PREPARING FOR SEISMIC INVESTIGATIONS USING THE INERTIAL MEASUREMENT UNIT ON THE VOLATILES INVESTIGATION POLAR EXPLORATION ROVER (VIPER) LUNAR MISSION. K. Gansler[1], N. Schmerr[1], J. Wang[1], N. McCall[2], C. Stoker[3], L. Wike[1], J. Giles[1], J. West[4], C. Barry[2], K. Lewis[5], and B. Fernando[5], [1]Univ. of Maryland, College Park, Department of Geology (ganslerk@umd.edu), [2]NASA Goddard Space Flight Center, [3]NASA Ames Research Center, [4]Arizona State University, [5]Johns Hopkins Univ.

Introduction: The Volatiles Investigation Polar Exploration Rover (VIPER) mission is set to launch for the lunar South Pole in late 2024 as part of NASA's Commercial Lunar Payload Services (CLPS) program [1]. The rover will traverse the areas around Mons Mouton, home to several permanently shadowed regions (PSRs), for 100 days and has 2 main science objectives: 1) characterizing the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith to understand their origin, and 2) provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions [1]. Science operations are expected to find volatiles that may be extractable up to a meter deep in the lunar regolith. However, there is still a lack of consensus regarding how deep these volatiles may be stored in the lunar crust [2,3,4,5]. The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT), VIPER's drilling tool, will reach a maximum of 1020 mm into the surface, unable to examine any possible deeper deposits of volatiles. Thus, accessing deeper depths will require geophysical exploration.

We are characterizing how the VIPER inertial measurement unit (IMU) can be used as a seismometer to capture TRIDENT and other rover activities and use these data to interrogate variations in lunar subsurface structure. IMUs provide a novel way to conduct geophysical exploration, for example, Lewis et al., [6] demonstrated how rover-based IMUs on the Curiosity rover on Mars could provide gravity science. The IMU selected for the VIPER mission is the Northrup Grumman LN-200S IMU [7], identical to Curiosity's on Mars. VIPER's IMU is installed as close as possible to the rover's center of mass [1]. Each LN-200S IMU is equipped with three MEMS accelerometers designed to measure movement in three axes [8]. VIPER IMU data collected during rover operations will be collected at 100 Hz and transmitted to Earth for study.

Methods: Our goals are to 1) quantify the IMU sensitivity to seismic signals generated by both TRIDENT and the rover itself; 2) characterize the rover transfer function before VIPER launches; and 3) to develop seismic methods for assessing subsurface structure with these signals as the rover traverses on the Moon. With a clear characterization of the accelerations caused by the rover's movements, the variability in seismic velocities and other relevant properties of the lunar subsurface can be isolated and related to the presence of volatiles or other near surface resources (Fig. 1).

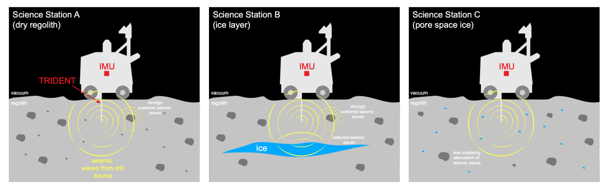

Figure 1. As the VIPER mission traverses across a PSR, differing ice content and expression in the shallow subsurface will result in changes to the response of the ground (e.g., changes in seismic velocity and attenuation) to a vibrating/percussive drill source. We seek to quantify how detectable these signals will be to the rover's IMU.

In seismology, observed signals are made of four components: the instrument response, the source function, the transfer functions of rover itself, and the ground response. In the case of VIPER, the seismic source will be the TRIDENT drill and the actual movement of the rover across the surface. The rover will also have resonances determined by its chassis, wheel suspension, wheel shape, and temperature. A baseline measurement of the source and transfer functions of VIPER and its instruments will make it easier to isolate the ground response in the observed data.

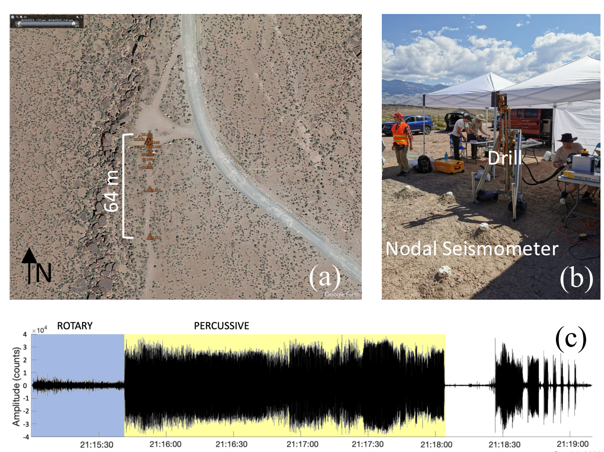

Figure 2. (a) Bishop Tuff field site (37.43ºN, -118.42º E, elev. 1341.0 m); (b) field experiment setup; (c) An example of seismic waveforms from the rotary and percussive mode of a TRIDENT-analog instrument

Source Characterization: TRIDENT will be the primary source of seismic energy that will be measured by the IMU. It has both percussive and rotational modes, at 16.2 Hz and 2 Hz, respectively [9]. Engineering models of the drill have been tested and recorded by seismometers in a field test on the Bishop Tuff in Long Valley Caldera, California (Fig. 2). Both the rotary and percussive modes of the instrument were recorded by a seismometer located a meter away from the source, while the drill depth was simultaneously logged. The difference in signals between the two drilling modes can be observed in initial data (Fig. 2c).

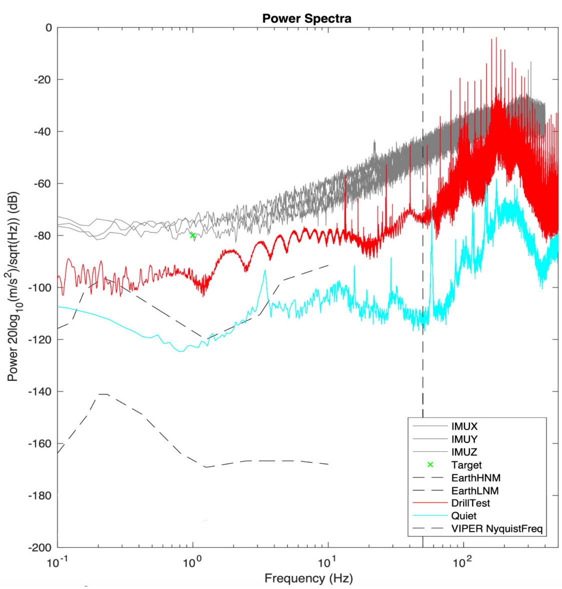

Figure 3. The relationship of background seismic signal to drilling at the Long Valley experiment location (cyan) and the response during the percussive drilling (red, solid) compared to the idealized expected seismic performance of an IMU with performance comparable to the VIPER IMU (grey). The dashed lines are the high and low noise seismic models of the Earth (black) and Mars (red). Drill resonances below the Nyquist frequency of the IMU are present between 10-50 Hz.

Rover Response: To characterize the transfer functions of each rover component, two accelerometers will be used for each experiment as per [10]. One IMU will be located on the ground as a control, ideally measuring only the IMU's instrument response, while the other will be located within 1m of the active instrument to approximate the IMU's location on the rover itself. The data from these IMUs will be downsampled to a sample frequency of 100 Hz to match what is expected from the VIPER IMU. By subtracting the power spectra of the control IMU from the IMU collocated with each instrument, the noise floor of the IMU can be estimated. This is also the best way to characterize the transfer function between the components of the rover and the ground.

Preliminary Conclusions: The expected seismic performance of the VIPER IMU is shown in Fig. 3 and based upon test data collected with the Curiosity IMU [6]. While most of the drill test data falls below the threshold of what the IMU should detect, a signal at 40 Hz falls just within what may be observable in IMU data. This spike is not replicated in the ambient background spectrum, indicating that the 40 Hz signal may be caused by subsurface structure.

In the Long Valley Caldera test, the seismometer was not attached to the drill; as a result, the amplitudes and energy measured in the Bishop Tuff are likely smaller than what would be measured by an IMU attached to a seismic source owing to attenuation in the volcanic ash of the site. Furthermore, the instrument sensitivity may be different under lunar and vacuum conditions, affecting attenuation and total energy transmitted. Thus, further experiments are needed.

Future Work: Forthcoming experiments of the TRIDENT in a vacuum chamber on various substrates will be used to further constrain the expected IMU measurements during drilling operations on the lunar surface. Additionally, VIPER is using a new wheel design and suspension system that has never flown before. As a result, numerous studies of the wheel and suspension system have been conducted, including a 40 km endurance test [11]. As the wheels and suspension continue testing before launch, it is critical to measure expected accelerations on the IMU both for the wheels as a seismic source when the rover is driving and as a conduit of seismic energy during drilling and other activities.

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