated Lunar/ Planetary Science (LPS) Objective(s)[2]
1	South Pole-Aitken Basin Sample Return	LPS-1, LPS-2
2	Lunar Geophysical Network	LPS-1, LPS-2
3	Cryogenic Volatile Sample Return	LPS-3
4	Lunar Chronology	LPS-1, LPS-2
5	Lunar Formation and Evolution	LPS-1, LPS-2
6	Lunar Volatiles	LPS-3

Architecture-Dependent Challenges

The first three challenges are listed in the priority order established by the planetary science community. These are architecture-dependent challenges, meaning that they require specific architectural functions or elements to conduct scientific investigations that attain specific data.

South Pole-Aitken Basin Sample Return

For example, the OWL strategy recommended the Endurance-A mission concept[9] to accomplish South Pole-Aitken basin sample return. This concept would leverage Artemis sample return capabilities in tandem with a sample collecting rover.

The OWL strategy recommended that this concept "should be implemented as a *strategic medium-class* mission as the *highest priority* of the Lunar Discovery and Exploration Program." Conducting the mission as described requires long-lived, long-distance roving capabilities coupled with robotic sampling and large cargo sample return via crewed Artemis missions.

Lunar Geophysical Network

The OWL also recommended the Lunar Geophysical Network concept[10] as a high-priority mission under the New Frontiers Program.[11] This mission concept would require 6 to 10 years of concurrent operations on the lunar surface at more than four nodes spread across the lunar globe to gather data that would allow the scientific community to better understand the nature of the lunar interior and — more broadly — the geologic processes that evolve planetary bodies.

To enable the Lunar Geophysical Network concept, the lunar architecture would require long-lived surface assets (i.e., power and thermal control), global access, and communications and data transfer to both the near and far sides of the Moon.

Cryogenic Volatile Sample Return

An architecture capable of cryogenic volatile sample return would need to overcome numerous challenges in order to collect, transport, and curate the samples in a manner that closely mimics the environment in which they were collected. It would require cryogenic freezers and sampling techniques, large cargo return, access to permanently shadowed regions, curatorial, and analytical facilities capable of storing, processing, and analyzing cryogenic samples.

Progressive Exploration Challenges

Challenges four to six map directly to the OWL's science themes for lunar exploration (page 572)[6] and Moon to Mars Objectives LPS-1, LPS-2, and LPS-3.[2] These scientific focus areas will build upon themselves as NASA conducts progressively evolved investigations across the lunar surface, including in-situ measurements, geologic field observations, and sample return.

As noted in appendix C of NASA's Moon to Mars Strategy and Objectives Development document (page 46),[1] each science objective may be further decomposed down to strategic research topics and specific investigations. These investigations may create a multitude of architectural needs, including local/global access to diverse locations, sample return, in-situ analyses, deployment of diverse instruments, access to the lunar subsurface, and more.

Architecture Enables Science

NASA's Moon to Mars Architecture can enable all six of these science challenges through a mixture of robotic and human capabilities. While crewed operations and sample return are essential for many of the strategic research investigations identified in the guiding documents discussed above, some investigations may be carried out or supplemented by robotic missions, including NASA's Commercial Lunar Payload Services program,[12] directed or competed missions, or uncrewed human-rated platforms (e.g., Lunar Terrain Vehicle[13]). Thus, as the human architecture capabilities evolve and robotic mission opportunities continue, missions to non-polar destinations will allow science to address objectives that need global access to fully address specific objectives.

As the Moon to Mars Architecture progresses from the Human Lunar Return through the Foundational Exploration and into the Sustained Lunar Evolution segments, it will incorporate new assets on the lunar surface that will enhance mobility (e.g., Pressurized Rover[14]), habitation (e.g., the initial surface habitat element), and surface power. These assets will allow for a more robust scientific campaign in the lunar South Pole region, enabling more comprehensive and long-duration investigations into space biology, fundamental physics, physical sciences, and human research.

Conclusion

The Implementation Plan for a NASA Integrated Lunar Science Strategy in the Artemis Era[5] offers a strategic insight into the planetary science that NASA plans to achieve through robotic and crewed exploration. NASA will augment the implementation plan with an Artemis strategy designed to capture the agency's plans to achieve the science objectives for other scientific disciplines, as laid out in decadal surveys[3] and NASA's Moon to Mars Objectives.[2]

Science continues to drive NASA's architecture definition process. As the architecture evolves, NASA is realizing a strategy that will achieve groundbreaking science and revolutionize our understanding of the Moon, our solar system, and the universe.

Key Takeaways

NASA's robotic and crewed architectures are essential to addressing the scientific community-derived priority science objectives.

NASA's science priorities are established by a variety of sources, including the Moon to Mars Objectives and decadal surveys by the National Academies.

The Science Mission Directorate will produce an overall Artemis strategy document that includes science strategies for all directorate-specific science disciplines, as well as science defined by the Human Research Program.

The specific needs of scientific investigations contributing to NASA's science goals drive architecture definition efforts.

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