LRAD – A RADIOMETER FOR THE LUNAR SOUTH POLE HOPPER µNOVA.

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Introduction: The Lunar Prospector discovery of areas of neutron suppression and the subsequent interpretation of hydrogen enrichment near the lunar poles [1] brought the possibility of volatile resources sequestered at the poles to the forefront of the lunar science community. Subsequently the LCROSS experiment showed that water ice is present within at least one permanently shadowed region (PSR) near the south pole and that it can be stable over geological timescales inside permanently shadowed regions (PSRs) [2]. Analysis of UV observations gathered by the Lunar Reconnaissance Orbiter Diviner instrument are consistent with the presence of surface frost in some PSRs with temperatures below 110 K [3]. Further, the depth-to-diameter ratios of simple craters as determined from Lunar Orbiter Laser Altimeter (LOLA) altimetric measurements indicate that deposits of water ice in these cold traps may be up to 50 m thick [4]. Moreover, water ice may be present in small PSRs at scales down to, and below 10 meters [5]. Such small-scale cold traps could significantly increase water inventory estimates and eventually simplify extraction.

The Nova-C lander, build by Intuitive Machines as part of the NASA Commercial Lunar Payload Service (CLPS) program, will land near the lunar south pole providing the opportunity for in-situ investigations of volatile presence [6,7]. Nova-C will carry the µNova Hopper to the Moon which will in a sequence of short flights land within PSR inside Marston crater (informal name). The µNova Hopper (S.P. Hopper) will map the lunar surface with two cameras and a mid-infrared Radiometer (LRAD).

The LRAD Instrument: The Lunar Radiometer (LRAD) is an instrument that uses thermopile sensors to measure radiative flux in the thermal infrared wavelength range [8,9,10]. LRAD houses six thermopile sensors, which can be equipped with individual IR-filters to fulfill specific scientific measurement goals. Onboard µNova, LRAD will address the following science goals:

1. Determination of surface brightness temperature in the illuminated and shadowed terrain.
2. Determination of the mm to cm-scale surface roughness.
3. Determination of surface thermal inertia.

The instrument design is based on the miniRAD radiometer of the Martian Moons Expolorer's (MMX) rover [11]. LRAD will weigh approximately 90 g, while the electronics including the enclosure will add approximately 340 g to the mass. The power consumption during science operation lies typically around 1.5 W and peak consumption of up to 2 W. The thermopile sensor consists of 72 Bismuth-Antimony ($Bi_{0.87}Sb_{0.13}$) thermocouple junctions. At the hot junction interference absorbers are used as in the miniRAD instrument.

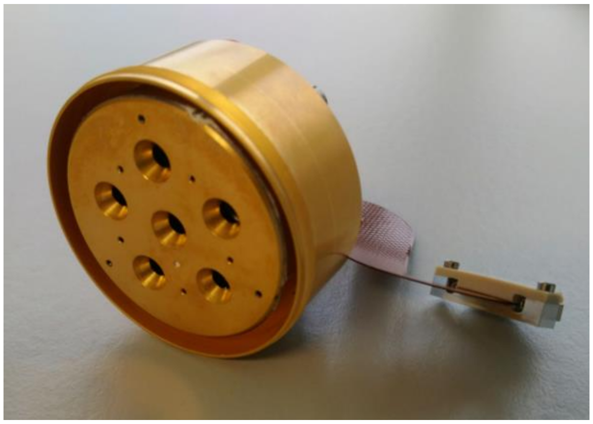

Figure 1: *Photo of the qualification model of the miniRAD radiometer for the MMX mission. The miniRAD instrument is the predecessor of the LRAD instrument.*

Surface Brightness Temperature Determination: The main scientific goal of LRAD is a determination of surface brightness temperatures to provide ground truth for thermophysical models of the south polar region and the stability of water ice over geological timescales. The main challenge is the determination of brightness temperatures inside the PSRs, for which temperatures below 100 K have been predicted [12]. Measurements of infrared flux at such low temperatures require a dedicated IR-filter and absorber design.

To obtain high quality temperature data, the LRAD sensor head temperature is stabilized to the mK level, thus minimizing disturbances from instrument self-radiation. Further, the instrument needs to be thermally decoupled from the environment as much as possible to reduce temperature inhomogeneities across the sensor head, and direct solar illumination must be avoided. A large field of view of 60° further maximizes the collected signal. The estimated uncertainty of the temperature measurement, including systematic disturbances, is 10 K for a target temperature of 70 K and 5 K for a target temperature of 100 K.

Temperatures inside the PSRs are primarily controlled by indirect irradiation from the illuminated parts of the crater walls. Furthermore, interior heat flow resulting from secular cooling of the Moon [13] as well as lateral heat transport by heat conduction play a role. Therefore, temperature measurements inside a PSR are essential data to calibrate thermal models which allow us to predict the potential presence and stability of water ice deposits.

Surface Roughness Determination: The lunar regolith is not a Lambertian emitter, i.e., it does not represent an ideal diffusely emitting surface. Rather, surface roughness causes radiation to be emitted anisotropically, an effect that is primarily caused by small scale (sub-pixel) temperature heterogeneities. Such inhomogeneities can result in a larger amount of heat radiated at high emission angles, thus affecting the temperatures within the PSRs [12].

Besides the observation and illumination geometry, the influence of surface roughness depends on the wavelength of the observation and is largest at short wavelengths. Therefore, to determine the roughness parameters of the regolith in the Hopper landing area (i.e., rms slope or crater density [14]), an observation of a single spot on the surface at short wavelength and changing illumination conditions would be required. LRAD will be equipped with an IR-channel dedicated to this measurement. Given the opportunity to observe the surface for a significant fraction of the lunar day enables the characterization of the mm to cm scale roughness of the regolith [15].

Thermal Inertia Determination: Apart from the energy input through direct and indirect illumination, surface temperatures are influenced by the thermophysical properties of the regolith and in particular the surface thermal inertia, which parametrizes the speed with which the surface temperature reacts to changing illumination conditions. This parameter is best estimated from a time-series of temperature measurements of a single spot on the surface. For highest quality results, night-time data should be included in the time series, as regolith cooling following sunset is diagnostic for the surface thermal inertia [16] which is usually not available from orbiter instruments [17, 12].

While long-term surface brightness temperature measurements at the final hopper landing site go a long way for determining surface thermal inertia, an extension of the measurement into few hours of lunar night will add strong constraints on the possible inertia range.

Summary: The Nova-C CLPS lander mission offers a unique opportunity to characterize and improve thermophysical models of the thermal environment both illuminated terrain and within a PSR. The in-situ measurements at decimeter to meter scale resolution to be collected by LRAD will complement LRO Diviner observations that is providing global temperature data at a scale of 200-300 m per pixel. Further, the data will allow for a comprehensive characterization of the thermophysical properties of the lunar regolith including small scale surface roughness and thermal inertia. The data gathered by the S.P. Hopper will thus provide important constraints for the study of small scale PSRs and micro cold traps, which will support future exploration and in-situ resource utilization efforts.

References:

[1] Feldman, W.C., et al. (1998) *Science*, 281, 5382, 1496-1500
[2] Colaprete, A., et al. (2010) *Science*, 330, 6003, 463-468
[3] Hayne, P.O., et al. (2015) *Icarus*, 255, 58-69
[4] Rubanenko, L. et al., (2019) *Nat. Geosci*,12, 597-601
[5] Hayne, P. O., et al. (2021). *Nat. Astr.*, 5, 169
[6] Atwell, M., et al., (2020). *Lunar Surface Science Workshop 2020*, 6011
[7] Voosen, P., et al., (2021). *Science*, 373, 6560, 1188-1192
[8] Spohn, T., et al. (2007). *Space Sci. Rev.*, 128, 339
[9] Grott, M., et al., (2017). *Space Sci Rev.*, 208, 413
[10] Spohn, T., et al. (2018). *Space Sci. Rev.*, 214, 96
[11] Ulamec, S., et al., (2021). *72nd IAC*, IAC-21-A3.4A.7
[12] Paige, D. et al. (2010b). *Science*, 330, 479
[13] Paige, D. A., et al. (2010c), *AGU Fall*, P31E-04
[14] Davidsson, B.J.R. and Rickman, H., (2014) *Icarus*, 243, 58–77
[15] Wu, Y. et al., (2021). *GRL*, 48, e89226,
[16] Grott, M., et al. (2019). *Nat. Astr.*, 3, 971
[17] Paige, D. et al. (2010a). *Space Sci. Rev.*, 150, 125,