Payload Design For The Lunar Flashlight Mission. B. A. Cohen[1], P. O. Hayne[2], B. T. Greenhagen[3], D. A. Paige[4], J. M. Camacho[2], K. Crabtree[5], C. Paine[2], R. G. Sellar[5]; [1]NASA Marshall Space Flight Center, Huntsville AL 35812 (barbara.a.cohen@nasa.gov), [2]Jet Propulsion Laboratory, Pasadena CA 91109, [3]Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723, [4]UCLA, Los Angeles, CA 90095, [5] Photon Engineering, Tucson AZ 85711.

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 [1-3]. Understanding the composition, quantity, distribution, and form of water and other volatiles associated with lunar permanently shadowed regions (PSRs) is identified as a Strategic Knowledge Gap (SKG) for NASA's human exploration program. These polar volatile deposits are also scientifically interesting, having potential to reveal important information about the delivery of water to the Earth-Moon system.

Mission: The goal of the Lunar Flashlight mission is to determine the presence or absence of exposed water ice and map its concentration at the 1-2 kilometer scale within the PSRs at the lunar south pole. Lunar Flashlight is a very small satellite (10x20x30 cm, with deployable solar panels) that will be launched as a secondary payload on the first test flight (EM-1) of the Space Launch System (SLS), currently scheduled for late 2018. After being ejected in cislunar space by SLS, Lunar Flashlight uses 'green' propellant to maneuver 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. The science data collection will take place over 30-60 orbits (1-2 months), after which the spacecraft will make a controlled crash into the Moon.

Instrument: Lunar Flashlight carries a multi-band reflectometer to measure surface reflectance in permanently shadowed regions at four near-IR wavelengths. A laser system emits pulses at the four discrete wave-

lengths in rapid sequence, while a receiver system detects the reflected light. Derived reflectance and water ice band depths will be mapped onto the lunar surface in order to identify locations where H_2O ice is present at or above 0.5 wt% concentration.

In the past year, we have advanced the design for the Lunar Flashlight payload to meet our measurement requirement within the limited mass and power available for the instrument system. We optimized the laser wavelengths for maximum sensitivity to water ice absorption bands. The selected wavelengths are 1.064 (-0.060 / + 0.230) μm & 1.850 (-0.030 / +0.020) μm for continuum measurements and 1.495 (-0.015 / +0.015) μm & 1.990 (-0.020 / +0.025) μm for absorption bands. The 1.064 μm band also enables a comparison with LOLA, though at a different spatial scale. The continuum bands are off-the-shelf procurements; we also procured custom laser epitaxies for the water bands from DILAS, Inc.

We developed an end-to-end instrument performance model 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. This model enabled us to make several important trades in system power and optical design parameters. The preliminary optical design for the receiver is shown in Fig. 1.

Our time-averaged laser output power is 20-50 W. While the expected return flux at the detector is on the order of 10^7 photon/s, stray light from directly solar-illuminated regions outside the field of view of the receiver, as well as background light scattered from illuminated terrain into the shadowed regions can be significant sources of noise. We modeled the three-dimensional solar and earthshine illumination of the Moon's poles and the resulting radiation distribution, during the primary Lunar Flashlight mission. We then modeled the signal and stray light fluxes received at the detector as a function of time along the predicted trajectory, for different candidate optical designs.

Using the illumination model from [4], we calculated the intensity of each surface element, and convolved this with the spectral response function and optical transmission function of the instrument receiv-
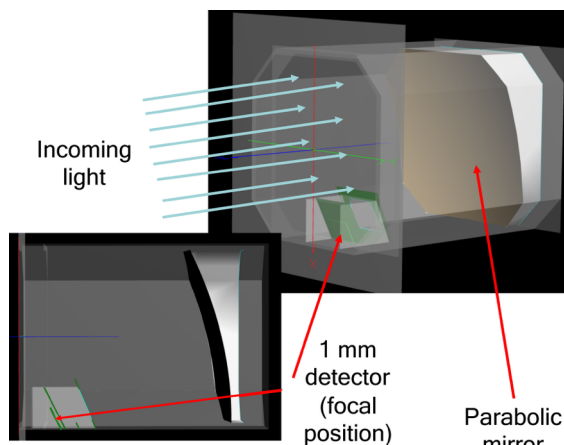

Fig. 1. Optical design for the Lunar Flashlight detector, an off-aperture paraboloidal mirror

er. This requires knowledge of the position of the spacecraft, which was determined using the best available trajectory predictions for the first ˜60 days of the mission. The illumination model includes direct insolation and earthshine. Multiple reflections between surface elements are included, as is the actual lunar topography at a resolution of 475 m/pixel [5]. Surface elements are assumed to reflect radiation uniformly in all directions, i.e. they are Lambertian.

Stray light is modeled as a background contribution to the received signal from the lunar surface. To quantify the background, we calculate the radiation contributions from each surface element, as viewed from the spacecraft. These contributions are weighted by the optical transmission function, which typically decreases at larger angles θ from the center of the field of view (FOV).

To model stray light suppression, we define an optical transmission function, $Y(\theta, \varphi)$, which describes the fraction of light from the direction (θ, φ) transmitted to the detector. Both geometric blocking of direct radiation (e.g., from a baffle) and suppression of scattered light within the optical system contribute to the transmission function. The results show that suppression of out-of-field (i.e. 'stray')radiation may be important to obtaining usable measurements.

Combining the predicted instrument performance with the illumination model, we can calculate the measurement confidence for all points along all of the Lunar Flashlight orbits (Fig. 2, top). Though each individual laser pulse may have low signal-to-noise, we intend to co-add individual measurements along-track to distinguish a detection from a blank (dry regolith) at 3σ confidence. Fig. 2 (bottom) shows the number of observations that would show a 3σ detection binned at resolutions of 10 km/pixel. Therefore, our expected coverage of lunar PSRs at adequate signal-to-noise ratio is expected to be quite good over the nominal ~60-day mission, at the scale of 10 km/pixel. To achieve finer resolution means co-adding fewer measurements, which may be done for those areas with particularly dense coverage at adequate SNR.

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 be the first planetary mission to measure reflectance at multiple wavelengths using active illumination from orbit.

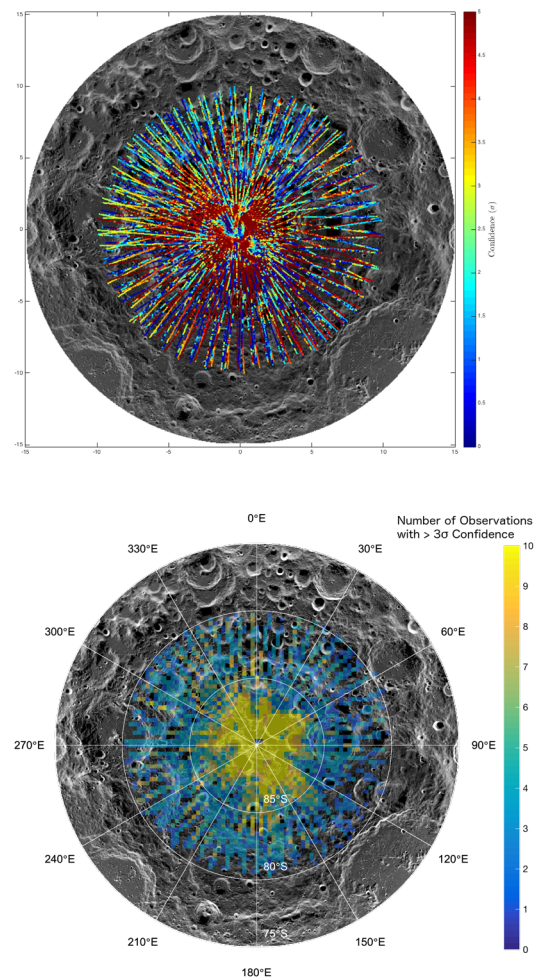Two other missions currently being considered for the EM-1 launch (Lunar IceCube and LunaH-Map)

Figure 2: (top) Measurement coverage and detection confidence for 0.5 wt% water ice for the planned Lunar Flashlight mission (60 days) using the illumination model described in the text, and (bottom) the number of observations binned at 10 km/pixel resolution.

would make complementary lunar volatile measurements [6,7]. 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] Paige, D. A. et al. (2010) *Science* **330**, 479–482. [5] Smith, D. E. et al. (2010) *GRL* **37** L18204. [6] Clark, P. E., et al. (2016) DPS Meeting 48, id.223.03. [7] Hardgrove, C., et al. (2015) LEAG Meeting, abstract #2035.