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]. 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 distinguish the composition of the PSRs from that of the sunlit terrain, and to compare with 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. However, with the available sail area (constrained by the volume of the cubesat), the solar sail provided insufficient thrust to capture the spacecraft into and maintain lunar orbit. In addition, no available orbits were found with dark-to-light passes, which allow the instrument to achieve its required thermal range/instrument performance. Finally, the ability of the sail to direct (or concentrate) a sufficient fraction of the collected sunlight within a 1 km field-of-view on the lunar surface was in question.

In the fall of 2015, the Lunar Flashlight project changed its technical approach, moving to a low-toxicity chemical propellant for propulsion 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 laser illumination. We are continuing to refine the design of the new system, by both analysis and testing.

The team has developed an extensive 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, and optical efficiencies, spectral bandpasses, detector dark current, instrument background, stray light, ranges of reflectances for dry lunar regolith and predicted reflectances 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 reduction in signal.

Our spectral model uses input spectra. 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 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 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 are using illumination models from Diviner to calculate "stray light" radiance from illuminated terrain.

We have also begun construction of an instrument breadboard to verify the computer model of system performance. This breadboard 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 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.

Summary: Lunar Flashlight will be a low-cost cubesat mission 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 CubeSat to reach the Moon, the first planetary CubeSat to use low-toxicity chemical propulsion, and the first mission to use remote reflectometry..

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 water 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.

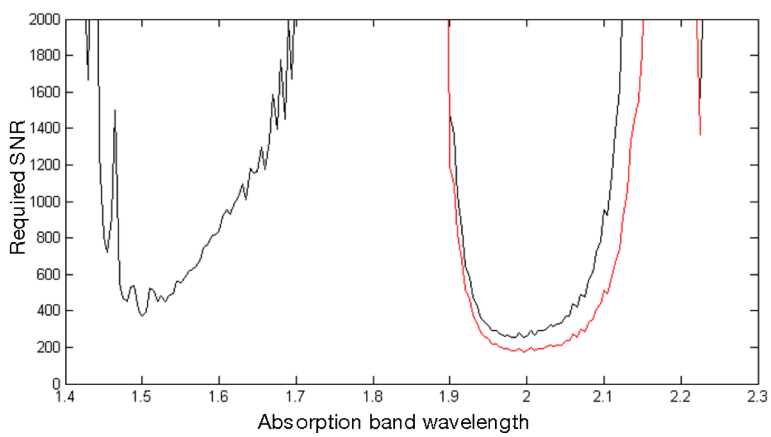

Fig. 1. Signal-to-noise (SNR) ratio required to identify a 0.5 wt% ice target to better than 0.5wt% uncertainty as a function of wavelength. Required signal is lowest at the center of water ice absorption features. Black trace uses two continuum channels at 1.4 and 1.84 microns. Red trace shows potential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

References: [1] Gladstone, G. R., et al. (2012) JGR 117, CiteID E00H04. [2] Zuber, M. T., et al. (2012) Nature, 486, 378-381.