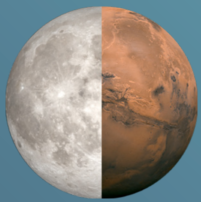
National Aeronautics and
Space Administration



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.

Benefits to Planetary Science

For planetary science, crewed missions offer particular advantages over robotic missions. Human explorers can understand the context and setting of a geologic sample, thinking independently to make sampling stops and adjusting traverse plans to take advantage of serendipitous sampling opportunities. They can collect the most valuable samples, which is essential given sample return mass constraints. NASA can build an optimal scientific sample return program by relying on the observations of well-trained astronauts aided by modern tools and real-time communication with scientists on Earth.

Experiments with complex deployments benefit from a human touch. Deployed experiments consist of autonomous instrument packages installed on the lunar surface, either robotically or by astronauts. These “suitcase science” packages enable a variety of geophysical and environmental investigations. They can also improve astronauts’ awareness of the survey area in real time, enabling them to collect more valuable samples.

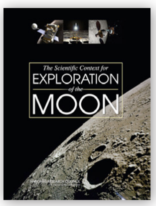
Geophysical and geochemical instruments can benefit from more interaction, such as precise siting, alignment, and strong coupling with the surface or subsurface. Humans can carry out this work and troubleshoot issues more effectively than robots, especially for sensitive instruments that require precise placement.[2]

Science Community Documents

Many documents produced by the science community outline the benefits of crew involvement in particular priority science campaigns. The following reports from the National Academies and other NASA science community study or analysis groups (e.g., Mars Exploration Program Analysis Group (MEPAG)) demonstrate how effective, efficient science can greatly benefit from crewed exploration.

Science Community Report: National Research Council [2007]

The Scientific Context for Exploration of the Moon



“Guidelines on how the lunar science concepts might be addressed with different possible elements of the VSE (Vision for Space Exploration) are provided in Table 4.1... column (e) provides examples of human fieldwork to be undertaken for each science concept. These are activities that specifically benefit from the abilities of humans present to carry out integrated or challenging tasks. Well-designed human-robotic partnership will be central to the success of the activities.”

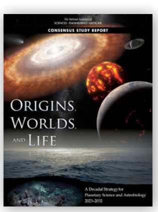
The Scientific Context for Exploration of the Moon[5] bases its guidelines for setting science priorities on those outlined in the National Research Council’s decadal survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy*.[6] Those are, in order of importance:

1. Scientific Merit
2. Opportunity and Realism for Achieving a Goal
3. Technological Readiness

Using these criteria, the report ranks science goals across a range of topics. These include the early Earth-Moon system, terrestrial planet differentiation and evolution, solar system impact record, and lunar environment. It also notes the associated human fieldwork needed to accomplish these objectives. The report calls for a well-designed complement of human and robotic capabilities to conduct diverse scientific investigations on the lunar surface.

Science Community Report: National Academies [2022]

Origins, Worlds, and Life



“The retrieval and return to Earth of a substantial suite of samples collected from diverse locations across [the South Pole-Aitken basin] represents an ideal synergy between NASA’s human and robotic exploration of the Moon. It would produce flagship-level science at the cost of a medium-class mission...Planetary Science and Astrobiology field studies benefit from an astronaut’s ability to observe sites in striking detail, recognize unexpected observations, analyze critically in real-time to create and refine conceptual models, and react to changing conditions, hypotheses, and interpretations while in the field.”

The National Academies of Science, Engineering and Medicine produce decadal surveys that recommend science and missions in each Science Mission Directorate science discipline over the next 10 years. *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032*[1] notes that astronauts’ ability to make sharp observations of geologic context and respond to unexpected real-time scientific sampling opportunities can enable the Artemis campaign to conduct breakthrough science.

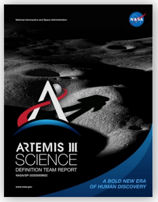
The report prioritizes three overarching science themes:

1. Solar System History
2. Geologic Processes
3. Water and Volatiles

NASA adopted these themes as the basis for the first three Lunar and Planetary Science Objectives documented in NASA's Moon to Mars Objectives.[7] The report details how a combination of human and robotic missions can accomplish new science associated with these themes.

NASA Document [2015]

Artemis III Science Definition Report

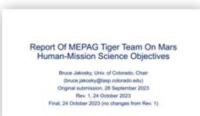


"With this notional program, mission planners can weigh operational constraints to develop a science implementation plan for the mission, including the collection of samples, deployment of instruments, and key in situ observations by the crew. Procedures and operations techniques, particularly for sample acquisition and curation, developed for the Artemis III mission will influence future Artemis missions...and future expeditions to Mars."

NASA's Science Mission Directorate provided planning input for Artemis III through the science definition team. Their report[2] builds on the seven overarching Artemis III science objectives by adding proposed goals and investigations. It also details how human explorers can enable field geology, sample collection and return, in situ and field science, and deployed experiments. The report offers recommendations for specific training, investigations, mass requirements, and data collection to maximize the science that Artemis III and follow-on missions can accomplish.

Science Community Report: Mars Exploration Program Analysis Group (MEPAG) [2023]

Report of MEPAG Tiger Team on Mars Human-Mission Science Objectives


Report Of MEPAG Tiger Team On Mars Human-Mission Science Objectives

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"Vital science can be accomplished by humans on Mars that would be much harder or impossible to do with robotic spacecraft; the capabilities of human missions have the potential to change both the objectives and the priorities — and can definitely accelerate the pace — for Mars scientific exploration."

NASA's Science Mission Directorate tasked MEPAG with identifying science objectives for the Moon to Mars Architecture's Humans to Mars segment. Their *Report of [the] MEPAG Tiger Team on Mars Human-Mission Science Objectives*[8] includes a discussion of the wide range of benefits that human explorers offer for observation and analysis on the Martian surface. These advantages are not limited to human missions to Mars — MEPAG's findings on the advantages of human explorers are easily applied to the Moon or other potential human destinations.

Summary

While teleoperated robotic probes play the major role in space science missions, human explorers can offer significant advantages to the exploration architecture. Astronauts' complex problem-solving abilities, adaptability, and creativity can help NASA to address high-priority science goals. Many of the documents and organizations that establish NASA's scientific objectives highlight the benefits of crewed exploration.

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.

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