SCIENCE LEVERAGED BY A HUMAN LUNAR PRESENCE.

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Introduction: In the next decade, humans will be traveling back to the Moon and landing at the lunar south pole. This endeavor drives a new era of scientific investigation of deep space, building on the foundation set during the Apollo program and propelling human spaceflight forward towards further discovery. These missions will enable crews to support NASA's key science goals through direct lunar surface exploration, specifically the 2013-2022 Planetary Decadal Survey which identifies a prioritized set of cross-cutting themes focused on 1) building new worlds, 2) planetary habitats, and 3) workings of the solar systems [1].

Lunar Science Investigations: A human presence at the lunar south pole provides planetary scientists and geologists an invaluable avenue for making on-site observations in 'real-time', displaying and communicating science targets with the flight crew based on in-mission surface and sub-surface high resolution imagery capture, and conducting expansive lunar volatiles sampling tasks and analysis through astronauts residing directly at the Moon. These samples will be carried back to the Gateway on the Human Landing System (HLS) vehicle, which has a threshold requirement of 35 kg for scientific return mass, and a goal requirement of 100 kg [2]. The samples would then be returned to Earth with the crew in Orion, which can be configured to support this return mass. These surface sortie missions provide minimally time-delayed responses between astronauts and the mission operations team, allowing for EVA data collection and feedback to occur fairly rapidly. By implementing efficient surface sortie navigation and tasking with opportunity for in-mission addition and/or recalibration of surface objectives, humans on the surface will optimize the mission's scientific return. A human exploration initiative initially confined within a 2 km radius relative to lunar landing sites will allow for the early definition of the local surface and sub-surface terrains. Understanding, analyzing, and characterizing site characteristics, including crater and/or lava channel/tube accessibility as well prospective lunar resource opportunities, will provide NASA a roadmap for establishing a sustainable lunar surface infrastructure for future crewed missions. With the support of lunar rovers, humans can then begin to explore an expanded region, 10 km or greater, outside a lunar landing site. By accessing the cold and heavily cratered regions of the lunar south pole, astronauts will be capable of collecting (via directly or through the use of robotics) lunar volatiles samples from areas of interest within the polar regions capable of housing water ice deposits (e.g. meteoric impact sites, lava pits, permanently shadowed regions etc.). Visits to these locations and others will include the capturing of high-resolution imagery, along with on-site characterization of unexplored lunar landscapes, to further define the lunar geologic scale through in-situ measurements and analysis. This capability also lays the path for collecting other lunar science data, including the transient phenomena between the lunar day and night.

Fig. 1: Astronauts on EVA conducting lunar surface science near the Lockheed Martin lunar lander. [3]

Exploration Maturation: In order to design for an extended lunar surface presence, exploratory investigations can be performed to encompass human-directed and observed implementation of advanced science experiments within the lunar environment, in coordination with investigations occurring in orbit on the Gateway [4]. Payload experimentation and demonstrations, specifically those focused on the definition and maturation of surface and orbital lunar-based assets, can include topics in the fields of ISRU (testing excavation, processing, filtration, and storage of volatiles technology) [5], fluids transfer (for future ISRU and cryogenic fueling capabilities, etc.), materials exposure testing (to advance dust mitigation technologies, lander and surface or sub-surface infrastructure design, etc.), in-situ manufacturing and assembly (for testing regolith base materials with additive manufacturing systems), power systems (to advance technology maturation in power beaming, solar concentration, etc.), and other areas to support future deep space exploration.

As the crewed surface missions proceed, additional capabilities for longer surface stays such as habitats, and for more mobility such as pressurized rovers, will become available. Maturation and advancements in spacecraft design, from current vehicles in production to future concepts in development, can be aided by the invaluable science observed, collected and delivered by a human presence on the Moon. Understanding the deep space environment while residing on the lunar surface (soil characteristics, surface traversability, sub-surface accessibility, etc.) can strengthen our overall knowledge of the Moon for various deep space surface and orbital assets. One example is the Orion spacecraft, NASA's human-rated deep space exploration vehicle, which is planned to support lunar sample collection and return. With astronauts on the Moon supporting in the advancement of extraterrestrial sample caching at the lunar south pole, knowledge gained from the capture, handling, storing and deployment of these samples into lunar orbit will help to evolve Orion, Gateway and other crewed spacecraft in supporting these in-space activities. Other deep space vehicles supported through a human-derived lunar science campaign includes science payloads, robotics, lunar rovers, habitats (surface and sub-surface), ISRU plants, landing pads, the Commercial Lunar Payload Services (CLPS) landers including the Lockheed Martin McCandless lunar lander [6], power generation systems, roadways and general surface infrastructure.

With missions on the surface extending beyond those durations experienced during Apollo, humans returning from the Moon will serve a critical role in the future prognosis of the long-term biological impacts while residing on the lunar surface. Understanding the effects of lunar dust intrusion on and within the body (e.g. ocular, cardiac, respiratory, etc.) will support the future implementation of dust mitigation, filtration and removal technologies/services. On the other hand, the effects of high-dosage exposure from space radiation on humans (e.g. vision impairment, organ/tissue effects, nervous system functions and disorders, genetic mutations, etc.) are of significant concern that will require increased scrutiny over its mitigation and implementation for deep space. Humans residing on the Moon face a more serious issue from space radiation, particularly Solar Particle Events (SPEs), compared to residency onboard the International Space Station. Astronauts in Low Earth Orbit typically experience annual radiation exposure rates at 200-400 mSv, while humans on the Moon may see SPE exposure as high as ~1 Sv [7].

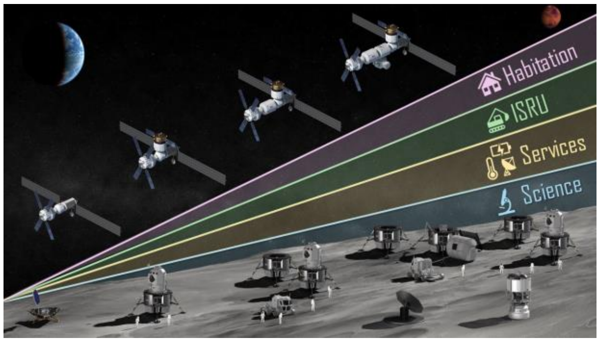

Fig. 2: Both the Gateway and Lunar surface infrastructure will evolve and expand over time. [8]

Summary: Establishing a sustainable lunar presence relies significantly on the exploratory tasks and objectives achieved through human surface exploration of the Moon. Understanding its surface and subterranean makeup, as well its chemical composition and distribution, will allow NASA to definitize the optimal sites and resources allocated to support a permanent lunar presence. In addition, by answering key science questions through human exploration on the surface, NASA and the technical community can define the phenomena of our species' origin and its evolution within the solar system.

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