The First Deep Space Cubesat Broadband IR Spectrometer, Lunarcubes, and the Search for Lunar Volatiles.

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Context: BIRCHES is the compact broadband IR spectrometer of the Lunar Ice Cube mission. Lunar Ice Cube is one of 13 6U cubesats that will be deployed by EM1 in cislunar space, qualifying as lunarcubes. The LunarCube paradigm is a proposed approach for extending the affordable CubeSat standard to support access to deep space via cis-lunar/lunar missions. Because the lunar environment contains analogs of most solar system environments, the Moon is an ideal target for both testing critical deep space capabilities and understanding solar system formation and processes. Effectively, as developments are occurring in parallel, 13 prototype deep space cubesats are being flown for EM1. One useful outcome of this 'experiment' will be to determine to what extent it is possible to develop a lunarcube 'bus' with standardized interfaces to all subsystems using reasonable protocols for a variety of payloads. The lunar ice cube mission was developed as the test case in a GSFC R&D study to determine whether the cubesat paradigm could be applied to deep space, science requirements driven missions, and BIRCHES was its payload. JPL's Lunar Flashlight, and Arizona State University's LunaH-Map, both also EM1 lunar orbiters, will also be deployed from EM1 and provide complimentary observations to be used in understanding volatile dynamics [1, 2] in the same time frame.

Instrument Overview: The versatile GSFC-developed payload BIRCHES, Broadband InfraRed Compact, High-resolution Exploration Spectrometer, is a miniaturized version of OVIRS on OSIRIS-Rex [3, 4, 5, 6]. BIRCHES is a compact (1.5U, 2 kg, 12-25 W) point spectrometer with a compact cryocooled HgCdTe focal plane array for broadband (1 to 4 micron) measurements. The instrument includes an AIM microcryocooler with Iris controller. The instrument will achieve sufficient SNR (>100) and spectral resolution (10 nm) through the use of a Linear Variable Filter to characterize and distinguish several spectral features associated with water in the 3-micron region, and potentially other volatiles already detected by LCROSS (H_2S, NH_3, CO_2, CH_4, OH, organics) and mineral bands. Typical footprint size will be 10 x 10 km, but will be somewhat smaller at the equator and larger toward the poles. We are also developing compact instrument electronics which can be easily reconfigured to support future instruments with H1RG focal plane arrays in 'imager' mode, when the communication downlink bandwidth becomes available. The instrument will enable the lunar ice cube science goals: determination of composition and distribution of volatiles in lunar regolith as a function of time of day, latitude, regolith age and composition, and thus enable understanding of current dynamics of lunar volatile sources, sinks, and processes, with implications for evolutionary origin of volatiles.

Science Investigation: The Lunar Ice Cube mission is designed to address NASA HEOMD Strategic Knowledge Gaps related to lunar volatile distribution (abundance, location, and transportation physics of water ice). Amplifying and extending the findings of lunar missions over the last decade [7, 8, 9], BIRCHES is designed to provide the basis for deriving the forms and sources of lunar volatiles in spectral, temporal, spatial, and geological context by:

- being flown as the Lunar Ice Cube mission payload in a low equatorial periselene, nearly polar, highly elliptical lunar orbit with repeating coverage at different times of day during several lunar cycles,
- being capable, unlike previous orbiting spectrometers, of analysis that encompasses not only many features associated with water and other volatiles, but the broad 3-micron band associated with water species,
- utilizing data obtained from previous missions, such as composition, regolith age, terrane, and slope, and by calibrating its results for the same volatile or mineralogical features obtained from previous observations to provide geological and geochemical context.

In this way, Lunar Ice Cube will achieve its primary goal: to measure the water components (weak physi-adsorbed OH, strong chemi-adsorbed OH, molecular water, ice) as a function of lunation, solar zenith angle, slope, and surface properties as a means of addressing the NASA HEOMD Strategic Knowledge Gap of understanding the distribution and transportation of water on the Moon as a means of enabling potential resource prospecting. Measuring the abundance and distribution of water and water components is also crucial for determining whether OH and water sources are interior, chemogenic, or exterior.

Science data-taking with the BIRCHES payload will occur in two phases, following the approximately 9-month journey on a low energy trajectory initiated at EM1 deployment. Phase 1 will occur between lunar capture and the science orbit, Phase 2 during the science orbit (100 km x 5000 km, equatorial periapsis, nearly polar), highly elliptical, with a repeating coverage pattern that provides overlapping coverage at different lunations. During phase 1, translational propulsion burns are occurring during major portions of most orbits in order to progressively lower periapsis and achieve the desirable incidence angle. Periodically (up to once a week), an orbit will be used for instrument calibration and capture of spectral signatures for larger portions of the lunar disk, traversing from terminator to terminator. Particular attention will be paid to systematic or solar activity dependent transient effects resulting from charged particle interactions around the terminators. Once the nominal full science orbit is achieved, phase 2 will begin, and the main propulsion system will no longer be required. Phase 2, the 'science mission' will last approximately 6 months, 6 lunar cycles, allowing for sufficient collection of systematic measurements as a function of time of day to allow derivation of volatile cycle models.

BIRCHES will detect incoming radiation from reflectance from the lunar surface (our 'measurement'), thermal emission generated by the sun at the lunar surface and thermal emission generated by incoming light on detector surfaces. Absorption features will be superimposed on the reflectance measurement. Radiometric models for our instrument configuration, assuming 4 cm aperture and 6-degree field of view indicate that lunar surface emission does not become significant at temperatures within the instrument according to our thermal models until beyond the three-micron band. Emission from detector surfaces remains a minor component regardless of wavelength. These models also allow us to remove thermal emission as a function of wavelength. In addition, for the three-micron band, we should have adequate signal to noise ratio (SNR) to see the absorption features even as we approach the terminator as long as we have water at the hundredths of a percent level or above.

References: [1] Cohen B. et al. (2015, Lunar and Planetary Science XLVI, 2020.pdf; [2] Hardgrove C. et al. (2015) 5th International Workshop on Lunarcubes, http://lunar-cubes.com/images/docs/LCW5-Abstract-C-Hargrove.pdf; [3] Reuter, D., A. Stern, J. Scherrer, D. Jennings, J. Baer, J. Haney, L. Hardaway, A. Lunsford, S. McMuldroch, J. Moore, C. Olkin, R. Parizek, H. Reitsma, D. Sabatke, J. Spencer, J. Stone, H. Throop, J. VanCleve, G. Weigle, L. Young (1997) SPIE Proceedings, 2597, Advanced and Next-generation Satellites II, 154; [4] Reuter, D., A. Stern, J. Baer, L. Hardaway, D. Jennings, S. McMuldroch, J. Moore, C. Olkin, R. Parizek, D. Sabatke, J. Scherrer, J. Stone, J. VanCleve, L. Young (2005) SPIE Proceedings of the Optics and Photonics Conference, Astrobiology and Planetary Missions, 5906-51, 59061F-1 to 59061F-11, 5906-51; [5] Reuter, D., A. Stern, J. Scherrer, D. Jennings, J. Baer, J. Hanley, L. Hardaway, A. Lunsford, S. McMuldroch, J. Moore, C. Olkin, R. Parizek, H. Reitsma, D. Sabatke, J. Spencer, J. Stone, H. Throop, J. VanCleve, G. Weigle, L. Young (2008) Space Science Reviews, 140, 1-4, 129-154; [6] Reuter, D. and A. Simon-Miller, (2012) Lunar and Planetary Science, 1074.pdf; [7] Pieters C. et al. (2009) Science, 326, 568-572; [8] Sunshine J. et al. (2009) Science, 326, 565-578; [9] Colaprete A. et al. (2010) Science, 330, 463-468.