Leto Mission Concept for Green Reconnaissance of the Marius Hills Lunar Pit. S. W. Ximenes[1], A. Shaffer[2], D. M. Hooper[3], R. Wells[3], [1]XArc Exploration Architecture Corporation, 110 E. Houston Street, 7th Floor, San Antonio, TX 78205, [2]Texas A&M University, [3]WEX Foundation. (sximenes@explorationarchitecture.com).

Introduction: Lava tube caves are potentially important sites for long-term human presence on the Moon because they provide shelter from surface hazards, including micrometeorites, radiation, extreme temperatures, and dust. The discovery of a lunar lava tube cave opening at the bottom of the Marius Hills Skylight or Pit (Fig. 1) is compelling motivation for robotic and eventually human exploration missions to this site for in situ investigations and site assessments to determine habitation and lunar resources viability.

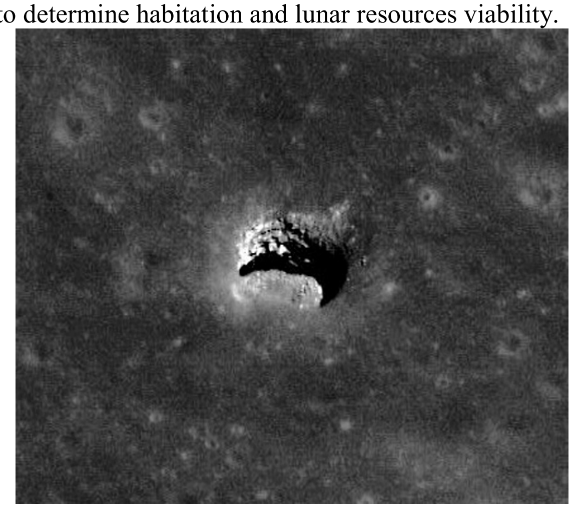

Figure 1. MHP (NASA/GSFC/Arizona State University)

Our Lunar Ecosystem and Architectural Prototype (LEAP2) program uses the Marius Hills Pit (MHP) as a case study for determining required technology development needed to access these types of planetary features for exploration and eventual human settlement. These planetary features serve as the basis of our LEAP2 space exploration technology development projects, and also as a framework for our sponsored Lunar Caves Analog Test Sites (LCATS) space-STEM education programs for project-based student learning performance [1].

Green Reconnaissance: When exploration begins and first contact is made, it will be important to preserve these pristine cave-like environments from the employed reconnaissance technologies. This concept of preservation or "green reconnaissance" for in situ exploration of pristine lunar environments was introduced by Exploration Architecture Corporation (XArc) as a challenge to safeguard the science inherent in such environments during their first contact by human and robot explorers and their associated equipment, systems, and spacecraft [2]. Our objectives are to define a green reconnaissance approach and illustrate a robotic reconnaissance first contact mission. Accordingly, employed "green reconnaissance" exploration technologies would include such criteria as:

- minimizing site contamination from lunar lander blast ejecta and fuel exhaust plumes
- study, modeling, and measurements of the outgassing of space materials
- study, modeling, and measurements of the water vapor signatures from astronaut life support systems
- emphasizing science protection protocols for descending into the pit and entering the cave for the first time in a manner that helps preserve the fidelity of the science inherent in that pristine environment.

Longer-term development activities of these sites for potential outposts, settlements, or surface mining operations would eventually see a relaxation of science protection protocols.

For the MHP example, green reconnaissance is defined as descending into the pit and entering the sublunarean void for the first time in as unobtrusive a manner as possible in order to preserve the fidelity of the science inherent in that environment. This "preservation-first" approach can be considered a type of planetary protection. A green reconnaissance strategy seeks to minimize site contamination from the lunar lander blast ejecta and exhaust plume. The most straight-forward solution to lander contamination is by landing behind natural protective features—terrain or topographic barriers—at a protected distance from the pit. We suggest establishing a 1 to 2 km proximity zone surrounding a lunar pit, Fig. 2.

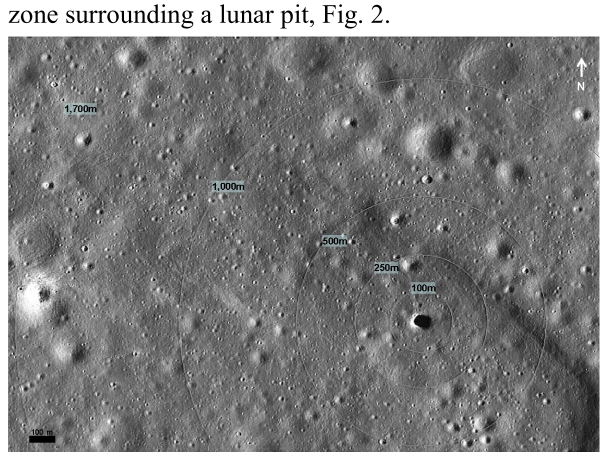

Figure 2. MHP recommended proximity zones

Leto: A Robotic Reconnaissance First Contact Mission: Our LEAP2/LCATS program is developing a concept of operations for a green reconnaissance approach for robotically accessing the MHP cave refuge. We named the mission to honor Leto, the mother of Apollo and Artemis *(impregnated by Zeus sought a place of refuge to be delivered).*

To protect the pit from contamination by a lander's rocket exhaust and plume blast ejecta, a robotic rover is landed at some distance behind high hills or geologic structures such as volcanic domes found in the surrounding area. The robotic rover traverses a 1 km path to find the lunar pit for deploying our Multi-Utility Legged Explorer (MULE) robot(s), Fig. 3.

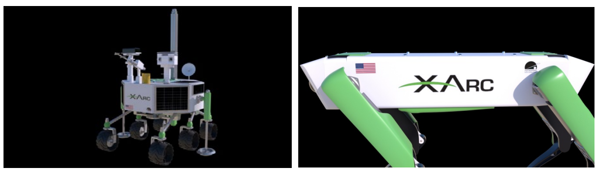

Figure 3. Leto Rover and MULE payload

MULE is a terrain-adaptable quadruped robot capable of traversing rugged cave terrain. These robots, colloquially named Spot, were developed by Boston Dynamics through Defense Advanced Research Projects Agency (DARPA) funding. NASA/JPL has also adapted the robot for their Collaborative SubTerranean Autonomous Resilient Robots, or CoSTAR program. The JPL "Au-Spot" is a modified version of "Spot", equipped with networked sensors and software to help it safely and autonomously scan, navigate and map its environment.

The Leto rover negotiates a traverse to a safe distance from the pit edge for staging and launch of a smart zip line across the pit void. The zip line is a tether with power, data, and communications. The zip line deployment is essentially a harpoon cannon mounted on the lander for shooting a ground penetrator for anchoring to the cliff walls of the pit. Once the zip line is secured, the stored payload is offloaded and lowered into the pit. The zip line delivers the MULE robot(s) with a payload suite of science instruments for remote measurements of the pit as it descends, and for exploring the pit and lava tube cave.

Impact: It is critical for first entry to be performed in a manner that preserves the pristine pit environment. The mission objective is to gain an understanding of pit and cave characteristics for suitability as a refuge for future habitation and birth of a lunar settlement.

Deployment of a zip line is conducive to a concept of operations for site characterization of pit openings and prevents contamination of the pit from plume and fuel of a lander flyover or other intrusive robotic activity trying to traverse down the cliff walls. The zip line lowers down instruments/equipment from the center of the pit opening for 360° field of view Light Detection and Ranging (LiDAR) measurements for a 3D point cloud of the entire pit. Science investigations, site contamination mitigation, and initial infrastructure buildup of the site are all accomplished with the initial zip line science reconnaissance mission; essentially providing the first infrastructure emplacement at the site for an eventual outpost.

Modeling, Animation, and Future Work: High resolution digital elevation or terrain morphology models of the MHP are not available. We have created interpretations of the pit edges and slopes for animating the mission concept, Fig. 4. Pit diameter, size and depth are accurately modeled [3].

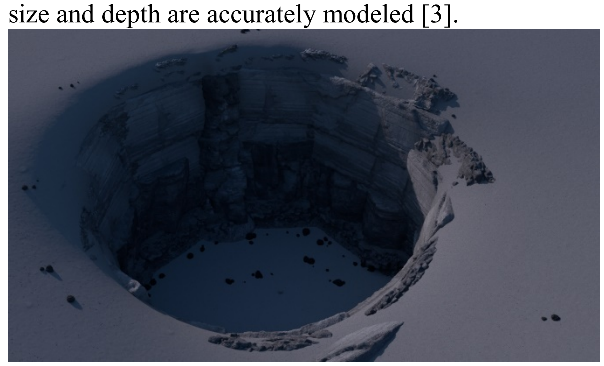

Figure 4. MHP was modeled for concept video animation

A two minute video was produced illustrating the mission profile as developed to-date. Future work will further develop the concept with animation of how the MULE robot enters the cave and maintains power and communications while in the cave. A field test in a local Texas cave using a Boston Dynamics Spot robot with mounted LiDAR is planned for spring 2021, by our LCATS program for student exercises.

Conclusion: Green reconnaissance describes entering skylights, pits, and lava tubes in a non-disturbing way that preserves any original features and resources. Before entering any extraterrestrial void for the first time, an effort needs to be made to determine optimum ingress/egress to minimize site disturbance and contamination while getting instruments, robots, and eventually human explorers down the pit for investigative science.

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References: [1] Ximenes S. W. et al. (2019) *Acta Astronautica, Vol 157 61-72*. [2] Ximenes S. W. (2012) *13th Space Resources Roundtable and the Planetary & Terrestrial Mining Sciences Symposium,* Boulder, CO. [3] LROC MHP imagery, 2017 update.