

Mapping of lunar volatiles with Moon Mineralogy Mapper spectra: A challenge due to thermal emission

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Abstract

Removal of the thermal emission contribution to lunar surface reflectance spectra measurements by the Moon Mineralogy Mapper is critical for characterizing the surface composition. We use a surface roughness-based thermal emission model in order to correct M^3 spectra and to monitor time of day variations of the 3- μm absorption band.

1. Introduction

Spectral signatures of hydroxyl and perhaps water molecules have been observed at 2.8 and 3 μm by the Moon Mineralogy Mapper (M^3) onboard the Chandrayaan-1 spacecraft [1-3], and confirmed by the EPOXI mission [4] and Cassini Visual and Infrared Mapping Spectrometer (VIMS) [5]. If those volatiles are endogenic, their identification would imply a role in lunar interior geological processes. If OH and H_2O result of surficial processes, they are likely related to the space environment and surface properties of the Moon, possibly by interaction of solar wind particles with minerals of the lunar soil [2]. The main objectives in our study are 1) the interpretation of the OH-bearing composition, which is based on the position of the bands, 2) quantifying the components, which is partly related to the depth of the bands, 3) monitoring temporal variations of the volatile distribution, which is a way to determine if the volatiles are endogenic or at the uppermost surface, and 4) determining the association of various types of volatiles to different mineralogical compositions, which may provide insights on geological processes or how the minerals interact with solar wind particles.

2. Spectral thermal removal

Measurements of the position, strength and shape of the absorption bands have significant uncertainties [2]. Thermal emission contributes significantly to the lunar radiance in the 3- μm region above 250 K [6, 7]: It fills and distorts the absorption bands of volatiles (Fig. 1), and it is correlated to illumination (latitude, local slope, surface roughness and time of day), surface albedo and composition [2, 8].

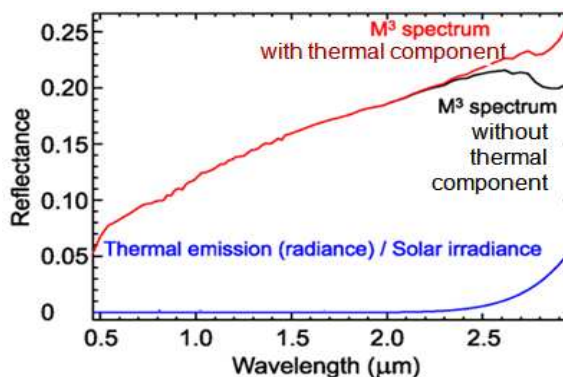


Figure 1. Example of an M^3 spectrum of a volatile-rich area acquired while the surface temperature was about 350 K. The 3- μm absorption band is mostly filled by the thermal emission. Adapted from McCord et al. [2]

The accuracy of thermal removal based on reflectance spectra [6, 7, 8] is degraded by the broad 2- μm band of pyroxenes and the presence of the 3- μm band of volatiles. Photometric properties of the lunar soils have also significant spectral effects. Improvement of the thermal correction can only be achieved using independent measurements or modeling.

We have used the brightness temperature at 8 μm measured by the Diviner Lunar Radiometer Experiment [9] on Lunar Reconnaissance Orbiter (LRO), where data are available at the same lunar local time of day than M^3 observations. However, 8- μm brightness temperatures measured by Diviner are generally lower than brightness temperatures at 3 μm . The reason is that a given area on the Moon has a distribution of temperatures and not a single one because it is rough. Because Diviner measures longer wavelength radiation than M^3 , it is more sensitive to the low-temperature components of the surface, which produces a different brightness temperature and leads also to an incomplete thermal emission removal [8].

We now use M^3 reflectance spectra with thermal emission correction based on a rough-surface thermal emission model [10]. The mean slope (theta-bar parameter [11]) estimated from Diviner is 25 degrees over the whole Moon. From the surface roughness model, shades and shadows are calculated as function of local incidence angle and solar azimuth. Then, a histogram of the solar incidence angles is calculated. For each bin of the histogram, the temperature is calculated assuming thermal equilibrium of the surface because the thermal inertia is low. A Planck function is associated to each temperature, assuming a black body emission. Then, all the black body curves are averaged as function of the area-weight given by the histogram. Models of thermal emission depend only on albedo, incidence angle and wavelength. The thermal emission model has been validated against brightness temperatures derived from Diviner.

Mapping of surface volatiles

Relative absorption bands at 2.8 and 3 μm are calculated as described in McCord et al. [2]. The color composite of the near side shown in Fig. 2 is from M^3 data acquired under similar conditions of illumination (morning). It reveals that the 3- μm band is mostly anti-correlated with mare basalts (blue, cyan and magenta), and it shows some loose correlation as function of latitude (deeper band towards the poles). The dependence with latitude has to be interpreted carefully because the presence of mare basalt mostly at low latitude introduces a bias. The 2.8- μm band depth (green, cyan and orange) does not seem to be correlated to composition. However it appears to vary as a function of the

surface state: The 2.8- μm band is weaker on fresh craters and ejecta. It is also correlated with latitude more clearly than the 3- μm band, similar to what was reported in McCord et al. [2]. The influence of the surface state needs to be studied in more details, as the thermal emission model is based on assumptions of the surface roughness. In particular, values of surface mean slopes vary within 4 to 5 degrees between mare basalts and highlands.

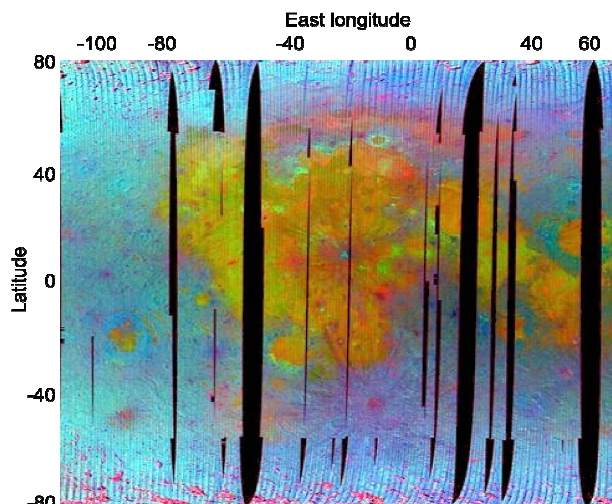


Figure 2: Color-composite map of volatiles on the near side of the Moon using M^3 spectra. Red: 1- μm integrated band depth. Green: 2.8- μm relative band depth. Blue: 3- μm relative band depth.

Possible variation of the surface content in volatiles with lunar local time of day will be investigated as well, which is one way to determine their origin.

References

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