National Aeronautics and
Space Administration

Artemis III Science Definition Team

Planetary Science and Astrobiology Decadal Survey 2023-2032

Barbara Cohen, GSFC, Committee co-chair

Nov. 20, 2020

Artemis III SDT Membership

Co-chairs
- Renee Weber, NASA MSFC
- Barbara Cohen, NASA GSFC
- Sam Lawrence, NASA JSC

Community consultants
- Amy Fagan, LEAG Chair
- Carlé Pieters, SSERVI Chief Scientist
- Juliane Gross, CAPTEM Lunar Sample Subcommittee Chair

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- ***Ex officio observers:*** Sarah Noble (PSD), Debra Needham (ESSIO), James Spann (HPD), Kevin Sato (BPS), Jake Bleacher (HEOMD), Julie Mitchell/Francis McCubbin (JSC curation), David Draper (OCS)

Charge to the Committee

- The Artemis III SDT was charted by Thomas Zubuchen for NASA SMD. The Committee was charged to:
  - Define compelling and executable science objectives for the Artemis III mission, the first human mission to the surface of the Moon in the 21st century.
  - Assess objectives for the mission to achieve the science goals articulated by NASA including investigation approaches, key surface science activities, and potential inputs into the concept of operations.
  - Submit a final report to the Planetary Science Division that contains prioritized science objectives for all aspects of the Artemis III mission, including sampling strategies and science goals and priorities of deployable instrument packages.
- Schedule
  - White Papers due September 8
  - First meeting September 10
  - Town Hall #1 September 14 (LEAG meeting)
  - Draft report released October 14
  - Town Hall #2 October 22
  - Public comments deadline October 26
  - Final report submitted November 13

Artemis III Science Definition Team Report

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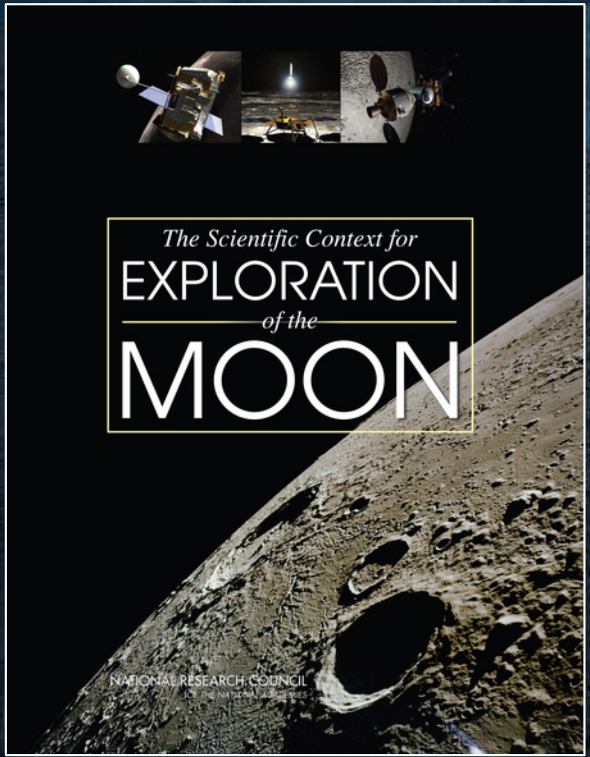
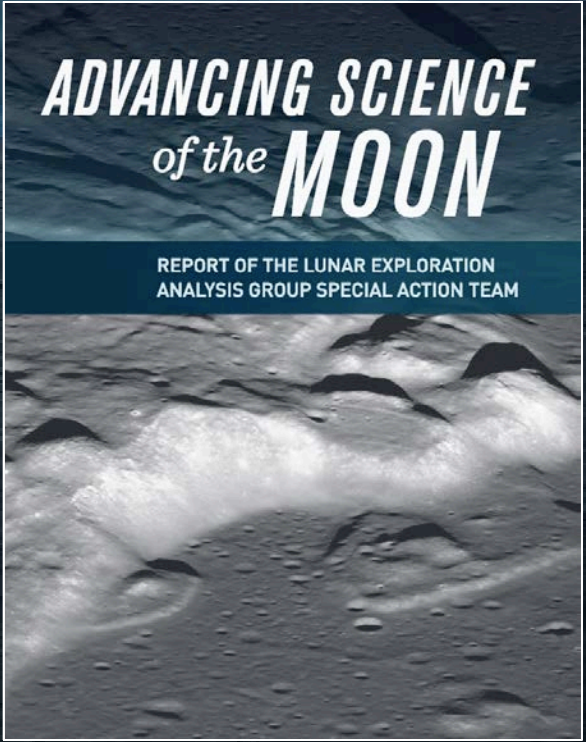
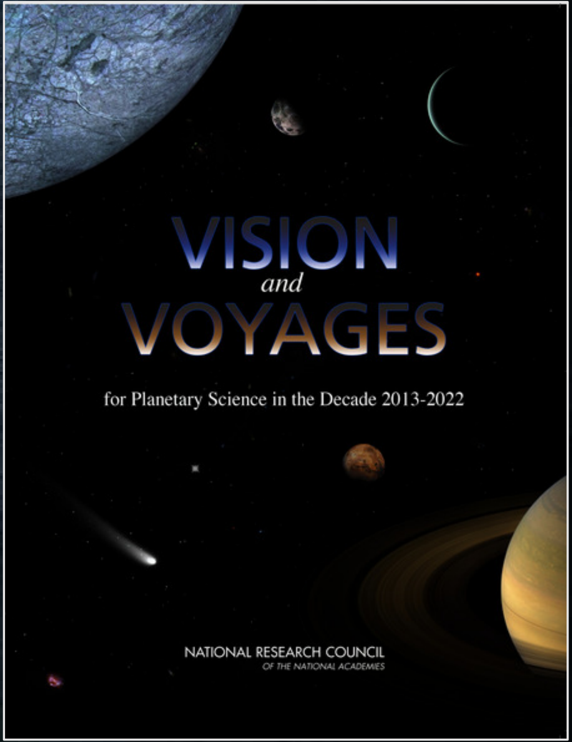
3. Overview of Guiding Community Documents







plus community-submitted white papers and draft report comments

4. Artemis Program and Architecture Summary

NextSTEP H: Human Landing System

Solicitation Number: NNH19ZCQ001K_APPENDIX-H-HLS

https://www.nasa.gov/nextstep/humanlander2

Table 11: Scientific Payload Delivery

Items	Qty	Mass (kg)	Storage Environment	Geometry	Length (cm)	Height (cm)	Width (cm)	Volume (m3)	Notes
Down Mass Total		**100**							
Science Equipment		80							
long axis of tools such as rakes or drive tubes		60-70	Unpressurized	box	145	165	50	1.2	Tools, cameras and sensors will remain on lunar surface
cameras or other sensors for use in the habitable environment	2	10-20	Pressurized	box	48	38	18	0.06	Dimensions are for each container, 0.06 for both
Sample Return Equipment*		20						0.16	total volume of all containers.
sample return container	2		Pressurized	box	48	30	20		Dimensions are for each container, 0.06 m3 for both
sample return collection bags	7		Pressurized	box	42	22	15		Dimensions are for each container, 0.1 m3 for all

*Sample Return Equipment would be empty during descent and used to carry lunar samples back to Gateway during ascent. During descent, they could be filled with other items. In the event that full return mass goal is not met and the full complement of sample return equipment is not needed, the remainder of the allocation of down mass and volume will be filled with additional science items.

4. Artemis Program and Architecture Summary

Table 10: Scientific Payload Return

Items	Qty	Mass (kg)	Storage Environment	Geometry	Length (cm)	Height (cm)	Width (cm)	Volume (m3)	Notes
Up Mass Total (Goal)		**100**							
Sample Return Equipment		20						0.16	total volume of all containers.
sample return container	2		Pressurized	box	48	30	20		Dimensions are for each container, 0.06 m3 for both
sample return collection bags	7		Pressurized	box	42	22	15		Dimensions are for each container, 0.1 m3 for all
Lunar Samples		80	Pressurized						would be contained in the Sampler Return volumes above
Up Mass Total (Threshold)		**35**							
Sample Return Equipment		9						0.07	total volume of all containers.
sample return container	1		Pressurized	box	48	30	20		Dimensions are for each container
sample return collection bags	3		Pressurized	box	42	22	15		Dimensions are for each container
Lunar Samples		26	Pressurized						would be contained in the Sampler Return volumes above

Note: Orion does not have specific storage to match the HLS sample return volume. Sample return mass to Eath via Orion might require mission-by-mission decisions on storage within Orion and possible considerations for different sample return container/bag design.

5. Artemis Science Objectives and Traceability to Science Priorities

- NASA HQ Artemis Plan laid out seven Science Objectives

  Objective 1: Understanding Planetary Processes

  Objective 2: Understanding the Character and Origin of Lunar Volatiles

  Objective 3: Interpreting the Impact History of the Earth-Moon system

  Objective 4: Revealing the Record of the Ancient Sun and Our Astronomical Environment

  Objective 5: Observing the Universe and the Local Space Environment from a Unique Location

  Objective 6: Conducting Experimental Science in the Lunar Environment

  Objective 7: Investigating and Mitigating Exploration Risks

- The SDT was charged with expanding upon science these Objectives. We chose to map science Goals (areas of research) down to Investigations (specific activities undertaken to address Goals).

5. Traceability and Prioritization

- Both traceability and prioritization drew on community-submitted white papers and our guiding documents.
- Each investigation was ranked on two independent criteria:
  - Compelling science (e.g., how fundamental is the investigation to making a significant scientific advancement)
  - Whether Artemis III presents an enabling opportunity given the architectural constraints

Artemis Science Objective	Science Goal	Science Investigation	Traceability	Science Priority	Enabled by Artemis III
1. Understanding Planetary Processes	1c. Volcanism: Partial melting, eruptions, flow sequence and compositions	Determine the compositional range and physical characteristics of pyroclastic deposits and vents.	LER Investigation-Sci-A-5B	H	N
2. Understanding the Character and Origin of Lunar Polar Volatiles	2a. Determine the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and with depth) of the volatile component in lunar polar regions.	**2a-7. Determine distribution of micro cold traps across lunar surface within illuminated regions**	SCEM 4a, 8d; VVM-SAT; ASM-4a, 4c; LER Investigation-Sci-A-3A; LER Investigation-Sci-A-3B	H	Y
3. Interpreting the Impact History of the Earth-Moon System	3b. Understand changes to the Earth-Moon bombardment rate	Determine the composition and source of impactors with time	LER Investigation-Sci-B-1C	M	Y

6. Candidate Program

- We constructed a notional program that would capture the highest-priority science for Artemis III and provide the greatest feed-forward to follow-on missions and the build-up to the Artemis Base Camp
- a cohesive program contains a mix of activities including
  - **sample collection and return**
  - ***in situ* and field science**
  - **deployed experiments**
- This candidate set of activities, taken collectively, would address the highest investigation priorities as well as a multitude of additional Investigations.
- A more detailed mission operations plan will need to be developed by NASA when HLS system capabilities, a landing site, and other architectural details come into sharper focus

6. Candidate Program: Samples

- Samples for Earth return would address a wide range of investigations – not just those that were highly ranked
- Committee recommends "traditional" sample collection (like rake samples) and advanced techniques like hermetically sealed and cryogenically maintained regolith core samples to preserve volatiles in soils
- Continued investment in terrestrial laboratory facilities, analysis techniques, and workforce are also needed to make the best use of the returned samples.

Sample	Type	*Sample mass (kg)*	N	Mass (kg)	N_{min}	$Mass_{min}$ (kg)	Investigations
Contingency	bulk	*1*	2	2	1	1	
Small clast	rake	*1*	4	4	1	1	1a-1, 1a-2, 1a-3, 1b-1 ,1b-2, 1b-3
Large clast	hand	*1*	15	15	4	4	1a-1, 1a-2, 1a-3, 1b-1 ,1b-2, 1b-3
Sealed core	drill	*4.5*	36	8	18	4	1f-1, 2a-6, 2b-1, 2c-1, 2c-3
Sealed surface	bulk	*1*	24	20	0	0	2b-1, 2c-1
Regolith surface	CSSD	*0.5*	2	4	1	2	1f-1, 2b-1, 2c-1
Totals				79		25	

6. Candidate Program: In situ and Deployed Science

- The HLS downmass allocation (60-70 kg) has to be first reserved for sample collection tools (rakes, core tubes, etc) and other items that have to be guaranteed to be with the crew
- Therefore there may be little mass for astronaut *in situ* tools like handheld instruments, or for crew-deployed experiments left on the surface
- Pre-delivery of such instrumentation is recommended to achieve the full spectrum of high-priority science. In particular, the Artemis III mission is an opportunity lost if the first of a series of geophysical and environmental network nodes is not deployed.

Measurement technique	Primary investigation(s)
1. *In Situ* Volatile Monitoring	2a-1, 2a-2, 2a-3, 2a-4, 2a-5, 2a-6, 2a-7, 2b-1, 2c-1, 2c-3, 2d-1, 2f-1
2. Deployed Environmental Monitoring	7m-1, 7m-2, 7k-1, 7k-2, 7l-1, 7l-2, 5b-1
3. Deployed Geophysics Instruments	1a-3, 1b-2, 2c-2
4. *In Situ* Geochemistry/Mineralogy	1a-1, 1a-2, 1b-1, 1b-2, 1b-3, 1f-1
5. *In Situ* Geotechnical Properties	1f-1
6. *In Situ* Geophysics (Traverse Instrumentation)	1a-3, 1b-2

7. Enabling capabilities

- **Power:** Long-lived deployed science experiments, which would address many of the highest-priority science Objectives identified here, require operations over time periods longer than the Artemis III surface mission. Several of the Investigations prioritized in this report would be maximally enabled by a long-lived power source and communications capability for deployed experiments
- **Pre-deployment:** Compelling and executable science investigations for the Artemis III mission based on the architecture as we currently understand it, but the ability to pre-deploy science assets using CLPS landers would dramatically increase the capability of early Artemis landings.
- **Mobility:** The Artemis III mission does not, as presently formulated, include availability of an unpressurized lunar rover. Crew mobility on the lunar surface is a key factor for enhancing the scientific Investigations outlined in this report.
- **Data availability:** existing lunar data should be readily and easily available to scientists and mission planners. Accurate landing and localization during surface operations are dependent on the accurate and robust use of existing data. Continued support for the PDS and LRO mission are vital.

9. Landing site considerations

- The scientific return of the Artemis III mission will be intrinsically linked to the Artemis III landing site.
- The SDT suggested the following factors be considered in the Artemis III site selection process in order to fully inform the ultimate selection of the Artemis III landing site, in addition to other physiographic parameters such as block abundance, crater frequency, and slope:
  - Sufficient illumination for long-duration solar power stations to enable long-lived surface experiments (if solar power is used);
  - Availability of a range of sizes of craters for radial traverses and sampling, which will inform our understanding of the impact process;
  - Comprehensive sampling which will inform our understanding of the complex geology of the landing site and its link to both surface and internal processes;
  - Accessibility of larger blocks to enable sampling of large crater ejecta;
  - Proximity and accessibility of mostly or permanently shadowed regions to understand volatile processes;
  - Proximity to multiple geologic units of differing time-stratigraphic age;
  - Proximity to geologic units that enable specific, high-priority investigations (SPA and PSRs)

Cross-directorate commonality

- Most science objectives for the Artemis III mission have constructive synergies with each other and with the objectives of other mission directorates
  - Importance of sample acquisition and handling
  - Importance of establishing long-lived experimental stations on the surface
  - Feed-forward aspects of Artemis III discoveries towards understanding lunar resource potential, commercial development strategies, and resource utilization efforts
  - Applicability of results from Artemis III towards future Artemis missions, the Artemis base camp, and exploration of other destinations (small bodies, Mars)
- In light of the importance of the Artemis III scientific results towards implementation of commercial resource extraction strategies and the construction of the Artemis Base Camp, efforts should be maintained to promote cross-directorate integration between the diverse stakeholders within NASA in HEOMD, SMD, and STMD, and in the external scientific, engineering, and commercial communities.

For the Decadal Panel’s Consideration

- Lunar polar volatiles
  - The Artemis III mission will be well-suited to making significant progress on many polar volatiles-related investigations of wide interest to the community
  - Particularly useful will be the potential capability for deep drilling and cryogenic sample return. Both good for science and an enabling investment in robotic missions to the lunar poles and other cold places like comets and Mars.
  - However, given the limited down- and upmass planned for the Artemis III mission, and mission constraints like not going into deep PSRs, there is lots to be done
- South Pole – Aitken Basin Sample Return (New Frontiers)
  - The Nov. 5 Community Announcement of the New Frontiers draft AO contained the following language: “Lunar South Pole-Aitken Basin Sample Return (pending Artemis landing site selection(s) and science objectives)”
  - From the SDT report: “Impacts melts or ejecta specifically from the SPA basin may be recognizable at a South Polar landing site on the basis of geochemical differences with other highlands rocks. However, missions that select landing sites directly for the purpose of returning samples from the interior of SPA (or other targeted basins) would have a significantly higher probability of addressing the science aims for this specific investigation, so steps made toward this investigation by Artemis III do not act as a replacement for other possible missions (human or robotic) to SPA (or other targeted basins).”
  - We strongly recommend that the Decadal Survey panel read the LEAG mission priorities paper, which advocates for the specific science of an SPA mission, along with missions to other key basins across the Moon, to help craft future New Frontiers priorities.

THE MOON ENABLES SCIENTIFIC EXPLORATION

A CORNERSTONE
For Solar System science and exoplanet studies

A NATURAL LABORATORY
To study planetary processes and evolution

A TRAINING GROUND
To learn how to conduct scientific exploration from a planetary surface, working synergistically with crew and robotic explorers

AN OPPORTUNITY
To use infrastructure and resources associated with human exploration to leverage support for autonomous scientific investigations