TELESCOPIC HYDRATION OBSERVATIONS OF CHANG'E 5 LANDING SITE 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 H2O (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 H2O 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 data from 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, allowing for an accurate thermal correction based off of the data.

In this work we obtained data of the Change-5 site

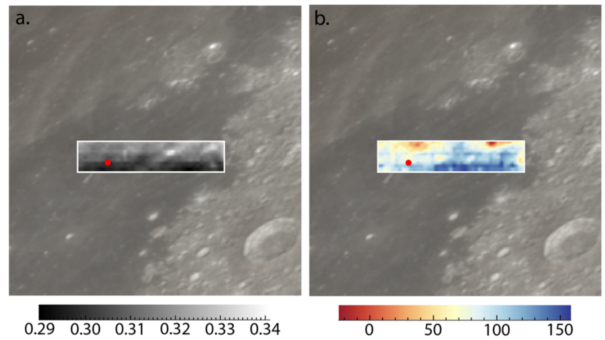

Figure 1: *a. White box contains measured reflectance at 1.7 μm overlain on a context image of the site. b. White box contains total water ($OH + H_2O$ ppm). Red points in both over Chang'e 5 landing site.*

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.

Data: Spectra were collected using the SPeX infrared cross-dispersed spectrograph at the NASA InfraRed Telescope Facility. This instrument collects data from 1.67 to 4.2 um with a spatial resolution of 2 km on the Moon. Observations of the area around and including the Chang'e 5 landing site (Figure 1) were obtained on November 30th, 2020 at 07:08 UT (full illumination) and 09:27 UT (Partial Eclipse) shortly before the landing of the spacecraft. Data were also collected shortly after the departure of the sample return capsule to search for evidence of hydration by the spacecraft operations and will be presented at the meeting.

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.

First, the data must be corrected for effects due to the telescope and the atmosphere. To remove effects of atmospheric emission a sky spectrum is taken near by the target and then subtracted from the data. Then, 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

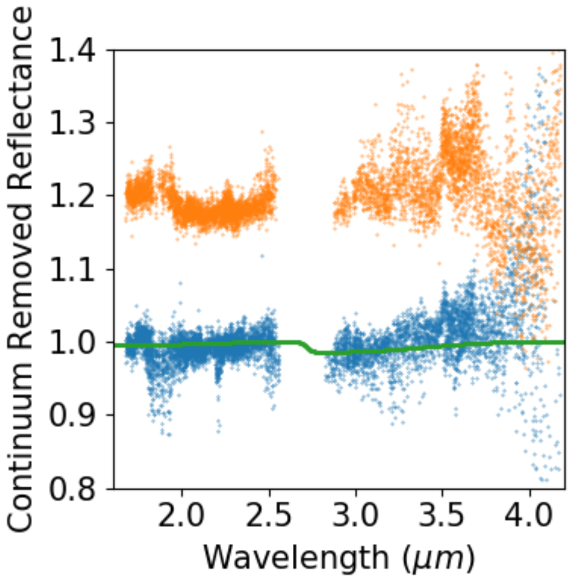

Figure 2: *Top: Continuum removed reflectance spectrum from full illumination conditions before eclipse (orange). Bottom: Conntinuum removed reflectance spectrum from partial (40%) illumination conditions during eclipse (blue) overplotted with MORB glass with 1046 ppm water, scaled down by a factor of 0.02 to match the observed spectrum (green).*

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 effects are taken into account [6]. The thermal emission was removed following the methods of Honniball et al. 2020 [9] and a new correction that fully accounts for the emissivity variations due to Kirchhoff's law [10].

Results: Measurements taken in full illumination before the beginning of the eclipse were corrected using both by Honniball et al. [9] methods and by solving for reflectance using Kirchhoff's law [10]. The Honniball corrected spectrum (Figure 2) shows no evidence of a hydration band, however, this method does not fully account for possible thermal infill due to enhanced emissivity near 3um (neglects Kirchhoff's Law). The Kirchhoff method assumes Kirchhoff's Law applies; the spectrum reduced using that model also shows no evidence of a hydration band.

The measurements taken during partial eclipse at the Chang'e 5 landing site closest to the maximum eclipse (40% of the illumination relative to full illumination) were converted to reflectance using Kirchhoff's law and show an evident hydration band (Figure 2). This band was converted to total water abundance using the methods of Honniball et al. [9], giving between 50 and 200 ppm total water for the region (Figure 1).

Discussion: The agreement between the two thermal correction methods for the full illumination spectrum indicate that there is no hydration band. This is consistent with predictions for this latitude and time of day from Li et al. [7] and Honniball et al. [9]. This is also most likely the condition that the Chang'e 5 spacecraft experienced during its sample collection.

Given the lack of a band in the full illumination data, the presence of a hydration band in the eclipse data set is unexpected. If there is bound hydration in the surface, it should be evident in the full illumination data as well. The two prevailing hypotheses for the variation in hydration band on the illuminated Moon with temperature are: 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.

The analysis of the Chang'e 5 samples will be an excellent opportunity to investigate the complexity of lunar hydration. This work provides context to inform the analysis of hydration in the Change'e 5 samples.

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