IN SITU MEASUREMENTS OF A LUNAR SWIRL USING THE *LUNAR VERTEX* ROVER MULTISPECTRAL MICROSCOPE.

Rachel L. Klima[1] (Rachel.Klima@jhuapl.edu), Kieran A. Carroll[2], John P. Hackett[2], Heather M. Meyer[1], William F. Ames[1], Scott A. Cooper[1], Ann L. Cox[1], Frank Teti[2], Alexandra R. Dupont[1], James P. Mastandrea[1], Alexandra V. Ocasio Milanes[1], Frank Morgan[1], Howard W. Taylor[1], Joshua T. S. Cahill[1], Edward A. Cloutis[3], Myriam Lemelin[4], Frederic Diotte[4], Benjamin. T. Greenhagen[1], and David T. Blewett[1]. [1]The Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, U.S.A; [2]Canadensys Aerospace, Bolton, Canada; [3]University of Winnipeg, Winnipeg, Canada; [4]Université de Sherbrooke, Sherbrooke, Canada.

Introduction: *Lunar Vertex* [1] is a suite of instruments and rover, that will be used to explore and characterize the Reiner Gamma swirl in Oceanus Procellarum (landing site at 7.585°N, 301.275°E [2]). Selected through NASA's first Payloads and Research Investigations on the Surface of the Moon (PRISM) call, *Lunar Vertex* will land on the Moon on a Commercial Lunar Payloads Services (CLPS) lander built and operated by Intuitive Machines. The lander will deploy the Lunar Vertex Rover, a version of Lunar Outpost's Mobile Autonomous Prospecting Platform (MAPP) product. The rover carries the Rover Multispectral Microscope (RMM), designed and built by Canadensys Aerospace, to characterize the texture and composition of the lunar regolith as the rover traverses the Reiner Gamma swirl.

Scientific Objectives: The RMM will be used to characterize the fine-scale physical properties and the visible-near infrared spectral signature of the lunar regolith beneath the rover in variety of terrains. The threshold mission is met by characterizing the region affected by the impinging rocket plume (the "blast zone", estimated to be <50 m from the lander) and locations outside of the blast zone in the high-reflectance zone. The baseline mission continues with science stops en route to and within the low-reflectance 'dark lane' of the Reiner Gamma lunar swirl. Characterization of the microtexture of the lunar regolith can be accomplished at any wavelength and/or with solar illumination on the target. Determining the visible to near-infrared (vis-NIR) spectral properties of the lunar regolith, requires measurement of reflectance at specific wavelengths. The RMM will accomplish these objectives by using active illumination at discrete LED wavelengths. For spectral measurements, solar signal is treated as background noise and removed from the data. Texture measurements drive requirements on the depth of field, pixel scale, and field of view, while spectral measurements drive the number and wavelength of the LEDs, as well as the scattered-light tolerance of the system.

The texture and spectral properties of the lunar regolith within the low and high reflectance zones will provide inputs to help test different hypotheses for swirl formation. If the swirls were formed by a comet or meteoroid swarm scouring [e.g., 3-4], the texture on the swirl would be similar to that found in the blast zone of the lander. The spectral slope and curvature at the longer wavelength would be consistent with a lesser degree of space weathering than at locations outside of the bright swirl, and there would be less evidence of agglutinates. In contrast, if swirls are formed by solar-wind shielding [e.g., 5], the texture and porosity of the bright areas of the swirl are expected to be similar to that in areas outside of the blast zone, and contain a normal proportion of agglutinates. However, those agglutinates may have higher reflectance and/or exhibit a spectral slope that suggests a low content of submicroscopic metallic iron, due to a lack of iron reduction by the solar wind. If the swirls are formed by dust levitation or compaction of fairy castles [e.g., 6-7], the regolith should lack the fairy castle structure, contain agglutinates, and/or exhibit different spectral slope and curvature, due to a more felsic lithology.

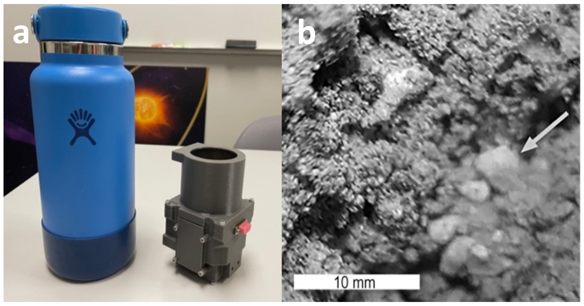

Fig. 1. (a) A 3-D printed, full-scale model of the RMM, compared with a 32 oz water bottle. **(b)** Example image of sifted lunar regolith at the required pixel scale, showing that clasts, voids, and clumps can be clearly distinguished.

The Rover Multispectral Microscope: The RMM is designed to provide active, multispectral microscopic imaging within a very small, low-mass (<0.5 kg) package. RMM consists of a camera, with heritage from Canadensys' Nano Immersive Situational Awareness (NISA) space camera, combined with an illumination board with 10 LEDs (two LEDs for each of five wavelengths), to illuminate the lunar surface at discrete wavelengths. The camera uses a CMOS detector array containing 3000 × 4000 pixels, and the camera lens optics (12 mm f/4 lens) are designed to provide a pixel scale of 30 μm at the working focal distance of 20 cm at best focus, transmitting light across the wavelength range of 350–1000 nm. The required field of view is a

2-cm diameter circle at the nominal working distance, with a depth of field of ≥0.5 cm, to account for uncertainty in the compressibility and topography of the regolith. While the detector array will image a region much larger than 2 cm in diameter, the inner 2 cm will have the most uniform LED illumination.

The RMM illumination board contains LEDs at each of the following wavelengths: 365 nm, 740 nm, 850 nm, 910 nm, and 940 nm. These wavelengths were selected in order to characterize the vis-NIR spectral slope, as well as the edge of the 1-µm ferrous absorption band, enabling the relative degree of space weathering to be distinguished between sites (Fig 2). For site-to-site comparisons, many or even all of the pixels across the working field-of-view may be averaged to increase the signal to noise (SNR).

Images taken by the RMM will be at a scale that enables millimeter-scale clasts to be discerned, as well as clumps of finer material and pore space in uncompressed soils. Shown in Fig. 1b is an image of lunar regolith, taken in the laboratory and resampled to the spatial resolution of the RMM. The arrow points to a grain that is several millimeters across. For most of the mission, when the Sun is high enough in the sky to be shaded by the rover, the SNR is expected to be sufficient for such grains to also analyzed spectrally.

RMM will be mounted inside the rover behind a recloseable door on the rover baseplate that protects it from dust while driving. A calibration target on the inside of the door allows collection of dark images and characterization of changes in LED irradiance over the course of the mission.

Calibration Strategy: Calibrated radiance (and percent reflectance relative to a perfect Lambertian reflector) is needed for each spectral band to ensure that we can relate the spectral properties of the regolith to laboratory measurements and other multi- and hyperspectral data sets obtained from orbit. Characterization of the texture of the surface beneath the rover requires calibration to correct image artifacts and allow for ≥90 µm-sized grains to be resolved and measured. Radiometric calibration of the flight model will be performed at APL, and an identical engineering model will also be available, in case measurements are required after the flight model is integrated onto the rover.

Data products will include calibrated spectral image "cubes": arrays where *x* and *y* are the spatial directions and *z* is a spectral plane with each of the LED color images with contributions from solar illumination removed and stacked, image cubes with contributions from solar and LEDs remaining. Another data product is a single-plane image illuminated only by scattered and potentially direct solar light. Because the rover is not moving during measurements, images do not need to be georeferenced to one another to build the image cubes. However, the best-focus distance for each color will be slightly different, potentially enabling users to investigate slightly different depths within the regolith.

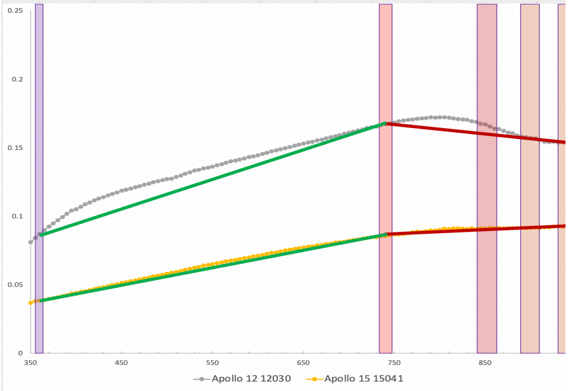

Fig. 2. Laboratory spectra, measured in the RELAB [8], of mare soils from *Apollo 12* (less space weathered) and *15* (more space weathered). The positions and approximate bandpasses of the nominal RMM LED wavelengths are shown. While the five wavelengths provide a more robust characterization of the spectral shape, as few as three wavelengths would still allow the visible and infrared slopes to be distinguished and compared from site to site or within a single image.

All images, with or without LED illumination, will be corrected for detector bias, dark current, and gain nonuniformity. Dark measurements will be obtained on the lunar surface, before and after each image cube is collected. LED output (intensity, center wavelength, and spectral shape), as a function of instrument temperature will be measured in the laboratory. Images of a calibration target, taken at the focal distance with each set of LEDs, will be collected so that any nonuniformity in illumination across the field of view can be corrected.

Acknowledgments: *Lunar Vertex* is funded through NASA's PRISM1 program, managed by MSFC. Thanks to our NASA Mission Manager D. Harris, Program Scientist R. Watkins, Project Scientist H. Haviland, CLPS Integration Manager M. Dillard, and the NASA HQ and PMPO teams.

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