THERMAL INFRARED MEASUREMENTS AS PART OF A COORDINATED LUNAR RESOURCE CAMPAIGN.

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Introduction: Using thermal infrared measurements, the Diviner radiometer onboard NASA's Lunar Reconnaissance Orbiter has shown [1, 2] that the Moon hosts some of the coldest permanently shadowed regions (PSRs) in the solar system, where water and other volatiles may be cold-trapped for billions of years [3]. Thermal environments at the Moon's poles are complex, with strong temperature gradients separating shadows from nearby sunlit surfaces. Shadows smaller than ~250 m ("micro cold traps" [4]) have yet to be resolved in the thermal IR, are prevalent on illuminated terrain, and are of significant interest to future exploration due to their potential to cold-trap water. Given the paramount importance of temperature in controlling ice stability at all spatial scales, thermal infrared measurements should be a key component of a coordinated lunar resource campaign.

Identifying Potential Resources with IR: Regardless of their origins [5, 6], the ultimate fate of lunar polar volatiles depends on temperature [7]. Thermal models have been remarkably successful in predicting the locations of spatially resolved stable ice reservoirs on airless bodies (e.g., [3, 8, 9, 10]), in large part due to the availability of thermal IR measurements. By simulating subpixel topography, thermal models can place constraints on the volume of cold-trapped volatiles below an instrument's resolution [11]. Infrared emission provides a critical constraint on surface and subsurface ice stability, which are highly dependent on spatial scale [4].

An integrated campaign to identify operationally useful ice deposits on the Moon [12] would combine knowledge of both critical environmental variables with real-time measurements of the lunar surface. In resource assessment, temperature and the local impact history are critical [13]. Visible images measuring instantaneous shadows cannot directly identify PSRs, whose temperatures depend on their size, shape, latitude, and surrounding topography. Therefore, acquiring temperature measurements should be among the first steps in a resource campaign. When combined with visible imaging and high-resolution topographic measurements, thermal IR images could enable detailed thermal models capable of predicting surface and subsurface ice stability at orbital and surface scales [1, 3, 10].

Thermal IR Imaging Systems: Several cutting-edge, high-heritage infrared imaging systems are available for deployment on the lunar surface and in lunar orbit. Diviner and its successors provide high-accuracy measurements over an extremely large range of scene temperatures using uncooled thermopile detectors [14]. Alternatively, microbolometer systems are available in large-format arrays, enabling imaging in either framing or push-broom modes [15].

For example, the Lunar Compact Infrared Imaging System (L-CIRiS), planned to deploy on the Moon's surface as part of the payload on the NASA CLPS-19C mission, uses a rotation stage to acquire panoramic images in four spectral bands from ~7 to 14 μm. Based on heritage from Ball Aerospace's Compact Infrared Imaging System (CIRiS) deployed in low-Earth orbit, L-CIRiS employs an innovative 3-point calibration system to achieve better than 1.5 K accuracy and precision at temperatures ranging from ~100 K to 400 K. From a height of 1 m above the surface, a system like L-CIRiS would fully resolve any micro cold traps ~1 cm in size within 5 meters, and those >40 cm within 100 m.

By observing and monitoring the thermal environments of potential cold traps at resolutions extending to the rover/astronaut scale, IR imaging would thus enable efficient prospecting for stable ice deposits.

References: [1] Paige, D. A. et al. (2010), *Science, 330*(6003), 479-482 [2] Williams, J-P. et al. (2019), *JGR, 124*(10), 2505-2521 [3] Landis, M. E. et al. (2022), *Planet. Sci. J., 3*(2), 39 [4] Hayne, P. O. et al. (2021), *Nat. Astron. 5*(2), 169-175 [5] Mandt, K. E. et al. (2022) *Nat. comms., 13*(1), 1-6 [6] Wilcoski, A. X. et al. (2022) *Planet. Sci. J., 3*(5), 99 [7] Schörghofer, N. (2022), *ApJ Lett. 927*(2), L34. [8] Paige, D. A. et al. (2013), *Science, 339*(6117), 300-303 [9] Hayne, P. O. and O. Aharonson (2015), *JGR*, *120*(9), 1567-1584 [10] Siegler, M. (2015), *Icarus*, 255, 78-87 [11] Rubanenko & Aharonson (2017), *Icarus,* 296, 99-109 [12] Hayne, P. O. et al. (2014), *Keck Inst. Space Studies* [13] Cannon, K. M. and D. T. Britt (2020), *Icarus, 347*, 113778 [14] Mariani, G. et al. (2015), *40th Int. Conf. IR, mm, THz*, pp. 1-2, IEEE [15] Osterman, D. P. et al. (2019), *CubeSats and SmallSats for Remote Sensing III,* p. 111310F