

**Lunar Laser Surface Solar Occultation (LLSSO), a Payload Concept for Lunar Landers.** K. W. Farrell Jr.<sup>1</sup>, D. S. Bomse<sup>2</sup>, R. E. Milliken<sup>3</sup>, J. F. Mustard<sup>3</sup>, and J. W. Head III<sup>3</sup>, <sup>1</sup>Jacobs Missile Defense Group, Schriever AFB, 720 Irwin Dr., Colorado Springs, CO 80912, karr.farrell@jacobs.com, <sup>2</sup>Mesa Photonics, <sup>3</sup>Brown University.

**Introduction:** Optical absorption measurements acquired by multiple instruments have demonstrated the presence of OH/H<sub>2</sub>O at the lunar surface [1, 2, 3], and perhaps the most intriguing aspect of these observations is the indication that OH/H<sub>2</sub>O is gained/lost by regolith over the course of a lunar day [3, 4, 5]. Key questions remain as to the form of this water (OH or H<sub>2</sub>O), the rate and amount of ‘water’ that is lost, and the physical processes that drive these apparent changes in surface hydration. Here we describe a small, cost-effective instrument that can be used to directly measure the form and abundance of water cycled in the lunar regolith. The Lunar Laser Surface Solar Occultation (LLSSO) instrument is a laser heterodyne radiometer [6, 7] that uses recently available interband cascade laser technology [8, 9] to detect the presence of water resources that are cycled from the lunar surface.

As an instrument on a lunar lander and/or rover, LLSSO is a remote sensor designed to indicate the presence of OH/H<sub>2</sub>O (hereafter, “water”). LLSSO addresses Strategic Knowledge Gaps (SKGs) that evaluate surficial water as a lunar resource, including the distribution, mobility and abundance of water on the lunar surface. LLSSO aims to detect water molecules present near lunar regolith throughout the lunar day [10, 11]. LLSSO measures occultation of solar light in the 2.6 to 2.9  $\mu\text{m}$  wavelength range by water vapor columns along a line of sight from a landed detector to the Sun (Figure 1).

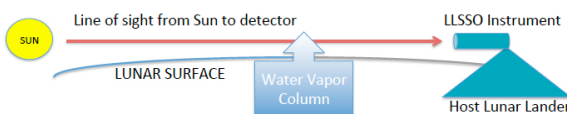


Figure 1: Schematic of solar occultation by water released from the lunar surface to LLSSO detector attached to host lander.

**Objectives:** As an instrument on a lunar lander, LLSSO is designed to provide low-cost, in-situ confirmation of diurnal release of water in specific lunar locations, and conduct temporal measurements of release of volatile lunar water throughout a lunar daily transport cycle. The sensitivity of the LLSSO instrument is designed to provide a signal above noise threshold for relatively low detection levels of water/hydroxyl molecules in a column above the lunar surface expected in lunar landing sites [3, 4, 12, 13]. The engineering performance of LLSSO is designed to detect water column densities at lower threshold levels

approaching 150ppm-m (or lower, depending on vapor temperature). This low threshold necessitates the application of laser heterodyne spectroscopy within the 2.6 to 2.9  $\mu\text{m}$  wavelength region to detect optical absorption of solar light by water using a sensitive, tuned detector aimed at the sun across the lunar surface. LLSSO is designed to periodically power on throughout the lunar day to detect absorption levels, and remain in a dormant state between observations. A nominal mission would place the LLSSO instrument on a single location near the lunar surface to capture the solar transit from the lunar dawn to sunset. (Figure 2).

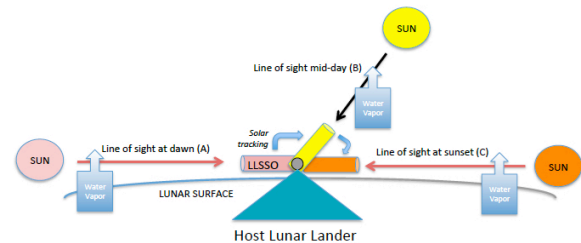


Figure 2: Orientation of LLSSO solar occultation tracker showing articulation at solar dawn, mid-day, solar sunset.

**Background:** The conceptual design, laboratory development and initial tests of an applied Laser Heterodyne Radiometry (LHR) technique suitable for integration with a lunar lander stems from work completed on precision heterodyne spectrometry by team members at Mesa Photonics [14]. Optical heterodyne methods are similar to their electronic counterparts used in radio and television, among other applications and were pioneered by NASA researchers beginning in the 1970's. Incoming light is combined with light from a narrow-band laser source (the local oscillator or LO) on a photodetector. The detector output will contain AC electronic signals at the (optical) difference frequencies. Heterodyne signals are proportional to the solar spectrum at the LO wavelength, when the LO coincides with an optical absorbance, the heterodyne signal intensity will drop by an amount proportional to the absorbance.

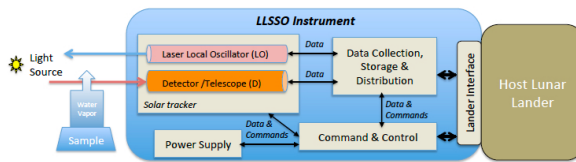


Figure 3: Prototype LLSSO Engineering Test article block diagram with lander host interfaces (instrument data, command, control, power).

**Engineering Tests:** An engineering prototype of LLSSO is being designed and constructed for testing. The current LLSSO design is composed of seven components that together provide an end-to-end water vapor detector on an integrated platform, shown in Figure 3. These components include an interband cascade laser tuned within a selected range between 2.6 and 2.9  $\mu\text{m}$ , solar tracker, telescope, detector, power supply (required for standalone operations), an integrated data collection, storage and distribution unit and a command and control unit with an data and power control interface to the host lander.

In planned tests, sunlight and laser light are combined onto a detector, where the detector outputs rf power at the difference frequencies between the laser optical frequency and the adjacent solar spectrum. Optical absorption by gases in the line of sight to the sun are detected as reductions in the rf power as the laser wavelength is varied. The interband cascade laser used in LLSSO will likely have different noise characteristics from lasers—such as  $\text{CO}_2$ , InGaAsP, and quantum cascade—that have been used successfully in previous LHR instruments. Detection of lunar OH/ $\text{H}_2\text{O}$  requires using this type of laser that has the needed sensitivity at 2.6 and 2.9  $\mu\text{m}$ , and has yet to be demonstrated in a heterodyne spectrometer. The prototype LLSSO is expected to undergo testing at Brown University using a controlled environment with a known amount of water vapor under high vacuum conditions. Tests on the LLSSO mid-infrared configuration in 2019 are expected to validate the sensitivity and precision of the instrument package for lunar water detection at levels expected on a range of lunar landscapes. LLSSO is planned to be available for integration with commercial lunar landers in 2020.

**Mission Design:** During the testing timeframe, our team will integrate data acquired by previous and current lunar instruments (e.g., terrain models and near-IR Moon Mineralogy Mapper data) to model likely values of water vapor concentrations in prospective high-value landing sites, including areas that contain pyroclastic deposits (e. g., Sulpicius Gallus, Aristarchus Plateau, Rima Bode) [15], mature soil locations of variable water/hydroxyl concentrations (Plato), and cra-

ters with volatile signatures (central peaks of Copernicus, Bulliadus).

**Engineering Specifications:** The engineering design model of the landed LLSSO instrument includes 2U Cubesat volume, 2 kg. of integrated laser, optics, communications and power supply, with lander requirements of 20W power (LLSSO on) and 1W (LLSSO in standby dormant state).

**Potential Evolution of LLSSO:** LLSSO is expected to undergo value engineering in 2020-21 to provide an integrated instrument of less than 1U Cubesat volume, low-mass laser and optics, and tuned laser frequencies capable to discriminate  $\text{H}_2\text{O}$  from OH Hydroxyl. LLSSO is suited for multiple deployments. In distributed configurations, multiple LLSSO instruments would be designed for coordinated measurements across a three-dimensional landscape and deployed across the lunar surface to measure the column of water / hydroxyl vapor with reflectors from different azimuth locations (Figure 4).

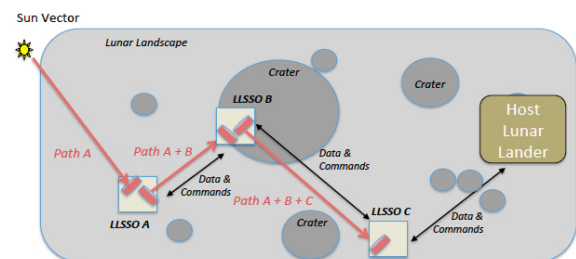


Figure 4: Notional combination of multiple, distributed LLSSO instruments combining absorption pathways across irregular lunar surface topography.

## References:

- [1] Pieters C. M. et al. (2009) *Science*, 326, 568-572.
- [2] Clark R. N. (2009) *Science*, 326, 562-564. [3] Sunshine J. M. et al. (2009) *Science*, 326, 565-568. [4] Li S. and Milliken R. E. (2017) *Sci. Adv.*, 3:e1701471. [5] Wohler C. et al. (2017) *Sci. Adv.*, 3:e1701286.
- [6] Menzies R. T. and Shumate M. S. (1974) *Science*, 184, 570-572. [7] Menzies R. T. et al. (1981) *Appl. Opt.*, 20, 536-544. [8] Wilson E. L. et al. (2013) *Appl. Phys B*, 1-9. [9] Melroy H. R. et al. (2015) *Appl. Phys B, Letters and Optics*, 120, 609-615. [10] Pieters C. M. and Milliken R. E. (2014) *Annual Mtg. of LEAG*, 3051. [11] Klima R. L. and Petro N. E. (2017) *Philos Trans A Math Phys Eng Sci.*, 375, 2094. [12] Milliken R. E. and Li S. (2017) *Nature Geo*, 10, 561-565.
- [13] McCord T. B. et al. (2011) *J. Geophys. Res.*, 116, E00G05. [14] Bomse D. S. and Kane D. J. (2006) *Appl. Phys B*, 85, 461-466. [15] Head J. W. and Wilson L. (2017) *Icarus*, 283, 176-223.