**THE ARTEMIS LUNAR EXPLORATION PROGRAM: A PLANETARY SCIENCE EXPLORATION PERSPECTIVE.**
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**I. Introduction:** The goals of the Lunar Surface Science Workshop (LSSW) are to provide "input and early integration of science into the exploration architecture…essential to maximizing the science return from the Artemis missions"…which are to place "human beings…on the lunar surface near the Moon's south pole, and…create a sustained human presence on the lunar surface". The intent of the workshop is "to provide an open forum for the presentation, discussion, and consideration of various concepts, options, capabilities, and innovations to advance scientific discovery on the lunar surface." Here we seek to provide a *planetary science* perspective on these LSSW goals.

**II. Fundamental Goals & Objectives:** In order to frame a fundamental *planetary science* perspective and strategy, we ask: Why, Where, How, and When.

**1) Why?:** What is the legacy, the long-term impact of our efforts? Apollo revealed the Earth as a planet, showed the inextricable links of the Earth-Moon system, and made the Solar System our neighborhood. We now ask: What are our origins and where are we heading?: We seek to understand the origin and evolution of the Moon, the Moon's links to the earliest history of Earth, and its lessons for exploration and understanding of Mars and other terrestrial planets. A basis for our motivation is the innate human qualities of curiosity and exploration, and the societal/species-level need to heed Apollo 16 Commander John Young's warning that "Single-planet species don't survive!". These perspectives impel us to learn the lessons of off-Earth, long-term, long-distance resupply and self-sustaining presence, in order to prepare for the exploration of Mars and other Solar System destinations.

**2) <u>Where?</u>:** The combination of Transformative Lunar Science (TLS) questions [1] and exploration operational requirements compel us to explore the South Polar Region (SPR) of the Moon. The *scientific goals* are clear: 1) What is the origin, nature and abundance of polar volatile deposits and what do they tell us about internal and external sources and volatile history? [2-3] 2) What is the nature, composition and age of the South Pole-Aitken Basin (the largest known impact basin on the Moon) and its ejecta, and how does this inform us about the lunar interior, lunar chronology, the bombardment history of the Moon, and the dynamics of the early Solar System? [4-5] The *scientific objectives* are: 1) to explore, document and sample volatile deposits in permanently shadowed and stratigraphically related regions. 2) To explore, document, sample and date SPA ejecta deposits and pre-SPA crustal materials. The *exploration operational goals and objectives* are also clear: 1) Define regions that optimize the realization of the scientific goals and objectives. 2) Define regions that provide continuous or near-continuous solar illumination to provide sufficient power to survive lunar night and establish a long-term presence. 3) Explore the SPR to establish the nature, abundance, mode of occurrence and "grade" of candidate volatile deposits. 4) Characterize the surface physical properties and trafficability in order to optimize scientific and operational activities. 5) Prepare for dedicated human and robotic exploration missions to other parts of the nearside and farside of the Moon and on Mars. 6) Test nascent technologies required for sustained human Moon/Mars presence (habitation, energy storage, radiation protection, ISRU).

**3) <u>How?</u>:** Necessary is the development of a conceptual and operational framework built on a firm foundation of existing knowledge and data, and inclusion and optimization of new ideas and technologies. This will permit us to continue the exploration of the Moon to the next logical stages following the remarkably successful Apollo Lunar Exploration Program and the multiple followon orbital/surface robotic missions that have set a firm foundation for the next stages of human-robotic exploration. What are some of the pillars of this foundation? a) <u>Science and Engineering Synergism (SES)</u>: Apollo was successful because of the shoulder-to-shoulder engineer-scientist work culture that developed during the program, and enabled longer-duration stay times and EVAs, significant mobility, additional equipment and experiments, and significantly greater sample return. SES requires concentrated and dedicated effort, but the rewards are clear, essential and *synergistic*. SES maps out into operations at all levels of mission planning and execution. b) <u>Human-Robotic Partnerships</u>: Exploration is not a technique contest, but a partnership. The US sent 21 robotic missions to the Moon prior to the Apollo 11 landing. The key to continual success lies in developing an architecture that complements and optimizes robotic and human capabilities. c) <u>Exploration Guidelines</u>: Define human and robotic strengths and weaknesses, and optimize exploration plans from the beginning. Longer-term stays will mean both increased interactions with Earth and exploration independence of the Astronauts. Avoid "creeping determinism" [6], and encourage the Apollo $T^3$ approach (Train 'em, Trust 'em and Turn 'em loose). Science and operational goals and objectives require exploration of broad areas: build in extensive Apollo LRV-like mobility from the beginning (Fig 1). New remote-sensing technologies will enable more in situ characterization, sample analysis and selection but Earth laboratory technology advances will always outpace in situ analysis. Build in the ability for significant sample return mass from the beginning. d) Exploration Architectures: Individual missions should be viewed as integrated elements in an operational strategy and architecture that is designed to accomplish the overarching goals. Candidate elements include: I) *Precursor* (What do we need to know before we send humans?). II) *Context* (What are the robotic mission requirements for final landing site selection and regional context for landing site results?). III) *Infrastructure/Operations* (What specific robotic capabilities are required to optimize human scientific exploration performance?). IV) *Interpolation* (How do we use robotic missions to interpolate between human traverses?). V) *Extrapolation* (How do we use robotic missions to extrapolate beyond the human exploration radius?). VI) *Progeny* (What targeted robotic successor missions might be sent to the region to follow up on discoveries during exploration and from post-campaign analysis?). The way in which the NASA Commercial Lunar Payload Services (CLPS) Program complements the Artemis Program can be readily viewed in this manner. e) Flexibility and Adaptability: *Science is the exploration of the unknown.* From a planetary science perspective, we currently have a fundamental baseline of information about the Moon that enables us to define TLS questions and propose exploration solutions. Each new discovery will define new questions and the exploration architecture should be flexible enough to adapt and accommodate this evolution (as was done with each succeeding Apollo mission).

**4) When?:** Temporal goals for accomplishment of key exploration events and milestones are important for motivation and decision making. Integrated exploration architectures are modular long-term strategies and thus subject to national and international events and should be designed to adapt to these. International coordination and cooperation are essential to the scientific and political success of exploration and should be appropriately cultivated and embedded.

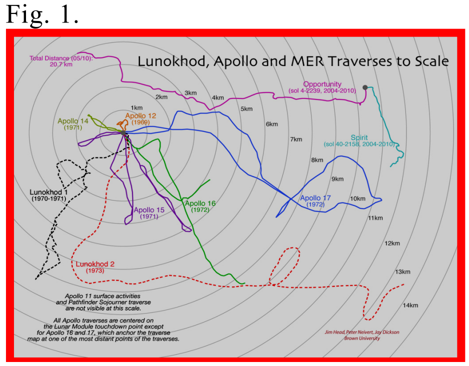
**III. Data Requirements:** In addition to the significant baseline of scientific and engineering data in hand, new data and re-analysis of existing data are essential. The NASA Lunar Reconnaissance Orbiter (LRO) is currently optimal for this due to its near-polar orbit and consequent high density of data essential for exploration in the SPR. Topography, slopes, roughness, illumination-shadowing and reflectance (LOLA) [e.g., 7], high resolution imaging, stereo DTMs, and illumination (LROC), and roughness/physical properties data (Diviner) are among the key resources for science and exploration planning. New dedicated experiments and orbital/surface missions will complement and supplement these data.

**IV. Site Selection and Traverse Planning Guidelines:** Landing site selection always involves a balance of mission goals and objectives, and landing and operation safety and success. Science and Engineering Synergism (SES) is the key to this success as demonstrated during Apollo, and should be implemented throughout the exploration architecture. The same principles apply to traverse planning. SES ensures that the science and engineering data needed for key decisions will be available and that decisions will be optimized. SES also optimizes the long-term goal of lunar base siting: for example, Mons Malapert, an inviting target for base siting due to favorable illumination and power, has been shown from LRO LOLA/LROC data to be difficult to traverse with Lunokhod and Apollo LRV-type vehicles [7]. Furthermore, new discoveries concerning the location and "grade" of polar volatile deposits will dictate adaptive lunar base locations.

**V. Surface Operations:** Scientific, engineering, operations and exploration activities on the surface in the SPR will require integrated and flexible planning. New instrumentation and technologies will significantly enhance exploration planning and accomplishment of goals. For example, a multispectral laser reflectometer on the surface can confirm the presence of water ice and its location and distribution on scales relevant to human operations (cm to m), and be used to direct sampling and ISRU efforts undertaken by Artemis astronauts, a capability [9] highly complementary to orbital approaches. The parallel operations of robotic rovers, CLPS payload deliveries, and human activities will require continuous engineering and science operations/analysis centers on Earth. Lessons from the ISS should be incorporated, while also recognizing the human exploration capabilities of the Astronauts on the Moon [6].

**VI. Conclusions:** At the end of the first 60 years of the Space Age, we have entered a new era of human/robotic exploration partnerships for *planetary science* that will enable us to build on the lessons of past successes and incorporate new concepts, innovations and technologies "to advance scientific discovery on the lunar surface", to Mars and beyond.

Fig. 1.

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