Science Objectives for Artemis III Crewed Activities

Authors: J.D. Stopar (LPI/USRA) and C.K. Shearer (LPI/USRA; University of New Mexico)
Co-signers: B.W. Denevi (JHU-APL)
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Artemis III will be the first human mission to the Moon in nearly 50 years, thus while there is a strong desire to advance beyond the Apollo exploration paradigm (e.g., by returning to the same area and building infrastructure over time), by necessity this first mission will be largely focused on learning to live and work again in the lunar environment and a polar environment unlike previous missions. This mission will also need to address objectives that pave the way scientifically and technologically for future, more complex missions and infrastructure construction. Information gained from this first mission will feed-forward to the design and strategy of future missions. Thus, it is reasonable to expect that the science strategy would also have a similar flavor, beginning with in situ characterizations, field studies, and/or sampling experiences that will inform future efforts.

The ***Artemis Science Plan*** *(released 5-2020)* identified the following capabilities for the program: EVAs (field geology) and sample collection (including rocks and boulders), access to PSRs either robotically or with crew, sealed cold sample containers, core tubes (regolith), dexterity to deploy instrumentation on surface, and characterizations of local environment. The science objectives of a two-person crew that will conduct "multiple walking excursions" (EVAs), will best scale to science objectives in the "middle" timeframe outlined in the **LEAG Roadmap** (*v. 2016*). This timeframe post-dates many orbital objectives and/or robotic surface objectives, but precedes longer and more complex human missions. The Artemis III's crew surface activities might include collection of lunar samples, field geology, and the use of surface instruments, either deployed or portable.

The overarching science objectives of Artemis are stated as investigate: #1) planetary processes past and present; #2) volatile cycles; #3) impact history of the Earth-Moon system; #4) record of the ancient Sun; #5) observe the universe; #6) experimental fundamental science; and #7) mitigate exploration risks to humans. This white paper identifies several science objectives that align with LEAG and Artemis objectives and that can be achieved by an early crewed mission as part of a longer-term strategy, at the same general region or site, while buying down risk to future human exploration. More challenging objectives that require pristine or complex sampling strategies, including Artemis #2 and #4, can be initially addressed but will likely require additional studies as capabilities, technologies, and infrastructure evolve. Artemis #1, #3 and #7 objectives, in particular, should be high-priorities for Artemis III.

Potential Science Objectives for a 2-person Crew with Multiple Short EVAs

- ***Understand any potential differences in lunar materials or processes between polar (both PSR and non-PSR) and non-polar regions*** *(*LEAG objs. Sci-A-3; A-4*)*. Characterizing any potential latitudinal or polar effects on space weathering is a high-priority science objective, particularly as it might be affected by increasingly retained abundances of volatiles near the poles (e.g., [1-3]). Furthermore, it is important to understand how impact gardening and bombardment affect the preservation and distribution of polar volatiles (e.g., [4]). Development and testing of technologies and techniques to study undisturbed delicate structures of the uppermost few millimeters of regolith in situ would also provide invaluable insight into adhesion and porosity of the regolith and their effects on remote observations [1].
- ***Ground truth orbital data and current geological understanding of polar regions*** *(*LEAG Sci-A-3; Artemis #3*)*. Field investigations during astronaut EVAs can focus on identifying samples for return that would enhance field study, as well samples appropriate for age dating (e.g., LEAG Sci-A-2). Depending on the final landing site, materials and ages from several major impact events might be identified, including at least one of the following: South Pole-Aitken (SPA) basin, Schrodinger basin, Tycho crater, Shackleton crater (e.g., [1;5-7]). Precise ages of specific impact events will contribute to improving: the overall geologic history of the south pole, knowledge of basin timing and stratigraphy, overall understanding of the sources and timing of impactors, placing constraints on the timing and flux of volatile delivery to the poles and their preservation, and understanding impact mixing processes and regolith formation and surface properties (e.g., [1;5-9]). Linking samples and their ages to remotely sensed data and field studies enrich context for all data sets. Individual samples can be placed within the planetary, regional, and local context and provide high-precision perspectives for orbital and in situ data.
- ***Critical new insights into lunar and planetary differentiation and structure*** (LEAG Sci-A-5; Artemis #1) Impact-excavated materials can also provide materials brought up from various depths, including mantle-derived SPA material and/or impact melt, as well as geochemical terranes far from the Apollo zone and PKT

(e.g., [10]). Recent sample analysis on Apollo materials have shown a cluster of 4.3-4.4 Ga ages for mare source regions, ferroan anorthositic suites, urKREEP, and Mg-suite rocks (e.g., [11-13]). These young ages might reflect differentiation and the global lunar magma ocean (LMO), or a more regional event (such as a large impact or cumulate overturn) that affected the PKT after LMO solidification. Samples from outside the PKT would allow testing of these different interpretations, as well as establish the chronology and character of the farside crust and mantle (including LMO).

- ***Ground truth expected volatile abundances within the uppermost regolith in PSR and non-PSR soils*** (LEAG Sci-A-4). H_2O is a crucial ISRU resource and is present along with other chemical species in some polar soils (e.g., [14]). In situ measurements would test pre-mission expectations of lunar volatile abundances and distributions along the EVAs, complementing any similar data from VIPER or other robotic missions.
- ***Inform future sampling strategies, enhance scientific analysis of future samples, and buy down risk (****Artemis #7****).*** We do not currently fully understand how polar volatile-bearing regolith will react to sampling methods and transport (LEAG Sci-A-2). From in situ experiments, we might learn: volatile abundances, forms, and composition; their hazards; effects of sampling and transport; illumination and temperature effects; chemical reactions; and degassing pathways. We would also gain insight into how to detect degradation or contamination of future returned surface volatile-bearing samples (e.g., [15]). In situ investigations might include deployable sensors and instruments to measure degassing from disturbed polar soils as a function of time and temperature. Disturbed soil samples might be returned to Earth, or cached for future study/return, if determined safe or feasible.
- ***Understand the environmental impacts of lunar exploration.*** Artemis III might deploy a sensor network to monitor effects of surface activities (LEAG Sci-A-1).

Science from Artemis Returned Samples

To achieve the science objectives above, samples returned (e.g., core, scoop, rake, and/or sieve collections) do not necessarily need to preserve pristine polar volatiles (i.e., samples could be degassed before loading into spacecraft). The precision, types of materials returned, and science measurements that can be met by conventional types of sample collection techniques are well understood from the Apollo experience as well as more recent mission concept studies (e.g., MoonRise and ISOCHRON) [6;16-17]. The sampling experiences of Artemis III can inform later strategies (LEAG Sci-A-2). For example, along EVAs, astronauts could investigate small-scale and localized cold traps (beneath large boulders, in small craters), in addition to larger PSRs, with instrumentation to study and interact with these localized environments. While returning polar volatiles is of extremely high value, owing to the short development cycle for Artemis III, if it is determined infeasible to return pristine polar volatile samples, more conventional regolith and rock samples remain critical to improving understanding of many key lunar and planetary processes beyond what can be accomplished with in situ or orbital measurements (Artemis #1), including LEAG Sci-A-5: differentiation; Sci-A-6: volcanism; Sci-A-7: impact processes; Sci-A-8: geologic history of the Moon; and Sci-A-9: formation of the Earth-Moon system.

Proposed landing site/mission requirements to achieve objectives

The following are required to achieve the above science objectives: 1. access to non-PSR and PSR locales (ideally with a range of expected near-surface H_2O abundances); 2) capability to return regolith and rock samples for studies of impact processes, lunar geologic history, and space weathering processes (without a strict need to necessarily preserve pristine volatile content); 3) be able to perform soil sampling and monitoring of disturbed soils in a PSR and non-PSR and observe changes over timescales of seconds to days; 4) in situ studies of regolith and rocks on scales down to a millimeter; and 5) monitor the environment around the landing site.

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