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Ion irradiation of solids of planetological interest

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Abstract. Silicates, carbonaceous materials, and icy species are the constituent of the surfaces of solid objects in the Solar System. We present some results obtained by ion-irradiation of Epinal, an ordinary chondrite, and frozen ices, namely benzene and mixtures water-carbon dioxide. The aim is to study physico-chemical modifications that include changes in the spectral reflectivity of refractory materials and the formation of molecules originally not present in the icy target.

Key words. Methods: laboratory - Asteroids- Planets and satellites- techniques: spectroscopic

1. Introduction

Knowledge of the physico-chemical properties of the surfaces of the solid objects in the Solar System is still scarce. We have only a rough knowledge of the actual composition and only sparse information about the ageing of the observed surfaces and the relative importance of the various weathering processes: impacts, solar UV, energetic particle irradiation and thermal processing. Here we present some experimental results obtained by our group on ion irradiation of solids, namely silicates, carbonaceous materials and frozen gases. The experiments are performed with the aim to simulate one of the weathering processes: the alteration of planetary surfaces induced by cosmic ion bombardment.

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2. Laboratory results

Fast ions penetrating solids deposit energy in the target, thus bonds are broken producing physico-chemical modifications that include changes in the spectral reflectivity of refractory materials and the formation of molecules originally not present in the icy target. When carbon is an important constituent of the irradiated material a refractory residue results; that residue remains after warming the sample and, after prolonged irradiation, evolves to form a hydrogenated amorphous carbon.

2.1. Silicates

The importance of laboratory experiments to simulate space weathering processes on asteroid-like materials is clear since a long time. Ion irradiation using H^+ and He^+ ions (Dukes, Baragiola, & McFadden 1999; Hapke 2001), and high energy (MeV) proton implan-

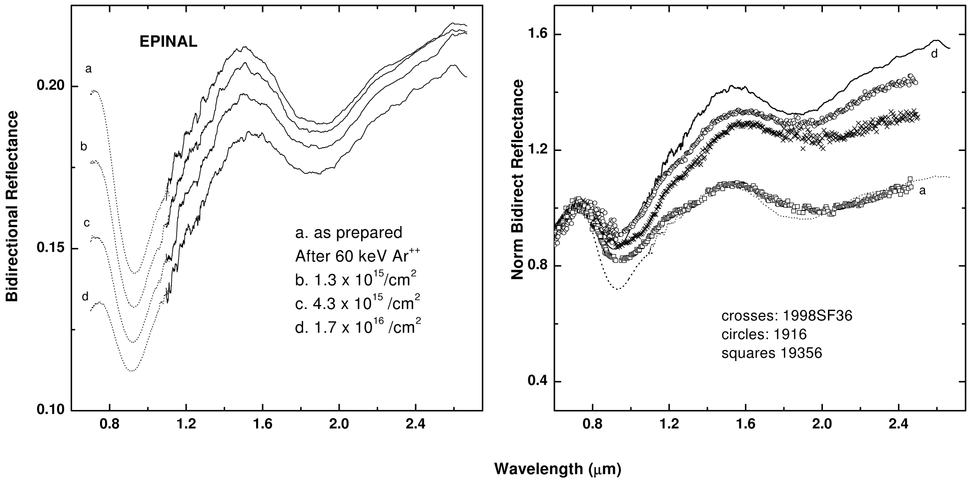

Fig. 1. Reflectance spectra of the ordinary chondrite Epinal in the range 0.6-2.75 μm. Left panel shows an as prepared sample spectrum (a) and spectra after the sample has been irradiated at increasing doses (b,c,d) with 60 keV Ar^{++} ions. Right panel shows spectra normalized to 1 at 0.7 μm of Epinal as prepared (a), and after irradiation to the maximum dose (d), compared to spectra of 3 S-type NEOs.

tation (Yamada et al. 1999) produced only small changes in the spectra of olivines and pyroxenes. A different result was obtained by Strazzulla et al. (2005a), who performed ion irradiation of ordinary chondrite Epinal (H5) with Ar^{++} 60 keV, producing strong darkening and reddening of the Vis-NIR spectra. This is evidenced in the left panel of Fig.1 where reflectance spectra (0.6-2.75 μm) before irradiation and after three different ion fluences (60 keV Ar^{++}) are shown. In the right panel of Fig.1 the initial reflectance spectrum of Epinal (a) and that obtained at the highest ion fluence (d) are shown normalized to 1 at 0.7 micrometers. The normalized observed spectra of three NEOs are also shown for comparison. We can see that the different colors of some S-type NEOs can be reproduced by ion-induced space weathering on time-scales of the order of 10^5 years at about 1 AU (Astronomical Unit) from the Sun. A plausible explanation of the discrepancy between our results and those obtained by irradiating with protons is that irradiation effects are much more efficient with high mass ions than low mass. Consequently, Brunetto, & Strazzulla (2005) have performed ion irradiation experiments of bulk silicates, rich of olivine, pyroxene and serpentine, using different ions (H^+, He^+, Ar^+, Ar^{++}) having different energies (60-400 keV); it has been found that the increase of the spectral slope is strongly related with the number of displacements caused by colliding ions inside the sample, i.e. the elastic collisions with the target nuclei.

2.2. Frozen hydrocarbons

Centaurs, TNOs (Trans Neptunian Objects), and other cometary nuclei exhibit relevant color variations in the visual and near-infrared spectral regions from steep red to flat gray (Luu & Jewitt 2002). The diversity of colors could arise from competition between cosmic ray irradiation assumed to produce reddening, and resurfacing by interplanetary dust impacts and collisions with other large bodies, which presumably excavate more pristine material with neutral colors.

In Fig.2 we present "in situ" diffuse reflectance spectra (0.6-2.75 μm) from frozen benzene (80 K) samples that remain in the chamber throughout the irradiation processing and the reflectance measurements. This is a

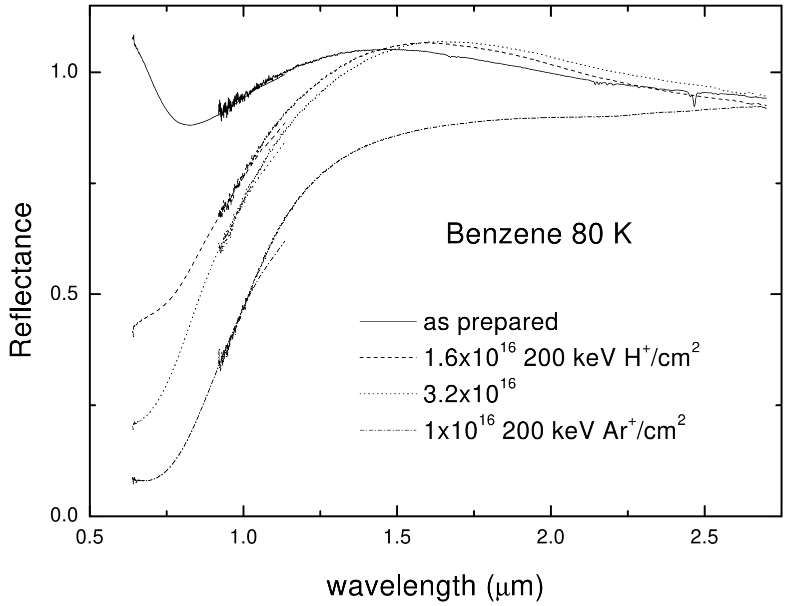

Fig. 2. Diffuse reflectance spectra (0.6-2.7 μm) from a sample of frozen benzene (at 80 K) before and after ion irradiation. The results indicate that the initially "white" spectrum progressively reddens and darkens with increasing ion fluence. The broad feature at about 0.75 μm is due to an interference pattern.

first example of the more general goal to study relevant materials such as ice mixtures, silicates with and without icy and/or carbonaceous layers. From Fig.2 we see that the simulated "ageing" effect indicates that the initially "whited" spectrum characteristic of frozen ices (the band that appears with a minimum at about 0.75 micrometers is due to interference) progressively reddens and darkens with increasing ion fluence.

2.3. *Water-Carbon dioxide frozen mixtures*

It has been demonstrated that ion irradiation of frozen water ice is the primary candidate to explain the presence of H_2O_2 on the Galilean moons detected by space observations (Carlson et al. 1999; Moore & Hudson 2000; Strazzulla et al. 2003; Gomis et al. 2004; Gomis, Leto, & Strazzulla 2004; Baragiola et al. 2004). We have performed some experiments concerning irradiation of different mixtures H_2O/CO_2 (Strazzulla et al. 2005b). The obtained results are summarized in Table 1. Infrared spectra obtained before, during, and after irradiation show that the intensities of the bands of the original species (water and carbon dioxide) decrease and new features appear due to the synthesis of other species. These features indicate the synthesis of CO, H_2O_2, and H_2CO_3. After warm up the volatile species are lost and a refractory residue, made essentially of carbonic acid, is left over as already demonstrated in previous studies (Moore & Khanna 1991; Strazzulla et al. 1996; Brucato, Palumbo, & Strazzulla 1997). Upon irradiation of mixtures, CO_2 is destroyed at a rate larger than that of H_2O. Thus the molecular number ratio CO_2/H_2O decreases, more rapidly at 80 K, and reaches an asymptotic value of about 10% (Strazzulla

Table 1. Species synthesized after ion irradiation (1.5-200 keV ions) of the given icy mixtures at the indicated temperature ranges

$H_2O:CO_2$	Temperature (K)	Synthesized species
0:1	16, 80	CO, CO_3, O_3
1:1	10-16	H_2O_2, CO, H_2CO_3, O_3
1:0.4	80	H_2O_2, CO, H_2CO_3, CO_3
1:0.2	16	H_2O_2, CO, H_2CO_3
1:0	16-150	H_2O_2

et al. 2005b).
CO is formed from pure CO_2 whatever is the mixture. Interesting is the case of O_3 and CO_3: O_3 is detected only for pure CO_2 and the mixture 1:1 i.e. with the largest amount of CO_2. It is significant to outline that the synthesis of ozone is connected to the significant (more than 30%) presence of carbon dioxide in the mixture. CO_3 has been detected only for the mixture prepared and irradiated at 80 K, for which we have noticed a lower efficiency in the production of carbonic acid. This is due to the high mobility of H_2 that easily escape from the target at 80 K instead to react with CO_3 as it occurs at 16 K.

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References

Baragiola, R. A., Loeffler, M. J., Raut, U., Vidal, R. A. & Carlson, R. W. 2004, 35th Lunar and Planetary Science Conference, abstract no.2079.
Brucato, J.R., Palumbo, M.E., & Strazzulla, G. 1997, Icarus 125, 135
Brunetto, R., & Strazzulla, G. 2005, Icarus submitted
Carlson, R. W., & 13 co-authors 1999, Science 283, 2062
Dukes, C. A., Baragiola, R. A., & McFadden, L.A. 1999 J Geophys Res 104, 1865
Gomis, O., Satorre, M. A., Strazzulla, G., & Leto, G. 2004a, Planet. Space Sci. 52, 371
Gomis, O., Leto, G., & Strazzulla, G. 2004b, A&A 420, 405
Hapke, B. 2001 J Geophys Res 106, E5, 10,039
Luu J.X.,& Jewitt D.C. 2002 ARAA 40, 63
Moore, M.H., & Khanna, R.K. 1991, Spectrochim. Acta 47, 255
Moore, M. H., & Hudson, R. L. 2000, Icarus 145, 282
Strazzulla G., Brucato, J.R., Cimino, G., & Palumbo, M.E. 1996 Planet. Space Sci. 44, 1447
Strazzulla, G., Leto G., Gomis, O., & Satorre, M. A. 2003, Icarus 164, 163
Strazzulla, G., Dotto, E., Binzel, R., Brunetto,R., Barucci, M.A., Blanco, A. & Orofino V. 2005a, Icarus 174, 31
Strazzulla, G., Leto, G., Spinella, F., & Gomis, O. 2005b Astrobiology, in press
Yamada, M., Sasaki, S., Nagahara, H., Fujiwara, A., Hasegawa, S., Yano, H., Hiroi, T., Ohashi, H., & Otake, H. 1999 Earth Planets Space 51, 1255.