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Radiative transfer modeling of combined SIR-1 and Clementine UVVIS/NIR spectra

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Abstract

The mafic absorptions in the near-infrared offer the possibility to determine the mineral composition of the lunar regolith. Due to the great potential many of the current and past satellite missions to the Moon carry instruments for investigating that wavelength range. The SIR-1 spectrometer, on board the SMART-1 mission, measured point spectra between 0.9 and 2.4 micrometers along its orbit track of approximately 18% of the Moon. This point spectra together with the Clementine UVVIS/NIR filter measurements for the filters at 0.75, 0.9, 0.95, 1.0, 1.1, 1.25, 1.5 and 2.0 micrometers (UVVIS/NIR basemap mosaics [1,2]) serve as input for the developed regolith reflectance model, which is based on the Bidirectional reflectance theory of Bruce Hapke [1], an approximate solution of the radiative transfer equation for particulate media. The complexity of the lunar surface regolith which is characterized in the model by twelve free parameters, seven for the diversity of minerals and another five to account for the products of space weathering and the physical properties of the lunar surface can result in non-unique solutions. The ambiguity increases with the increasing degree of space weathering of the observed surface. Due to absorptions of nanometer-sized iron particles, there is a decrease in visibility of mineral absorption bands. Hence we concentrate on immature spectra which we select by an automated routine from the SIR-1 data set. This spectra offer a set of test spots where relatively young craters uncovered less weathered immature material of local mineral composition.

Data preparation

To combine the two data sets of SIR-1 point spectra and Clementine UVVIS/NIR images, image pixels within each SIR-1 footprint are extracted. These pixels are averaged and result in photometric values corresponding to the SIR-1 measurements at wavelengths of Clementine UVVIS/NIR filters. Filters between 0.9 and 2.0 micrometers are used to derive an absolute calibration for SIR-1 and connect SIR-1 spectra to the Clementine UVVIS/NIR calibration spectrum of soil sample 62231 from Apollo 16. At shorter wavelength the Clementine UVVIS filters at 0.75, 0.9 and 0.95 micrometers are used to extend the modeled wavelength range. SIR-1 measured the lunar infrared reflectance between 0.9 and 2.4 micrometers with a spectral sampling of 6 nm. By adding UVVIS filter measurements we gain additional information at the short wavelength side of the 1 micrometer mafic absorption. Due to the gaps between these three UVVIS filters the constraints on the regolith reflectance model below 0.9 micrometer are much weaker, than between 0.9 and 2.4 micrometers where the high resolution spectra of SIR-1 are employed.

Selection of spectra

A major difficulty for interpretation of lunar reflectance spectra in the near-infrared is the obliterating effect of space weathering which leads to a strong red slope and subdued absorption features in spectra of mature lunar soils. Hence we concentrate on spectra of immature surface areas, where generally comparatively young craters excavated less mature material or step slopes prevented strong space weathering due to gravitational slumpings. On average, the thickness of the mature surface regolith reaches 5 meters in the mare and 10 to 15 meters in the older highlands [2]. The size of a SIR-1 footprint is, on average, 1 kilometer, depending on the spacecraft height. On the Moon craters of that size (1 km) already have a depth of approximately 200 meters, and excavated well below the surface regolith. By employing spectra from footprints covering immature craters we analyse materials less altered by space weathering. How can we identify immature materials? For modeling we predominantly concentrate on regoliths rich in mafic minerals that manifest themselves through strong absorptions around 1 and 2 micrometers. These absorptions are even more striking in relative spectra, which are used for selection. Due to a weakening of absorption bands with surface exposure time, mainly immature surface areas are selected,

[1] http://pds-imaging.jpl.nasa.gov/Admin/resources/cd_clementine.html#clmUVVIS
[2] ftp://pdsimage2.wr.usgs.gov/cdroms/clementine/Clem_NIR_V0.1

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especially in the more mafic regions of the nearside mare, of crypromare and South Pole Aitken basin. This selected spectra are used for modeling with the regolith reflectance model.

Regolith reflectance model

Due to absolute calibration of SIR-1 point spectra with Clementine UVVIS/NIR images, the SIR-1 measurments become radiance coefficient measurements (i.e. reflectance relative to a Lambert surface identically illuminated).

$$r_c = K\frac{w}{4}\frac{1}{\mu_0+\mu}([1+B(g)]P(g)+H(\mu_0)H(\mu)-1)$$

Here the radiance coefficient equation (equ.37,[1]) is extended to also include porosity [4]. Model spectra are calculated from the radiance coefficient equation by allowing the twelve free parameters to vary and define the best set of parameters for a certain spectrum from Levenberg-Marquardt's least-squares fitting. Twelve parameters are used to describe the complexity of the lunar regolith.

Seven parameters account for the variation of the mineral content of the regolith: the fraction of plagioclase (anorthite), of olivine (80% fosterite), of ilmenite and of four pyroxenes. The variation between different pyroxenes is accounted for by following Taylor et al.[3], employing augite, pigeonite, orthopyroxene and Fe-clinopyroxene as endmembers of the pyroxene variation within the pyroxene quadrilateral. Agglutinates, a product of space weathering, are represented by an agglutinate seperate from a Luna 20 soil. The degree of space weathering is parameterized following Hapke 2001 [5] through the volume fraction of iron. Physical properties of the regolith are described by the porosity, through the porosity parameter K [4] and by the grain size. The angular scattering pattern is accounted for by the single particle phase function at standard geometry of incident angle 30 degrees, emergence angle zero degrees and phase angle 30 degrees. All spectra are transformed to this standard observing geometry.

For selected spectra of SIR-1, model results of combined data from SIR-1 and Clementine UVVIS/NIR will be shown. An example for a modeled spectrum is displayed in Figure 1. This spectra is observed at Eimmart A, a young crater excavating immature material within Mare Angius north of Mare Crisium.

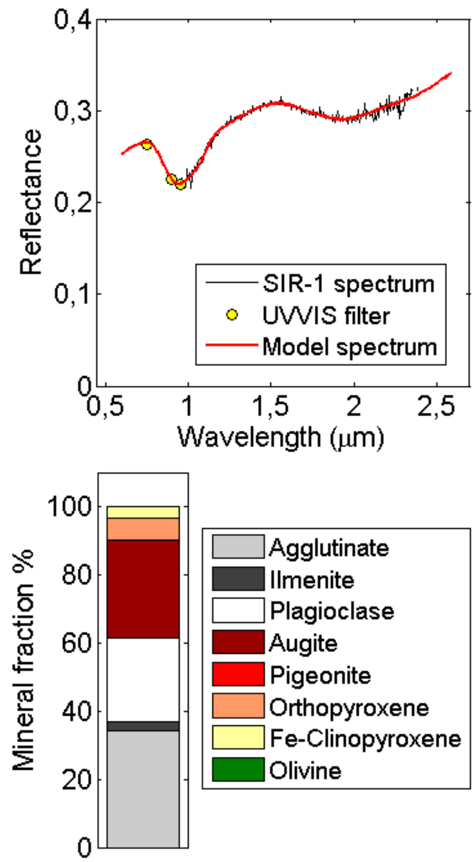

Figure 1: Example for a spectral fit: Reflectance spectrum of a footprint observed within the crater cavity of Eimmart A north of Mare Crisium. **Upper panel:** SIR-1 measurement together with UVVIS filter measurements (0.75, 0.9, 0.95 micrometers) and the least-square fit. **Lower panel:** Bar diagram of the resulting mineral fractions.

References

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[5] Hapke, B. (2001), *JGR*, 106, 10039-10074.