

**LUNAR FLASHLIGHT: MAPPING ACCESSIBLE WATER FROST.** B. A. Cohen<sup>1</sup>, P. O. Hayne<sup>2</sup>, B. T. Greenhagen<sup>3</sup>, D. A. Paige<sup>4</sup>, P. Russell<sup>4</sup>, M. Sullivan<sup>4</sup>, W. J. Ready<sup>5</sup>, G. Lightsey<sup>5</sup>, P. Adell<sup>6</sup>, J. D. Baker<sup>6</sup>; <sup>1</sup>NASA Goddard Space Flight Center, Greenbelt MD (barbara.a.cohen@nasa.gov), <sup>2</sup>University of Colorado, Boulder CO; <sup>3</sup>JHU Applied Physics Laboratory, Laurel MD, <sup>4</sup>UCLA, Los Angeles, CA; <sup>5</sup>Georgia Tech / GTRI, Atlanta GA; <sup>6</sup>Jet Propulsion Laboratory, Pasadena CA.

**Introduction:** Lunar Flashlight is a 6U satellite (12x24x36 cm) developed and managed by the Jet Propulsion Laboratory that will search for water ice exposures and map their locations in the Moon's south polar region. The Lunar Flashlight mission will demonstrate technologies for NASA such as green propulsion and active laser spectroscopy while proving the capability of performing a planetary science investigation in the CubeSat form factor. Lunar Flashlight was selected in 2013 by the NASA Advanced Exploration Systems (AES) program within the Human Exploration and Operations Mission Directorate (HEOMD); the mission is currently funded as a technology demonstration mission within NASA's Space Technology Mission Directorate (STMD) portfolio. Lunar Flashlight is manifested as a secondary payload to the Intuitive Machines IM-1 launch, on a Falcon 9 rocket currently scheduled for December 2022 [1].

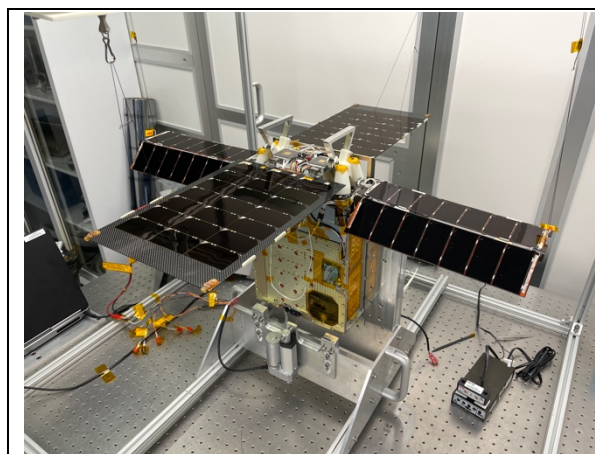


Figure 1. The fully integrated Lunar Flashlight spacecraft.

**Polar water deposits:** Near the poles of the Moon, permanently shadowed regions (PSRs) may hold a record of volatile delivery, transport, sequestration, and loss through geologic time [2-3]. Trapped water could be an important target of in situ resource utilization (ISRU), for life support or fuel and propellant [4-6]. Lunar polar water ice consists of two reservoirs: deeply buried ice deposits, and surficial water frost. The Clementine, Lunar Prospector, and Lunar Reconnaissance Orbiter (LRO) missions made observations consistent with ice deposits cm- to meters-deep with ~1% H<sub>2</sub>O by

mass [7-10], but not all PSRs contain ice signatures. LCROSS revealed 5-7 wt% of H<sub>2</sub>O in the upper few m at Cabeus, along with a comet-like array of volatiles [11]. At the lunar surface, LRO and the Moon Mineralogy Mapper (M3) data are consistent with water frost at concentrations ranging from ~0.1 up to ~10 wt% with a patchy distribution [12-14]. However, the distribution of apparent water frost does not match the subsurface distribution, and neither is its occurrence proven everywhere temperatures are cold enough to permit trapping of water molecules [15]. Current data are not yet sufficient to conclude the form, quantity, or distribution of lunar H<sub>2</sub>O at concentrations sufficient for in-situ resource utilization (ISRU), or to predict the distribution of ice at scales of a rover or human landed mission. To be "operationally useful" for such missions, H<sub>2</sub>O concentrations of greater than ~0.5 wt% are required [16].

**Lunar Flashlight measurements:** The Lunar Flashlight mission will make definitive detections of surficial water frost within PSRs if it is present in quantities above ~2 wt% in areas measured by the mission. The Lunar Flashlight illumination system uses stacked laser diode bars to emit short (few ms) energy pulses at four near-IR wavelengths diagnostic of water ice in rapid sequence, while a receiver system detects the reflected light [17]. Derived reflectance and water ice band depths will be mapped onto the lunar surface to identify locations where H<sub>2</sub>O ice is present. Individual measurements have a surface footprint of ~30m, but will need to be added along-track to increase the SNR, resulting in an along-track mapping resolution of ~10 km. The total duration of laser firing per pass will be approximately 2-3 minutes during closest approach over the south pole, including multiple PSRs and potentially other areas of interest such as the landing sites for VIPER CLPS landers and Artemis III. By repeating these measurements over multiple points, Lunar Flashlight will create a map of surficial water frost concentration that can be correlated to previous mission data. All calibrated and derived data will be publicly archived in NASA's Planetary Data System (PDS).

**Synergy with other missions:** Two missions on Artemis-1 (Lunar IceCube and LunaH-Map) will make complementary lunar volatile measurements [18-19]. Although each mission uses a different design and measurement approach, the results from these missions will be synergistic as a fleet of missions simultaneously

exploring the nature and distribution of water on the Moon ahead of human exploration.

**References:** [1] <https://spacenews.com/intuitive-machines-first-lunar-lander-mission-slips-to-2022/> [2] Anand, *Earth, Moon, and Planets*, 107, 65-73, 201. [3] Lawrence, in *Encyclopedia of Lunar Science*, 10.1007/978-3-319-05546-6\_16-1, 2018. [4] Anand et al., *Planet Space Sci.* 74, 42-48, 2012 [5] Sanders, AIAA SPACE and Astronautics Forum and Exposition, 2018, 10.2514/6.2018-5124. [6] Kornuta et al., REACH, 13, 2019. [7] Nozette et al., *Science* 274, 1495-1498, 1996. [8] Nozette et al., *J. Geophys. Res.* 106, 23253-23266, 2001. [9] Feldman et al., *J. Geophys. Res.* 106, pp. 23231-23252, 2001. [10] Sanin et al., *J. Geophys. Res.* 117, 2012. [11] Colaprete et al., *Science* 330, 2010. [12] Hayne et al., *Icarus* 255, 58-69. [13] Fisher et al., *Icarus* 292, 74-85, 2017. [14] Li et al., *PNAS* 115, p. 8907, 2018. [15] Paige et al., *Science* 330, 479-82, 2010. [16] Hayne et al., LEAG #7043. 2013. [17] Vinckier et al., *Remote Sensing* 11, 2019. [18] Clark et al., LPSC 47, #1043, 2016. [19] Hardgrove et al., LEAG, 2015.