ONE-METER RESOLUTION THERMAL INFRARED HYPERSPECTRAL IMAGING OF POLAR LANDING SITES.

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]University of Hawaii, Honolulu HI, [2]Goddard Space Flight Laboratory, [3]University of Colorado at Boulder, [4]Johns Hopkins Applied Physics Laboratory, [5]Stony Brook University. Email: cfw@hawaii.edu

Introduction: The combination of abundant photon flux at thermal wavelengths, and modern infrared arrays and high speed data readouts that can take full advantage of this flux, enable hyperspectral imaging at the 1-m spatial scale. 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 thermal IR spectrum would be obtained for each square on the image.

Thermal photon flux in the 5-11 micron region: Solar reflected flux and thermal emitted flux is usually plotted in units of watts, and using this unit, there is typically far more power in reflected flux than in thermal flux. However, the number of photons is proportional to wavelength, and in units of photons flux near 10 microns dominates over reflected flux for surfaces near 300K. (Figure 2). The consequence of this is that a thermal photon detecting instrument can achieve high signal to noise ratios with much lower integration times than near-infrared reflectance spectrometers. To achieve reasonable signal to noise ratios, on the order of several hundred, a thermal spectrometer with a photon sensitive detector only requires a few hundred microseconds of integration. At lunar orbital velocity, a meter is traversed in about 600 microseconds.

A meter-scale hyperspectral imager: Recognizing the high signal available in the thermal infrared, we did a design study for a hyperspectral

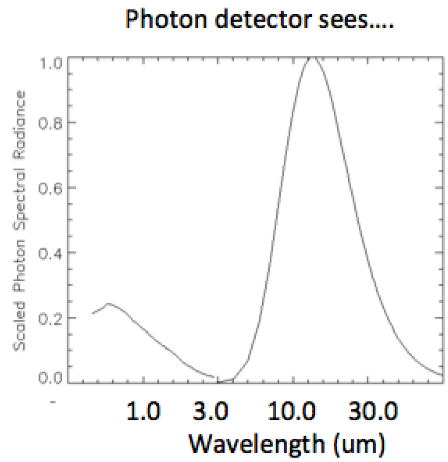

Figure 2. Photon radiance for a 273K surface in radiance equilibrium with solar input. The photon flux is much higher than in the thermal infrared.

imager based on an instrument are building as a 6U cubesat for NASA ESTO called HyTI (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, but collects data similar to filter cameras such as WAC and Themis and collects spectral data by registering frames to assemble the spectrum. Translating that instrument to a 50 km lunar orbit, 6-m resolution is technically feasible, except that the HyTi focal plane, a JPL HOT BIRD strained layer superlattice array with an SBF-193 ROIC has too low a frame rate/pixel rate to support the apparent ground speed from low lunar orbit. From a 10 km orbit, proven by GRAIL, the HyTI IFOV would be just over 1-m, 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. 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 our point design we would operate the instrument at 2000 Hz frame rate with a 256x640 window. This would provide submeter frame advances, and a 640-m swath width, sufficient to capture most of a typical landing site in one pass.

Sensitivity: We used the HyTI performance model to determine signal to noise ratios achievable at 1-m

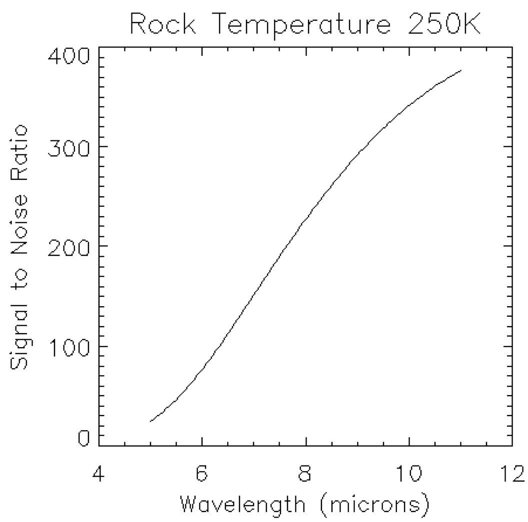

Figure 3. Signal noise ratio for HyTI thermal spectrometer operated at frame rates needed to achieve 1-m imaging.

spatial resolution, 20 wavenumber spectral resolution, from 5.5 to 10 microns. To improve sensitivity we assumed a HgCdTe detector array with a quantum efficiency of 70% rather than SLS. We assume that large upright boulders facing the Sun for most of the lunar day will have temperatures of 250K. We base this 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 250K assuming a subsolar temperature of 380K. Figure 3 shows signal to noise ratios of about 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.

Mission design: The HyTI sensor (Figure 4) and spacecraft in development have a total 25 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.

Conclusion: One-meter scale spectral imaging of polar landing sites to characterize silicate mineralogy and possibly water is feasible and would revolutionize traverse planning. Compositional mapping at this scale may provide also provide a scientific revolution, similar in impact to the NAC for geomorphology.

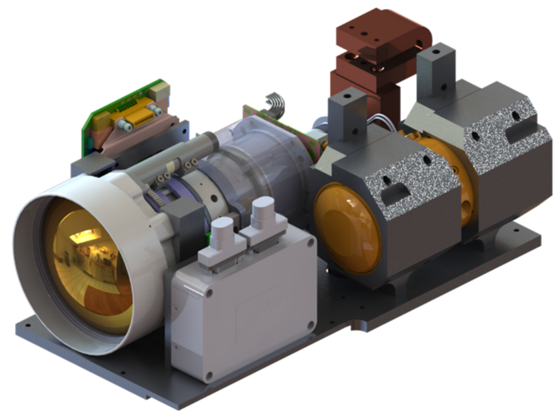

Figure 4. HyTI spectrometer being built for NASA ESTO for launch in 2021.

References: [1] R. Wright et al. HyTI: thermal hyperspectral imaging from a CubeSat platform, Proc. SPIE: CubeSats and SmallSats for Remote Sensing III, 11131, 2019. DOI: 10.1117/12.2530821. [2] Pettit, E. and S.ÊB. Nicholson (1930). Astrophys. J. 71, 102-135.