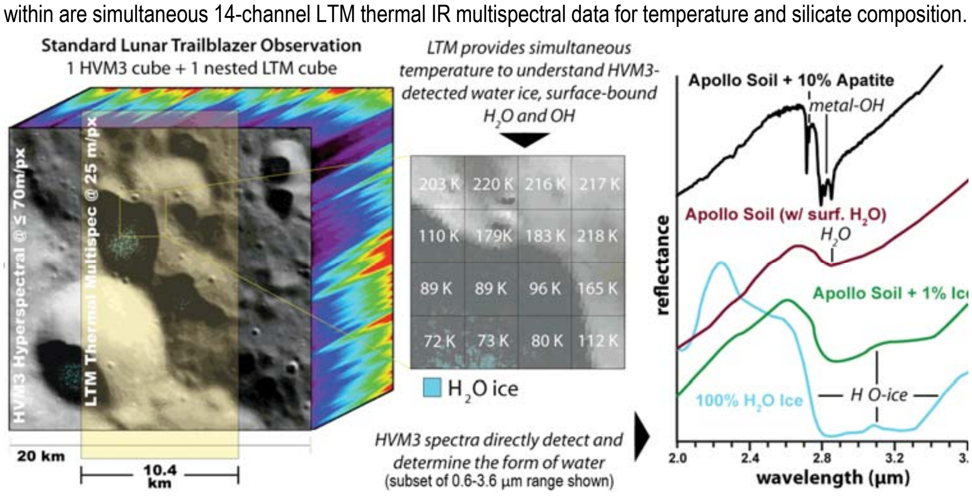
DIRECTLY MEASURING THE DISTRIBUTION OF SURFACE HYDROXYL/WATER ON THE MOON WITH LUNAR TRAILBLAZER: A PIONEERING SMALLSAT FOR LUNAR WATER AND LUNAR GEOLOGY. B.L. Ehlmann[1,2], R.L. Klima[3], L. Bennett[4], D. Blaney[2], N. Bowles[5], S. Calcutt[5], M. Cannella[6], J. Dickson[1], K. Donaldson Hanna[7], C.S. Edwards[8], R. Evans[5], W. Frazier[2], R. Green[2], G. Helou[4], M.A. House[9], C. Howe[10], B. Marotta[6], J. Miura[1], C. Pieters[11], M. Sampson[6], E. Scire[4], R. Schindhelm[6], C. Seybold[2], K. Shirley[5], D. Thompson[2], J. Troelzsch[6], T. Warren[5], J. Weinberg[6]. [1]Div. Geological & Planetary Sciences, California Institute of Technology, Pasadena, CA, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [3]JHU Applied Physics Lab, Laurel, MD, [4]IPAC, California Institute of Technology, Pasadena, CA [5]Univ. of Oxford, United Kingdom, [6]Ball Aerospace & Technologies Corp., Boulder, CO [7]Univ. of Central Florida, Orlando, FL [8]Northern Arizona Univ., Flagstaff, AZ [9]Pasadena City College, Pasadena, CA, [10]Science & Technology Facilities Council, RAL Space, Didcot, United Kingdom [11]Brown Univ., Providence, RI

Introduction: Water on the Moon was one of the most exciting discoveries of the late 2000's. In 2008, [1] measured Apollo lunar glasses indicating magmas enriched in water. In 2009, OH and potentially H_2O were detected on the sunlit surface of the Moon by shortwave-infrared (SWIR) spectrometers, Chandrayaan-1/Moon Mineralogy Mapper (M^3), EPOXI/HRI-IR and Cassini/VIMS [2,3,4]. The LCROSS mission impact into a permanently shadowed region (PSR) in Cabeus crater detected H_2O ice [5], confirming inferences from a variety of remote sensing measurements and modeling [summarized in 6].

However, key questions remain about lunar water, as well as the water cycle on airless bodies more generally, highlighted in the Decadal Survey [7]. Some PSRs have water ice, including those directly detected with M^3 using terrain-scattered light [8], while others show detections in some datasets and not others [6]. M^3 provided the best spatially-resolved (70-280 m/pixel) coverage for OH/water detection; however, because the discovery of water on the sunlit Moon was not expected, M^3 was not optimized to rigorously quantify its abundance. M^3's 3-μm cutoff wavelength results in ambiguities in the strength, shape, and exact position of the absorption band, which are critical for quantifying the abundance and form of hydrated species. Thermal emission further complicates the data, as thermal radiance needs to be removed from reflectance to accurately quantify the water band depth. Discrepancies exist between different thermal correction techniques, leading to conflicting results about whether the species is more likely water or hydroxyl, where it is concentrated, its abundance and whether it migrates over the course of the lunar day [e.g., 9-13].

Mission Objectives: In June 2019, NASA selected the SIMPLEx mission Lunar Trailblazer for Phase A/B development, culminating in a Preliminary Design Review in September 2020 and follow-on decision to proceed to flight. Lunar Trailblazer is optimized to make targeted measurements of the infrared properties of the lunar surface to directly measure the form, distribution, abundance and possible migration of water/OH on the lunar surface by acquiring compositional data to distinguish hydrated materials at the same time as data to derive surface temperature (Fig. 1). Lunar Trailblazer's objectives are to (1) detect and map water on the lunar surface at key targets to determine its form (OH, H_2O, or ice), abundance, and distribution as a function of latitude, soil maturity, and lithology; (2) assess possible time-variation in lunar water on sunlit surfaces; and (3)

Figure 1. Graphic of the simultaneous composition and temperature data that will be acquired by Lunar Trailblazer. The HVM3 imaging spectrometer acquires data in 100's of infrared channels (0.6-3.6 μm) and nested within are simultaneous 14-channel LTM thermal IR multispectral data for temperature and silicate composition.



map the form, abundance, and distribution of water ice in the PSRs, finding any operationally useful deposits of lunar water and locations where it is exposed at the surface for sampling. In all cases, Lunar Trailblazer simultaneously (4) measures surface temperature to quantify the local gradients and search for small cold traps. These measurements advance understanding of volatiles on airless bodies by study of the lunar water cycle and incorporation of water into the lunar crust. Trailblazer will also—particularly if NASA selects a proposed communications system enhancement option—provide reconnaissance for candidate landing sites and provide the highest spatial and spectral resolution shortwave infrared and mid-infrared maps of lunar lithologies across the surface (e.g., irregular mare patches, silicic domes, spinel-rich locations, “dunite regions”, pyroclastic deposits).

Table 1. Current best estimate Lunar Trailblazer science observing parameters from 100±30 km orbit

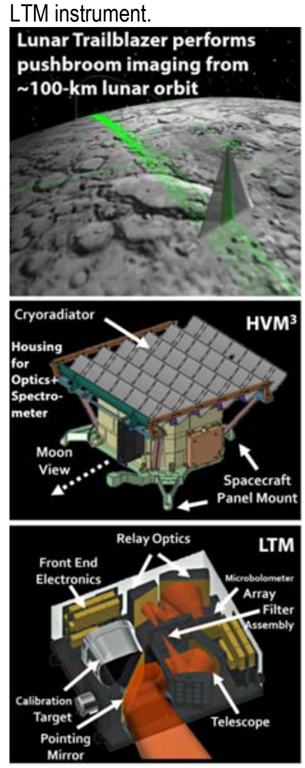
HVM^3	
Spatial Sampling	≤ 100 m/pixel
Swath Width	≥ 20 km
Spectral Range	0.6 – 3.6 µm
Spectral Sampling	10 nm
SNR	>200 at 3-µm for low sun (85°) scene
Uniformity	>90% cross track
# Data Cubes*	1000
LTM	
Spatial Resolution	≤ 35 m/pixel
Spatial Width	≥ 10 km-swath
Thermal	Temp. retrieval 110-400K (± <5 K) 4 broad bands, 6-100 µm
Composition	7-10 mm 11 channels; < 0.5 mm
SNR	> 50 when sunlit
# Data Cubes*	1000

*optional greater (near-global) coverage under Data Enhancement Option

Spacecraft, Mission Design & Instruments: Lunar Trailblazer is the first generation of ride-along planetary smallsats, selected under SIMPLEx. An ESPA Grande craft, compatible with most ESPA Grande rideshare opportunities to GTO/GEO and beyond, Lunar Trailblazer’s schedule baseline is to be delivered for launch by end of 2022. During the Phase A/B study, NASA directed Trailblazer to baseline a launch opportunity with NASA’s Interstellar Mapping and Acceleration Probe (IMAP), launching in 2024. From its separation with the primary, Trailblazer uses its solar electric propulsion system to enter into a ~100-km polar orbit around the Moon. In pushbroom mode, the spacecraft acquires data with its two science instruments: the High-resolution Volatiles and Minerals Moon Mapper (HVM^3), similar to M^3 but explicitly designed to measure hydrated materials, as well as the Lunar Thermal Mapper (LTM), a thermal infrared (TIR) mapping instrument to measure the temperature, composition, and thermophysical properties within each HVM^3 pixel (Fig. 2; Table 1).

HVM^3 is a MatISSE-developed, JPL-built, modernized version of the successful M^3 imaging spectrometer and has been optimized to identify and quantify water [14]. LTM is a UK-contributed, University of Oxford/STFC RAL Space-built miniaturized TIR multispectral imager optimized to simultaneously measure temperature, composition, and thermophysical properties [15]. Over Trailblazer’s 1-year primary science mission, each instrument will acquire ≥1000 targeted images. Targets include measurements to determine the composition of all PSRs using terrain-scattered light, and coverage of multiple latitudes at 3 times of lunar day.

Figure 2. A schematic of the Lunar Trailblazer observing geometry, HVM^3 instrument, and LTM instrument.



Lunar Trailblazer is a PI-led mission at Caltech, managed by JPL with industry partner Ball Aerospace integrating the spacecraft. Science and mission operations will be led from Caltech. A student collaboration at Caltech and Pasadena City College involves undergraduate students—as well as graduate students and postdocs of the Co-Is—in all aspects of mission design and operations.

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