LUNAR FLASHLIGHT: MAPPING LUNAR SURFACE VOLATILES USING A CUBESAT. B. A. Cohen[1], P. O. Hayne[2], C. G. Paine[2], D. A. Paige[3], B. T. Greenhagen[4]; [1]NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov), [2]Jet Propulsion Laboratory, Pasadena CA 91109, [3]UCLA, Los Angeles, CA 90095; [4]Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723.

Introduction: The Diviner instrument on the Lunar Reconnaissance Orbiter (LRO) spacecraft measured temperatures in permanently shadowed regions (PSRs) of the lunar poles as cold as 25K [1]. Over time, significant amounts of volatile molecules are likely have accumulated in lunar PSRs [2,3]. Recent narrow-band reflectivity data from LRO's LOLA and LAMP instruments suggest volatiles may be present on the surface, though surface roughness or porosity effects cannot yet be ruled out [4, 5].

Surface water ice and other volatiles, if they exist in sufficient quantities, would be extremely useful for in situ extraction and utilization by future human and robotic missions. Understanding the composition, quantity, distribution, and form of water/H species and other volatiles associated with lunar cold traps is identified as a NASA Strategic Knowledge Gap (SKG) for Human Exploration. These polar volatile deposits could also reveal important information about the delivery of water to the Earth-Moon system. The scientific exploration of the lunar polar regions was one of the key recommendations of the Planetary Science Decadal Survey.

Mission: NASA's Advanced Exploration Systems (AES) program selected three low-cost 6-U CubeSat missions as secondary payloads on the first test flight (EM1) of the Space Launch System (SLS) scheduled for 2018. The Lunar Flashlight (LF) mission was selected as one of these missions, specifically to address the SKG associated with lunar volatiles. The goal of Lunar Flashlight is to determine the presence or absence of exposed water ice and its physical state, and map its concentration at the 1-2 kilometer scale within the permanently shadowed regions of the lunar south pole. The Lunar Flashlight mission goals underwent a non-advocate peer review in June 2014 and the project passed its Mission Concept Review in August 2014.

After being ejected in cis-lunar space by SLS, Lunar Flashlight deploys solar panels and uses a cold-gas thrust maneuver to align the spacecraft for the first of three lunar fly-bys; this expends 30% of the stored propellant, the remainder of which will used only for momentum-wheel desaturation during the remainder of the mission. LF employs an ~80 m^2 solar sail for its primary propulsion; the solar sail and deployment mechanism occupies slightly less than 3U of the 6U CubeSat, and contributes ~2.5 kg to the ~11 kg total mass. The sail is deployed shortly after the first lunar flyby, and over the next 8 months provides vectored thrust to slow the spacecraft and align for capture into lunar polar orbit at an initial altitude of ~9000 km.

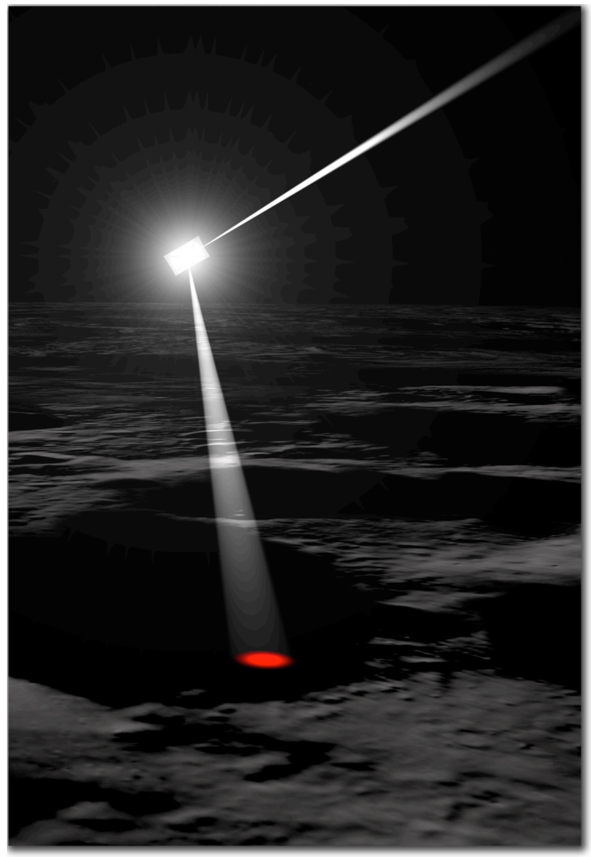

Fig. 1: Artist's concept of the Lunar Flashlight mission over the lunar surface.

Once in lunar orbit, LF lowers its orbit over 14 months to ~20 km perilune for the science phase. Further constraints on the orbit are that the perilune be in the vicinity of the lunar south pole and that the lunar south pole be in darkness for the science phase. The science phase consists of the 60 orbits for which the perilune is less than 30 km and within 10 degrees of the lunar south pole. During passage over the pole, the spacecraft is rotated to orient the solar sail 45° to the sunline such that the reflected sunlight illuminates the lunar surface. At this orientation, the reflected beam and the spectrometer field-of-view (FOV) are co-aligned, so that the spectrometer views the illuminated area of the lunar surface and collects light reflected back to the spacecraft.

The LF ground tracks will extend 15° in each direction from the pole before the lunar surface falls away from the spacecraft. The moon's rotation results in ground tracks evenly spaced in longitude; 60 orbits yield somewhat more than one full rotation of the moon. The mapping is sparse, however, since the ground track width is <2 km wide. At the end of the mission, the spacecraft will impact the lunar surface.

Lunar Flashlight uses its solar sail to shine reflected sunlight into PSRs and non-PSRs on the lunar night side, measuring surface albedo with a four-filter point spectrometer at 1.1, 1.5 1.8, and 1.95 μm. Water ice will be distinguished from dry regolith from these measurements in two ways: 1) spatial variations in absolute reflectance (water ice is more reflective in the continuum channels), and 2) reflectance ratios between absorption and continuum channels. Derived reflectance and reflectance ratios will be mapped onto the lunar surface in order to distinguish the composition of the PSRs from that of the sunlit terrain.

The presence of water cold-trapped at or near the lunar surface will modify the surface spectral reflectance from that of dry regolith. The LF science instrument is a spectrometer with four optical wavelength bands, two in the continuum and two in water-ice spectral absorption bands. The optical wavelengths were selected for detection of water ice, comparison to other data (e.g., 1.064 um from LOLA), and to optimize detector noise performance in the continuum or absorption bands.

The four spectrometer channels view the same ground spot simultaneously. Science data are the ratios of reflected light detected in pairs of spectral channels: comparison of the as-detected ratios with the ratios expected for dry regolith constrains the quantity of water ice present at the surface. We use the ratio of reflected light in the various bands because the surface illumination is not expected to be precisely known.

The spectrometer optical package consists of four mirror-symmetric telescopes, each with a flat optical-bandwidth-defining filter in front of an off-axis parabolic (OAP) reflector that directs the light onto a single detector of circular active area. The individual detectors are tilted off-normal to the FOV centerline, to optimize light collection in each individual telescope. All four telescopes view the same scene. The use of OAPs enables locating the four detectors in very close proximity at the center of the four channels. Co-locating the detectors significantly simplifies cooling and temperature stabilization of the detectors. The optical package incorporates an integral cold finger which extends from the detector block through to the back of the instrument, where it connects to a cryoradiator viewing cold space to cool the detector block to <200K.

The optical detectors are InGa:As single-element photovoltaics, with cutoff wavelength selected for minimum detector noise at each optical wavelength. Devices from Teledyne-Judson are currently base-lined, and published data on detector performance is used in performance modeling.

The LF spectrometer occupies less than 40% of 1U of CubeSat volume: The optical package is 5 cm x 6 cm x 8 cm, and the electronics package is expected to be smaller than a single standard CubeSat board; i.e., less than 1 cm x 8 cm x 8 cm (TBC). The cryoradiator occupies most of one 1U x 2U face of the CubeSat, but is only 0.5 cm thick. Power draw is expected to be less than 0.5 W. The total mass is not yet well-defined, but will probably be less than 350 g.

A critical component of this approach is obtaining sufficient illumination of the lunar surface via reflection of the sun from the solar sail. This functionality is currently being developed at MSFC. We have developed a performance model for the instrument that includes temperature-dependent detector noise, thermal noise sources, realistic electronics performance, and preliminary optical throughput for the current design. Our modeling indicates that, with only 1% of the sunlight incident on the solar sail reflected onto the lunar surface within the spectrometer FOV (which is not totally trivial to achieve), we have the capability to discriminate surface water ice present at 0.005 weight fraction from dry regolith at the 3σ confidence level in both the short-wavelength and long-wavelength spectral band ratios, from an altitude of 20 km above the lunar surface, with spatial resolution of 1 km. This is a very robust detection capability, which will easily satisfy the Lunar Flashlight mission requirements.

Summary: The Lunar Flashlight mission concept addresses Strategic Knowledge Gaps for NASA's HEOMD through novel or unique technology applications. Achieving lunar orbit with a solar sail, and using a remote source for active spectroscopy of permanently-shadowed regions are, to our knowledge, unprecedented. The detection capability for water ice at engineering-usable levels is robust and flexible. Further, this design of the spectrometer optical and electronic system could easily be modified for similar CubeSat-scale missions.

References: [1] Paige, D. A., et al. (2010) Science, 330, DOI: 10.1126/science.1187726. [2] Vasavada, A. R., et al. (1999) Icarus, 141, 179-193. [3] Zhang, J. A. and D. A. Paige (2009) GRL, 36, 16203. [4] Gladstone, G. R., et al. (2012) JGR 117, CiteID E00H04. [5] Zuber, M. T., et al. (2012) Nature, 486, 378-381.