

Key Science Questions to be Addressed by the Volatiles Investigating Polar Exploration Rover (VIPER):, A. Colaprete¹, R. C. Elphic¹, M. Shirley¹, K. Ennico-Smith¹, D. S. S. Lim¹, K. Zacny², J. Captain³, M. Seigler⁴, E. Balaban¹, R. Beyer^{1,5}, Z. Mirmalek^{1,6}, D. Lees¹, and the VIPER Science Team ¹NASA Ames Research Center, Moffett Field, CA, ²Honeybee Robotics, Pasadena, CA, ³NASA Kennedy Space Center, FL, ⁴Planetary Science Institute, Tucson, AZ, and the Department of Earth Sciences, Southern Methodist University, Dallas, TX, USA, ⁵SETI Institute, ⁶BAER Institute.

Introduction: The Volatiles Investigation Polar Exploration Rover (VIPER) mission is a lunar polar volatiles prospecting mission developed through NASA’s Science Mission Directorate (SMD) Planetary Science Division with launch in late 2024 [1]. The mission includes a rover-borne payload that (1) can locate surface and near-subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials. VIPER’s primary mission goal is to characterize the distribution of water and volatiles across a range of thermal environments. This characterization will assist in understanding the origin of lunar polar volatiles and help evaluate the In-Situ Resource Utilization (ISRU) potential of the lunar poles. VIPER will be optimized for lunar regions that receive prolonged periods of sunlight (short lunar nights); prospectively, the mission duration will be more than 90 Earth days, and result in a traverse distance of up to 20 km.

Measurement Goals: A critical goal to both science and exploration is to understand the form and location of lunar polar volatiles. The lateral and vertical distributions of these volatiles inform us of the processes that control the emplacement and retention of these volatiles, thereby helping to formulate ISRU architectures. While significant progress has been made from orbital observations [2-6], measurements at a

range of scales from centimeters to kilometers across the lunar surface are needed to validate “volatile mineral models” for use in evaluating the resource potential of volatiles at the Moon. To this end, the primary mission goals for VIPER are to (1) provide ground truth for models and orbital data sets, including temperatures at small scales, subsurface temperatures and regolith densities, surface hydration and hazards, (2) correlate surface environments and volatiles with orbital data sets, and (3) address key hypotheses regarding polar volatile sources and sinks, retention and distribution, which are key to developing economic models and identifying potential locations for further resource evaluation.

Rover and Payload Design: The VIPER rover system design meets these scientific requirements as well as requirements imposed by the unique lunar polar environment, schedule, and budget. Detailed analyses of traverses, including rover models that include power, data, and mobility models, have found that a solar powered rover with Direct to Earth (DTE) communications could meet all mission goals within about one Lunar day (mission length ~12 Earth days).

The rover navigation system utilizes eight cameras, including gimballed stereo navigation cameras located on a 2-meter mast, fixed stereo cameras at the rear of the rover, and hazard cameras near each rover wheel. LED lamps provide illumination for these cameras as

Table 1 VIPER Payload / Measurement Summary

Instrument	Measurements	Observations
NSS	Thermal and Epithermal Neutrons	Water Equivalent Hydrogen and burial depth along traverse
NIRVSS	NIR reflectance spectra from 1300-4000 nm	Surface composition (mineralogy, hydration, frosts) along traverse and from drill cuttings pile
	Imaging (2048 x 2048 pxl max resolution) with 7 color LEDs from 348 to 940 nm	Context imaging below the rover along the traverse; High resolution imaging (<100 um/pxl) at drill sites
	Thermal Radiometry at 10, 14, 18 and 6-25 um	Imaging of drill cuttings pile
		Surface temperatures under the rover and during drilling down to <100 K
MSolo	Mass spectra between 1-70 amu	Subliming surface volatiles along traverse and from drill cuttings pile Key isotope ratios
TRIDENT	Excavation of subsurface material in 10 cm increments down to 100 cm	Regolith geomechanical properties, including discerning ice-rich from dry regolith
	Subsurface temperatures at 2 depths (separated by 20 cm)	Subsurface temperatures and thermal conduction
VIS	Imaging at one color, resolutions of ~1 cm out to 10 meters	Surface morphology, rock and crater morphologies and distributions, and surface albedo at 460 nm
	Stereo imaging	
IMU	Accelerometry while roving and drilling	Subsurface structure and ice concentrations down to several meters
	Gravimetry while driving and seismic observations while drilling	

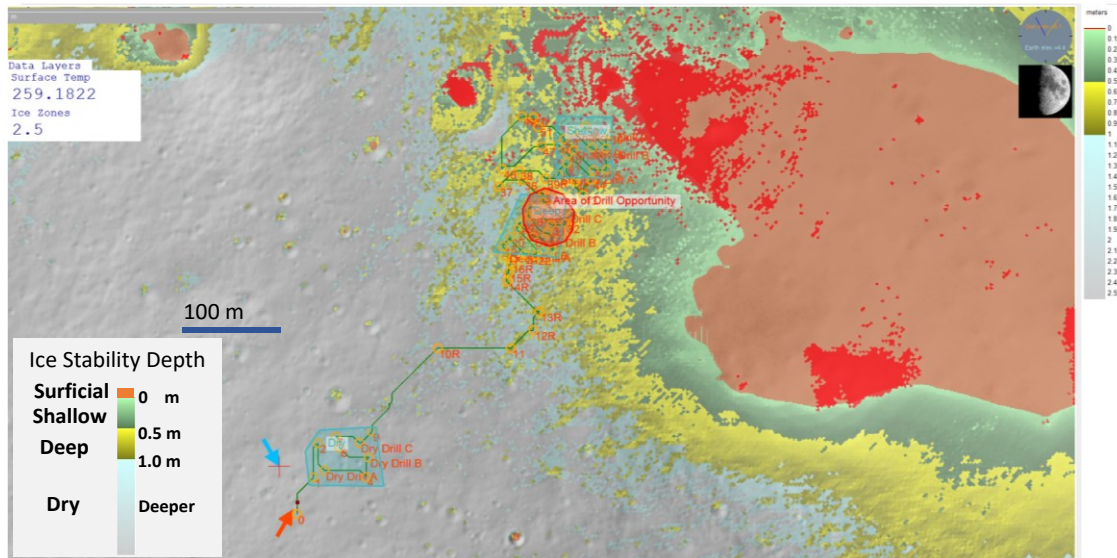


Figure 1 Traverse planning example against high resolution data products within the Mission Area west of the crater Nobile. The colors indicate locations where the subsurface temperature is predicted to allow for long-term water ice stability.

needed. The position and pose of the rover are determined using a star tracker and Inertial Measurement Unit (IMU).

The VIPER payload [7] consists of three “prospecting” instruments which operate continuously while roving, including the Neutron Spectrometer System (NSS), the Near InfraRed Volatiles Spectrometer System (NIRVSS) and the Mass Spectrometer observing lunar operations (MSolo). A 1-meter auguring/percussive drill called the The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) is used to bring subsurface cuttings to the surface in 10 cm increments where they are interrogated by NIRVSS and MSolo. TRIDENT also includes a temperature sensor at the bit and a heater/temperature sensor combo 20 cm above the bit. In addition to these instruments the Visible Imaging System (VIS), all navigation and hazard camera systems, and the IMU, will be providing scientific observations. A summary of each instrument’s measurement and observations is provided in Table 1.

Polar Solar “Safe Havens”: Numerous studies have identified regions near the lunar poles that have sustained periods of solar [e.g., 8-9]. In some cases, the periods of sustained sunlight extend across several lunations, while others have very short (<50 hours) nights. While the Earth would set, as seen by the rover, approximately every 2-weeks, these “Safe Havens” could provide enough power, and have lunar-nights short enough, for the rover system to survive. VIPER returns to one of these areas each lunar day to wait out the loss of communications with Earth.

Multi-Lunar Day Mission Traverses: In September 2021 the VIPER Mission Area, an approximately 10 x 10 km area west of the crater Nobile, was approved by SMD. This area is referred to the Primary Mission Area. An Extended Mission Area has been defined which captures maximum potential traverse distances (see Beyer et al. 2023 LPSC abstract). Traverse planning continues within the Mission Area including traverse planning against high resolution data products, for example 1 meter DEM and 4-meter thermal maps (Figure 1).

Unlike Mars rover missions, VIPER’s operations demand real-time decision support in order to make progress in a challenging and dynamic lighting and communications environment. Operators and scientists will utilize real-time measurements and rover and instrument status. A team in VIPER’s Mission Science Center (MSC) will advise and support real-time operations to maximize science return. For example, TRIDENT drill hole placement and subsequent sample analysis activities will be guided by both the MSC and Mission Operators.

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