CALIBRATION OF THE LUNAR RADIOMETER FOR INTUITIVE MACHINES' S.P. HOPPER.

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Introduction: The discovery of areas of neutron suppression by Lunar Prospector, interpreted as hydrogen enrichment near the lunar poles [1] indicated the presence of volatiles that could be used as in-situ resources. In fact, the LCROSS experiment showed the presence of water ice within at least one permanently shadowed region (PSR) near the south pole with sufficiently low temperatures to allow a stable presence of water ice over geological timescales [2]. UV observations obtained by the Lunar Reconnaissance Orbiter LAMP instrument [3] were consistent with water ice within some PSRs with temperatures below 110 K. The morphology of cold craters determined from Lunar Orbiter Laser Altimeter (LOLA) indicated that subsurface ice deposits may be up to 50 m thick [4]. Water ice might not be limited to larger and mid-sized craters but could also be present in small-scale roughness features [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 S.P. Hopper to the Moon, which will in a sequence of short flights land within the Marston crater (informal name) PSR, carrying the radiometer LRAD, two cameras, and a neutron spectrometer (PLWS).

The LRAD Instrument: The Lunar Radiometer (LRAD) 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 S.P. Hopper, 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 Explorer's (MMX) rover [11]. LRAD sensor head weighs approximately 90 g, while the avionics including the enclosure add ~390 g. The thermopile sensors consist of 72 Bismuth-Antimony ($Bi_{0.87}Sb_{0.13}/Sb$) thermocouple junctions. At the hot junction interference absorbers are used as in the miniRAD instrument. The power consumption during science operation lies typically around 1.5 W and peak consumption of up to 3 W.

Fig. 1: *LRAD instrument with sensor head on PEEK bracket and avionics box integrated into the S.P.Hopper behind the solar panel*

Surface Brightness Temperature Determination: The main purpose of LRAD is to determine surface brightness temperatures of the lunar regolith. These measurements provide ground truth for thermophysical models of the south polar region and the stability of water ice over geological timescales. The main challenge is determining brightness temperatures inside the PSRs, for which temperatures below 100 K have been predicted [12]. The LRAD sensor head temperature is stabilized to the mK level, thus minimizing disturbances from instrument self-radiation. Further, the instrument is thermally decoupled from the environment as much as possible to reduce temperature inhomogeneities across the sensor head. The field of view is 60° to maximize the collected signal.

Determination of Small-Scale Roughness and Thermal Inertia: The lunar regolith is not a Lambertian emitter, i.e., it does not represent an ideal diffusely emitting surface. Instead, 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 significant heat radiated at large emission angles, thus affecting the measured brightness temperatures within the PSRs [12]. LRAD carries two narrow-band filters centered around 9 µm and 12 µm. Comparing fluxes observed in these filters to each other and the broad band filters will allow for the determination of small-scale roughness in illuminated regolith outside the PSR. Observing the variation of temperature with varying insolation enables determination of the thermal inertia of the regolith. For the highest quality results, night-time data should be included in the time series, as regolith cooling following sunset is diagnostic of the surface thermal inertia [13], which is usually unavailable from orbiter instruments [14, 12]. An extension of the measurement into a few hours of lunar night will add strong constraints on the inertia range.

Calibration: The signal voltage U of an LRAD thermopile can be expressed as: $U = S\ \Delta P + S_2\ (\Delta P)^2 + S_H\ P_H + U_{Off}$, where ΔP is the net radiative power falling onto the absorber area, S is the sensitivity of the detector, S_2 a quadratic term describing the small deviation from linearity, and U_{Off} the offset voltage. P_H is the heating power used to stabilize the sensor head at the chosen setpoint, and S_H a correction factor which provides a correction for the slightly varying instrument background radiation with P_H.

LRAD underwent radiometric calibration in a small vacuum chamber equipped with a He-cooled cold head (Fig. 2). The LRAD sensor head was placed inside a temperature-controlled aluminum box representing the thermal environment while viewing a blackbody mounted to the cold head. By varying the blackbody temperature from 70-330 K and the box temperature between 200 K and 280 K the four calibration coefficients could be fitted for each thermopile channel. The estimated uncertainty of the brightness temperature measurement, including systematic disturbances, is 10 K for a target temperature of 80 K and 5 K for a target temperature of 100 K.

Summary: As part of the NASA-CLPS mission PRIME-1 (IM-2), LRAD will measure the brightness temperature of regolith near the south pole and perform the first in-situ temperature measurement within a PSR. These first-time measurements will advance our understanding of the regolith at a potential Artemis landing site.

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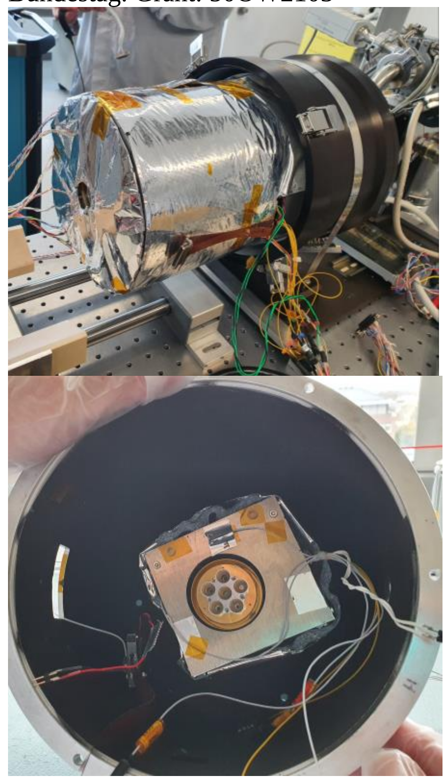

Fig. 2: *Setup of the radiometric calibration. LRAD is placed within a temperature-controlled aluminum box, which is mounted inside a small vacuum chamber facing a black body.*

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