S. P. HOPPER: FIRST IN-SITU EXPLORATION OF LUNAR POLAR TERRAIN. T. D. Martin[1], M. J. Atwell[1], M. L. Oelke[1], T. P. Crain[1], M. S. Robinson[2], R. V. Wagner[2], E. J. Speyerer[2], N. M. Estes[2], M. Grott[3], M. Hamm[3,4], J. Knollenberg[3], [1]Intuitive Machines, 3700 Bay Area Blvd., Houston, TX 77058, USA, tmartin@intuitivemachines.com, [2]Arizona State University, SESE, Tempe, AZ. [3]German Aerospace Center (DLR), Berlin, Germany, [4]Freie Universität Berlin, Berlin, Germany.

Introduction: Intuitive Machines Mission - 2 (IM-2) Nova-C lander is slated to land on the Spudis crater side of the Shackleton – de Gerlache connecting ridge (89.5°S, 222.0°E) in late 2022 or early 2023 [**1**]. The Nova-C carries three core payload elements: the NASA-funded Polar Resources Ice-Mining Experiment-1 (PRIME-1) [**2**], a 4G/LTE communications network developed by Nokia of America Corporation on the Nova-C lander, the Micro-Nova and a Mobile Autonomous Prospecting Platform (MAPP) rover developed by Lunar Outpost Inc. [**3**], and Micro-Nova, a deployable hopper robot developed by Intuitive Machines [**4**]. Here we summarize the capabilities of the Micro-Nova (named S.P. Hopper for this mission) and its goals and objectives.

Goals: The overarching goal of S.P. Hopper is to test the technologies (propulsion, terrain relative navigation, hazard avoidance, power systems, communications, thermal stability) that allow the vehicle to explore relatively inaccessible environments in a cost-effective manner.

The secondary goal is to collect observations in support of lunar science and exploration objectives with a payload that includes a medium angle camera (MAC), a horizon camera (186Cam), a navigation camera (NAVCAM), and a Lunar Radiometer (LRAD) [**5**].

Technology Objectives: Demonstrate 1) deployment from the host lander, 2) independent power generation and power management on the lunar surface, 3) end-to-end communication between Micro-Nova and mission operators (via Nova-C relay), 4) autonomous flight to a pre-determined surface location at least fifty meters via a propellant-optimized trajectory, 5) autonomous flight to a pre-determined surface location via a constant-altitude traverse, 6) hazard detection and avoidance, 7) flight into and out of a permanently shadowed region (including proper thermal management).

Science Objectives: 1) Determine polar regolith properties within illuminated terrain, and 2) within a Permanently Shadowed Region (PSR), 3) document geologic context, and 4) determine the temperature of regolith surface (PSR and illuminated terrain). Imaging capabilities to retire the objectives include: 1) inflight stereo observations with 3-cm pixel scale covering >20,000 sq m illuminated terrain, 2) on-surface imaging of illuminated terrain at <1 cm/pixel, and 3) RGB-color and BW imaging in shadowed terrain. In addition, measurements will elucidate the thermophysical properties (temperature, roughness, thermal inertia) in both illuminated and shadowed regions.

S. P. Hopper Description: The hopper is a fully independent spacecraft with its own propulsion, avionics, power, flight control, and communication systems. It has a mass of 29 kg when fully fueled for the demonstration mission, as well as capacity for 6 kg of additional propellant. The spacecraft flies from spot to spot on the lunar surface via a simple monopropellant propulsion system. It utilizes a suite of sensors and algorithms based on the Nova-C landing system for guidance, navigation, and control. This system includes visual odometry for high-accuracy state determination and a hazard detection and avoidance algorithm, which guides the vehicle to a safe landing site. Its power system includes side-mounted solar arrays that double as a Sun shield. For communication, a Nokia LTE radio is used. This system downlinks data to the Nova-C host lander, which forwards it to Earth. Micro-Nova also carries a backup UHF radio if the primary communication system fails.

Payload Description: The two science cameras (MAC, 186Cam) are provided by Canadensys, and each has 32 GBytes of internal memory and built-in data processing capabilities (e.g. thumbnails, windowing, compression). The MAC FOV is 39° x 51° with a 3000 x 4000 pixel format and the 186Cam has a 186° FOV with a 3000 x 3000 pixel format. Both science cameras will acquire continuous stereo observations during flight. The 186Cam will image inside the PSR with a custom LED panel that provides RGB and broadband near-field (5 m) illumination; long exposures will provide synoptic PSR images under natural lighting. The NAVCAM LRAD houses six thermopile sensors, equipped with individual IR-filters to measure surface brightness temperature. LRAD sensor head temperature is stabilized to the mK level and decoupled from the surrounding environment providing temperature measurement accuracy of 10 K for a surface temperature of 70 K, and 5 K for a 100 K surface.

ConOps Summary: Micro-Nova rides to the lunar surface hard-mounted to its deployment system on the side of Nova-C and is designed to mount to any lunar lander. This system includes power and data connections as well as redundant launch locks. After Nova-C touches down, a series of system health checks will be performed to confirm that Micro-Nova is ready for deployment. In parallel, mission operators will survey landing imagery to establish the exact Nova-C landing site and select a safe deployment landing site for the hopper. With this information, the target deployment site will be uplinked to the hopper computer.

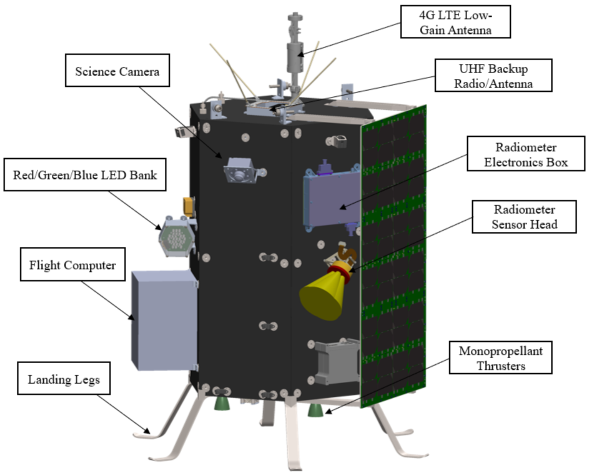

Fig. 1. Micro-Nova Hopper System Overview

Deployment is achieved by firing the hopper's monopropellant thrusters to "launch" it on a rail system from the vehicle and then land on the surface approximately 20 m away. The Nova-C landed clocking azimuth is constrained to avoid the need for a hopper roll on the initial deployment hop. After landing, the hopper will downlink images and telemetry to Nova-C, which will then transmit to the Earth. Mission operators will evaluate the data and confirm the lander location and the following target site, while monitoring vehicle health in real-time. After the deployment flight, four more demonstration flights will be conducted, with all data downlinked between each flight. Flight #2 is a 90-meter flight in which the vehicle will demonstrate taking-off from the ground, flying a propellant optimized trajectory, and utilizing hazard detection and avoidance. Flight #3 is a 300-meter flight that will include a constant-trajectory traverse at an altitude of 100-meters, enabling stereo-imaging of a wide swath of terrain. In flight #4, Micro-Nova will fly into Marston crater and land within a PSR. Once inside, the vehicle will acquire images and radiometer measurements while continuously monitoring system temperatures that are maintained via heaters. The 4G/LTE communications system allows for non-line-of-sight communication with the Nova-C lander and will be used as primary communication link in the PSR. If any temperature limits are exceeded that could threaten vehicle survival, the system will automatically perform Flight #5 early to retreat to a warmer environment and avoid loss of mission. Otherwise, after approximately 45 minutes, the vehicle will complete the final flight to exit the PSR and allow last data downlink. The hopper health and residual propellant status will be assessed after Flight #5. Additional hops for an extended mission will be considered if sufficient propellant is left. The final hop will roll the hopper to maximize the duration of illumination of its solar array after landing. It will continue collecting and transmitting science data back to Nova-C while both vehicles remain active.

References: [**1**] https://tinyurl.com/2bxtn7ze.
[**2**] https://tinyurl.com/37n2xdvk
[**3**] https://tinyurl.com/2wvv3p98. [**4**] Atwell M. et al. (2020) *LSSW LPI 2241,* Abstract #6011. [**5**] Hamm M. et al. (2022) *LPS LIII*, this volume.

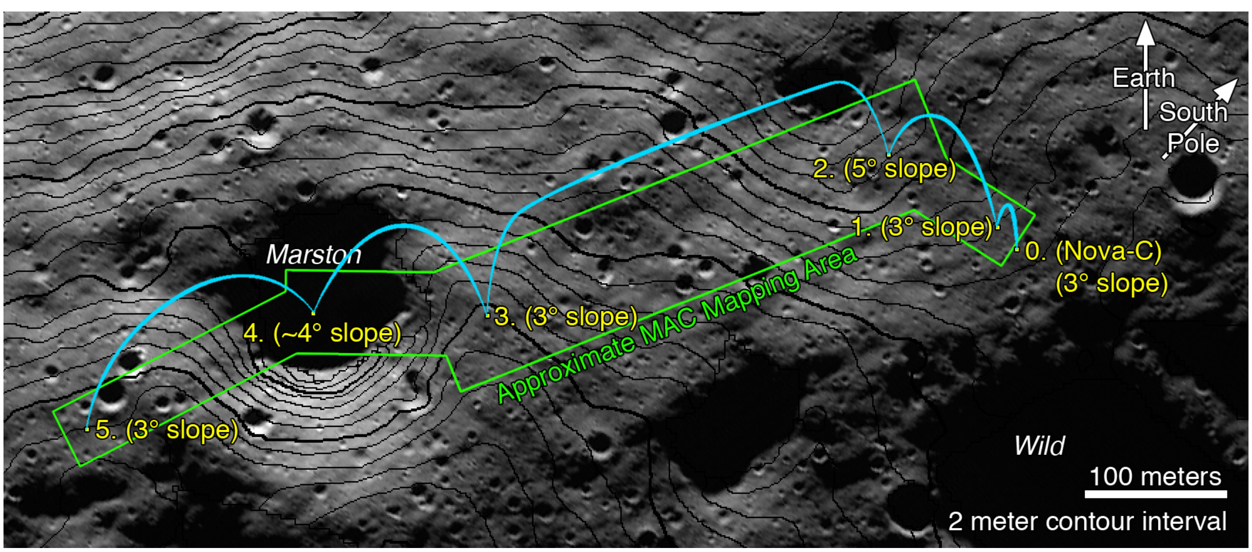

Fig. 2. S.P. Hopper Mission ConOps. Blue lines trace the five planned flights, or hops. Slopes are from LROC NAC DTM, except landing site 4 is from LOLA 5 m/px DTM. MAC stereo coverage outlined in green; 186Cam covers the entire map area.