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# Hapke modeling of pyroxenes: effects of phase angle, grain size and mixture composition

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## Abstract

Laboratory spectra of four pyroxenes have been investigated applying the Hapke model. The aim of this work is to test the Hapke model on minerals that can be found as analogs of planetary surfaces, focusing on the spectral effects induced by observing geometry, powder grains size and mixing of different end-members. Here we present preliminary results.

## 1. Introduction

Remote sensing represents, in most cases, the most effective method to retrieve informations about mineralogical composition of planetary surfaces. However, to constrain physical properties of the medium we are observing, such as grain size and minerals abundances, a radiative transfer model is needed. A number of models describing spectral and photometric behavior of particulate media have been developed [1, 2], and they are able to give quantitative constrains on the physical properties of the medium and on the scattering mechanisms at work. In this paper we applied the Hapke radiative transfer model to laboratory reflectance measures of four pyroxenes of known composition and grain size. We produced spectra in the 350 - 2500 $nm$ range under different viewing conditions: this enabled us to study both spectral and photometric properties of these minerals. In particular we have studied band depth variations with grain sizes for all the investigated pyroxenes, while for one of them we also studied band depth correlation with phase angle ($g$), the single particle phase function and as a further step we tried to estimate the imaginary part of the refractive index with an approach similar to [3].

## 2. Hapke model

In the framework of the Hapke model the acquired laboratory spectra can be described by the well-known equation of bidirectional reflectance (BDR) for a smooth surface without opposition effect ($g > 20°$) [4]:

$$r(i,e,g) = \frac{K}{\mu+\mu_0}\frac{w}{4}\left[p(g) + H(\mu)H(\mu_0) - 1\right] \quad (1)$$

where $\mu$ and $\mu_0$ are respectively the cosines of the emission and incidence angles, $H(x)$ is the Chandrasekhar function, $K$ is a parameter which describes the porosity of the sample and $p(g)$ is the single particle phase function. In [1] single scattering albedo is calculated from physical properties of the medium such as grain size and imaginary refractive index $m = n + ik$.

## 3. Dataset

The dataset is composed of reflectance measurements of four pyroxenes: an orthopyroxene En88 (E), and three clinopyroxene high in Ca, En48Wo41 (A), En45Wo50 (D) and En33Wo49 (AD). The chemistry of these minerals was determined by Electron Microprobe Analysis (CAMECA SX50, CNR-IGG laboratory, Padova). The bidirectional reflectance spectra were measured with a Fieldspec-Pro spectrophotometer mounted on a goniometer in use at the SLAB (Spectroscopy LABoratory) at IASF-INAF, Rome. The spectra were acquired with 1 nm spectral sampling. The used source was a QTH lamp. The calibration was performed with Spectralon optical standard (registered trademark of Labsphere, Inc.). For the E sample (100-125$\mu m$ grain size) we acquired spectra in the $30° - 100°$ phase angle range. For all the minerals, measurements at fixed viewing geometry ($i = 30°$ $e = 0°$) have been performed for various grain sizes (<63 $\mu m$, 100-125 $\mu m$, 125-250 $\mu m$, 250-500 $\mu m$, 500-800 $\mu m$). As an example, spectra of the E sample are plotted in fig.1, while in fig.2 spectra of the different pyroxenes with a grain size of 125-250 $\mu m$ are reported.

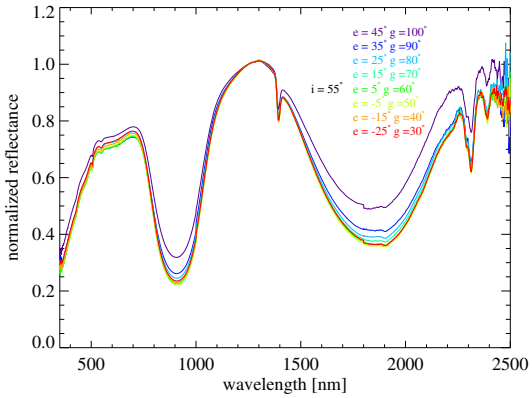


Figure 1: Normalized spectra (@ 1250 $nm$) of E orthopyroxen acquired at various viewing geomtries. Incidence, emission and phase angles are indicated in the plot.

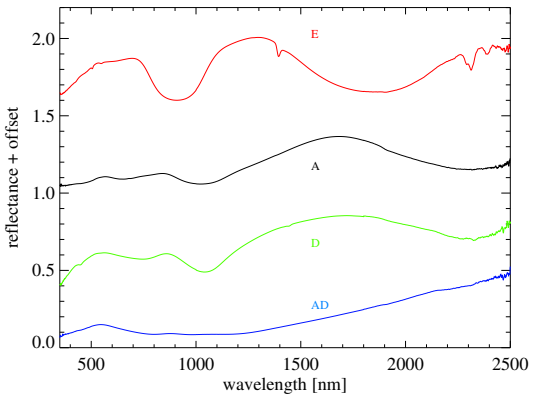


Figure 2: Spectra of, E, A, D and AD acquired at $i = 30°$, $e = 0°$ and $g = 30°$. The grain size is 125-250 $\mu m$ for all the samples. An offset to the reflectance is added for clarity.

## 4. Band depth variations with phase angle

As pointed out in fig.1 spectra of E orthopyroxene acquired at different phase angles show different band depths at ca. 900 $nm$ and 1900 $nm$. This behavior can be addressed to a relative variation of the contributes of single scattering (which is relevant in the band minimum) and multiple scattering (which dominates on the wings of the band) with phase angle. A fit of the phase function of the mineral for all the wavelengths of the spectral range is performed in order to give a description of the single particle phase function which drives the single scattering process and an estimation of $w$ whose value determines the effectiveness of multiple scattering. Results will be shown in the presentation. However, apart from the geometric effects, it must be noted that similar and stronger modifications of the band depth can be produced also by grain size variations and mixing with other compounds: this must be taken into account in the analysis of remote sensing spectra.

## 5. Summary and future work

We investigated spectra of four pyroxenes applying the Hapke radiative transfer model. Spectral variations induced by viewing geometry (for the E orthopyroxene) and grain size distribution have been analyzed. A further step of this study will be the acquisition of spectra at various phase angles for all the other pyroxenes (A, D and AD). This will permit to show similarities or differences in the scattering mechanisms among the minerals. Another application of the Hapke model will concern the derivation of the optical constants of the four pyroxenes [5]. They can be used to compute simulated spectra of mixtures which then can be compared to lab spectra in order to test the capabilities of the Hapke model applied to remote sensing of planetary surfaces with unknown composition.

## Acknowledgements

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