LUNAR FLASHLIGHT: MAPPING ACCESSIBLE WATER FROST. B. A. Cohen[1], D. R. Cremons[1], B. T. Greenhagen[2], P. O. Hayne[3], D. A. Paige[4], R. R. Petersburg[2], P. S. Russell[4], M. Sullivan[4], G. Lightsey[5], P. Adell[6], J. D. Baker[6], and the Lunar Flashlight team. [1]NASA Goddard Space Flight Center, Greenbelt MD (barbara.a.cohen@nasa.gov); [2]JHU Applied Physics Laboratory, Laurel MD; [3]University of Colorado, Boulder CO; [4]UCLA, Los Angeles, CA; [5]Georgia Tech / GTRI, Atlanta GA; [6]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 is demonstrating 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) Small Spacecraft Technology program.

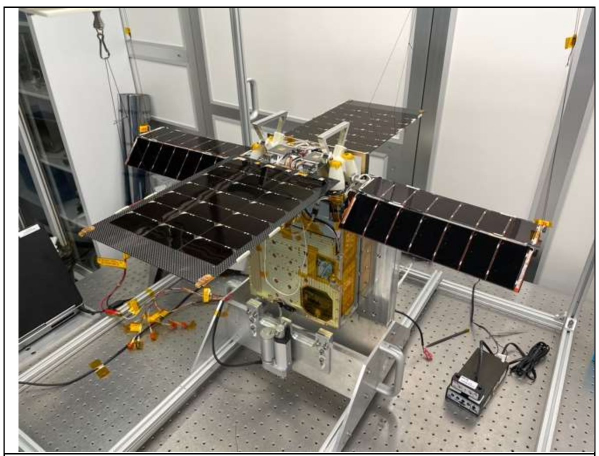

Figure 1. The fully integrated Lunar Flashlight spacecraft. The spacecraft Z-axis is shown pointing up.

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: 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_2O by mass [7-10], but not all PSRs contain ice signatures. LCROSS revealed 5-7 wt% of H_2O 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 hydrogen 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_2O at concentrations sufficient for in-situ resource utilization (IRSU), or to predict the distribution of ice at scales of a rover or human landed mission. To be "operationally useful" for such missions, H_2O concentrations of greater than ~2wt% are required [16].

Spacecraft Overview: The 6U CubeSat has a mass of approximately 14 kg after fueling, and includes power, command and data handling, communications, attitude control, propulsion, and payload subsystems. The power subsystem includes four solar arrays developed by Blue Canyon Technologies (BCT) and MMA, an Electrical Power Systems (EPS) management board, and a battery built with Panasonic NCR18650B cells. The arrays are capable of providing over 55W at end of life. Command & Data Handling (C&DH) is provided by a JPL-developed Sphinx single-board computer, which includes a GR712RC radiation-hardened microprocessor and a ProASIC3 FPGA. The flight software utilizes JPL's F Prime framework. The spacecraft uses an Iris Radio, a small satellite transponder developed by JPL and built by Utah State University's Space Dynamics Laboratory. A pair of low-gain antennas sits at each end of the spacecraft on the Z-axis, providing transmit and receive capability independent of the spacecraft's orientation. The attitude determination and control system (ADCS) for the spacecraft is provided by a BCT XACT-50. It utilizes sun sensors mounted around the spacecraft as well as an internal star tracker and three internal reaction wheels.

The Lunar Flashlight Propulsion System (LFPS) was designed to provide over 3300 N·s of impulse, allowing for lunar orbit insertion, correctional maneuvers, and reaction wheel desaturation during the mission. Lunar Flashlight's propulsion system was developed by NASA Marshall Space Flight Center with development and integration support from Georgia Tech and financial support from NASA's Small Business Innovation Research program and the Air Force Research Laboratory.

Lunar Flashlight is operated by Georgia Tech, including graduate and undergraduate students. Though it is the first time GT is doing a deep space mission, JPL is providing expertise and support in all subsystems and mission management.

Lunar Flashlight measurements: Lunar Flashlight's science instrument is a compact Short Wave Infrared (SWIR) laser reflectometer designed to identify water ice on the lunar surface. Diode lasers sequentially emit infrared energy at four different wavelengths: 1064, 1530, 1850, and 1990 nm. This light reflects off the lunar surface and is received by the onboard paraboloidal mirror which focuses the incoming light onto a passively cooled InGaAs detector [17]. Differences in the received signal amplitude across the sequence of laser pulses (and a "blank" period) will be used to identify the water ice signature. The lasers are powered from a separate battery built with Sony NCR18650B cells and thermal energy from the lasers and laser electronics is dissipated into adjacent phase change material.

The surface area occupied by water ice cold traps on the Moon is ~10^5 km^2, predominantly poleward of ~80°S, more-or-less evenly distributed in longitude. Individual measurements have a surface footprint of ~200m, depending on spacecraft altitude. The total duration of laser firing per orbit will be approximately 2-3 minutes during closest approach over the south pole. Therefore, we expect Lunar Flashlight to resolve (>2 measurement across) the largest PSRs along its orbit track; this translates to a spatial resolution of <10 km for the largest (~20 km) PSRs.

The Science Operations Center is led by UCLA, using tools derived from LRO Diviner operations. The science team visualizes the spacecraft ground track, altitude, and roll effects in QuickMap, and can choose potential targets (*e.g.,* PSRs, landing sites for CLPS landers, Artemis III candidate landing sites, Shadowcam images). LF instrument data will be calibrated using an instrument model derived from end-to-end test data collected at JPL. The science team will process the data, including the potential to integrate along-track to increase the SNR (up to an along-track mapping resolution of ~10 km). The team will create derived normal albedo and water ice band depths that can be correlated with previously mapped geologic characteristics, including latitude, temperature, topography, lighting, proximity to young fresh craters, etc. Cross-calibration with the Lunar Orbiter Laser Altimeter (LOLA) global reflectance map [18] will also be performed using LF's 1064-nm channel. All calibrated and derived data, along with the instrument model and a user's guide, will be publicly archived in NASA's Planetary Data System (PDS) PDS Geosciences Node.

Mission Status: Lunar Flashlight launched as a secondary payload with the HAKUTO-R mission, on a Falcon 9 rocket on December 12, 2022. Lunar Flashlight is currently heading toward the Earth-Moon L2 point, where it will use a low-energy transfer point to go into an energy-efficient near-rectilinear halo orbit. The science orbit will have a perilune of 15 km over the lunar South Pole and an apolune of 70,000 km with a roughly 5-day period. As of this abstract, Lunar Flashlight is power positive, sun-pointed, and regularly communicating with NASA's Deep Space Network. The mission is working through initial checkout activities for all its subsystems and we will provide a status report at this meeting.

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