MiLuV DOES IT GOOD - THE MINI LUNAR VOLATILES MISSION: A PLANETARY SCIENCE DEEP SPACE SMALLSAT STUDY OF A LUNAR ORBITING MISSION.

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Introduction: The remote detection of lunar volatiles, specifically H_2O/OH, by several recent lunar and planetary spacecraft [1-3], has dramatically shifted our perspective from the old, dry Moon (<1 ppb) to the new, wetter Moon both within its crust and on its surface (~100 ppm). The understanding of volatiles on the Moon is a major planetary science objective for NASA, as exemplified by the LRO, LCROSS, and Resource Prospector missions. These spacecraft have or will provide important data on the presence of volatiles, sometimes with great precision locally. However, these missions will not be able to draw the complete picture of the distribution and possible mobility of volatiles on the lunar surface. We argue that the best-suited instrument to definitely answer this topic is a laser spectrometer that measures surface reflectance at several key wavelengths through active remote sensing. This yields a dataset that is unbiased in temporal sampling (day, night, and permanent shadow), naturally calibrated (always at a phase angle of ~0º), and of a high spatial resolution relevant to determining physical processes driving the presence and mobility of H_2O/OH and to future exploration.

We propose a SmallSat concept, the Mini Lunar Volatiles (MiLuV) mission that will carry an efficient, heritage-based laser spectrometer into lunar orbit to obtain a comprehensive dataset. This instrument, the Lunar Ice LIdar Spectrometer (LILIS), is a multi-wavelength evolution of successful NASA GSFC Earth and planetary laser altimeters (GLAS, MOLA, MLA, LOLA), and brings to planetary exploration key new measurement capabilities. We will perform an engineering and mission study with both Goddard and the Wallops Flight Facility to demonstrate that MiLuV can be implemented and flown within the resource constraint of a SmallSat. In particular, we will ascertain that low-cost subsystems developed at GSFC, such as the avionics processor board, are adapted to the MiLuV requirements. We will investigate ridesharing options to deliver MiLuV into lunar orbit, which could greatly decrease the total cost to NASA.

LILIS Instrument: The LILIS instrument is a multi-band, active spectrometer, measuring the strength of a 3.0μm absorption feature (Figure 1) in areas that receive sunlight, areas in darkness and in permanently shadowed regions. Its design enables a robust characterization of surface volatile content (and its temporal variability) over the whole lunar diurnal cycle, including night.

The question of lunar volatile presence and its variability are recognized by NASA as important questions, with the Lunar Resource Prospector [4] set to quantify the surface and near-surface volatile abundance at the South Pole, the Lunar Exploration Analysis Group (LEAG) identified the abundance and variability of surface volatiles as a critical science question [5], and as a goal of the upcoming LRO extended science mission [6]. Additionally, there are a number of CubeSat missions in development to which MiLuV would provide complementary data.

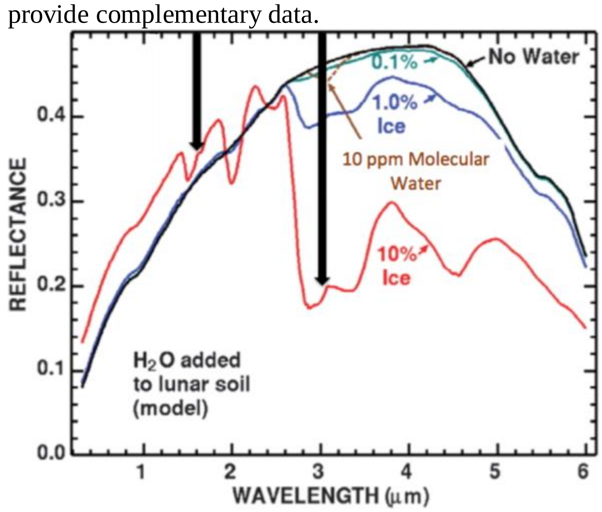

Figure 1. Lunar surficial water is directly characterized by measuring laser absorption near 3.0 μm wavelength over the strong water absorption band with an anticipated detection sensitivity of 100 ppm water. Another laser measurement near the 1.6μm band is sensitive to ice abundances of ~10% of the regolith. The locations of two proposed spectral bands measured by LILIS are marked. Figure after [1].

Science Objectives: The presence of volatiles on airless bodies has become one of the most active topics in planetary science over the past decade [e.g., 7]. With the detection of a 3.0 μm absorption feature (Figure 1) by the Moon Mineralogy Mapper (M^3) on Chandryaan-1, Cassini, and Deep Impact [1-3] across the lunar surface, the earlier paradigm that water exists only in areas of permanent shadow [8] shifted, where lunar volatiles are actually distributed based on interactions with the space environment and not just cold traps [9-

12]. Additionally, observations from multiple instruments [3, 13-15] suggest that surface and near-surface volatiles migrate as a function of lunar time of day. However this observation is still subject to debate since they all suffer from some form of uncertainty in the measurement [16-18]. To directly address this open controversy, we are developing a novel approach to actively measure the 3.0 μm absorption feature with the LILIS instrument.

The LILIS spectrometer operates in two key water ice bands in the near-infrared: 1.6 and 3.0 μm. Near 1.6 μm, water ice has a weak absorption at abundances at the 1% level or higher enabling surface frost to be detected unambiguously (Figure 1). At 3.0 μm, all forms of water are intensely absorbing, and the presence of water can be detected to lunar background levels of 100 ppm. LILIS can detect any abundance of surface water in regions of permanent shadow at or above this level, and through radiative transfer models to quantify its abundance. Furthermore, the LILIS spatial resolution of 100 m is ten times that of the current data, enabling detection of localized ice deposits such as in the ejecta blankets from small craters.

LILIS, with its complete immunity to the lunar thermal signal, will allow quantification of the strength of the 3.0 μm absorption Moon-wide and through radiative transfer modeling, determining the abundance of water to the lunar background level of about 100 ppm. The active LILIS measurements will always be performed at zero phase, which obviates the need for any further photometric calibration, which is, another significant advantage compared to passive methods, particularly in the polar regions. This capability will also allow us to detect and distinguish surface water from implantation of solar wind hydrogen and from internal lunar water.

The presence of pure reflectance data from LILIS will enable much more accurate calibration of the existing passive data (i.e., M^3), multiplying the value of the LILIS data set. Not only was the remote measurement of a lunar 3.0 μm water band significant, but equally compelling was the observation that this band varied across the lunar surface with time of day. This variation was interpreted by Sunshine et al. [3] to be evidence of diurnal mobile water on the Moon. Mobile surface water at this level has strong implications for mass transport of water to the poles and throughout the lunar exosphere but various data sets (LADEE, LRO) have not been reconciled with these observations. However, the passive spectrometer signal is affected by thermal emission that also correlates with time of day [16,19], so mobile water detected depends on the quality of the thermal correction. Models show that water *is* mobile during the lunar day, and has characteristic distributions, being concentrated toward the poles and on the night side of the dawn terminator. LILIS will allow the direct detection and characterization of the mobility of water and how much water is mobile relative to immobile surface water. This in turn will enable more forceful attempts to reconcile LADEE atmospheric measurements [20] and LRO (and LILIS) surface ice measurements to result in a larger understanding of the lunar volatile system.

MiLuV as a Planetary Science Mission: MiLuV is directly relevant to the Planetary Science Division's objectives as defined in the 2014 NASA Science Plan. Specifically, knowing the distribution of surface volatiles on the Moon, and how that distribution changes with local time, is key to understanding how volatiles migrate on airless bodies, not just the Moon. As such this mission concept would directly address the science goal to "Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve." Here the critical connection to the 2014 NASA Science Plan is in the interaction and evolution of volatiles on an airless body. At this point there is evidence that volatiles migrate across the lunar surface. By measuring the interaction of volatiles with varying illumination/thermal conditions we will constrain the evolution of lunar volatiles and their present distribution. The knowledge gained with these lunar observations may also shed light on the apparent discrepancy between what is observed at the Moon and what is observed at Mercury.

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