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Ion irradiation of eucrite and diogenite meteorites: implication for asteroid *4 Vesta*

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Abstract. In an ongoing research performed at the Laboratory of Experimental Astrophysics (LASp) of Catania Observatory we analyze, in the spectral range Vis-NIR (0.3-2.7 μm), reflectance spectra of materials representative of asteroid surfaces to simulate effects of space weathering induced by solar and cosmic ions. To this purpose we have irradiated meteorites and terrestrial silicates using different ions (H^+, He^+, Ar^+, Ar^{++}, etc.) having different energies from 30 keV to 400 keV. Experiments conducted on eucrite and diogenite meteorites, believed to be fragments of asteroid 4 Vesta, have shown important spectral changes, i.e. reddening and darkening. These results agree with previous experiments on ordinary chondrites, olivine, and pyroxene. Moreover, we find that the time-scales required for solar wind ions to cause on the surface of Vesta the same spectral changes observed in the laboratory are on the order of 10^5 years. So, if solar wind ions reach the surface of Vesta, we should observe these changes, but we do not. This implies that either Vesta is shielded from solar wind ions by a magnetosphere or some event refreshed the whole surface recently (less than 10^5–10^6 years).

Key words. Solar System: Minor planets, asteroids – Methods: laboratory – Magnetic fields – Molecular processes

1. Introduction

Irradiation by cosmic and solar wind ions, as well as bombardment by interplanetary dust, are believed to induce ”space weathering”, i.e., time-related processes able to change progressively the solar reflectance spectra of airless planetary surfaces. The main effect in the Vis-NIR range (0.3-2.7 μm) is a progressive change in the surface color of minor bodies: the spectrum grows darker and redder in time (Marchi et al. 2005).

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These spectral changes can be reproduced by both laser pulse and ion irradiation experiments on asteroid analogues, simulating respectively micro-meteorite bombardment (Brunetto et al. 2006) and solar wind ion irradiation (Strazzulla et al. 2005).

At the Laboratory of Experimental Astrophysics of Catania Observatory we simulate the effects of ion irradiation on materials considered good analogues of Solar System minor bodies: terrestrial silicates (olivine, pyroxene, serpentine, plagioclase, etc.), carbons (asphaltite, kerite, etc.), meteorite fragments (ordinary chondrites, carbonaceous chondrites, etc.) and frozen ices (methanol, methane, benzene, etc.).

In particular, in this work we present results of ion irradiation experiments conducted on eucrite and diogenite meteorites.

Simulations of solar wind space weathering are studied using in-situ bi-directional reflectance spectroscopy (0.7-2.5 μm) and ex-situ hemispherical reflectance spectroscopy (0.3-2.5 μm). In-situ spectra are collected in a stainless steel vacuum chamber (10^{-7} mbar) faced to a spectrophotometer through KBr windows, before, during and after ion irradiation without tilting or removing the sample (several irradiation steps). Ex-situ spectra are collected outside the vacuum chamber (atmospheric pressure) after removing the samples from it. Further experimental details are described in Brunetto & Strazzulla (2005).

2. Vesta and HED meteorites

Vesta is the third largest asteroid in the Main-Belt, with a mean diameter of about 516 km and a mass of about 2.7×10^{20} kg. It is the only large asteroid known to have a basaltic surface that retains a record of ancient volcanic activity. Furthermore, this asteroid is believed to have experienced significant heating and internal differentiation.

The basaltic nature of Vesta was discovered through Vis-NIR spectroscopy with ground-based telescopes (Gaffey 1997).

The high geological interest for this asteroid followed the discovery that howardite, eucrite, and diogenite (HED) meteorites could be samples ejected from Vesta (Keil 2002) due to a large impact of which now we can observe the effects on its surface: a very large (460-km-wide) circular crater near the south pole with a pronounced central peak of 12 km (Vernazza et al. 2005).

3. Results

The powdered meteorite fragments, provided us by the Museum National d'Histoire Naturelle (Paris), are named Bereba (eucrite) and Tatahouine (diogenite).

We irradiated them using 400 keV Ar^{++} ions at different values of ion fluences (up to 6.6×10^{15} ions/cm^2).

The obtained reflectance spectra are shown in Fig. 1, in which we can see that ion irradiation produces a progressive darkening (i.e. decreasing albedo) and reddening (i.e. variation of the spectra slope, with lower reflectance at lower wavelength) of the sample spectra with the increasing of the ion fluence. Moreover, we observe a progressive decreasing of the depth of the band at about 1 μm.

The qualitative mineralogical composition of Vesta's surface and HED meteorites is very similar to that of some lunar mare areas, terrestrial silicates (Brunetto & Strazzulla 2005), and meteorite fragments (Strazzulla et al. 2005) (all having pyroxene, olivine and plagioclase as main constituents); these end-member silicates were treated in previous experiments conduced at the LASp, so, in order to examine in more details the effects of ion irradiation on these materials, after converting the fluences to the corresponding time-scales at 2.36 AU (mean distance Vesta - Sun), we compared (Fig. 2) the spectral slope variations of these materials with progressive irradiation. The spectral slope is calculated by the linear continuum across the 1 μm band from the spectra scaled to 1 at 0.7 μm (more details in Vernazza et al. (2006)).

In Fig. 2 we can see that the time-scale necessary to obtain at 2.36 AU the same spectral changes observed in the laboratory is estimated to be on the order of 10^5 years, then a question arises: Why Vesta's surface is not weathered although HED meteorites are altered in laboratory experiments?

4. Conclusions

If solar wind ions reach the surface of Vesta, one should observe in its spectra the same meteorite/terrestrial rocks spectral variations but we do not. This implies that either Vesta is shielded from solar wind ions by a magnetic field or some event refreshed recently (less than 10^5-10^6 years) the whole surface.

This latter case appears to be ruled out (Vernazza et al. 2006); though observations from the Hubble Space Telescope (Thomas et

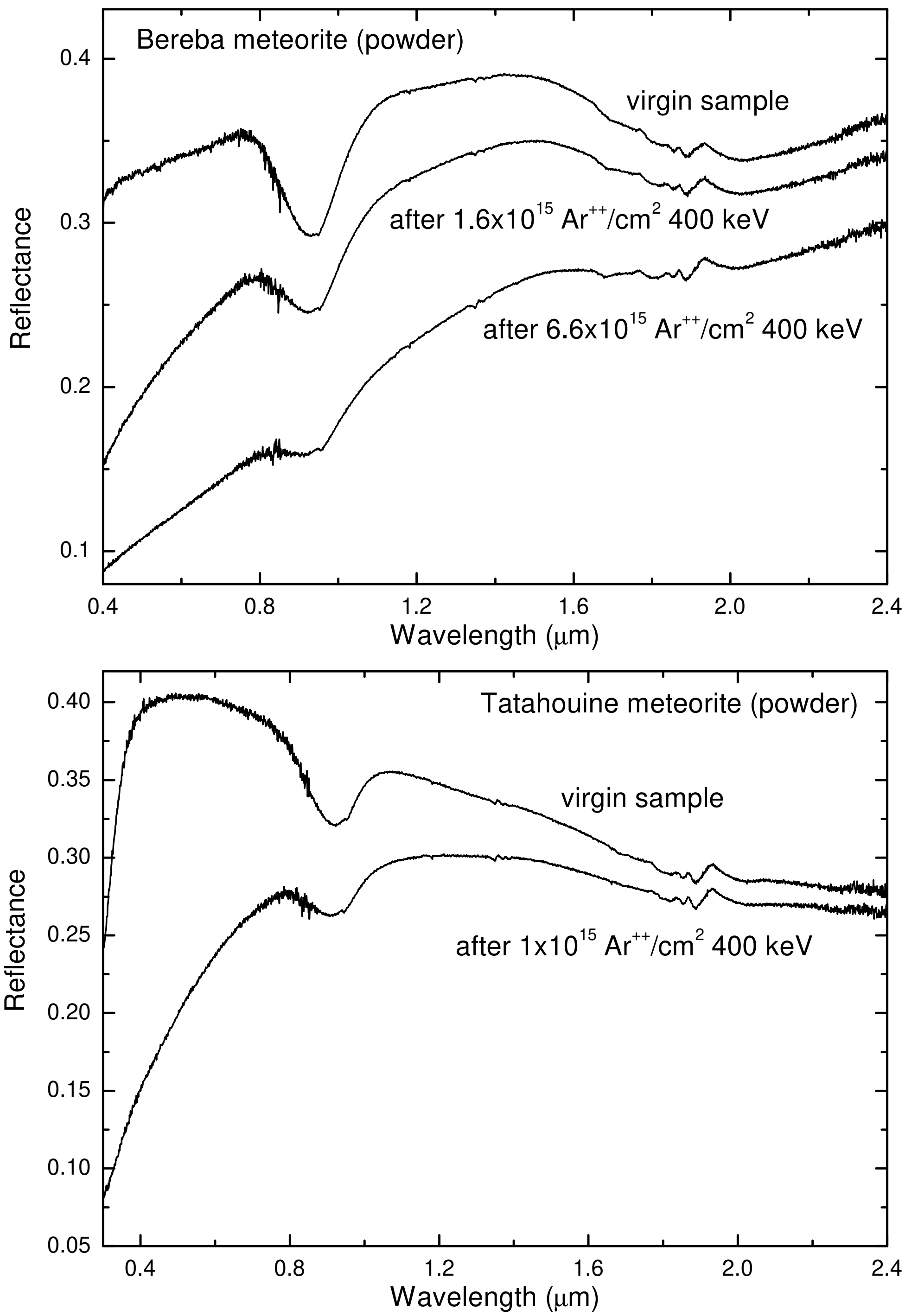

Fig. 1. Upper panel: Vis-NIR (0.4-2.4 μm) reflectance spectra of the eucrite meteorite Bereba before and after irradiation. Lower panel: Vis-NIR (0.4-2.4 μm) spectra of the diogenite meteorite Tatahouine before and after irradiation.

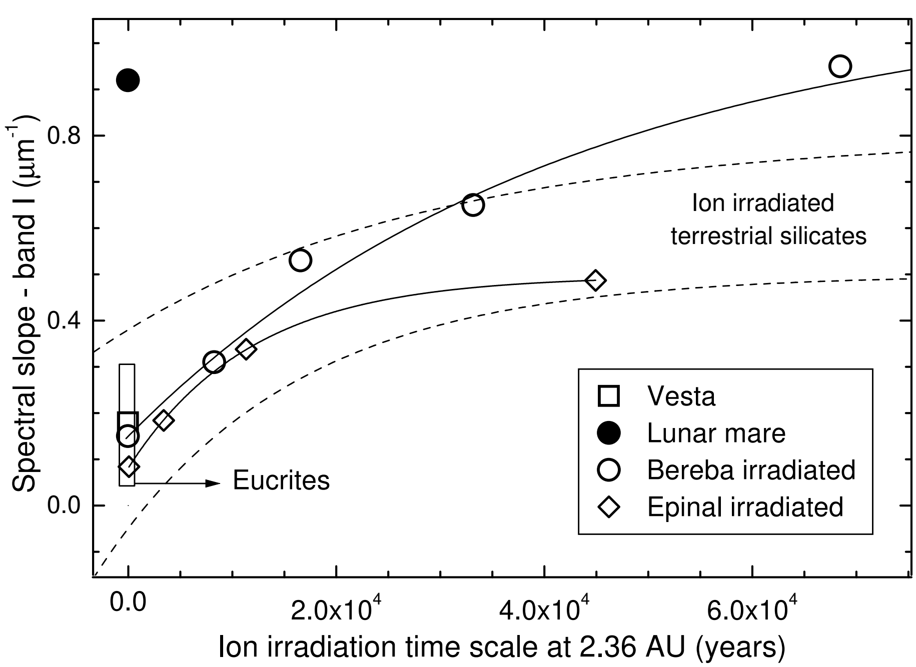

Fig. 2. Spectral slope variations after ion irradiation of Bereba, Epinal meteorite and silicates rich in olivine and pyroxene, as a function of time. The spectral slopes of Vesta and of Lunar mare area are also reported.

al. 1997) show that Vesta experienced in the past a big impact producing the 460 Km crater on its surface, collisional modeling results suggest that this impact took place about 1 Gyr ago.

The hypothesis of the presence of a magnetic field is supported by the model of the differentiated interior of Vesta (with an iron core) and by paleomagnetic studies conduced on HED meteorites indicating a residual magnetization (Collinson & Morden 1994).

The magnetic field of Vesta has been estimated to be about 0.2 μT at the surface (Vernazza et al. 2006).

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