1-METER RESOLUTION HYPERSPECTRAL THERMAL INFRARED IMAGER CONCEPT FOR LUNAR EXPLORATION C. M. Ferrari-Wong[1], P. G. Lucey[1], R. Wright[1], C. I. Honniball[2], P. O. Hayne[3], B. T. Greenhagen[4], T. Glotch[5], J. Cahill[4], K. Hibbitts[4], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, HI 96822, [2]Goddard Space Flight Laboratory, [3]University of Colorado at Boulder, [4]Johns Hopkins Applied Physics Laboratory, [5]Stony Brook University (cferrariwong@higp.hawaii.edu).

Background Beginning in 2021, NASA's Artemis program will send a suite of science instruments and technology demonstrations to the lunar surface, beginning with the South Pole, in search of resources like water and other volatiles that will be needed for long-term exploration. Hyperspectral imaging at the 1-meter spatial scale, enabled by the combination of abundant photon flux at thermal wavelengths and modern infrared arrays at high speed data readouts, enables compositional identification and classification of geologic features as small as individual boulders at polar landing sites, important for geologic sampling and analysis. At this scale compositional identification and classification of individual boulders at polar landing sites can be carried out prior to landings, enabling detailed planning for geologic sampling and analysis (Figure 1). This ability is compatible with very small satellites in the 50 kg class, and so be a low cost, very high payoff capability.

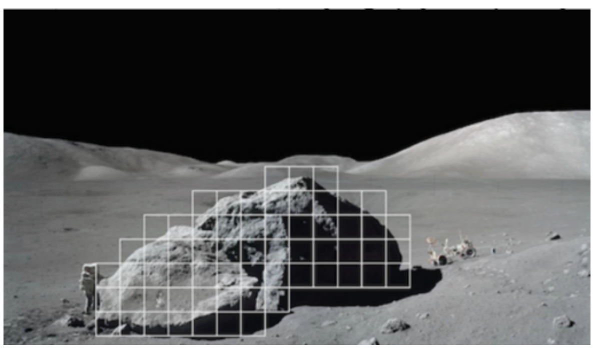

Figure 1: *Lunar HyTI pixel resolution superimposed on the Apollo 17 station EVA Station 6 boulder. A TIR spectrum would be obtained for each square on the image.*

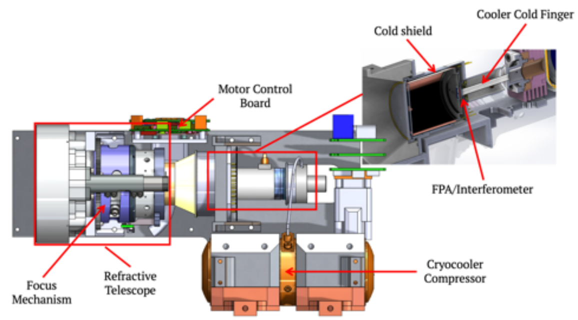

Figure 2: *HyTI spectrometer being built for NASA ESTO for launch in 2021.*

Instrument Recognizing the high signal available in the thermal infrared, we conducted a design study for a hyperspectral imager based on a thermal IR hyperspectral 6U CubeSat nearly complete for NASA ESTO called HyTI (Figure 2) [1]. HyTI will collect thermal hyperspectral data from 8-11 microns from 500 km Earth orbit with 60-m resolution. HyTI is an imaging interferomter, and collects data similar to filter cameras such as WAC and THEMIS and collects spectral data by registering frames to assemble the spectrum.

The same instrument is ideally suited for lunar science when translated to a lunar orbit (Table 1). At a 50 km lunar orbit, 6-m resolution is feasible without any optical redesign. 1-m resolution is technically feasible, except that the HyTI focal plane array, a JPL HOT BIRD strained layer superlattice array with an SBF-193 ROIC, has too low a frame rate/pixel to support the apparent ground speed from low lunar orbit. By using a larger telescope and flying the instrument in a 20 km orbit, the HyTI IFOV would be just over 1-meter/pixel, but require a frame rate on the order of 1600 Hz. Fortunately, extremely high speed readout arrays have been introduced by FLIR, the FLIR 0804 and FLIR 0207, and we have integrated an 0804 ROIC with an SLS camera in Hawaii and operated it at 4000 Hz with a 128x640 pixel window in a HyTI-like thermal IR spectrometer for chemical mapping. For this instrument, we would operate the instrument at 2000 Hz frame rate with a 256x640 window to provide submeter frame advances, and a 640-m swath width, sufficient to capture most of a typical landing site in one pass.

Orbit	Spatial Resolution	Optical Redesign
50 km	6 m/pixel	None
20 km	2 m/pixel	None
20 km	1 m/pixel	high speed readout array & larger telescope

Table 1: *Spatial resolution of the HyTI instrument translated into lunar orbit.*

Sensitivity We used the HyTI performance model to determine signal to noise ratios achievable at 1-m spatial resolution, with 20 wavenumber spectral resolution, from 6 to 11 microns. To improve sensitivity we assumed a HgCdTe detector array with a quantum efficiency of 70% rather than SLS.

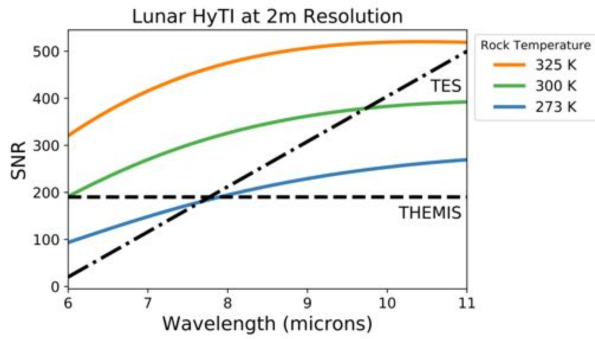

Figure 3: *Performance of the HyTI instrument at 2m resolution. The dashed lines compare the instrument performance of the Thermal Emission Spectrometer (TES) and the Thermal Emission Imaging System (THEMIS) to that of HyTI.*

We assume that large upright boulders facing the Sun for most of the lunar day will have temperatures >250 K. We base the estimate on the temperatures derived for full Moon observations from the earth that are biased toward sun-facing slopes. With a cosine to the 1/6 power relationship [2], a boulder at 85N latitude would have a temperature of about 250 K assuming a subsolar temperature of 380K. Figure 3 shows signal to noise ratios of around 200 in the critical 8 micron region needed for silicate mineralogy characterization. SNR for water mapping at 6 microns are sufficient for a detection limit of about 100 ppm. Comparisons to TES and THEMIS show SNR well within acceptable range to map the composition of boulders on the surface.

Mission Design The HyTI sensor (Figure 2) and spacecraft (Figure 4) in development have a total 12 kg mass including all the avionics needed so support the instrument and mission. The major delta we see is the need for propulsion to transition from a 50 km mapping orbit to obtain 10-m resolution regional maps (6 km swath width), to a 10 km orbit for high resolution 1-m imaging. Lunar thermal management is more challenging so that may impact spacecraft mass. We assume the satellite would be deposited into lunar orbit by external means. The mission could also support highly elliptical orbits targeting one pole.

Since we envision targeted data collection, data volumes are not large, and the HyTI spacecraft is already sized to accommodate the envisioned data volumes. The total mission data volume will be approximately 3.7 Gbytes, requiring a total mission lifetime downlink time of 64 hours at 256 kps. This will comprise 500 individual high resolution thermal hyperspectral images of the lunar surface.

At 1-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). The HyTI 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.

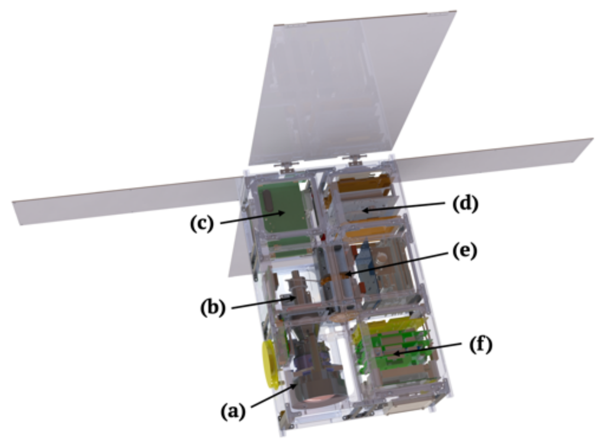

Figure 4: *The HyTI spacecraft consists of the following: (a) refractive telescope, (b) Fabry-Perot interferometer on an Integrated Dewar Cooler Assembly, (c) cryocooler driving electronics, (d) avionics, (e) cryocooler compressor, and (f) payload computer.*

Summary With new initiatives for a long-term lunar presence such as with Artemis and commercial landers and rovers, it is more important than ever to characterize the surface of the Moon. 1-meter scale spectral imaging of polar landing sites to characterize silicate mineralogy and possibly water is feasible and would revolutionize traverse planning for future vehicles and astronauts stationed at the lunar south pole. Compositional mapping at this scale may provide also provide a scientific revolution, similar in impact to the NAC for geomorphology.

References

[1] R. Wright et al. *Proc. SPIE: CubeSats and SmallSats for Remote Sensing III*, 11131, 2019.

[2] E. Pettit and S.B. Nicholson. *The Astrophysical Journal*, 71:102–135, 1930.