DETECTION AND MAPPING OF LUNAR ICE WITH ACTIVE ILLUMINATION FROM THE DEEP SPACE GATEWAY. P. O. Hayne[1], B. T. Greenhagen[2], D. A. Paige[3], B. A. Cohen[4], [1]University of Colorado at Boulder (Paul.Hayne@Colorado.edu), [2]Applied Physics Laboratory – Johns Hopkins University, [3]University of California – Los Angeles, [4]NASA – Goddard Space Flight Center

Introduction: Water and other volatiles are fundamental tracers of the formation and evolution of the Solar System, including the Earth and Moon. Water is also a critical resource for future human and robotic exploration. The need for better understanding of lunar water is evident in both the Planetary Science Decadal Survey [1] and in NASA's Strategic Knowledge Gaps [2]. In particular, SKG Theme 1 is to "understand the lunar resource potential," by quantifying and understanding the form and distribution of hydrogen species and other volatiles within the Moon's polar regions (SKG 1-D).

Ice deposits may also provide a record of delivery of exogenous materials by comets and asteroids [3]. Within at least one cold trap, inside Cabeus crater near the lunar south pole, this record strongly suggests a cometary source [4]. However, models indicate extremely heterogeneous volatile concentrations due to impact gardening [5]. So far, inside the Moon's permanently shadowed regions (PSRs), it has been exceedingly difficult to: 1) definitively identify water and other volatiles, and 2) map their distribution and concentrations at useful spatial scales.

Recently, NASA's Lunar Flashlight mission has presented a novel approach: using active illumination to measure surface reflectance spectra and search for features diagnostic of water and other volatiles [6]. This system is implemented onboard a low-cost CubeSat platform, which has inherent limitations. Here, we propose an active illumination system that leverages the potential capabilities of NASA's Deep Space Gateway to vastly improve knowledge of lunar volatiles.

Measurement Approach: Reflectance spectroscopy is a standard technique for determining the composition of planetary surfaces and atmospheres. Traditionally, reflected sunlight (or starlight) is used to measure the positions and depths of diagnostic absorption bands in the ultraviolet [7,8] to near infrared [9]. In the PSRs, this technique is challenging if not impossible, due to the low sunlight levels (from radiation scattered by surrounding terrain). Instead, we propose to use a light source onboard the Gateway (Fig. 1). A similar technique has already been successfully demonstrated using the Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter (LRO) at a single wavelength of 1064 nm [10].

For a collimated light source enclosed by the receiving telescope's field of view, emitted from the spacecraft with power P_T, the received power is

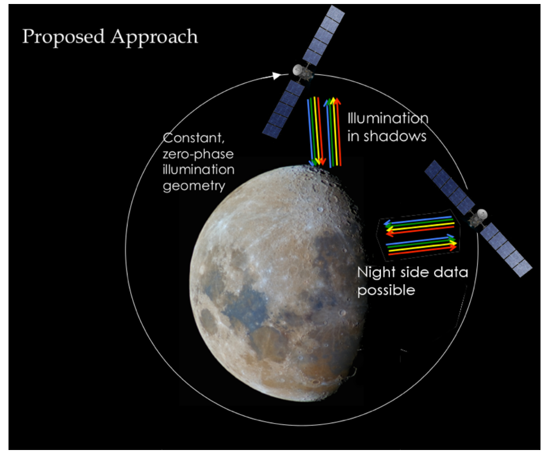

Figure 1: The proposed active illumination approach to measuring lunar surface reflectance and detecting water and other volatiles. Passes over the poles are required, but the DSG does not necessarily need to be positioned in lunar orbit.

$$P_R \sim \left(\frac{r}{z}\right)^2 \alpha P_T$$

where r is the receiver/telescope radius, z is altitude above the lunar surface, and α is the wavelength-dependent Lambert albedo of the surface. Therefore, the signal scales linearly with output power, and quadratically with both telescope aperture and distance to the surface.

Requirements for the Gateway: A trajectory with opportunities for line-of-sight views into the PSRs is required. Scaling from Lunar Flashlight's (LF) predicted performance provides useful estimates of required power, altitude, and aperture. From an altitude of ~30 km and ~8 cm aperture, LF has a detection limit and precision of ~1 wt% H_2O, using four lasers each with optical output power ~25 W, requiring peak delivered power of ~100 W to the laser subsystem. The electric power system includes super-capacitors, which charge between science passes in order to minimize the instantaneous power draw from the spacecraft. Thus, the relevant resource is energy. LF pulses its lasers during several minutes of a flyby, requiring ~10 Wh (36 kJ) per pass. If the Gateway were instead measuring from 300 km altitude, 1 kW peak power (~100 Wh for 5 min discharge) could accomplish the same measurements with this very small telescope. Alternatively, the telescope aperture could be increased to ~25 cm (10") diameter for the same boost in received signal.

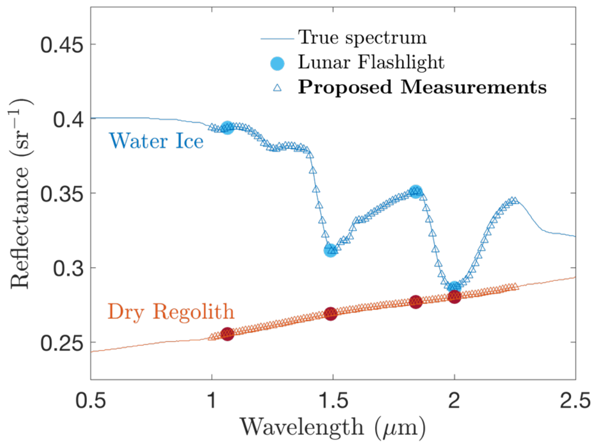

Figure 2: Example spectra for water ice and dry regolith, using two different spectral resolutions: a four-band measurement similar to Lunar Flashlight, and a 100-band measurement achievable by the proposed active illumination system with a simple grating spectrometer. The higher spectral resolution and/or signal-to-noise ratio would enable better discrimination of water and other condensed volatiles on the lunar surface.

Further enhancements in capability are possible. For example, with a 50-cm diameter telescope aperture and 1 kW peak power (discharging for ~1-5 min), SNR ~250x that of LF could be achieved from moderately low altitude (~30 km). In this case, a broadband "searchlight" could be used in combination with a grating spectrometer to achieve high spectral and spatial resolution. With enough power or lower altitude, high-resolution camera images could also be taken using a flashbulb approach during passes over the PSRs. Limited crew interaction would be necessary for instrument operations.

One of the challenges faced by the active illumination technique is heat dissipation; most light sources, including lasers, have optical efficiencies of < 50%. Therefore, the Gateway would need to be capable of removing at least ~100 W during laser operation. Temperature stability of < 5 K is necessary if lasers are used, in order to minimize wavelength shifts.

Anticipated Results: The proposed technique could yield high-resolution detections of water and other volatiles in the PSRs. Spectral resolution is limited by telescope aperture and optical power of the illumination source, as well as altitude above the lunar surface. Spatial resolution is limited by collimation of the light source and altitude of the platform. For anticipated capabilities, it may be reasonable to achieve ~100 m resolution on the lunar surface with ~10-100 spectral bands. Such data could quantify H_2O concentrations, and discriminate other volatiles, including CO_2 and methane. Multiple passes over both poles could build coverage to produce maps of volatile concentrations. Measurements on the lunar night side are also possible, which would constrain the mobility of water and also the mineralogy of the lunar surface without the complications of variable lighting and viewing geometries.

References: [1] *Vision and Voyages for Planetary Science in the Decade 2013-2022*. National Academies Press.
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