MEASUREMENT REQUIREMENTS AND INSTRUMENT PERFORMANCE FOR REMOTE MEASUREMENTS OF LUNAR SURFACE WATER ABUNDANCE AND VARIATION USING THE 6 MICRONS WATER ABSORPTION.

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Introduction: Water on the lunar surface was dramatically discovered in data collected by three spacecraft [1,2,3], and was manifest in reflectance spectra of the lunar surface as a strong absorption near 3 microns. The three micron region is a very sensitive spectral region for deteetion and characterization of water in its several molecular forms (see the voluminous FTIR literature) and the Chandryaan-1 Moon Mineralogy Mapper provides wide surface coverage of an important portion of the spectral region.

However, these data are inherently limited by the nature of spectral measurements of the Moon near 3 microns. The three micron absorption region is due to a combination of hydroxyl and water. The processes that give rise to the remotely sensed lunar surface water are still only partly understood [e.g. 4] and uncertainties in the remote sensing results limit the ability to apply constraints. Data in the 3 μm region also suffers from thermal contamination. In this wavelength region the spectral signal is a mixture of reflected light and thermal emission and these terms require very accurate thermal models to separate, if they can be separated at all. Beyond the startling detection of water, the variation in the depth of the water band is a crucial observation, interpreted to be due to diurnal variation in the amount of surface water [3]. But this variation may be entirely due to the competing effects of thermal emission and reflectance [5].

The 3 μm region expresses only two of the water molecule's three fundamental features. The third, the H-O-H bend, occurs at 6.07 microns. This absorption is about half the strength of the combined OH features near 3 microns, but is a strong and narrow feature (Figure 1), well suited for detection of the water molecule, and has no influence from hydroxyl. At 6 microns there is essentially no reflected contamination of the signal, whereas near 3 microns the solar and reflected signal are of similar values, with the reflected signal slightly larger. At 6 microns the ratio of thermal to reflected signal is 1000 times greater than at 3 microns.

The relatively weak spectral signal at 6 microns presents challenges in instrument design. In this work we define a point design for a multiband 6 micron imager as a simple step filter camera/spectrometer with transmission optics optimized for that wavelength. We will define a signal to noise requirement and determine at what lunar latitudes and temperatures this point design can meet the requirement.

The 6 micron feature in minerals and lunar samples: Salisbury et al. 1997 [6] noted the prominent 3 micron absorption feature in their diffuse thermal infrared reflectance spectra of lunar soils from several Apollo landing sites, and attributed that to water probably from terrestrial contamination. They also pointed out the 6 micron feature present in all the spectra and also attributed this to water (Figure 2). We have examined another 17 lunar soils measured at RELAB and each also features a prominent feature at 6 microns.

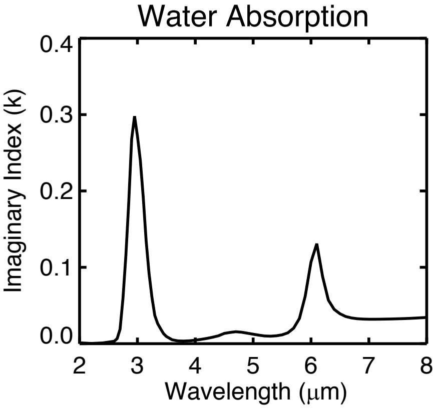


Figure 1: Imaginary index (that controls absorp-tion) of water showing strong peaks at 3 and 6 microns [7].

Li (2016)[8] measured the spectra of a MORB glass in a step-wise heating experiment and these data illustrate the effect of water abundance on the 3 and 6 μm bands. In these samples the 6 μm band depth is strongly correlated with the depth of the 3 μm band supporting its use for remote water detection.

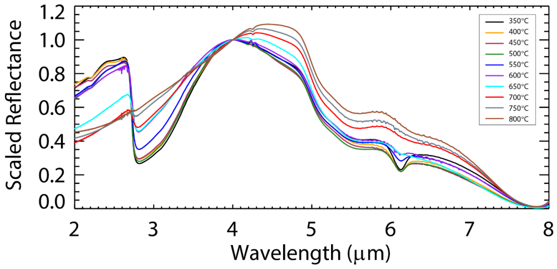


Figure 2: Infrared reflectance spectra of a MORB glass during step-wise heating experiments (Li, 2016) showing prominent, variable 3 and 6 micron bands.

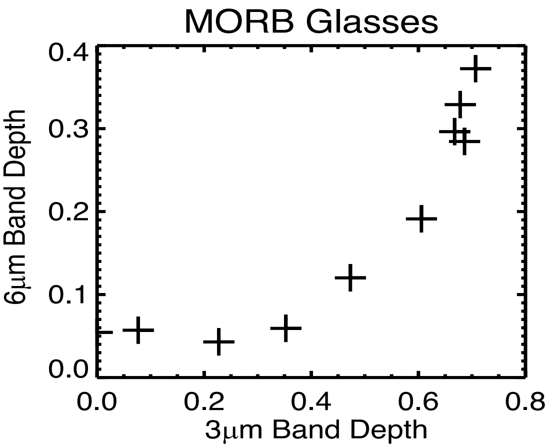
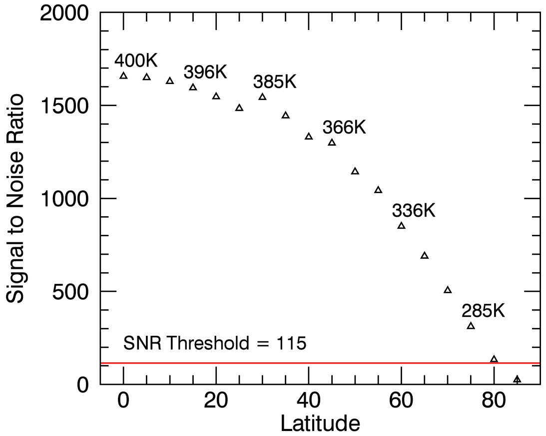


Figure 3: Correlation of 3 and 6 micron bands depths from data in Figure 2 (Li). Note 6 micron depth flattens below a 3um depth of 0.2 owing to loss of molecular water, but retention of hydroxyl.

Utility for lunar surface water studies: Paramount among questions raised by the 3 micron observations is whether the detected time of day spectral variations reflect a variation in water abundance. The observed spectral variations, if entirely attributed to abundance variations, imply a significant diurnal supply of water to the lunar atmosphere, an abundance not observed by LADEE [9]. A secondary question is whether the absorption is due to hydroxyl or water.

At six microns spectral variations cannot be due to mixing of the reflected and thermal signal because the reflected signal is negligible. Furthermore, an observed 6 micron feature must be due to water as hydroxyl contains no vibrational features at this long wavelength. This suggests that observations of the strength of the 6 micron feature during the lunar day will be a powerful test of the hypothesis that water abundance on the lunar surface varies during the diurnal cycle, and answer the question whether water or hydroxyl dominates the H-bearing species on the lunar surface.

Requirements: We found that 100 ppmw water gives rise to an emission feature just under 1% in strength, requiring an SNR of 115 for detection.The sensitivity requirement was derived by adding the k (imaginary index of refraction) of water from [7], proportional to its abundance to a model silicate k that results in a reflectance of 25%, a typical reflectance of lunar soil at 6 microns. Hapke theory is then used to compute the reflectance of the model soil, which is in turn converted to emissivity via Kirchoff's law.



We then computed the signal to noise ratio of the point design as a function of latitude assuming: 1) telescope optics are at ambient temperature of the spacecraft, taken as 0 Celsius; 2) dark current of 800Me/s, equivalent to $2x10^{-5}$ amps/cm^{2} 3) detector quantum efficiency of 25%; 4) read noise is 100 electrons; 5) surface temperature computed to be equal to 400K times cos(incidence angle)$^{1/4}$ [10]; 6) surface emissivity is 0.75.

Results: Figure 4 shows the signal to noise ratio of the point design vs. latitude, and the SNR requirement is met within 85 degrees of latitude from the equator (at beta = 0), provided the dark current is limited to be less than 20 microamps/cm^{2}.

Conclusions. Spectroscopic observations of the Moon at 6 microns offers a powerful and unambiguous view of water on the lunar surface enabling testing of the hypothesis that water may be mobile on the lunar surface, and determining the phase of water responsible for the 3 micron absorption feature. First order calculations show that the measurement is feasible with a simple multiband IR camera suitable for Discovery class mission and can cover essentially all illuminated surfaces.

References: [1] Pieters, C. M., et al. science 326.5952 (2009): 568-572. [2] Sunshine, J. M., et al. Science 326.5952 (2009): 565-568. [3] Clark, R. N. Science 326.5952 (2009): 562-564. [4] Hibbitts, C. A., et al. Icarus 213.1 (2011): 64-72. [5] McCord, T. B. et al. Journal of Geophysical Research: Planets 116.E6 (2011). [6] Salisbury, J.W., Basu, A. and Fischer, E.M., 1997. Icarus, 130(1), pp.125-139. [7] Hale, G. M., and M R. Querry. Applied optics 12.3 (1973): 555-563. [8] Li S, PhD Dissertation, Brown University, Providence RI, 2016 [9] Benna, M., Hurley, D.M., Stubbs, T.J., Mahaffy, P.R. and Elphic, R.C., 2015. LPI Contributions, 1863, p.2059. [10] Lawson, S.L., Jakosky, B.M., Park, H.S. and Mellon, M.T., 2000. Journal of Geophysical Research: Planets, 105(E2), pp.4273-4290.