

TOWARDS A QUANTITATIVE DETERMINATION OF THE MODAL MINERALOGY OF PLANETARY SURFACES USING NEAR-INFRARED SPECTROSCOPIC DATA FROM THE MOON.
 U. Mall¹, V. Korokhin², R. Bugiolacchi¹, Y. Shkuratov², ¹Max Planck Institute for Solar System Research, Max-Planck-Straße 2, 37191 Katlenburg-Lindau, Germany, mall@mps.mpg.de, ²Astronomical Institute of Kharkov V.N. Karazin National University, Sumskaia 35, Kharkov 61022, Ukraine.

Introduction: The investigation of the surface composition of astronomical objects ranging from the Moon to Trans-Neptunian Objects (TNOs) provides essential information on the conditions in the early solar system over a wide range of distances from the Sun. The Moon, asteroids and transneptunian belts are often considered as the “archeological sites” for the early Solar System history. Far-reaching conclusions on the evolution of the early solar nebula can be reached based on the inferred information from photometric measurements. The most detailed information on the composition of TNOs can be acquired only from spectroscopic observations. The wavelength range between 0.4 and 2.5 μm provides the most sensitive technique available from the ground to characterize the major mineral phases and ices present on TNOs. The necessary deconvolution process which has to be applied to a reflectance spectrum to arrive at a modal mineralogical abundance estimate - represents an extremely challenging task since the observed spectra are the result of complex processes which are modeled by nonlinear functions of several parameters. The abundance, grain size and opacity of the target materials are important factors in determining the shape of the reflectance spectra. Multiple scattering theories using optical constants of minerals can provide approximate solutions to the radiative transfer in compact media. Although it impossible to confront the derivations reached from the deconvolution algorithms which are applied to the spectra of the outer solar system bodies with in-situ measurements, real Moon samples have been investigated in great detail in the laboratory using the same observational techniques as flown on the lunar missions. Even though there is no shortage of VIS-NIR spectra of in-situ observed lunar surfaces areas, only the very recent lunar missions have returned data which are in quality comparable to spectra measured under laboratory conditions.

The modal mineralogy of many observed objects in the solar system has been obtained by modeling NIR reflectance spectra with various radiative transfer models. For example, the modeling of VIS-NIR laboratory spectra has been demonstrated to provide an accurate estimate of mineral abundances for basaltic mixtures of granular materials of a wide range of particle sizes [1].

Method of analysis: We investigate in our work data returned from the SIR-2 spectrometer flown on the Indian Chandrayaan-1 Indian Moon launched in

2008 with the Shkuratov spectral model. The Shkuratov et al. model [3] is a model based on a geometrical-optics approximation to describe the spectral behavior of the albedo of regolith-like surfaces. In addition, for taking into account the effects of space weathering, the following empirical formula is added to the model: $f_R(\lambda) = 1 + a_1 \cdot (\lambda - \lambda_0) + a_2 \cdot (\lambda - \lambda_0)^4$, where λ denotes the wavelength, a_1 and a_2 are free parameters and $\lambda_0 = 2.3 \mu\text{m}$ is the wavelength when the influence of reddening is absent. In order to simulate a measured bidirectional reflectance spectra of a lunar soil from individual known mineral components, a set of measured bidirectional reflectance spectra of the principal lunar soil components must be known which accurately describes the lunar soil composition. In the past, most investigators used different sets of basic mineral components. Due to the effects of space weathering and grain size distribution of the involved components, spectra of the same minerals may look very different in each set. The RELAB database holds dissimilar spectra of the same samples measured by the same spectrograph and the same author. Our approach starts with compositionally and morphologically mixtures of known mineral components whose spectra are accurately measured in the laboratory. Various iterations of fitting those sets with the Shkuratov spectral mixing model has led to the derivation of a set of seven mineral components which allows fitting a wide range of lunar samples with good precision.

Comp.	RELAB ID	RELAB spectrum
AGG	LU-CMP-007-3	C3LU07
GLS	LS-CMP-035-A	CALS35
OPX	PE-CMP-041	C1PE41
CPX	LS-CMP-009	C2LS09
ILM	JB-JLB-308	CJB308
	LRMCC ID	LRMCC spectrum
OLV	15555	LRCMP212_15555_ Olivine_Fine_BDR
PLG	70017	LRCMP217_70017_ Plagioclase_Fine_BDR

Table 1. Reduced set of laboratory spectra used for fitting

We have used in our work lunar soil samples from RELAB [4], LSCC [5,6] and from LRMCC [7].

To construct a data set which is capable of reproducing the observed remotely sensed lunar spectra we have chosen a minimal set of seven mineral components:

agglutinates (AGG), orthopyroxene (OPX), clinopyroxene (CPX), olivine (OLV), ilmenite (ILM), plagioclase, (PLG) and glasses (GLS) (Table 1). This dataset has been selected by applying our spectral mixing model to four samples of the lunar soils LSCC [5,6]: (1) mare immature soil 12030; (2) mare mature soil 15071; (3) highland high-Ti soil 14141; (4) highland low-Ti soil 61221. From a total of seven different datasets, the chosen set minimizes the deviation between the calculated spectra and the experimentally measured data (Fig. 1). It provides the best estimate of the relative concentrations of the principal mineral components of the measured values.

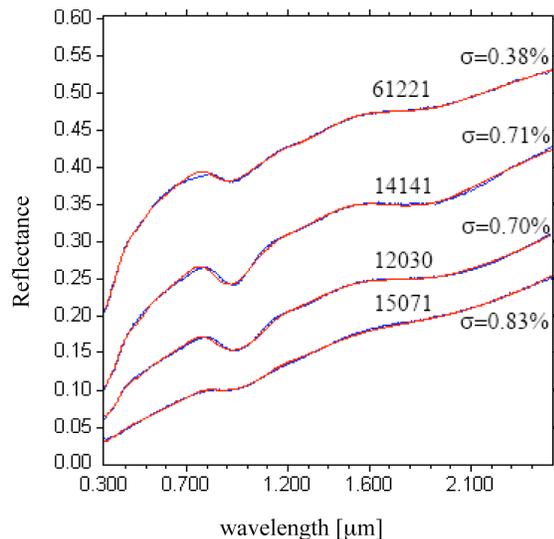


Figure 1. Result of the best fit for LSCC samples. Blue – laboratory spectrum. Red – calculated spectrum.

In order to test the applicability of our approach to real in situ observations we used data collected by the SIR-2 spectrometer flown on Chandrayaan-1.

The instrument and dataset. The SIR-2 instrument [2] is a lightweight, modular, grating-based, high-resolution point spectrometer operating in the spectral range 0.9–2.4 μm , with spectral resolution of ~ 6 nm (256 bands). The excellent quality of the data is directly related to the thermal stability of 1/10 of a degree under which the data were taken.

After having identified the best data set to fit the experimentally measured laboratory spectra we have used the same set to fit the spectra of 500 randomly chosen spectra acquired by the SIR-2 spectrometer. Figure 2 shows examples of three SIR-2 spectra together with their corresponding fits. The fitting procedure delivers directly the precise relative mineral abundances of the observed lunar surface area.

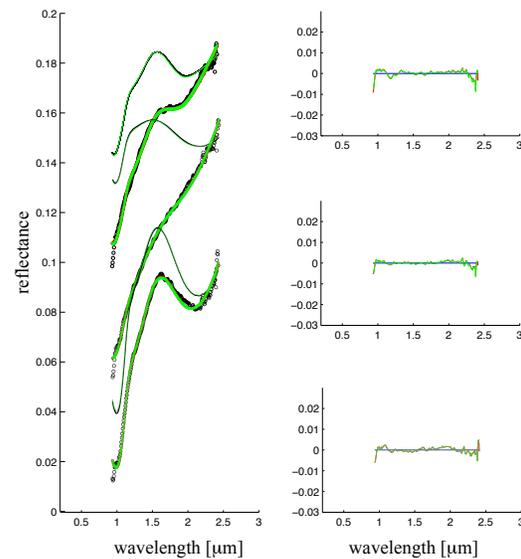


Figure 2. Three SIR-2 spectra together with their related fits (left panel) and residua of the corresponding fits (right panel). The two lower spectra in the left panel are arbitrarily shifted relative to the top one to increase their visibility.

While over 50,000 SIR-2 spectra are being processed to benchmark the quality of our data set we are going to confront this quantitative method with the the recently described Comparative Normalization Analysis method introduced by [8].

Conclusions: We have identified and selected from laboratory measured samples (1) an optimal set of seven mineral components for reliably describing the lunar soils composition. (2) Tests with LSCC data show that our model describes the various types of lunar spectra accurately and gives reasonable estimate concentrations of mineral components. (3) A random sample of 500 spectra covering all photometric conditions recorded by the SIR-2 spectrometer has been analyzed and produced good fitted spectra.

References:

- [1] Poulet, F. and Erard, S., (2004) *JGR*, Vol. 109, E2, CiteID E02009.
- [2] Mall U. et al. (2009) *Current Sci.* 96, No 4.
- [3] Shkuratov et al. (1999) *Icarus* 137, 235-246.
- [4] <http://web.utk.edu/~pgi/data.html>.
- [5] <http://www.planetary.brown.edu/pds/LSCCsoil.htm>
- [6] <http://web.utk.edu/~pgi/data.html>
- [7] <http://www.planetary.brown.edu/LRMCC/>
- [8] Bugiolacchi et al. (2011) *Icarus* 213, 43-63.