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Light-scattering simulations of space-weathering effects on asteroid and meteorite spectra

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Abstract

We present results of numerical light-scattering modeling for the measured VIS-NIR spectra of olivine. The space-weathering effects with nanophase iron inclusions are experimentally introduced to the olivine matrix, and modeled in the radiative-transfer simulations. A good agreement between the measured and the modeled spectra is found.

1. Space-weathering in laboratory samples

Space weathering introduces changes to the reflectance spectra of asteroid surfaces. In silicate minerals, space weathering is known to darken the spectra, reduce the silicate absorption band depths, and increase the spectral positive slope in visual and near-infrared wavelengths (see, e.g., [1], and references therein).

The space-weathering process is believed to influence the spectra by generating small nanophase iron ($npFe^0$) inclusions in the surface layers of mineral grains (see Fig. 1). The $npFe^0$ inclusions are believed to be one to some tens of nanometers in size. This mechanism has been linked to the Moon and to a certain extent also to the silicate-rich S-complex asteroids and to the ordinary chondrite meteorites.

Kohout et al. [1] have experimentally treated pure olivine powder to simulate the space-weathering effects. They have measured the VIS-NIR spectra of the powder consisting of untreated olivine, and olivine with various degrees of nanophase iron inclusions, see Fig. 1. In this work, we will model the spectral changes with light-scattering computations.

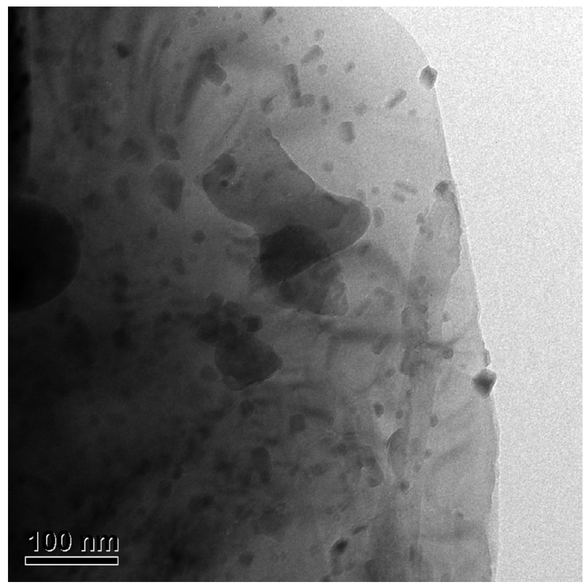

Figure 1: TEM image, originally published in [1], of nanoparticles on olivine powder grains. Two populations can be observed (∼5–20 nm and ∼40–50 nm).

2. Radiative-transfer simulations

We will present light-scattering simulations that validate the space-weathering and $npFe^0$ effects on the spectra of olivine. All the observed effects, i.e., the darkening and reddening of the spectra, as well as the flattening of the 1-µm absorption band, can be reproduced in the simulations. We use a radiative-transfer solution and the implementation by Muinonen et al. [2], the so-called SIRIS code. The code can treat surface and internal reflections by a random-shaped particle (i.e., olivine grain) that can include internal diffuse scatterers (i.e., nanophase iron inclusions), and compute the reflectance spectra over varying wavelengths. Laboratory-measured, wavelength-dependent complex refractive indices of olivine and iron are used in the model as input. The resulting spectra reproduces the observed space-weathering effects, see Fig. 2. This result is important in understanding the observed spectral space-weathering effects using the light-scattering theory.

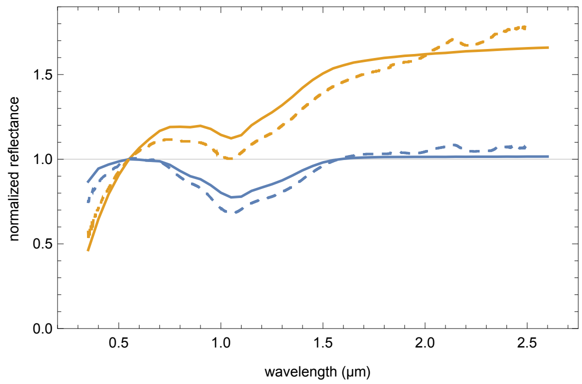

Figure 2: Measured and simulated normalized reflectance spectra of untreated and space-weathered olivine. The solid lines present the simulations, and the dashed lines the measurements. The blue lines are for the untreated olivine grains, and the orange lines for olivine with nanophase iron (0.023 wt%).

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