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Space weathering of asteroidal surfaces

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Abstract

We studied the changes induced by energetic ion irradiation in the UV-Vis-NIR (0.2-2.5 μm) reflectance spectra of targets - olivine samples pure or covered by an organic polymer (polystyrene) to mimic the space weathering processes going on the surfaces of airless bodies in the inner Solar System (SS).

1. Introduction

It is well known that the surfaces of airless bodies in the Solar System (SS) are continuously altered by the bombardment of micrometeoroids and irradiation by solar wind, flares, and cosmic energetic particles. Major effects of this process - space weathering (SW hereinafter) - are darkening and “reddening” (spectral reflectance increases with wavelength) of the spectra of surface materials, as well as “degrading" of absorption features [1]. Recently, the effects of SW have been studied on organic materials of low volatility (polystyrene has been used as a template [3]). Such materials - macromolecules or molecular solids - could be very abundant on small objects in the outer SS where they could be accreted directly from the nebular material at the beginning of the System or they could be produced by energetic processing of simple ices [4]. The same molecules or their space weathered daughters could be present on closer objects such as asteroids or even Mars satellites (Phobos and Deimos, [5]).

2. Experiments

Iradiation of different samples were carried out at room temperature inside a stainless steel vacuum chamber (P<10^{-7} mbar), faced to NUV-Vis-NIR (0.25-0.98 μm) mini-spectrometer. Our chosen targets are olivine pellets, pure or covered by an organic polymer (polystyrene), which is transparent before irradiation. Polystyrene is used as a template for organic matter of low volatility. The samples were irradiated with 200 keV H^+ or 200-400 keV Ar ions. Before, during, and after irradiation diffuse reflectance spectra were acquired. Moreower, polystyrene films were also deposited on quartz substrates and irradiated while transmittance spectra were recorded. The transmittance spectra of non-irradiated polystyrene and after its irradiation were achieved also ex-situ with Perkin-Elmer Lambda 19 spectrometer (0.25-2.5 μm). We measured the changes induced by ion irradiation in the absorption coefficient of the polymer (Fig. 1).

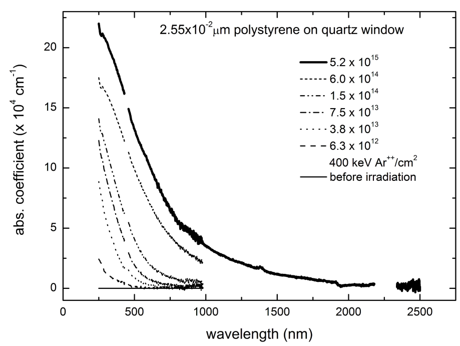

Figure 1: Relative absorption coefficient of polystyrene.

3. Results and Discussion

The used ions - 200 keV H^+ and 400 keV Ar^{++} - are a representation of two different kinds of the process of energy deposition into the material: 200 keV H^+ as ions with only an inelastic contribution and 400 keV Ar with both inelastic and elastic components.

The reflectance (R^*) of irradiated olivine sample covered with a layer of polystyrene can be expressed, in first approximation, by the relation

$$R^* = RT^2, \quad (1)$$

where R is the reflectance of the silicate, $T = e^{-\alpha s}$ is the transmittance of deposited polystyrene of thickness s, which absorbtion coefficient is α.

With this model we have estimated the effect of the solar wind ions on the olivine sample covered with a polystyrene layer. Because solar wind ions of 1 keV/u deposit the energy into the polystyrene through both elastic and inelastic interactions, the α of polystyrene after 400 keV Ar irradiation was considered in the model. The corresponding timescale for the solar wind ions effect on an hypotetcal object at the 2.7 AU (the average heliocentric distance of the Main Belt of asteroids) was estimated by dividing the dose transferred into the material through the ions by the stopping power of considered solar wind ions multiplied by the appropriate ion flux. We considered two cases: 1 keV H^+ i.e. the most abundant of the solar wind ions, and 36 keV Ar^+. Here the 36 keV Ar^+ is considered as representative of all of the heavy ions. Its flux was multiplied by a factor of 1000 to have an elastic dose corresponding to the total dose provided by all other solar wind ions (H, He, C, O, N, etc.; see [6]).

The measured absorption coefficient of fully carbonized polystyrene was effectively used to simulate the UV-NIR part of the reflectance spectra of the Centaur 5145 Pholus (Fig. 2). The fit of the unusually red spectra of Pholus was reached under the assumption of the relatively short exposition of its surface to the solar wind ion irradiation ($\approx 9 \times 10^5$ years) [3].

4. Summary

With polystyrene as an example of organic material it was shown that the effect of SW of SS objects which are covered with some amount of organic material is more effective with respect to the objects composed of pure silicates. Moreover, it was shown that the SW effects could be so great for organic materials that if these are present on the asteroids, the SW effect on these objects is almost independent of the substrate.

The spectral changes in organic material induced by fast ions seem to be mainly due to the elastic part of the ion energy deposition into the material. However, more experiments particularly with ions with a different ratio of elastic/inelastic energy deposition into the material are necessary.

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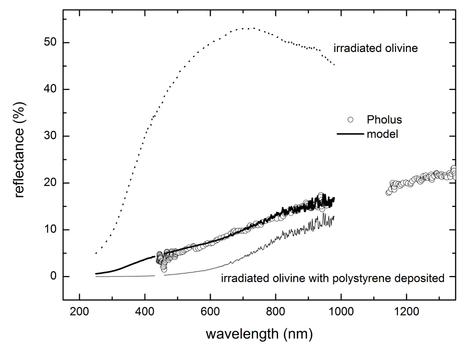

Figure 2: Simulation of the reflectance spectra of 5145 Pholus. The spectral data of Pholus [2] were fitted with a linear curve equal to 0.12 x S_o + 0.88 x S_{op}, where S_o is the reflectance spectra of irradiated olivine and S_{op} is the reflectance spectra of irradiated olivine covered with a layer of polystyrene.

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