

ROCKSTAR: A THERMAL INFRARED HYPERSPECTRAL IMAGER FOR METER SCALE DATA COLLECTION FROM ORBIT C. M. Ferrari-Wong¹, P. G. Lucey¹, B. Bussey², S. Gunapala³, C. I. Honniball⁴, M. A. Nunes¹, N. Petro⁴, D. Ting³, R. Wright¹, ¹University of Hawaii at Manoa, HI 96822, ²Johns Hopkins University Applied Physics Laboratory, ³Jet Propulsion Laboratory, ⁴NASA 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 that will be needed for long-term exploration. With abundant photon flux at thermal wavelengths and modern infrared arrays with high speed readouts, hyperspectral imaging at 4-meter spatial scale enables compositional identification and classification of geologic features as small as individual boulders at polar landing sites (Figure 1). Our instrument concept, "Rockstar," is a hyperspectral mapper using thermal infrared spectroscopy to detect silicate mineralogy on this spatial scale, and is compatible with very small satellites in the 50 kg class, providing a low cost, high payoff instrument.

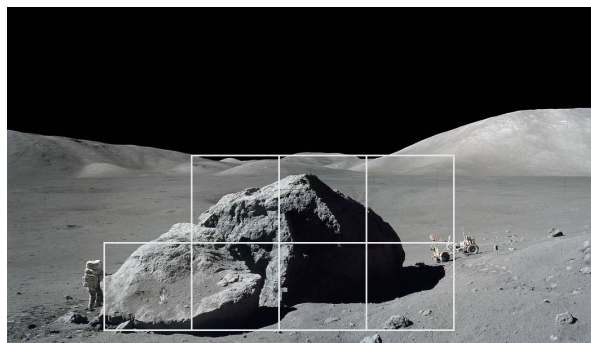


Figure 1: *Rockstar* pixel resolution (4-m) superimposed on the Apollo 17 station EVA Station 6 boulder. A TIR spectrum would be obtained for each square on the image.

Science Goals Rockstar will address two major scientific goals for the Moon directly from the Planetary Science Decadal Survey:

- (1) "How do the structure and composition of each planetary body vary with respect to location, depth, and time?"; and
- (2) "Understand the composition and distribution of volatile chemical compounds." [1]

Boulders are an important target for Rockstar to measure. Their lifetime on the surface is limited by impact and thermal breakdown, 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 might be able to be located and mineral compositions measured, minimizing mixing and the effects of space weathering. For example, the feldspar-to-mafic ratio of anorthosites

could be measured to shed light on their nature and variation and the lithologies present in the central peaks of craters could be determined.

Rockstar will additionally have the capacity to 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 can help determine mineralogies present at silicic volcanic constructs. With the 6 micron molecular water fundamental emission feature, Rockstar can produce maps of the distribution of molecular water globally and at Artemis sites.

Artemis Support In order to help understand the impact of exploration on the lunar volatile record, Rockstar will detect changes in the molecular water signature due to spacecraft traffic and surface operations by measuring changes in the 6 micron emission feature.

Additionally, to ensure that sample collection and in situ measurements are designed to maximize science return, Rockstar can determine the silicic mineralogy of boulders and deposits of small craters to inform pre-mission EVA planning and seek evidence of exotic material deposited from the rays of Jackson and Tycho by measuring the mineral abundance of rocks and soils.

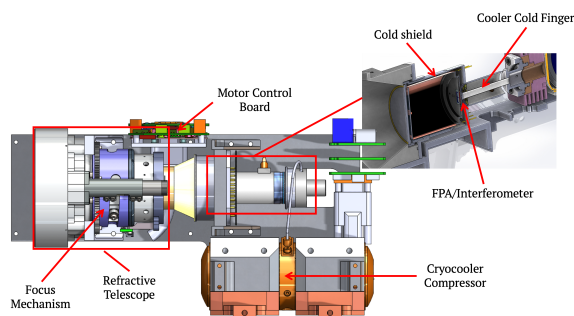


Figure 2: *HyTI* spectrometer being built for NASA ESTO for launch in 2021.

Instrument Rockstar is a maturation of HyTI, or the "Hyperspectral Thermal Imager". [2] It is currently being constructed under NASA's Earth Science Technology Office's InVEST program as a 6U CubeSat mission that is scheduled to fly in mid 2022.

The same instrument (Figure 2) is ideally suited for lunar science with the following changes:

- (1) Rockstar will use a high speed ROIC in order to meet spatial sampling requirements;
- (2) It will have radiation tolerant camera electronics;

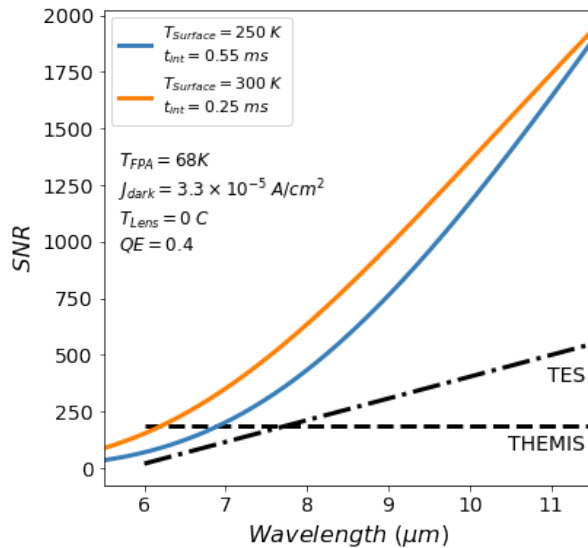


Figure 3: Predicted performance of Rockstar compared with TES and THEMIS. TES and THEMIS demonstrated successful mapping of silicate minerals on Mars using features in the 7-14 micron region. Rockstar meets or exceeds these SNRs.

- (3) It will be ruggedized and tested to the general environmental verification standard for planetary launches;
- (4) the thermal design will be upgraded for lunar orbit operation;
- (5) Rockstar will use an athermal telescope, while HyTI used a focus mechanism on the telescope objective.

Table 1: Rockstar instrument parameters.

| | |
|----------------------------|------------------------|
| Spectral Range | 5.5-11.5 microns |
| Spatial Resolution | 4-m at 20 km |
| Swath Width | 1.4 km |
| Frame Rate | 980 Hz |
| Spectral Resolution | 10.8 cm^{-1} |
| Spectral SNR | >100 at 6 microns |
| Broadband NEDT | 1K at 50K; 1mK at 300K |

Rockstar will operate between 5.5 to 11.5 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 about 150 near 6 μm to over 1000 past 9 μm for surface temperatures 250-300K (Table 1). These SNRs meet or exceed TES and THEMIS SNRs that demonstrated successful mapping of silicate minerals on Mars using their features in the 7-14 micron region (Figure 3). Broadband thermal imaging using the instrument is also available at 4-m resolution, with NEDT of 1K at 50K and about 1mK at 300K, which is sufficient to character-

ize any nighttime surface outside PSR.

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 4). The Rockstar instrument would be complementary to that of current and planned missions, targeting specific sites of interest returned from these missions to provide resolutions of rock abundances on a human scale.

Concept of Operation Monthly complete maps can be obtained within 100km of the pole, including most Artemis sites of interest. Bimonthly maps are obtained to 200km, and quarterly seasonal maps are obtained above 80 degrees latitude. Outside of the polar region, data collects are targeted 1.4km x 100km data strips.

Rockstar can acquire and process 1000km of data 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 at any time during the lunar day or night.

Summary With new initiatives for a long-term lunar presence, it is more important than ever to characterize the surface of the Moon. 4-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

- [1] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, pages 116–118.
- [2] R. Wright et al. *Proc. SPIE: CubeSats and SmallSats for Remote Sensing III*, 11131, 2019.

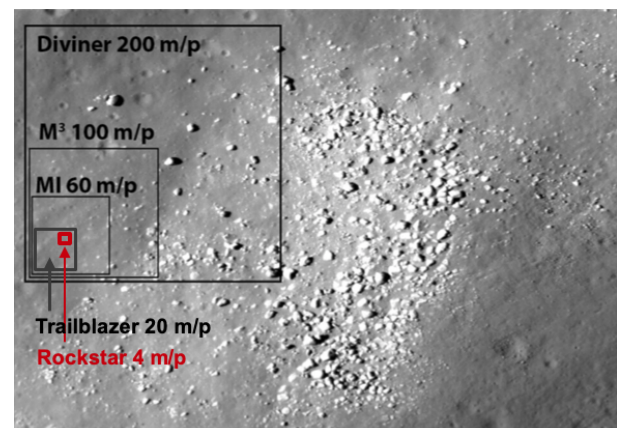


Figure 4: Instrument spatial resolution of Diviner Lunar Radiometer, Moon Mineralogy Mapper, Multiband Imager, Lunar Trailblazer, and Rockstar for comparison.