ROCKSTAR: A THERMAL INFRARED HYPERSPECTRAL IMAGER FOR METER SCALE DATA COLLECTION FROM ORBIT C. M. Ferrari-Wong[1], P. G. Lucey[1], B. Bussey[2], S. Gunapala[3], C. I. Honniball[4], M. A. Nunes[1], N. Petro[4], D. Ting[3], R. Wright[1], [1]University of Hawaii at Manoa, HI 96822, [2]Johns Hopkins University Applied Physics Laboratory, [3]Jet Propulsion Laboratory, [4]NASA Goddard Space Flight Laboratory (cfw@hawaii.edu).

Introduction NASA's VIPER, CLPS, and Artemis programs will send suites of science instruments and technology demonstrations to the lunar south pole in search of resources like water and other volatiles needed for long-term exploration. On the Moon, hyperspectral imaging on the meter-spatial scale is enabled by abundant photon flux at thermal wavelengths and modern infrared arrays with high-speed readouts, allowing for identifying and classifying geologic compositions and features as small as individual boulders at polar landing sites. Our instrument concept, "Rockstar," is a hyperspectral mapper using thermal infrared spectroscopy to detect silicate mineralogy on the meter-spatial scale (Figure 1). It is also compatible with very small satellites in the 50-kg class, making it a low-cost, high-payoff instrument.

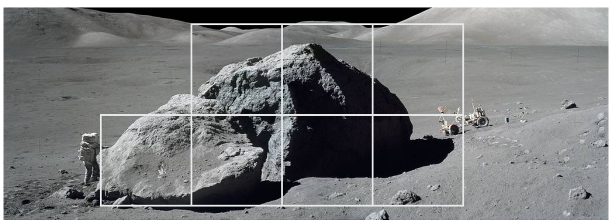

Figure 1: *A boulder from an Apollo 17 EVA, superimposed with 4-m scale spatial resolution.*

Science Objectives The lunar surface has been subject to impact mixing throughout its history. In lunar remote sensing, even the highest resolution existing, planned missions, or data sets (the highest currently available is visible multispectral imaging from Kaguya Multiband Imager at 20-m/pixel) are primarily measuring mixed lunar regolith, not individual rocks (Figure 2). Thus, all lunar remote sensing data is a mixing problem: the signal is a mixture of all the lithologies present at the target site. There are, in fact, geologically interesting locations that appear dominated by a single lithology, but this is only inferred from their extreme compositions that suggest low amounts of mixing. Thus, the ability to sense primary lithologies depends on scale, limiting the ability to target specific scientific problems.

Based on boulder counts around fresh craters, the number of rocks 20-m or larger on even fresh crater ejecta is fewer than one 20-m boulder per square kilometer. However, there are <1000 2-m boulders per square kilometer on that same ejecta [1]. Thus, Rockstar would have a statistically large sample of the rocks at scientifically interesting sites in every square kilometer measured. The lifetime of these boulders on the surface is limited by impact and thermal fatigue [2][3], and as a result, they exhibit less mixing and are less space-weathered than soils. If Rockstar were to look in settings like basin rings and central peaks, boulders of primary igneous lithologies could be located and mineral compositions measured, minimizing mixing and the effects of space weathering. Rockstar can also look for ultramafic rocks, silicic volcanic constructs, and molecular water. By searching for ultramafic mantle xenoliths, we will seek evidence of these ultramafic rocks in basin rings and pyroclastic deposits. Utilizing Rockstar's high spectral resolution, we can determine mineralogies at silicic volcanic constructs.

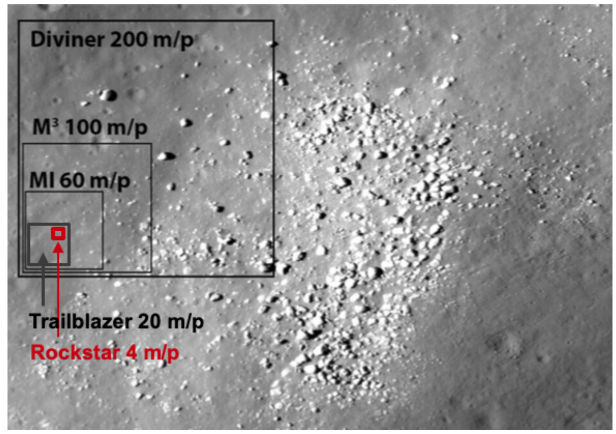

Figure 2: *Instrument spatial resolution of Diviner Lunar Radiometer, Moon Mineralogy Mapper, Multiband Imager, Lunar Trailblazer, and Rockstar for comparison.*

Artemis Support In addition to enabling new classes of science problems, Rockstar would support the Artemis program by providing the mineralogies of all large boulders at sites before landing, informing pre-mission EVA planning, and enabling the choosing of potential sampling sites ahead of time instead of in real-time. The Artemis sites likely feature important but rare exotic constituents thrown in by distant craters. These outliers would only be present at the one boulder per thousand level, and Rockstar would identify these prior to human landings. With the 6-micron molecular water fundamental emission feature, Rockstar can produce maps of the distribution of molecular water globally and at Artemis sites to help understand the impact of exploration on the lunar volatile record due to spacecraft traffic and surface operations.

Instrument Rockstar is a maturation of HyTI, or the "Hyperspectral Thermal Imager" (Figure 3)[4]. It is cur-

Orbit	Polar, 20 km at south pole
Spectral Range	5-10.7 microns
Spectral Resolution	10.8 cm^{-1}
Detector Pixel Size	25 microns
Pixel Count	640x512
Effective Focal Length	220 mm
f-number	3
Telescope Emissivity	0.2
IFOV (Geometric)	0.11 mrad, 2.2 m
IFOV (Diffraction)	0.2 mrad, 4 m
FOV	4.1 degrees, 1450 m
Ground Sample Distance	1.4 km
Frame Rate	980 Hz
Spectral SNR	$>$100 at 6 microns
Broadband NEdT	1K at 50K; 1mK at 300K

Table 1: *Rockstar instrument parameters.*

rently being constructed under NASA's Earth Science Technology Office's (ESTO) InVEST program as a 6U CubeSat mission scheduled to fly in early 2023. The lunar instrument, Rockstar, differs from ESTO HyTI in the use of a new focal plane, modification of the instrument for use in lunar orbit with its more rigorous thermal and radiation environment, and the need for a very high-speed data recorder.

Many of the ESTO HyTI components are at TRL 6, including the Unibap computer, Creare temperature controller, and the objective lens. The maturation of ESTO HyTI to Rockstar involves these developments: (1) Production of a new JPL HOTBIRD focal plane on a high-speed readout circuit that can run at 1000Hz (enabling a ground sample of 1.6 meters); (2) Refinement of the instrument thermal design to tolerate lunar orbit; (3) Radiation testing and hardening against the lunar radiation environment; (4) Design and testing of the instrument for likely lunar launch loads (GEVS); (5) Development of a high-speed data recorder to collect bursts of Rockstar data.

Rockstar will operate from 5 to 10.7 microns at 10.8 cm^{-1} resolution to map silicate and other mineral emissions, as well as molecular water. From a 20 km orbit, the diffraction-limited spatial resolution is 4-m, with a swath width of 1.4 km. Signal-to-noise ratios (SNR) vary from 150 near 6 μm to $>$1000 past 9 μm for surface temperatures 250-300K (Table 1). Broadband thermal imaging using the instrument is also available at the 4-m resolution, with NEDT of 1K at 50K and about 1mK at 300K, which is sufficient to characterize any nighttime surface outside the PSRs.

At 4-m/pixel, the instrument resolution is finer than that of Diviner (200-m/p), Chandrayaan-1 Moon Mineralogy Mapper (100-m/p), Kaguya Multiband Imager (20-m/p), and Lunar Trailblazer (30-m/p) (Figure 2). The Rockstar instrument would be complementary to current and planned missions, targeting specific sites of interest returned from these missions to provide resolutions of rock abundance on a human scale.

Concept of Operation Rockstar will obtain complete monthly maps within 100 km of the pole, including Artemis sites. Bimonthly maps are obtained to 200 km, and quarterly seasonal maps are obtained above 80 degrees latitude. Outside the polar region, the data collection is targeted 1.4 km x 100 km data strips. Rockstar can acquire and process 1000 km of data in each orbit, with a processed data volume of 130 GB. With a year of operation and some off-nadir pointing, individual locations can be sampled anytime during the lunar day or night.

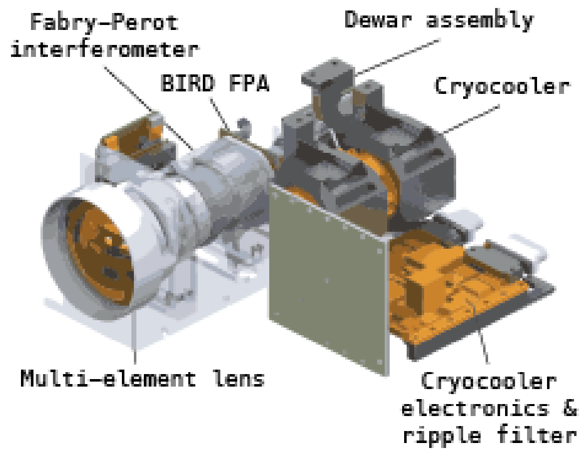

Figure 3: *Rendering of the HyTI spectrometer being built for NASA ESTO for launch in 2023.*

Summary With new initiatives for a long-term lunar presence, it is more important than ever to characterize the surface of the Moon. Meter scale spectral imaging of polar landing sites is feasible with our instrument concept "Rockstar," and would revolutionize traverse planning for future vehicles and astronauts stationed at the lunar south pole. Compositional mapping at this scale may also provide a scientific revolution similar in impact to the NAC for geomorphology.

References

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