µNOVA HOPPER: IN-SITU EXPLORATION OF CHALLENGING TERRAINS.

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Introduction: A deployable robotic hopper enables exploration of challenging terrains such as permanently shadowed regions (PSR), rough or blocky targets, pits, and steep slopes [**1,2,3**]. It can also serve as a low altitude remote sensing platform. The Intuitive Machines µNova hopper [**1**] was specifically designed to meet these challenges.

The first demonstration of the µNova hopper is scheduled for March 2025. IM Nova-C lander (Athena) will deliver the µNova hopper (Grace) to a landing site on Mons Mouton as part of the NASA Commercial Payload Services (CLPS) Polar Resources Ice Mining Experiment-1 (PRIME-1) Task Order, IM-2 Mission. The Nova-C will also deliver the Polar Resources Ice Mining Experiment-1 (PRIME-1) consisting of The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) and the Mass Spectrometer observing lunar operations (MSolo) [**4**] as well as a Lunar Outpost rover carrying a demonstration LTE communication system [**5**].

µNova System Description: The µNova hopper is 70-cm tall and has a total system mass of 35-kg (**Fig. 1**). The hopper is a fully independent spacecraft with propulsion, avionics, power, flight controls, and communication systems. The hopper utilizes a precision landing and hazard avoidance (PLHA) system that images the surface and autonomously guides the vehicle to a safe landing site. Landing on slopes up to 10° can be achieved, along with landing in low-light environments such as PSRs or pits. The hopper will communicate with the Nova-C through an LTE system enabling contact when out-of-sight with the lander.

This first µNova, Grace, will carry science cameras, the Lunar Radiometer (LRAD) [**6**], and the Puli Lunar Water Snooper (PLWS) [**7**]. S.P. Hopper is a demonstration of the µNova technology but it also has significant scientific objectives that will be fulfilled after completing the required flight objectives.

Objective 1: Geologic context and geotechnical properties in the vicinity of the landing site, including within a PSR. *Objective 2*: Determine surface brightness temperatures in illuminated and shadowed terrain. *Objective 3*: Derive the surface roughness and thermal inertia of illuminated polar regolith. *Objective 4*: Determine hydrogen (H) abundance in illuminated regions, and within a PSR.

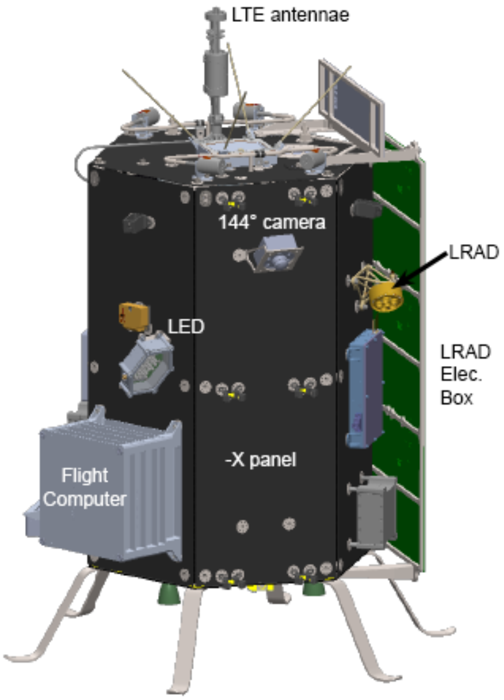

Fig. 1. View of hopper looking down line-of-flight.

Cameras: The imaging system consists of two Canadensys [**8**] CMOS imaging systems: Medium Angle (MA) monochrome 51° × 39° field-of-view (FOV), and Wide Angle (WA) monochrome 144° × 104° FOV. While inflight the two cameras will acquire continuous stereo observations. The MA is pointed nadir and maps a swath 120 meters wide (cross-track) with a pixel scale of 3 cm along the flight path enabling a digital terrain model (DTM) with 10-cm posting. The WA boresight is aimed 45° from nadir aligned 10° from the line of flight with a center pixel scale of 12 cm from 100 meter altitude. A 4-color LED lighting panel allows mm pixel scale near-field color imaging with the WA system while S.P. Hopper is on the surface within the PSR.

LRAD: Thermopile sensors measure the net radiative flux in the thermal infrared wavelength range [**9**]. The sensor head carries six thermopile sensors with individual IR filters to fulfill its measurement objectives (**Fig. 1**). The instrument design is based on the miniRAD radiometer of the Martian Moons Explorer's (MMX) rover [**10**].

LRAD will provide the first in-situ measurement of the brightness temperatures within a PSR. The main challenge for precise temperature measurement is the low flux emitted by the surface for the predicted temperatures, which could be below 100 K [10]. To this end, the LRAD sensor head temperature is stabilized to the mK level, minimizing disturbances from instrument self-radiation. A closed sensor will help to estimate residual disturbances caused by self-radiation. Furthermore, the instrument is thermally decoupled from the environment as much as possible. A large field of view of 40° (FWHM) maximizes the collected signal. LRAD uses two long-pass filters opening at a wavelength of 15µm and designed to measure low temperatures independently, allowing for a precise uncertainty estimate. A long-pass filter opening at 10µm enables measurements of the higher temperatures outside the PSRs.

PLWS: PLWS is a miniature, lightweight neutron spectrometer for lunar applications (**Fig. 2**), built by Puli Space Technologies. It detects incoming cosmic rays (CR) and neutron particles emitted from the regolith in the thermal and epithermal range. PLWS is a miniaturized (10 cm × 10 cm × 3.4 cm), simple and lightweight (<400 gr), low-cost, COTS (Commercial off-the-shelf) based system.

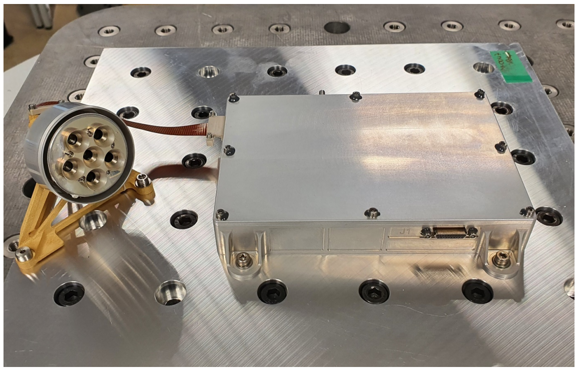

Fig. 2. LRAD undergoing vibrational testing with sensor head mounted on a thermally isolating bracket (left), and the avionics box (right.)

PLWS consists of three modified CMOS active pixel image sensors: a Thermal Neutron (TH), an Epithermal Neutron (EPI), and a Reference Sensor), as well as a FPGA. The TH and EPI CMOS have a thin neutron-sensitive coating. Neutron capture within the coating generates alpha and Li ions, which cause ionization tracks in the sensor. In front of the EPI sensor, a thin Gadolinium filter absorbs the thermal neutrons, enabling energy-selective neutron detection. The Reference Sensor collects background CR information for calibrating the TH and EPI counts. PLWS also utilizes a Gadolinium Ballistic Shield above the CMOS sensors to mitigate the effect of the lunar ballistic thermal neutrons that originate outside measurement area. Monte Carlo simulations indicate that several hours of integration at stationary locations results in ~1,000 thermal and epithermal neutron counts, allowing H abundance detection down to 0.3% WEH (water equivalent hydrogen).

Grace ConOPS: Within 24 hours of the Nova-C landing, Grace will execute a commissioning hop of ~20 meters. Cameras onboard the Nova-C will record the flight, as will the Grace cameras. After the commissioning hop images and housekeeping data are analyzed, Grace will demonstrate its flight capabilities with a >100-meter test flight. After another period of data analysis, a second long hop (>150-m) will position the vehicle on the rim of H-crater (informal name; 84.765°S, 29.151°E). Next, Grace will fly into and land within the H-crater PSR. The vehicle will remain on the PSR floor for ~45 minutes collecting images, radiometer, and neutron observations. Finally, Grace will fly up and out of the crater, landing again on the rim. Grace will collect more surface scientific observations, and if enough fuel is remaining, a sixth flight may be undertaken.

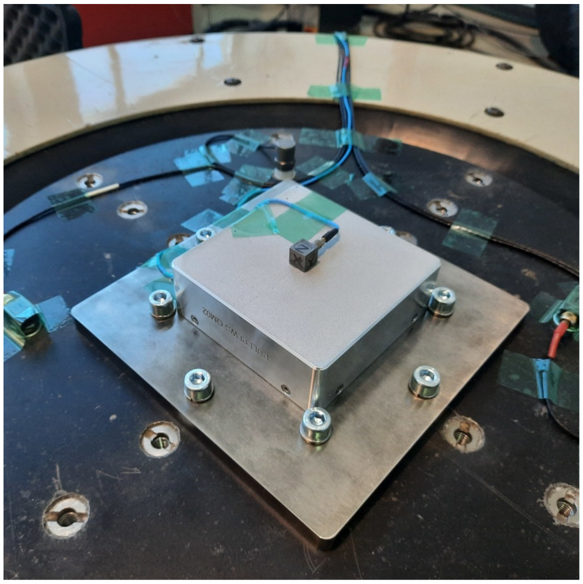

Fig. 3. PLWS on vibration test pad.

References: [**1**] Atwell et al. (2020) *LSSW*, Abstract #6011. [**2**] Robinson et al. (2021) *LSSW 2021* #8034,. [**3**] Martin et al. (2022) *ELS*, pp. 137-138. [**4**] https://tinyurl.com/2s3ehkhu [**5**] https://tinyurl.com/uejwvsch [**6**] Hamm, M., et al. (2022) *53rd LPSC*, #1393 [**7**] Pacher, T., et al. (2022) Abs. #39, *Lun. Surf. Innovation Cons. Fall Meeting* [**8**] https://www.canadensys.com/ [**9**] Grott, M., et al. (2017) *Space Sci. Rev.*, 208, 413 [**10**] Ulamec, S., et al. (2021) *72nd IAC*, IAC-21-A3.4A.7