Polar Resources Ice Mining Experiment-1 (PRIME-1) NASA's First Polar Drilling and Volatiles Detection Mission. J.W. Quinn[1], J.E. Captain[1], A.S. Eichenbaum[1], R. Augilar-Ayala[1], J.E. Kleinhenz[1], K.A. Zacny[2], P.C. Chu[2] and V.R.Vendiola[2], [1]NASA (Mailstop UB-E, KSC, FL 32899 Jacqueline.W.Quinn@nasa.gov), [2]Honeybee Robotics (2408 Lincoln Ave Altadena, CA 91001 kazacny@honeybeerobotics.com).

Introduction: The US Administration announced in 2019 that NASA would return to the Moon where it would seek to establish a sustainable lunar presence [1, 2]. In Situ Resource Utilization (ISRU) is needed to sustain and grow human surface exploration and it is therefore a vital part of ensuring this bold endeavor. ISRU requires ground-truth on physical, mineral, and volatile characteristics of the resources. Water, a key and game-changing resource, exists in the polar regions of the Moon. Learning to harvest and use this resource first requires understanding where the resource is abundantly located and on what scales. Harvested water, which is usable for life support and fuel, must be identified, quantified, and assessed for its mining feasibility.

The project goal for PRIME-1 is to develop a flight-ready instrumentation package that can assess the volatiles at a polar lunar landing location. PRIME-1 is the combination of two instruments; Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT). TRIDENT is an 1-meter percussive augering drill capable of bringing incremental lunar regolith samples to the surface for volatile analysis. MSolo is a modified, commercial-off-the-shelf (COTS) mass spectrometer capable of qualifying and quantifying atomic species in the 1-100 amu range, including isotopic differentiation. These two lunar flight instruments operating together make up the PRIME-1 instrument suite.

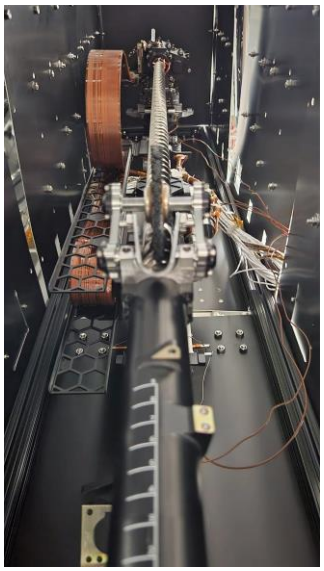
PRIME-1 intends to fly on and operate from a static lunar lander acquired by the NASA Commercial Lunar Payload Services (CLPS) acquisition process. The PRIME-1 payload suite was selected to fly on Intuitive Machines Nova-C lander, and is currently targeting a late Fall 2023 landing attempt.

Mission Objectives: With the intent of broadening our understanding of the presence of water ice and other volatiles at a lunar polar landing location, the PRIME-1 payload has the following objectives:

> **Objective 1:** PRIME-1 will drill into the lunar subsurface up to a meter deep, and deliver regolith cuttings to the surface for water and other volatiles evaluation.

> **Objective 2:** PRIME-1 will measure within its field of view, the composition of gases emanating near the drill before, during, and after drilling activities.

TRIDENT is a commercially-manufactured percussive auguring-drill specially designed to capture soil/regolith on the auger's flutes for transfer up the auger shaft and eventual deposition on the lunar surface. Honeybee Robotics first designed and built an engineering version of TRIDENT under the NASA Small Business Innovative Research (SBIR) program. Subsequent investment by NASA's Space Technology Mission Directorate (STMD) allowed for extensive testing of TRIDENT in a relevant lunar environment at NASA's Glenn Research Center's Vacuum Facility #13 prior to selecting it for the PRIME-1 mission [3,4] .

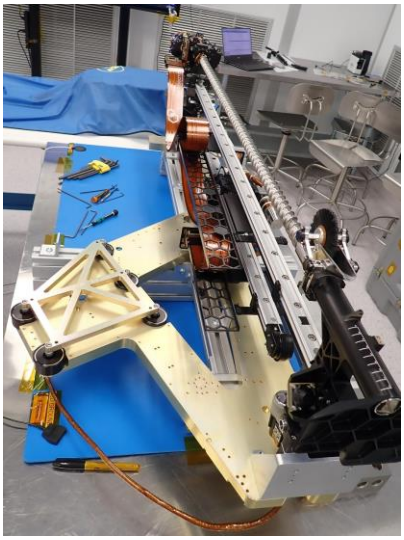


TRIDENT during thermal vacuum testing

MSolo is a modified COTS mass spectrometer originally acquired from INFICON. The unit is highly automated, provides fast-scan capabilities with high sensitivity, and is now ruggedized for spaceflight. The COTS instrument was tested in various space environments and thermal, structural, and electrical modifications were made to improve the instrument's performance, robustness, and spaceflight readiness.

MSolo mounted on its vibration test fixure during verification and validation testing at KSC

Lander Integration: The entire PRIME-1 suite is bolted high on the Nova-C lander body for its ride to the lunar surface. After landing, PRIME-1 is actively positioned on the lunar surface using a Nova-C deployable vertical pallet. The PRIME-1 payload suite is also integrated onto the Intuitive Machines Nova-C lander in such a way as to minimize thermal leakage to the lander; PRIME-1 is designed to handle its entire thermal footprint using radiative surfaces.



TRIDENT drill and MSolo back panel only mounted to the Intuitive Machines deployable pallet during mechanical fit check

Landing Location: The PRIME-1 payload will analyze lunar regolith for volatiles at a landing location at the lunar south pole; Shackleton's connecting ridge. The lunar landing site was chosen based on its potential to host volatiles (sufficiently cold subsurface temperature profiles), relatively mild slopes, uninterrupted lunar surface-to-Earth communications and solar lighting that would enable acceptable illumination of the landing location and solar power for the required mission duration. The PRIME-1 landing location will allow approximately an eight-day mission duration.

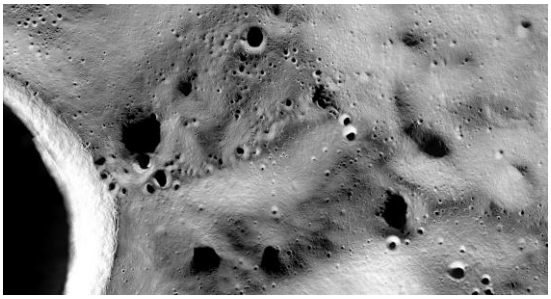


Image of Shackleton crater rim and the connecting ridge between Shackleton and de Gerlache craters

Summary: The PRIME-1 payload will be NASA's first robotic lunar drilling attempt at the lunar south pole. The data gleaned from a successful mission will inform future ISRU missions to the polar regions from a harvesting resources perspective and lunar construction perspective. The mission is expected to provide informative details regarding energy usage, timelines to reach targeted depth, volatile submilimation timelines and molecular definition, perhaps even fueling our understanding of the origins of any detected water through isotopic identification. The PRIME-1 instruments, their technical capabilities and the way in which they will be operated on the lunar surface will be shared during the 2023 Space Resources Roundtable oral presentations.

References:

[1] NASA'S Plan For Sustained Lunar Exploration and Development. (2020). https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf

[2] NASA Moon to Mars Objectives (2022) https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

[3] Kleinhenz, J. et al. Loss from Water Bearing Regolith Simulant at Lunar Environments. 2018 ASCE Earth & Space Conference. April 9-12, 2018. Pg 454-466.

[4] Zacny, K et al. TRIDENT Drill for VIPER and PRIME1 Missions to the Moon – 2023 Update, 54th Lunar and Planetary Science Conference 2023 (LPI Contrib. No. 2806), 13 - 17 March 2023, Woodlands, TX.