A Survey of Micro Cold Traps at the Artemis III Landing Site to Determine the Rate of Water Delivery to the Moon

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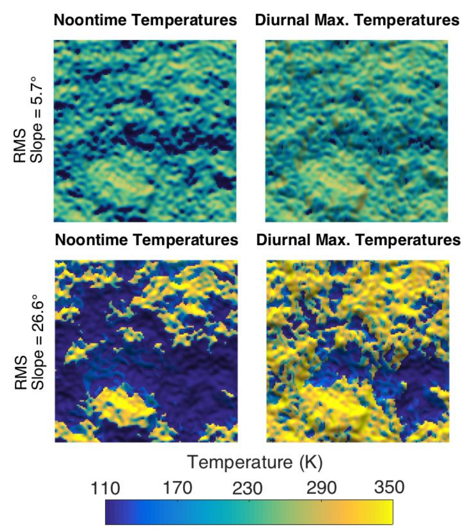
Summary: Measurements of temperature and water content within small-scale shadows at the Artemis III landing site can be used to test thermal models and constrain the recent delivery rate of water to the Earth-Moon system. Here, we describe the concept and present a possible methodology for performing this experiment with a two-person crew and readily available technology.

Introduction and Background: Large-scale permanently shadowed regions (PSRs) have been known to exist on the Moon since at least the 1960's [1]. Similarly, the lunar PSRs have been recognized for more than a decade as the coldest known surfaces in the solar system [2]. These regions are typically cold enough (annual maximum temperature < 110 K) to sequester H_2O ice for billions of years [3]. Although orbital remote sensing, primarily with NASA's Lunar Reconnaissance Orbiter (LRO) has been remarkably successful at mapping the PSRs and cold traps, these orbital temperature and compositional measurements are typically limited to resolutions > 100 m. Modeling and laboratory experiments indicate that cold traps should exist on spatial scales down to centimeters on the highly insulating regolith surface, producing a preponderance of "micro cold traps" (See Figure, and ref. [4]). If this hypothesis were to be validated, the micro cold traps should contain volatiles such as water, but only if the burial and destruction rates are outweighed by the volatile delivery rates. Since impact gardening is more rapid on smaller spatial scales, the smaller cold traps should be eroded more quickly. Therefore, probing lunar cold traps over a range of spatial scales could reveal important information on the sources and supply rates of H_2O and other important volatiles to the Earth-Moon system.



Proposed Experiment and Methodology: We propose that there should exist a threshold spatial scale where PSRs are both 1) cold enough, and 2) old enough to retain H_2O. Through modeling, this scale can be readily estimated based on thermal conduction and volatile supply and destruction/burial rates (e.g., [5,6]). *The proposed experiment is to measure the temperatures and water concentrations within shadows over a range of spatial scales accessible by astronauts near the Artemis III landing site.*

The methodology is as follows:

- Use thermal infrared imaging or a similar technique to map out instantaneous temperatures on shadowed surfaces over a range of scales from ~10 m to 1 cm
- Use reconstructed 3-d digital elevation models (DEMs) to determine the extent of permanent shadow within the instantaneous shadows
- Measure water content at the surface (and very near subsurface) within the PSRs, e.g., using near-IR spectroscopy, laser reflectometry, or shallow drilling
- Determine the threshold spatial scale, d_{min}, of cold traps where H_2O exists in significant abundance
- Compare d_{min} to gardening depths and sputtering rates to determine the required influx of volatiles to balance losses

Implementation: The essential objective is to measure temperatures and water content of PSRs over a range of spatial scales. Although we do not necessarily recommend a particular technical approach here, there are readily available instruments that can measure temperatures (e.g., [7,8]) and water content (e.g., [9]) remotely using indirect solar radiation and infrared emission. These instruments could be readily supported by astronauts, for example as hand-held devices or affixed to their helmets. Measurements could be acquired rapidly in real-time and with astronaut intervention in order to survey the landscape for the most compelling regions of interest. Panoramic scenes could be acquired from a rover-mounted instrument, for later analysis. In-situ sample collection could yield far more accurate water concentration measurements. Therefore, the proposed experiment is achievable from a variety of approaches, at varying levels of cost and oversight.

Conclusions: Water is the most important volatile in the solar system, and its history recorded in the lunar cold traps spans billions of years. By sampling water in various thermal environments on different spatial scales, we can determine the rate of water delivery to the Earth-Moon system -- one of the key outstanding questions in planetary science. The Artemis III landing site and the unique capabilities of this mission therefore present an important opportunity to test hypotheses about lunar water and advance understanding of the solar system.

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