WATER ABSORPTION AT 6 MICRONS: A NEW TOOL FOR REMOTE MEASUREMENTS OF LUNAR SURFACE WATER ABUNDANCE AND VARIATION. P. G. Lucey[1], C. I. Honniball[1], J. Gillis Davis[1], S. Li[1], K. Hibbitts[2], [1]University of Hawaii at Manoa, 1680 East-West Rd, Honolulu, HI 96822, lucey@higp.hawaii.edu, [2]JHU APL, Laurel, MD 20723.

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 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.

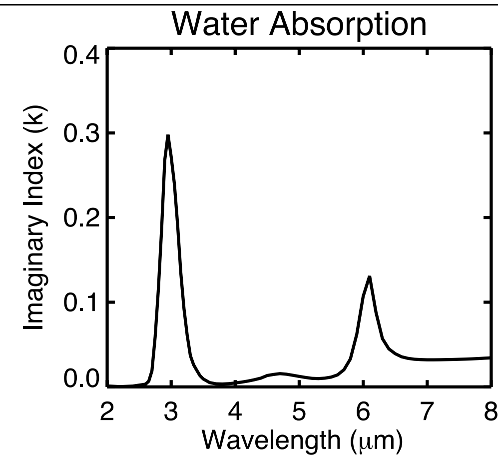

Figure 1. Imaginary index (that controls absorption) of water showing strong peaks at 3 and 6 microns [7].

Spectra of terrestrial mineral samples often show complex spectral structure in near 6 microns due to overlapping overtones and combination tones of Si-O and lattice vibrations, but glass made from a series of plagioclase feldspars, where long range structure was obliterated and lattice modes are absent, also show prominent 6 micron bands accompanying the 3 micron water and hydroxyl bands (Figure 3, [8]).

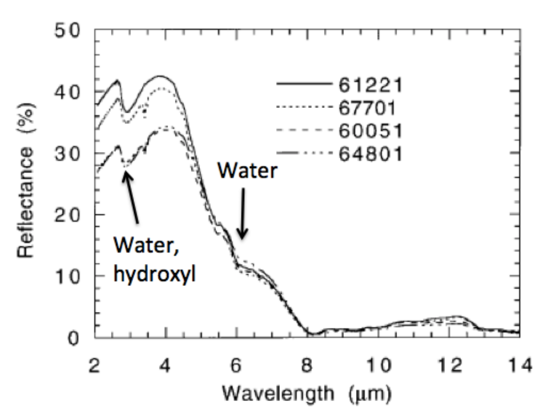

Figure 2. Thermal infrared spectra of Apollo 16 soils showing the 6 micron water band [6].

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, an hydration-dehydration cycle. 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.

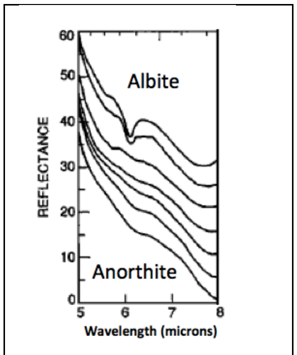

Figure 3. Spectra of vitrified plagioclase showing prominent 6 um water features. From [8].

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 specie on the lunar surface.

Preliminary Model: Stolper (1982) [10] presented absolute absorption estimates for water and hydroxyl in glasses of varying compositions; we use those to estimate the strength of the 6 micron water feature in emission for typically low lunar water abundances. Stolper did not measure to 6 microns, so we use the optical constants of liquid water appropriately scaled to match the quantitative absorption properties observed by Stolper at 1.9 microns. By multiplying the absorption coefficient of liquid water by ten, we can match the absorption v. concentration relationship observed by Stolper. We then applied Hapke theory to compute the reflectance and emission spectra at 3 and 6 microns. With 100 ppm water, the 3um band depth is about 10% in reflectance, roughly consistent with the observations of [1,2,3]. The corresponding 6 micron emission feature is about 1% in intensity.

Viability for remote sensing: Because of absorption by water vapor in the Earth's atmosphere, the six micron region is opaque to groundbased telescopes, so observations from space are an obvious solution. However, stratospheric balloon observatories are above the great majority of water and have excellent transmission through the 6 micron region [11]. Furthermore, the water problem does not require high spatial resolution as demonstrated by the EPOXI/Deep Impact results that clearly demonstrated the lunar time of day dependence of the 3 micron band depth with very coarse spatial resolution. The GHAPS (Gondala for High Altitude Planetary Science) stratospheric balloon observatory is a 1-m telescope project in development that is ideally suited to make these observations [11]. At 6 microns, the diffraction limited spatial resolution of this telescope is about 22 km, sufficient to resolve time of day effects at high local time resolution, and capture the spectral properties of major geologic features including large fresh craters and the differences between maria and highlands.

The ideal instrument would simultaneously measure the strength of the 3 micron and 6 micron features to enable intercomparisons and enable a direct comparison of the latitude, temperature and time of dependence of both features. The earth-based vantage point also offers a perspective similar to that of EPOXI/Deep Impact in that solar phase is constant while incident and emergence varies, unlike M3 observations where emergence was fixed and incidence and phase varies.

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.

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