TELESCOPIC OBSERVATIONS OF CHANG'E 5 LANDING SITE HYDRATION IN PARTIAL ECLIPSE

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Introduction: Over the last decade, the behavior of volatiles on the lunar surface has become an important question in lunar science. This began with the discovery of the Moon-wide 3 μm band by multiple remote sensing instruments: EPOXI High Resolution Instrument, Cassini Visual and Infrared Mapping Spectrometer (VIMS), and the Moon Mineralogy Mapper (M3) [1][2][3]. This band signifies the presence of OH and possibly H_2O (collectively referred to as hydration), which is supported by the discovery of hydroxyl with solar wind hydrogen in lunar agglutinate glasses [4] and the detection of an H_2O specific 6 um band [5]. Investigations of lunar hydration have important implications for understanding the conditions of the lunar surface environment as well as understanding volatiles on airless bodies throughout the Solar System. The Chang'e 5 sample return mission has returned the first lunar samples since the 1970s, providing an unprecedented opportunity to investigate the behavior of volatiles with the new perspective gained from the remote sensing discoveries.

Data in the 3 μm region is complicated by the presence of both emitted and reflected radiation, and there is debate about how to best correct for thermal emission in M^3 data, which does not contain any wavelengths beyond 3 μm to constrain thermal models for the data. Bandfield et al. [6] found a 3 μm feature across the Moon, but do not see differences with latitude or lunar time of day. On the other hand, Li et al. [7], Wohler et al. [8], and Honniball et al. [9] see strong strong differences with these parameters.

There is coverage of the landing site by M3. However, M^3 data is limited in its wavelength coverage. A strong test of thermal corrections is their quality at longer wavelengths where thermal emission is increasingly dominant. To deal with this thermal modeling problem, this work uses observations that are taken from the Mauna Kea Observatory using the SPeX infrared cross-dispersed spectrograph at the NASA InfraRed Telescope Facility (IRTF). This instrument collects data from 1.67 to 4.2 μm and the spectral range provides advantages over Moon Mineralogy Mapper data on the same region of the Moon. First, the complete 3 μm feature is covered allowing the whole absorption feature to be observed. Second, the spectrum extends out to longer wavelengths where the thermal emission dominates and a thermal model is better constrained.

In this work we obtained data of the Change-5 site under thermal conditions not available in M3 data: a local time of 8:30 am and during local partial eclipse where illumination was only 40% that of the fully illuminated site. These data provide a unique test of various models for the behavior of hydration on the Moon, and provide insight to the analysis of the Chang'e 5 samples.

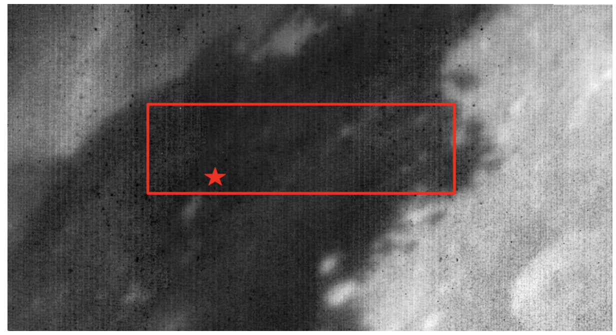

Figure 1: *Context image of Mons Rumker region of Oceanus Procellarum constructed by constructing mosaic of IRTF guider images. The red box is the approximate area sampled by the spectrometer to construct maps. The red star is the Chang'e 5 landing site (43°N, 51.9°W).*

Data: Observations of the area around and including the Chang'e 5 landing site (Figure 1) were obtained on November 30th, 2020 between 07:08 UT (full illumination) and 09:27 UT (Deepest Partial Eclipse) shortly before the landing of the spacecraft.

Methods: SPeX is a slit spectrograph, similar to M3. Maps of the landing site were created by scanning the spectrometer slit over the region as the detector array is read out. After the collection of each map, data were taken on the sky near by the moon and a standard star was observed at an airmass similar to the Moon observations. Spectra were obtained from the image data using the SPEXTOOL software [10].

A solar-type star at an airmass similar to the Moon is observed and used to correct for atmospheric transmission as well as instrument response. These data relative to a solar type spectrum are then converted to radiance assuming a surface reflectance at non-thermal wavelengths, a solar flux model, and a photometric model.

The spectral effects of thermal emission from Solar System objects are not present in the spectrum of a solar type star, and the thermal emission is manifest in Moon/Star ratios by sharply rising flux toward the infrared depending on the lunar surface temperature. This thermal excess is fit at the longer wavelengths and when fitting the data with the thermal model surface roughness

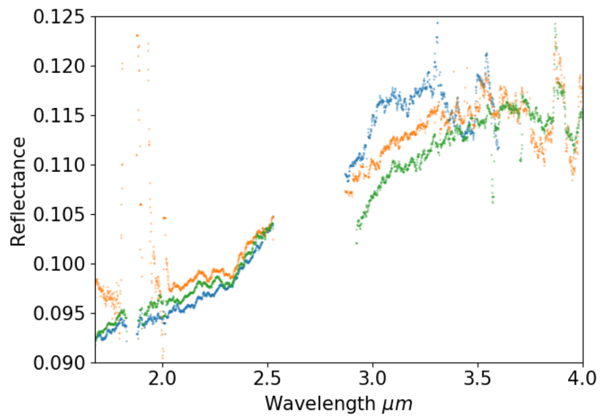

Figure 2: *Reflectance spectra at Chang'e 5 landing site at 100% illumination (blue), 60% illumination (orange), and 45% illumination (green). The 100% illumination data is cut off after 3.5μm due to detector saturation at longer wavelengths. Reflectance at 3 μm is systematically lower at decreased illumination, leading to an estimation of greater hydration.*

effects are taken into account [6]. The thermal emission was removed following the methods of Honniball et al. 2020 [9].

Results and Discussion: Under full illumination conditions, the Chang'e 5 site does not appear to have a 3 μm absorption band, which would indicate no hydration. However, the reflectance at 3 μm systematically decreases as the illumination decreases (Figure 2). The difference between the full illumination and 60% illumination cases may be explained by saturation affecting the 3 μm region in the full illumination data set. In contrast, the difference between the 60% illumination and 45% illumination is consistent with the appearance of a hydration band.

The presence of a hydration band is supported by ratioing the 45% illumination spectrum to 60% illumination. The ratio spectrum shows a distinct drop near 3 μm and is consistent with the shape of a hydration band, recovering towards the value of the flat ratio that is present in the reflectance dominated section of the spectrum between 2-2.5 μm (Figure 3). Interestingly, the ratio band depth is about 2% which is a level we would have expected to also be detectable in the 60% illumination case if it were present. This could indicate two different things. First, the hydration band in the 45% illumination case was finally revealed because the temperatures were low enough. Second, there could be changes in hydration occurring during the eclipse that caused a hydration band to develop as the eclipse progressed.

There are two processes hypothesized for the variation in hydration band on the illuminated Moon with temperature: 1) that it reflects migrating water along temperature gradients [2] or, 2) that it is due to the temperature dependent formation of metastable hydroxyl [11], [12]. Each has challenges to explain these observations. Migrating water requires that ballistic migration keeps up with the rapid passage of the Earth's shadow across the lunar surface, and there is enough water in the exosphere to adsorb to the cool surface. This requires modeling, but may be inconsistent with the upper limits to exosphere background water established by LADEE [13]. It is possible that the lower temperatures during eclipse could allow metastable hydroxyl formed by hydrogen diffusing out of the surface to be more stable. However, solar wind hydrogen is thought to fully diffuse from the surface on time scales of hours and at the time of the measurement the Moon had been in the Earth's magnetotail for a few days, shut off from hydrogen supply. This may indicate that the diffusion of hydrogen from the lunar surface occurs on longer timescales than previously thought.

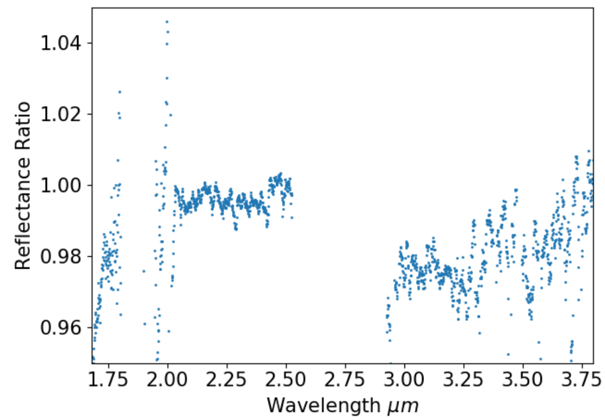

Figure 3: *Ratio of 45% illumination spectrum to 60% illumination spectrum at Chang'e 5 landing site. Normalized to 1 at 2.5 μm to illustrate the band depth at 3 μm. The drop at 3 μm indicates the presence of a deeper band and therefore more hydration in the 45% illumination case.*

References

[1] Clark R. N. *Science*, 326:562–565, 2009.
[2] Sunshine J.M. et al. *Science*, 326:565–568, 2009.
[3] Pieters C. M. et al. *Science*, 326:568–572, 2009.
[4] Y. Liu et al. *Nature Geoscience*, 11:779, 2012.
[5] Honniball et al. *Nat Astron*, 2020.
[6] J. L. Bandfield et al. *Icarus*, 248:257–372, 2015.
[7] S. Li et al. *Sci.Adv. 3:e1701471*, 2017.
[8] C. Wohler et al. *Sci. Adv. 3:e1701286*.
[9] Honniball et al. *JGR Planets*, 2020.
[10] D. W. Rayner et al. *PASP*, 115:362, 2003.
[11] Ferrell et al. *JGR Planets*, 2017.
[12] Tucker et al. *JGR Planets*, 2019.
[13] Benna et al. *Nat. Geoscience*, 2019.