A laser spectrometer for global mapping of the abundance, distribution and variability of water on the moon.

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Introduction: It is an understatement to describe the recent flood of data on the poles of the Moon and Mercury as revolutionary. MESSENGER and LRO reveal two planets nominally similar in surface state, yet drastically different in volatile character. The north pole of the planet Mercury appears to convey a straightforward story of a distribution of volatiles controlled entirely by the vapor pressure of water and the arrangement of temperatures on the planet [1]. Bright radar anomalies indicating buried ice are found everywhere model temperatures allow buried ice to be stable against sublimation for geologic time. Where model surface temperatures are low enough to preserve surface ice, the surface of the radar anomalies are bright in reflectance at 1064 nm as revealed by laser reflectance. Where model surface temperatures of the bright radar anomalies are too high for long-term preservation of exposed ice, the surfaces of the radar anomalies exhibit very low reflectance. These low reflectance anomalies are interpreted to be due to lag deposits of more refractory material either emplaced with the ice, or formed in situ from complex ices by interaction with radiation. Apparently the lags accumulated until the underlying ice was protected from further sublimation. Similar dark deposits are found away from the radar anomalies, but are found where subsurface temperatures are low, but not quite low enough to preserve ice for geologic time. These dark surfaces speak to the presence of former ice, where a lag also accumulated, but was not sufficient to protect ice in these warmer areas from sublimation over time.

These characteristics suggest that Mercury experienced a massive influx of volatiles that filled both long and short-term cold traps, and this massive influx has retreated to the thermal equilibrium we observe today. In stark contrast, the Moon exhibits none of the clear evidence that suggests the Mercury story. Cold surfaces that enable preservation of buried ice do not exhibit clear and obvious radar anomalies; there is no evidence for the dark lag deposits ubiquitous in polar Mercury. There are many indications of volatile-rich locations on the Moon, but indicators are frequently contradictory, and the distributions are certainly not well understood. If the Moon did experience a massive volatile influx as suggested for Mercury, it occurred so long ago that the thermally controlled dark lag deposits, and even thick ice deposits have succumbed to regolith turnover and space weathering.

To understand the distribution of volatiles on the Moon, we must understand the less catastrophic processes that govern the slow input, transport, sequester and loss of volatiles. We must quantify the steady drip of water originating from the solar wind and degassing meteors; the occasional squall from the impact of a small comet or wet asteroid; the meandering march of water to the poles, attritted by ionization and sweeping; the temporary capture into the cold traps and sequester by weak thermal pumping, chemical reactions and regolith overturn; and finally loss to sublimation, sputtering and ultraviolet.

Active laser measurements of the reflectance of the Moon in key water absorption features offer key pieces of evidence to fill in this picture. First, laser reflectance is free of thermal contamination that plagues determination of abundance variation using passive IR spectroscopy [2]. Global, day/night measurements of the strength of the 3um feature, made famous by [3,4,5], would 1) quantify the global abundance and distribution of adsorbed water on the Moon; 2) Detect and quantify diurnal variation in the abundance of surface water that would constrain the supply of water to the poles; 3) Quantify the abundance of water, and water ice, in regions of permanent shadow, at cold locations on the lunar night side, and regions seasonally shadowed; 4) Detect ice in the ejecta of any small craters that expose shallow buried ice in areas that can preserve buried ice for geologic time, and surface ice for shorter periods; and 5) Detect and quantify all exposures of igneous water present in lunar rocks.

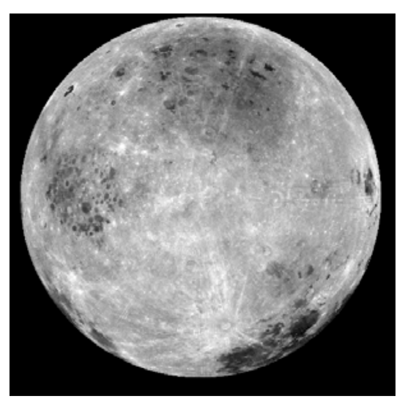

Figure 1. View of the Moon's South Pole from LOLA

These measurements, with spatial resolution as fine as tens of meters, would provide definitive answers to many questions: Is surface ice present in the polar regions and what is its geologic setting? Are there extensive regions of shallow buried surface ice suitable for sampling and exploitation? What proportion of surface water is mobile and hence ultimately available for polar cold trapping? Is transient surface frost present in areas only temporarily cold, for example on seasonal timescales? Do meteor showers emplace frost temporarily into the poles? What is the distribution of igneous water revealed Moonwide?

Instrument: The instrument is based on two developments at Goddard Space Flight Center. The first is an existing airborne lidar system operating in the near-IR near 1.5 microns that can be used to map the ice overtone bands for relatively abundant (>1 wt.%) surface frost [5]. The second, described here, is a laser system operating in the 3um region for extremely sensitive water detection. Both wavelength regions will be solar blind, and capable of obtaining high quality data during the lunar day and lunar night, and of course the permanently shadowed regions.

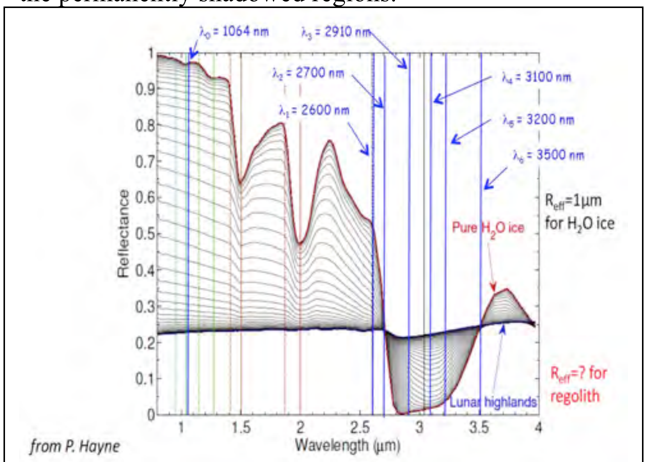

Figure 2. Locations of nominal 3um region bands for the laser system. The shorter wavelength system would cover the 1.4 micron ice band in two addition wavelengths.

The lidar (Figure 3) will measure the range along with reflectance of the surface in the same spot simultaneously at 7 wavelengths. The spectral distribution of example laser wavelengths is shown in Figure 2 plotted against the spectral signature of a surface with varying surface densities of water ice frost. The 1064 nm wavelength of the pump laser was chosen to match that of LOLA to allow intercomparisons with LOLA measurements. Six additional wavelengths were chosen distributed from 2600 to 3500 nm and are also transmitted to sample the continuum (2600 nm) and absorption signatures (2910, 3100, 3200 nm) of the O-H stretch of water ice. These bands shown are examples: for the flight mission a final band set might differ somewhat based on addition analysis.

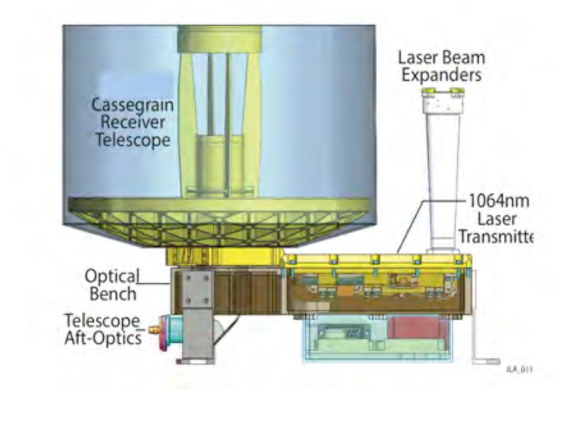

Figure 3. Rendering of the laser transmit and receive system.

All components have been shown to work in the laboratory, and the infrared detection system has had extensive field-testing. The laser subsystem is currently being used to collect ice reflectance data in the laboratory. The aggregate TRL of the system is 4.6 and ongoing efforts continue to raise the TRL.

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