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Chang'E rover spectra revealing multiple micro-scale properties of the Moon

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Abstract

Here we show the in situ reflectance spectra of the Moon acquired on the lunar surface by the Visible-Near Infrared Spectrometer (VNIS) onboard the Chang'E-3/4 (CE-3/4) rover. The VNIS detected thermal radiation from the lunar regolith, though with much shorter wavelength range than typical thermal radiometer. The in situ reflectance spectra reveal the thermal, absolute reflectance, compositional, and space-weathering properties of the Moon at micro-scale. It also provides a means for the calibration of optical instruments that view the surface remotely. The two landing sites (CE-3, CE-4) were suggested as new calibration sites of the Moon.

1. Introduction

The Moon's reflectance spectrum records many of its properties. A measurement with a calibration panel on the surface of the Moon is crucial for obtaining the accurate absolute reflectance and acquiring various information at micro-scale. Here we report the scientific results acquired using the in situ reflectance spectra measured with the VNIS onboard the CE-3/4 rover. Refer to [1-4] for details of the instrument, data processing and scientific outputs.

2. Instrument and data

The VNIS consists of a VNIR imaging spectrometer (0.45-0.95 μm) and a SWIR spectrometer (0.9-2.4 μm). The spectral sampling interval is 5 nm. The VNIS measures from a height of 0.69 m above the lunar surface at a 45° emission angle.

3. In situ absolute reflectance

The VNIS measurements were at large emission and phase angles, which complements existing photometric geometry and for a large range of wavelength. The in situ reflectance shown in Figure 1 reveals that 1) at large phase angles the lunar soil has more forward scattering than indicated by current models; 2) the M^3 and Chang'E-1 IIM data are smaller than LROC WAC and Kaguya SP, and the VNIS data fall between these two pairs.

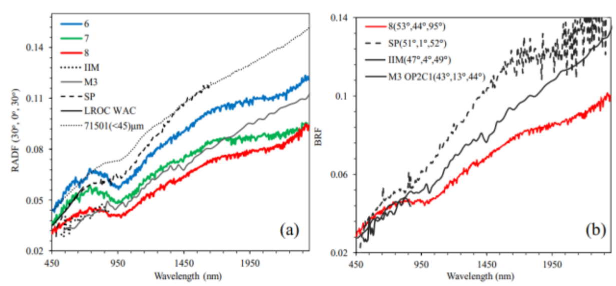

Figure 1: (a) Comparison of RADF from VNIS with Apollo sample and IIM, LROC WAC, SP and M^3. (b) Comparison of the BRF [1].

4. Thermal characteristics

The VNIS detected thermal radiation from the lunar regolith, though with much shorter wavelength range than typical thermal radiometer. This can be validated from the spectral upturn at long wavelength and local time for both CE-3 and CE-4 (e.g., Fig. 1).

Table 1 shows the micro-scale temperature derived from in situ spectra. The retrieved temperature is close to or higher than that of a smooth surface. The measured temperatures are higher than expected from theoretical model indicating the effects of grain facet on soil temperature in submillimeter scale. At local time 9:29 the thermal emission contribution can be >1% at 2.25 μm and as high as 22.18% at 3 μm.

Table 1: Temperatures and ε (in the brackets) measured by the VNIS, Diviner and modelled [1].

	VNIS	Modeled	Diviner
5	332.09 (0.85)	330.6 (0.95)	323.45

8	353.16 (0.90)	343.7 (0.95)	335.95

5. In situ Space weathering

The optical effects of the Moon’s space weathering have been largely investigated in the laboratory for lunar samples [5], simulants [6] and physical modelling [7]. The in situ spectra provide the unique opportunity of investigating space weathering by measuring the regolith in its undisturbed state, as well as comparison to the regolith naturally disturbed by rocket exhaust from the spacecraft. The VNIS reveal that brightness increases after the spacecraft landed are due to removal of the finest, highly weathered particles by the lander's rocket exhaust, not smoothing of the surface. Figure 2 shows the enhanced space weathering model of the lunar surface based on CE-3 observations [4]:

1) the uppermost surficial regolith is much more weathered than the regolith immediately below, and

2) the finest fraction is much more mature than the coarser fraction.

The effects on the spectral slope caused by space weathering are wavelength-dependent: the visible and near-infrared continuum slope (VNCS) increases while the visible slope (VS) decreases. In the visible wavelengths, the optical effects of space weathering and TiO_2 are identical: both reduce albedo and blue the spectra.

6. Summary and Conclusions

The CE-3/4 in situ spectra revealed 1) thermal radiation from the lunar regolith, though with much shorter wavelength range than typical thermal radiometer; 2) the absolute reflectance measured with a calibration panel, and CE-3/4 landing sites can be calibration site; 3) The effects on the spectral slope caused by space weathering are wavelength-dependent: the VNCS increases while the VS decreases.; 4) the returned soils could not represent pristine regolith, which is much weathered; 5) developing a new TiO_2 abundance algorithm and OMAT is needed. We propose specific sampling technologies such as electrostatically manipulating fine dust to sample the uppermost dust in the future missions.!

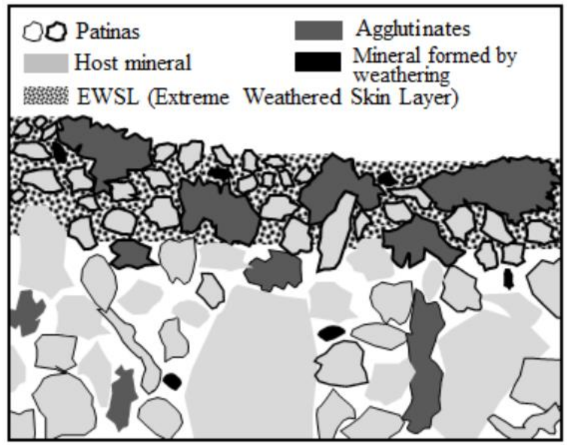

Figure 2: Model for space weathering on the real lunar surface [4].

Acknowledgements

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