

# DRAFT

National Aeronautics and Space Administration



## Science Strategy of the **MOON**

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## Introduction

On December 11, 2017, the president signed Space Policy Directive 1, a change in national space policy that provides for a U.S.-led “innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the Solar System and to bring back to Earth new knowledge and opportunities.” The effort will more effectively organize government, private industry, and international efforts toward returning humans on the Moon, and will lay the foundation that will eventually enable human exploration of Mars.

## NASA Science Role

For NASA, this policy provides critical strategic guidance for investments in human exploration, and technology investment, but also creates opportunity for NASA Science in three ways

- NASA Science will lead the way to the Moon through an innovative program enabled by commercial companies, the Lunar Discovery and Exploration Program.
- NASA Science will benefit from science opportunities enabled by investments in human exploration, such as the Gateway, and science enabled by humans on the lunar surface.
- Capabilities in NASA Science will help safeguard the journey to the Moon and beyond through providing information about the Moon and environmental constraints during the journey, including space weather.

To achieve an innovative and sustainable program of scientific and human exploration with commercial and international partners, NASA established the Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate. LDEP is a key component of NASA’s Exploration Campaign. The LDEP portfolio includes the establishment of commercial contracts for lunar landing transportation services; the development of lunar science instruments; the development of lunar SmallSats; continued operations of the Lunar Reconnaissance Orbiter; and the development of long-duration lunar rovers that will utilize commercially developed landers to get to the lunar surface. The payloads and services enabled by LDEP will address the nation’s lunar exploration, science, and technology demonstration goals, many of which are outlined in the National Academies of Sciences 2013 Decadal Survey: Vision and Voyages for Planetary Sciences in the Decade 2013-2022, the National Research Council 2007 Report: The Scientific

Context for the Exploration of the Moon, the LEAG Advancing Science of the Moon report and the NASA Strategic Knowledge Gaps (see <https://www.nasa.gov/exploration/library/skg.html>).

New and unique science observation vantage points will be borne from the development of the Exploration Campaign elements on and around the Moon. The Gateway platform that will be used by astronauts to access the lunar surface using reusable landers will be placed in a near-rectilinear halo orbit (NRHO). The Gateway provides new opportunities to conduct cross-discipline science with externally-mounted instruments, tele-robotics, and utilizing the communications and data relay capabilities of the Gateway.

Using existing capabilities and new ones enabled by the Gateway and future planned elements, NASA Science will provide critical support for the safety of our astronauts as they conduct exploration activities in deep space. Leveraging the accomplishments and on-going efforts of the space weather research and operational communities, forecasting and nowcasting capabilities will be expanded to ensure humans have the necessary situational awareness of potentially hazardous space weather events.

In addition to the Decadal Survey, the Committee on Astrobiology and Planetary Science (CAPS) released two reports in February 2019 that provided findings and conclusions concerning NASA's plans for achieving the lunar science and exploration goals associated with new space policy (SPD-1) and how new commercial ventures could provide "realistic opportunities to address meaningful lunar science and exploration objectives".

The CAPS concluded that LDEP is aligned with the decadal priorities and the portfolio "is a welcome development that has the potential to greatly benefit lunar science and could evolve into a program with large science return".

## Priorities and Principles

- Achieve the decadal survey objectives across the disciplines that can be addressed at the Moon or near the Moon
- Perform all research to the standards of NASA Science, including competitive selections, open data policies, etc.
- Enable competitive research through Mission of Opportunities or otherwise on or around the Moon
- Actively enable human exploration through providing situational awareness

## Science Goals

The science goals that can be achieved using a synergistic combination of robotic and human exploration assets span a multitude of science disciplines. The following science concepts which NASA Science will focus on include eight lunar science concepts, in priority order, from which were identified in the 2007 National Research Council report *The Scientific Context for the Exploration of the Moon* and additional science goals that support the heliophysics, astrophysics, and earth science decadal objectives.

1. Explore the history of the Solar System using the Moon
  - a. The bombardment history of the inner solar system is uniquely revealed on the Moon.
  - b. The structure and composition of the lunar interior provides fundamental information on the evolution of a differentiated planetary body.
  - c. Lunar volcanism provides a window into the thermal and compositional evolution of the Moon, and the terrestrial planets.
  - d. The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.
  - e. The origin of the Moon is inextricably linked to that of Earth
2. Explore Processes that shape Planetary Bodies
  - a. Key planetary processes are manifested in the diversity of lunar crustal rocks.
  - b. The Moon is an accessible laboratory for studying the impact process on planetary scales.
  - c. The Moon is an accessible laboratory for studying tectonism and seismicity on a one-plate planet.
  - d. The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
  - e. Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.
3. Use the Moon as a Platform for Novel and Unique Measurements
  - a. Unique solar observations and measurements can be acquired on and around the Moon, including solar coronal imaging, solar x-ray and gamma-ray spectroscopy, radio imaging of physical processes in the inner heliosphere, magnetospheric imaging, and in-situ plasma and solar wind measurements.
  - b. Early universe and cosmology observations are enabled by the radio-quiet far-side of the Moon.
  - c. Full-disk Earth viewing, observations at high temporal frequency, and coordinated observations with identical sensors located at GEO, LEO, and the Gateway will provide enhanced earth system science data.
4. Study lunar volatile science and explore the utility of lunar resources for exploration and beyond



- a. Work in the last decade has pointed to a lunar ‘water’ cycle, including primordial (interior) water, surficial water (linked to solar wind and meteorites), and polar (sequestered) water. Understanding the sources and sinks of these different components will not only help us understand how the Moon evolved and operates, but will also help us define the most appropriate architecture for utilizing lunar resources.

## Implementation Strategy

To achieve the exploration science goals, NASA Science will focus on a two-phased approach. The first phase will encompass those science investigations that can be achieved between now and the first human return mission to the lunar surface in 2024. The second phase will concentrate on science investigations beyond 2024. The following implementation strategies will be pursued to meet the science goals.

### Phase One: 2019-2024

- 1) Using the Commercial Lunar Payload Services (CLPS) contract, deliver science instruments on and near the Moon using commercial landers as early as 2020. As the CLPS program matures, we anticipate evolving from the current model where instruments are chosen largely based on their early availability to a model focused on science objectives to be addressed, for example the ability to have integrated suites of instruments delivered to a specific location on the lunar surface.

By 2024 we expect to have conducted investigations at the lunar poles using CLPS delivery services for our instruments. These missions will acquire the first direct measurements of polar volatiles, improving our knowledge of the lateral and vertical distribution, as well as their physical and chemical compositions. A south polar mission will provide new information on the geology of the South-Pole Aitken basin, the largest impact in the Solar System, and could potentially discover lunar mantle material.

Non-polar CLPS delivery services that transport critical science instruments to the surface can also make major scientific discoveries. Examples could include a mission to a lunar swirl where the first surface magnetic field measurement will help us to understand how these enigmatic features form; or a landing on the young volcanic features, such as Ina, so we can understand the volcanic evolution of the terrestrial planets.

Once suitable instruments exist, it will be possible to deploy long-lived seismometers, to build up a lunar geophysical network to learn about the Moon’s interior structure.

CLPS capabilities are likely to grow to eventually include sample return. Even simple “grab sample” sample return missions can yield decadal science, e.g. collect lunar regolith from the youngest lava flows on the moon, then return to Earth for age dating.

CubeSats or SmallSats could provide new orbital data, such as global mineral mapping, global elemental mapping, and improved volatile maps. These orbital assets could also provide a communication relay capability that would facilitate farside exploration by CLPS landers.

- 2) On an annual basis, release and award science instrument opportunities to fly on the CLPS-provided landers. In parallel, continue to fund the development of lunar instruments and technologies.

Instrument development will naturally be driven by what the community proposes. However, examples of instruments that could enable decadal science to be achieved include the development of long-lived seismometers, and also instruments that can do in-situ age dating.

- 3) Provide opportunities for science investigations utilizing the CLPS delivery services and Gateway platform by including both capabilities in Science Mission Directorate (SMD) announcement of opportunities (AO)

The science that is conducted on Gateway will be driven by peer-reviewed community submitted proposals. A science workshop held in 2018 identified the Gateway as an excellent enabler for a multitude of science disciplines. These included research in the areas of Space Weather, Earth Science, Astrophysics, Heliophysics and lunar and planetary sciences

- 4) Develop an international strategy to enable international partner contributions for conducting science on and around the Moon.

Several international space agencies have expressed both their commitment and desire to contribute to NASA's Exploration Campaign. NASA has been conducting and will continue to have discussions with the international partners concerning potential collaborations including participation on science teams, providing science instruments, and contributing landing, roving and orbiting capabilities.

- 5) Develop an exploration science mission plan for the first human return mission to the lunar surface to achieve the science objectives by:

- 5.1 Engaging the science community to develop ideas to conduct science on the surface with astronauts.

- 5.2 In coordination with the Human Exploration and Operations Mission Directorate (HEOMD), prioritize the science objectives and develop the necessary tools and commensurate training to conduct the science investigations.

- 5.3 Provide landing site intelligence and input into landing site selection discussions using data from previous studies and LRO

5.4 Consider the opportunities for potential pre-deployment of science experiments for the crews to set up.

5.5 Provide surface reconnaissance of the human landing site to help the planning of surface operations by the crew.

5.6 Organize a “science backroom” to provide real-time scientific guidance for astronaut surface science activities.

5.7 Ensure that curation is prepared to accept and curate new samples and provides input on the tools and sampling containers needed.

5.8 Organize a preliminary examination team (PET) to catalog and organize the returned samples to maximize their science value.

#### Phase Two: Beyond 2024

- 1) Continue using the Commercial Lunar Payload Services (CLPS) contract, including any enhanced capabilities that have been added to the contract (e.g., larger landing mass capability, mobility, orbiters, communications and data relay services, robotic sample return), to frequently deliver science instruments on and near the Moon using commercial delivery services. As the CLPS program matures, we anticipate evolving from the current model where instruments are chosen largely based on their early availability to a model focused on science objectives to be addressed, for example the ability to have PI-led integrated suites of instruments to a PI-selected location.
- 2) Continue an annual cadence of science investigation opportunities to fly on the CLPS-provided services through instrument calls, mission of opportunities (MO), and AOs.
- 3) As the Gateway platform evolves, continue to provide additional opportunities for science investigations utilizing the Gateway platform as enhanced capabilities become available.
- 4) Continually assess and revise, as needed, the international roadmap for partner contributions for conducting science on and around the Moon.



5) Develop exploration science mission plans for each of the human missions, following the first 2024 return mission, to the lunar surface by:

5.1 Engaging the science community to develop ideas to conduct science on the surface with astronauts.

5.2 In coordination with HEOMD, prioritize the science objectives and develop the necessary tools and commensurate training to conduct the science investigations.

5.3. Potential deployment of more capable systems, e.g. pressurized rovers, that enable to the crews to conduct more robust scientific exploration

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## Appendix A: Commercial Lunar Payload Services (CLPS) Providers

Astrobotic Technology, Inc

Deep Space Systems

Draper

Firefly Aeronautics, Inc

Intuitive Machines, LLC

Lockheed Martin Space

Masten Space Systems, Inc

Moon Express

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