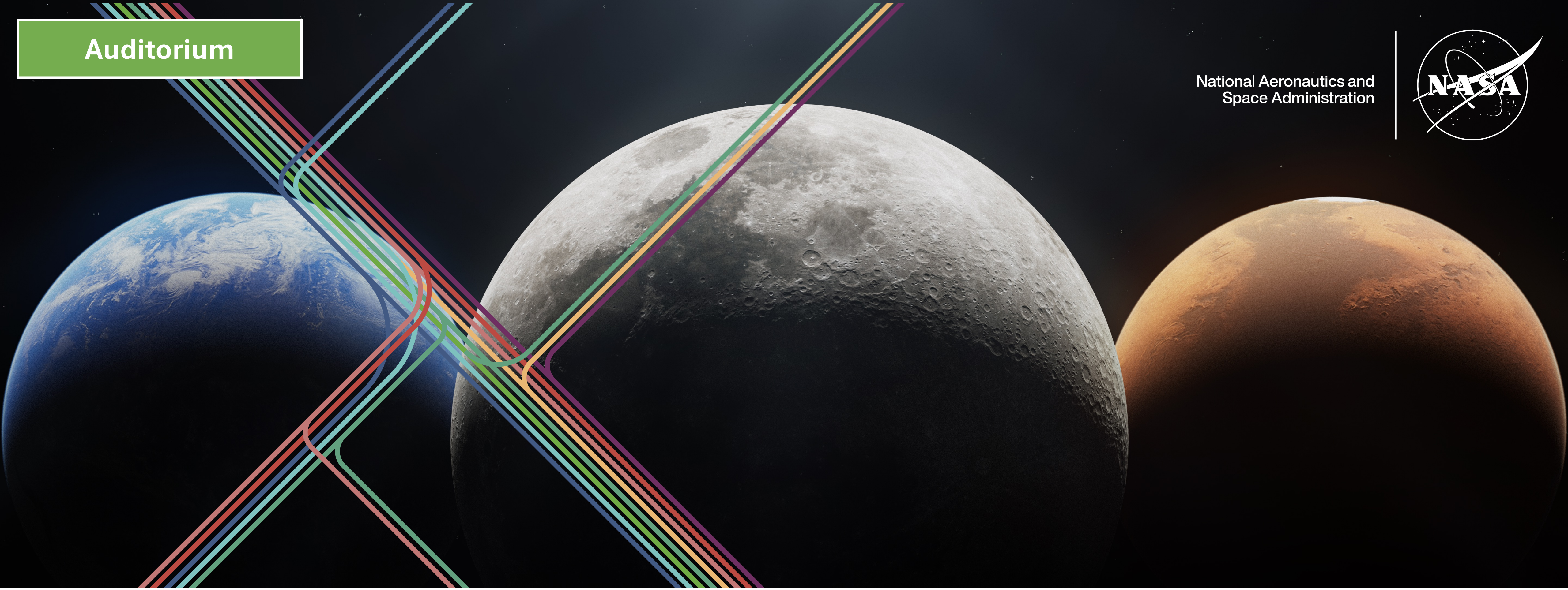

Human Exploration Enables Science: Science Mission Directorate White Papers

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White Paper: Humans in Space to Accomplish Science Objectives

National Aeronautics and Space Administration

National Aeronautics and Space Administration

2024 Moon to Mars Architecture

white paper

Humans in Space to Accomplish Science Objectives

Introduction

Teleoperated robotic probes are the primary means to conduct space science, but human explorers can enable or enhance particular types of science. Crewed missions are, of course, essential to investigations of the human body itself in space. Astronauts also possess complex problem-solving abilities and are adaptable to changing mission parameters. Additionally, human explorers inspire the public, engaging them in space science and discovery.

Astronauts can perform complex tasks that enable or enhance scientific investigations as researchers and operators, but also in building, integrating, and maintaining science instruments and experiments.[1] Astronauts can identify desired objects/specimens/situations, discover and react to unforeseen situations and events, and provide context of specimens and their curation. They are suited to tasks requiring complex movements, fine manipulation or dexterity, or hand-eye coordination. These include precision emplacement of scientific instruments, maintenance and calibration of scientific instruments, and operations of instruments to acquire measurements.

Sending human explorers to other worlds requires larger, more complex, and more costly systems than purely robotic missions. However, several space science community documents capture the particular advantages of crewed exploration to science. This white paper examines the scientific activities that may be enabled or enhanced by astronauts, specifically considering priorities identified by the National Academies of Science, Engineering, and Medicine; NASA; and the science community as a whole.

The Benefits of Crewed Science

Science enables exploration; exploration enables science.

In this white paper, *exploration* refers to missions by humans beyond low Earth orbit — crewed missions to the Moon, Mars, and other destinations — while *science* refers to the traditional space science disciplines (planetary science, astrophysics, heliophysics) as well as physics, biology, chemistry, and studies of human physiology, psychology, and human health countermeasures in space.

Astronauts on and around the Moon and Mars will conduct field work and fundamental research to answer longstanding planetary science questions and redefine our understanding of the solar system, the lunar and Martian environments, and the human body's response to those environments.[2]

NASA's Human Research Program focuses on developing methods to protect the health and performance of astronauts in space, and when they return to Earth. Currently, the International Space Station and Earth-based ground analogues conduct most of the U.S.'s space-based biological and physical science research.[3] The lessons learned aboard the space station and at ground analogues are informing planning for the Artemis campaign and beyond,[4] and their investigations will expand as the Artemis missions progress.

For space science disciplines, humans can enable more complex field science than robotic explorers. Humans demonstrably improve tasks that require complex movements, fine manipulation, and dexterity. Astronauts can empower precision emplacement, operation, maintenance, and calibration of scientific instruments in situ. Astronauts can identify objects, specimens, or situations relevant to a study area. They can react to evolving mission parameters, turning unforeseen events into opportunities for discovery.

2024 Moon to Mars Architecture Concept Review

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KEY TAKEAWAYS

- NASA's robotic and crewed architectures are essential to addressing the science 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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Key Science Community Documents

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Decadal surveys, NASA documents, and science community reports establish **priority topics for human exploration science**

Science Community Report:
National Research Council
The Scientific Context for Exploration of the Moon (2007)

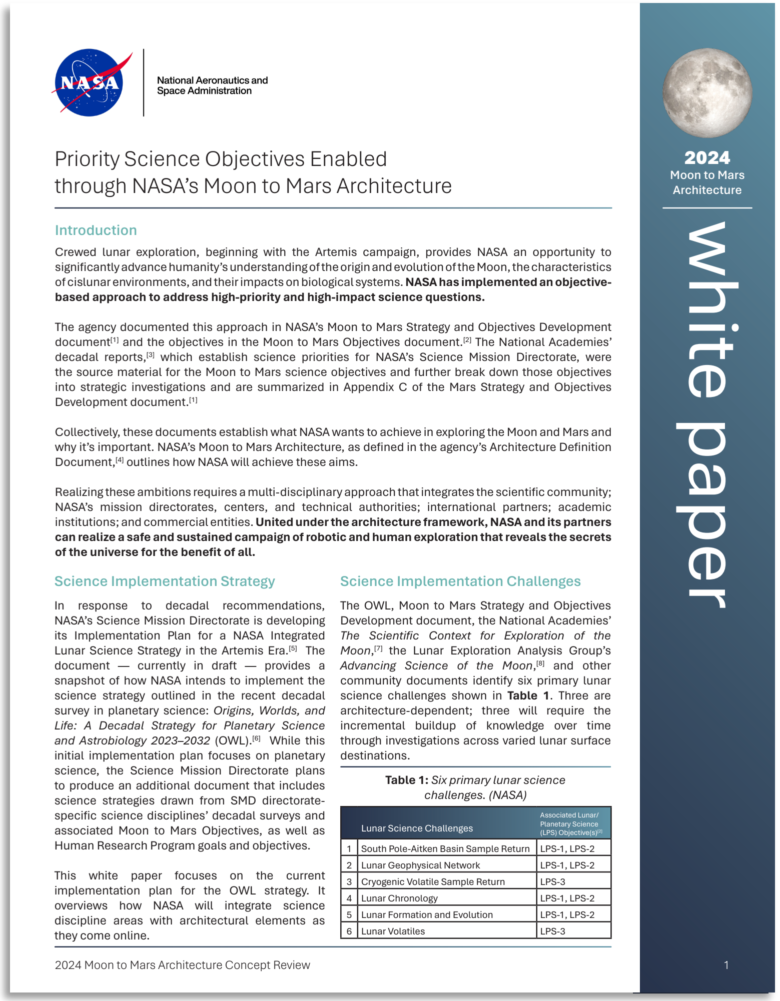
Science Community Report:
National Academies
Origins, Worlds, and Life (2022)

NASA Document:
Artemis III Science Definition Report

Science Community Report:
Mars Exploration Program Analysis Group
Report of MEPAG Tiger Team on Mars Human-Mission Science Objectives (2023)

White Paper: Priority Science Objectives Enabled though the Moon to Mars Architecture

National Aeronautics and Space Administration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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

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KEY TAKEAWAYS

- Crewed exploration offers particular advantages for ***accomplishing space science objectives***
- NASA's science objectives are informed by a variety of sources, many of which highlight the ***need for human explorers*** to achieve priority investigations and conduct groundbreaking science
- Reports from the space science community and NASA documents have consistently called for well-designed ***partnerships between human and robotic explorers***

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Science Implementation

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The Moon to Mars Objectives map to key ***science community priorities***; the Moon to Mars Architecture creates opportunities to conduct ***scientific investigations***

	Lunar Science Challenges from Science Community	Associated Lunar Planetary Science Objective(s)
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

Artemis III Science Team

National Aeronautics and Space Administration

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Artemis III Science Definition Report
https://go.nasa.gov/4g26l8f

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Summary

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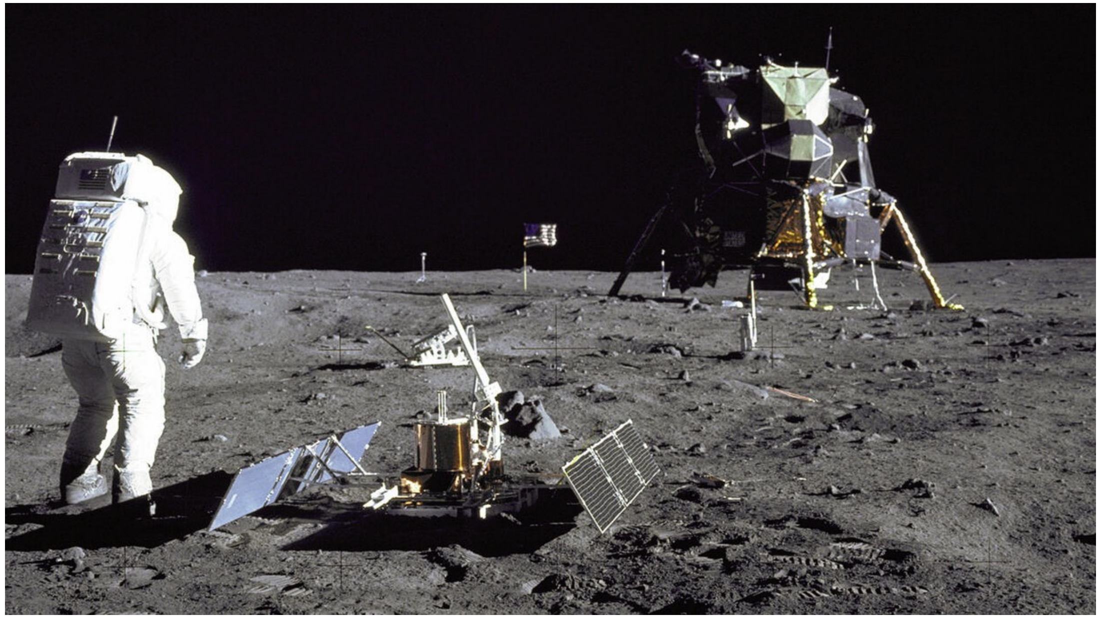
Key Takeaways

Crewed exploration offers particular advantages for accomplishing space science objectives.

NASA's scientific objectives are informed by a variety of sources, many of which highlight the need for human explorers to achieve priority investigations and conduct groundbreaking science.

Reports from the space science community and NASA documents have consistently called for well-designed partnerships between astronauts and robotic explorers.



Questions and Discussion

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Discussion Prompts

- How does your organization engage with the science community?
- What science community or NASA documents have been most helpful to your organization in understanding science priorities for Moon to Mars exploration?
- What aspects of Moon to Mars science remain unclear? What products or information would be most helpful to provide clarity to your organization?
- How does science help your organization enable exploration? How does having tangible NASA science objectives help your organization?

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NASA's Moon to Mars Architecture Website
www.nasa.gov/architecture