EPSC Abstracts
Vol. 10, EPSC2015-425, 2015
European Planetary Science Congress 2015

Wavelength dependence of spectro-photometric properties and link with the microtexture

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Abstract

The surface scattered sunlight carries major information about the composition and microtexture of surface materials, thus enabling tracing back the geological and climatic processes that occurred on the planetary body. Here we perform laboratory spectro-goniometric measurements of different kinds of granular samples over the VIS-NIR spectral range, coupling the spectral and geometric dimensions to analyze their scattering behavior. To quantify the evolution of the scattering properties with the wavelength, we use an innovative inversion procedure based on a Bayesian approach to estimate photometric parameters from the Hapke model. The granular samples are also characterized by optical and SEM techniques in order to link these scattering variations with the grains' physical properties.

1. Introduction

As solar light penetrates into a surface, it is partially reflected back by interaction with its constituents and structures. The reflected signal exhibits variations with both the wavelength and the illumination/viewing geometry. In particular the spectral dimension (spectroscopy) of this signal gives constraints on the surface material composition through absorptions bands, whereas the geometric dimension (photometry) can be used to infer the surface material physical properties (e.g. grain size, shape, roughness, internal structure). Determining the grain microtexture is crucial and can be used as a tracer for identifying and characterizing the geological processes responsible for their formation and their evolution.

Numerous spaceborne and in situ missions have shown that the surfaces of planetary bodies in the Solar System exhibit some photometric variability, suggesting a diversity of material microtextures (e.g. [1,2]). To interpret these datasets, models have been developed to better understand how the grains' physical properties affect light scattering. Laboratory experiments have also been conducted on various samples (e.g. [3,4]) generally at one or a couple of wavelengths in the visible and/or very near-IR, similar to spaceborne acquisitions. Usually those datasets have been analyzed by using the Hapke model [5]. These different works have enabled to start some basic characterization of the surface microtexture, though uncertainties remain on how to translate these signal variations into unambiguous surface physical properties. In particular the question remains: to what extent do the different photometric parameters (absorptivity, phase function, macroscopic roughness) evolve over the full VIS-NIR spectral range (0.4-2.5 μm), commonly used in remote observations of planetary surfaces, and what is the link with the grains' microtexture and absorption properties?

2. Methodology

For this study, we analyzed the spectro-photometric properties of five different mineral samples with various chemical and physical properties: a basalt (from Medicine Lake Oregon [6]), an anhydrous basaltic glass (from the Big Island, Hawaii [6]), an olivine (from the San Carlos formation), a nontronite (Fe-rich smectite NG-1, obtained from the Clay Mineral Society) and a magnesite (Mg-carbonate, from Wards mineral supply). These five mineral samples were crushed and then sieved to limit the grain size to the 45-75 microns fraction. The granular samples were first analyzed with a binocular microscope, to characterize the physical properties at large scale and check the grain size distribution. The samples were then analyzed with a scanning electron microscope (SEM) from the Caltech GPS Division Analytical Facility (e.g. Fig.1) to characterize the particles' structure down to the submicron scale. Their spectro-photometric properties were measured with the RELAB facility at Brown University [7] except for the olivine sample for which was used a manual spectro-goniometer setup developed at Caltech. The bidirectional reflectance was acquired at different geometries from 0.4 to 2.5 µm. The incidence angle was set to an intermediate value of 45 degrees and the bidirectionnal reflectance was measured in the principal plane at various emergence angles from -70 to +70 degrees. To quantify the evolution of the photometric behavior, we used the procedure developed by [8]. This methodology uses a Bayesian approach to estimate photometric parameters from the Hapke model. Four photometric parameters are obtained for each wavelength. Two parameters characterize the phase function of the grains (two-lobe Henyey-Greenstein phase function), another the grains single scattering albedo and the last one the macroscopic roughness. The final solution for each parameter is numerically sampled using a Monte Carlo Markov chain.

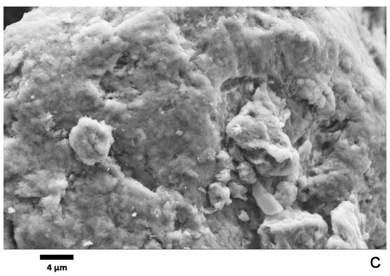

Figure 1: SEM image of the nontronite sample.

3. Results

Results have shown that for the derived photometric parameters, the single scattering albedo as expected, but also the phase function (through the asymmetry parameter b and the backscattering fraction c) and the macroscopic roughness, are wavelength dependent. In particular these can vary significantly over the VIS-NIR spectral range (e.g. Fig.2). The evolution of the photometric parameters with the wavelength appears to be a complex combination of multiple effects related to the grains physical properties (size, shape, roughness, transparency, etc.) and organization. Importantly, these photometric parameters are sensitive to the grains' external and internal structure at various scales from the grain scale down to the sub-micron one.

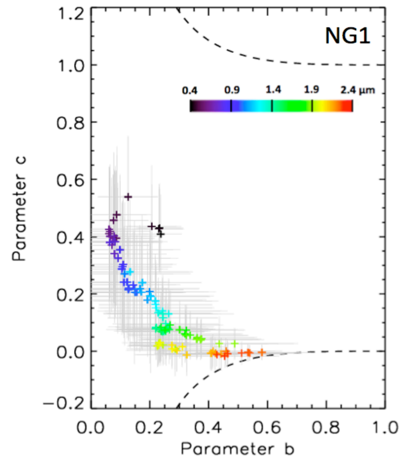

Figure 2: Evolution of nontronite sample phase function (through 2-lobe Henyey-Greenstein phase function parameters b and c) over the VIS-NIR spectral range. Here we represent the mean of the Probability Density Function. Only values of parameters b and c between the dashed upper and lower lines are allowed. Grey bars indicate the standard deviation around the mean of the PDF. Note that the mean is consistent with maximum of the PDF.

Acknowledgements

C.P and B.E acknowledge partial support from NNX14AG54G. C.P also acknowledges support from CNES and J.F support from the European Research Council under the European Union’s Seventh Framework Program (FP7/2007-2013)/ERC Grant Agreement No. 280168. We also acknowledge NASA SSERVI program which supports RELAB operation.

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