MISSION OPERATIONS FOR AUTONOMOUS SCIENCE-DRIVEN LUNAR MICRO-ROVING.

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Abstract: Lunar ice presents an incredible opportunity to further human space exploration. It can be used as water, as oxygen, and can be transformed into fuel, opening a gateway to space. The lunar poles, with extreme cold temperatures and permanently shadowed regions, host deposits of stable ice [1]. Stable ice exists in low, shadowed, cold regions which are quite the opposite from safe, well-lit landing sites. While robotic exploration is ideal to gain an understanding of meter-scale variations in ice deposits inferred from coarse orbital data, micro-rover traverse to Ice Targets requires the ability to rove beyond comm range. Thus, these robots cannot be teleoperated, nor can they stop and wait for operator intervention to address faults. This paper will profile the mission operations of MoonRanger, the first polar micro-rover manifested on a 2022 NASA CLPS flight, as it sets precedents with autonomous operations and new technologies that make polar micro-roving and higher resolution ice profiling possible.

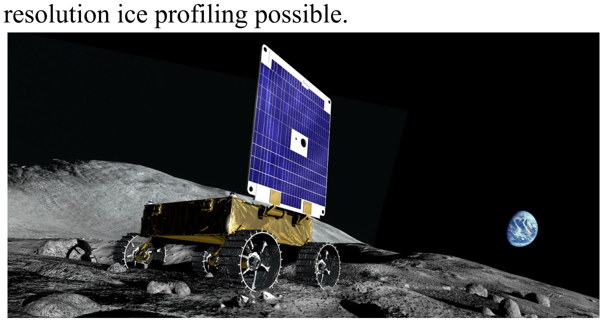

Fig. 1: Rendering of MoonRanger rover, Mark Maxwell.

This paper discusses our approach toward understanding viable landing regions. This process involves scoping the lunar environment, the rover's capabilities, and the science-purpose of ice-characterization. Analysis of ice-stability at depth, slope, elevation, lighting, and communication to Earth datasets are analyzed within the mission's context and scope, which then translate to a constructed lunar environment in simulation [3] [4].

Ice-Targets are defined as locations 1 km from the lander with stable ice within 1m of the lunar surface, hosting potential hydrogenous volatile deposits, detectable by MoonRanger's science-instrument. The team builds a mission operations structure around sparse communication windows to Earth and long autonomous traverses to Ice Targets, all of which result in a lean but high-powered operations team.

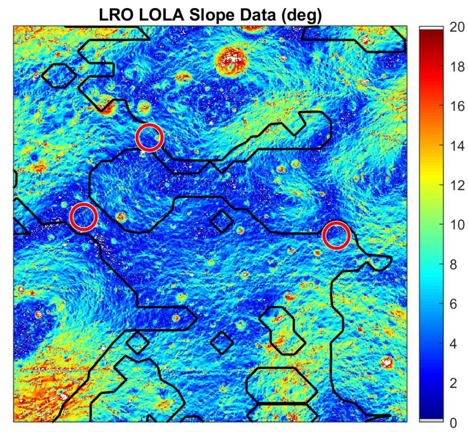

Fig. 2: ~ 10 x 10 km slope data, with three viable landing sites used for MoonRanger surface operations analysis [2].

MoonRanger is a lean program, which allows focused development toward mission critical subsystems. Simplicity minimizes the risk that plagues complex systems. MoonRanger's autonomy, in combination with a lean system, is essential for reaching Ice Targets, which lay far beyond the reach of the lander communication range.

Autonomy significantly affects operations, freeing operator bandwidth normally used during teleoperation. Mission operations can trust the system's performance out of range and can instead focus efforts on high-level planning, risk assessment, and fulfilment of mission purpose. This lean, focused, analytical mission operations approach for science-driven objectives paves the way for future rovers as they push the boundaries of planetary exploration.

Acknowledgments: This technology is enabling for autonomous micro-rover exploration. It will be integral to the MoonRanger rover which has been selected as a Lunar Surface Instrument and Technology Payload (LSITP). It will fly aboard the Masten X-L lander on a Commercial Lunar Payload Services (CLPS) mission to the pole of the moon in December, 2022.

References: [1] M. A. Siegler et. al. (2018) *Subsurface Ice Stability on the Moon* Abstract #5038. [2] D. E. Smith et. al. LRO LOLA Lunar Shape Map, urn:nasa:pds:GRD:polar:jp2:ldem_85S_10m_jp2, NASA Planetary Data System, 2012. [3] N. Otten, (2018), *Planning for Sun-Synchronous Lunar Polar Roving.* [4] U. Wong and P. M. Furlong, et. al. (2019) *Planetary Rover Simulation for Lunar Exploration Missions*.