LUNAR FLASHLIGHT: ILLUMINATING THE LUNAR SOUTH POLE. P. O. Hayne[1], B. T. Greenhagen[2], D. A. Paige[3], J. M. Camacho[1], B. A. Cohen[4], G. Sellar[1], J. Reiter[1]; [1]Jet Propulsion Laboratory, Pasadena CA 91109, [2]Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723, [3]UCLA, Los Angeles, CA 90095, [4]NASA Marshall Space Flight Center, Huntsville AL 35812.

Introduction: Recent reflectance data from LRO instruments suggest water ice and other volatiles may be present on the surface in lunar permanently-shadowed regions, though the detection is not yet definitive [1, 2, 3]. Understanding the composition, quantity, distribution, and form of water and other volatiles associated with lunar permanently shadowed regions (PSRs) is identified as a NASA Strategic Knowledge Gap (SKG) for Human Exploration. These polar volatile deposits are also scientifically interesting, having the potential to reveal important information about the delivery of water to the Earth-Moon system.

Mission: In order to address NASA's SKGs, the Lunar Flashlight mission will be launched as a secondary payload on the first test flight (EM-1) of the Space Launch System (SLS), currently scheduled for 2018. The goal of Lunar Flashlight is to determine the presence or absence of exposed water ice and map its concentration at the 1-2 kilometer scale within the PSRs. After being ejected in cislunar space by SLS, Lunar Flashlight maneuvers into a low-energy transfer to lunar orbit and then an elliptical polar orbit, spiraling down to a perilune of 10-30 km above the south pole for data collection. Lunar Flashlight will illuminate permanently shadowed regions, measuring surface albedo with a point spectrometer at 1.4, 1.5 1.84, and 2.0 μm. Water ice will be distinguished from dry regolith in two ways: 1) spatial variations in brightness (water ice is much brighter in the continuum channels), and 2) reflectance ratios between absorption and continuum channels. Derived reflectance and water ice band depths will be mapped onto the lunar surface in order to identify H_2O ice and distinguish the composition of the PSRs from that of the sunlit terrain. These data will be complementary to other lunar datasets such as LRO and Moon Mineralogy Mapper.

Instrument: The original Lunar Flashlight design intended to use a solar sail for both propulsion and illumination. In the fall of 2015, the Lunar Flashlight project changed its technical approach, moving to a chemical propellant and to an active illumination source for measurement. After considering several alternatives (inflatables, smaller deployables, flashlamps, various lasers, etc.) we found that stacked-bar diode lasers currently available can provide the power needed to conduct active remote spectroscopy. We continue to refine the design of the new system, by both analysis and testing.

The team has developed an end-to-end instrument performance model for Lunar Flashlight, in order to evaluate its capability to meet the mission requirements. This model takes as inputs all of the fundamental system parameters: aperture, detector characteristics and optical efficiencies, spectral bandpasses, instrument background, stray light, ranges of reflectance for dry lunar regolith and predicted reflectance for mixtures of ice and regolith, etc. The output of the system model is the uncertainty in weight-percentage of H_2O ice.

Within our limited mass and power space for the instrument system, the team has been conducting analyses on design parameters to minimize the uncertainty in weight-percentage of H_2O ice. We have already worked two major issues. First, readily-available laser diode wavelengths do not correspond to the exact absorption band centers for water ice. Because Lunar Flashlight is required to measure ice concentrations down to 0.5 wt%, measuring outside the band center corresponds to a significant reduction in signal.

Our spectral model uses standard optical constants for water ice [4] and various lunar regolith samples and simulants, and we calculate bidirectional reflectance using Hapke's formulas, for the given zero-phase illumination geometry [5]. Each spectral point is ratioed to a linear interpolation or extrapolation of the two continuum channels at 1.4 and 1.84 microns. Noise is simulated using a normal distribution for each

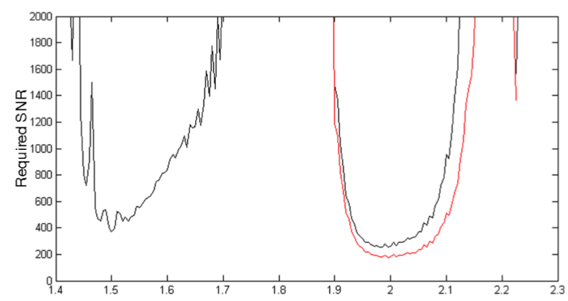

Fig. 1. Signal-to-noise (SNR) ratio required to identify a 0.5 wt% ice target to better than 0.5wt% uncertainty as a function of wavelength. Required signal is lowest at the center of water ice absorption features. Black trace uses two continuum channels at 1.4 and 1.84 microns. Red trace shows potential reduction in required signal with a third continuum channel at 2.24 microns.

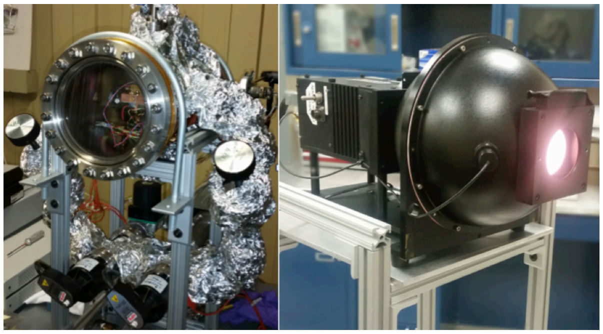

Figure 2: Components of the laboratory test facility in development for Lunar Flashlight. (Left) Cryogenic vacuum chamber for detector testing, with detectors inside. (Right) Calibrated broadband integrating sphere, operating as the illumination source. Future tests will incorporate laser diode stacks in place of the integrating sphere.

spectral channel. For a given sigma, the model is run one million times. The resulting statistics are compared to the nominal case to determine the relationship between measurement uncertainty and SNR (Fig. 1).

Second, our time-averaged laser output power is relatively low (20-50W), which is appropriate for illuminating permanently shadowed regions, but carries the potential for significant noise from stray light from the Moon itself, via terrain scattering. We modeled the spacecraft altitude above the lunar surface, using LOLA topography and LF candidate trajectory files. We then use illumination models from Diviner [6] to calculate "stray light" radiance from illuminated terrain within the instrument field of view.

We have also begun construction of a prototype instrument to verify the computer model of system performance. This system currently includes the InGaAs detectors, a vacuum enclosure, and a thermal control system to cool the detectors to desired temperatures. We designed and fabricated a system consisting of two silicon diode temperature sensors, two distinct InGaAs photodetectors, and a copper block that serves as a heat exchanger between a 25-Watt wire-wound resistor and a liquid-nitrogen-cooled hollow stage. The photodiodes are cooled to 77 K by allowing LN_2 flow through the hollow stage. Our set up allows us to have full control over the temperature of our system. This set-up (Fig. 2) is currently running under a cryogenic and vacuum environment to test the performance of our detectors. Future development of the breadboard will add the lasers and lunar regolith simulants to enable end-to-end testing of the instrument system under realistic conditions.

Summary: Lunar Flashlight is a low-cost cubesat mission to be launched as part of NASA's first SLS test flight. The mission goals are to detect and map the surface distribution of water ice within the permanently shadowed regions of the lunar south pole. This innovative mission will also demonstrate several new technologies, e.g., it will be the first planetary mission to demonstrate remote reflectance spectroscopy using active illumination from orbit.

Two other missions currently being considered for the EM-1 launch (Lunar IceCube and LunaH-Map) would make highly complementary measurements to Lunar Flashlight. Lunar IceCube would use passive reflectance spectroscopy to measure hydration in the solar-illuminated regions of the Moon, whereas LunaH-map would conduct neutron spectroscopy measurements of sub- surface hydrogen at the lunar south pole. Although each cubesat would use a different approach, the results from all three instruments would be synergistic when viewed as a fleet of tiny missions simultaneously exploring the nature and distribution of water on the Moon.

References: [1] Gladstone, G. R., et al. (2012) JGR 117, CiteID E00H04. [2] Zuber, M. T., et al. (2012) Nature, 486, 378-381. [3] Hayne, P. O., et al. (2015) *Icarus 255*, 58-59. [4] Warren, S. G. and Brandt, R. E. (2008), *JGR 113*, D14. [5] Hapke, B. (1981), *JGR 86*, B4. [6] Paige, D. A., et al. (2010), *Science 330*, 479-482.

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