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Ion irradiation of carbonaceous chondrites as a simulation of space weathering on C-complex asteroids

C. Lantz (1,2), R. Brunetto (3), M.A. Barucci (1), C. Bachelet (4), D. Baklouti (3), J. Bourçois (4), E. Dartois (3), J. Duprat (4), P. Duret (3), C. Engrand (4), M. Godard (4), D. Ledu (4), O. Mivumbi (3), and S. Fornasier (1)

(1) LESIA – Observatoire de Paris, CNRS / UPMC Univ. Paris 6 / Univ. Paris Diderot, Meudon, France, (2) Université Paris Diderot, Sorbonne Paris Cité, Paris, France (cateline.lantz@obspm.fr), (3) IAS, CNRS / Université Paris Sud, Orsay, France, (4) CSNSM, IN2P3 – CNRS / Université Paris-Sud, Orsay, France

Abstract

We are investigating the effects of space weathering on primitive asteroids using ion irradiation on their meteoritic analogs. To do so, we exposed several carbonaceous chondrites (CV Allende, COs Lancé and Frontier Mountain 95002, CM Mighei, CI Alais, and ungrouped Tagish Lake) to 40 keV He^+ ions as a simulation of solar wind irradiation using fluences up to 6.10^{16} ions/cm^2 (implantation platform IRMA at CSNSM Orsay). As a test for our new experimental setup, we also studied samples of olivine and diopside. We confirm the reddening and darkening trends on S-type objects, but carbonaceous chondrites present a continuum of behaviors after ion irradiation as a function of the initial albedo and carbon content: from red to blue and from dark to bright.

1. Introduction

The exposition of airless bodies to the harsh environment in which they evolve (solar ion irradiations, micrometeorite bombardments, etc.) leads to surface alterations affecting spectra. This phenomenon is known as space weathering (SpWe). Lot of studies have been made on S-type asteroids and silicate materials, including laboratory experiments [1] and direct confirmation on Itokawa grains [2] of the well know darkening and reddening trends. On the contrary, few results have been obtained on C-type asteroids and no general trend has been found [3-5]. In order to understand the influence of SpWe on primitive asteroids, we conduct laboratory simulations on carbonaceous chondrites. The goal is to develop a model of SpWe which will also support sample return missions (OSIRIS-REx/NASA and Hayabusa-2/JAXA).

2. Previous experiment

In a first step, we exposed fragments of CV Allende [6] and CM Murchison [7] to 40 keV He^+ and Ar^+ (fluences up to 3.10^{16} ions/cm^2, platform SIDONIE at CSNSM). They showed different spectral behaviors after irradiation in the 0.425-1.25µm range. Allende clearly reddened and darkened while Murchison had small spectral variations difficult to interpret taking into account the sample heterogeneity concern. It appeared clearly on both samples that in the 10 µm region, bands of silicates and/or phyllosilicates move toward longer wavelength {Fig.1}. Murchison, which is an aqueous altered meteorite, also presents a band shift in the 3 µm region. These modifications toward the Fe-rich spectral region suggesting a loss of the element Mg are probably due to a preferential sputtering of Mg and/or amorphization of Mg-rich materials. These results cannot confirm the presence of npFe0, but do not disagree with the forming mechanism [8].

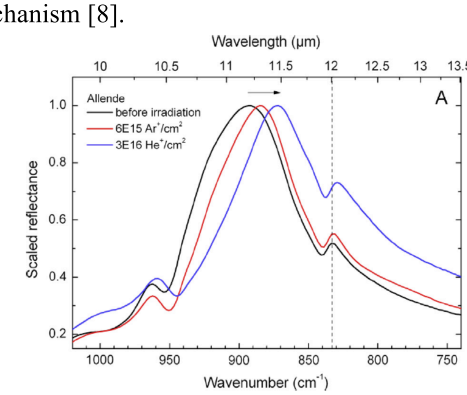

Figure 1: MIR confocal reflectance spectra (SMIS beam line at Synchron SOLEIL) of Allende around the silicate peak at 11 µm before and after the highest irradiation doses for both ions. Figure from Brunetto et al. 2014.

3. Comparison with other ion irradiations

We put together the results of other ion irradiations made by different teams [1, 3, 6, 7, 9]. We observe two distinct behaviours {Fig.2}. On one hand there are the brighter materials like ordinary chondrites (and olivine) showing clearly the well known darkening and reddening effects. On the other hand, we find the carbonaceous chondrites with transitional trend that seems to depend on the original composition.

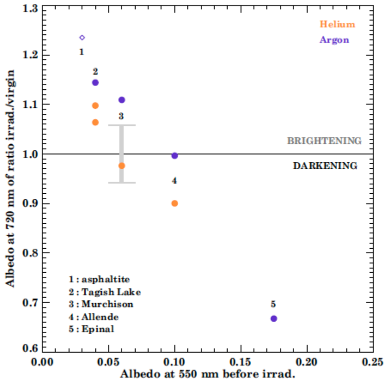

Figure 2: Reflectance of ratioed spectra (irradiated/unirradiated) as a function of the initial albedo. The grey error bar indicates the variations due to our Murchison sample heterogeneity. Figure from Lantz et al. 2015.

4. This new study

We use a new vacuum chamber (project INGMAR) to perform spectroscopic studies from 0.4 to 2.5 µm. This setup allows us to collect diffuse reflectance spectra of the same region of the sample as a function of the increasing dose (fluences of 5.10^5, 1.10^6, 3.10^6, and 6.10^6 He^+/cm^2 are used here). An example is given in Fig.3 for irradiated olivine, where reddening and darkening are seen.

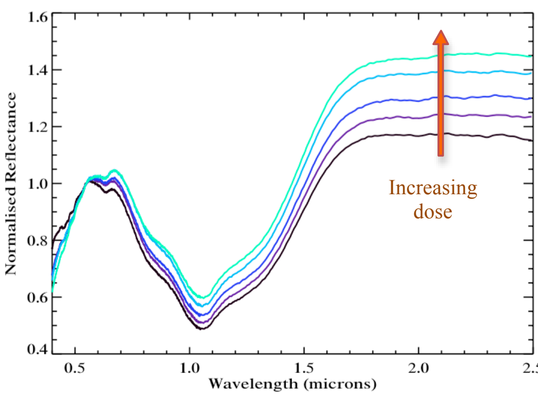

Figure 3: Spectra before and after irradiations (the brighter color, the stronger dose) for olivine.

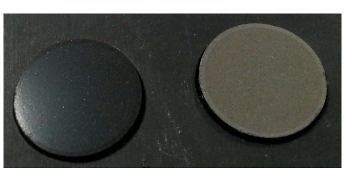

Figure 4: Pellets (13mm in diameter) of CM Mighei (left) and CO Lancé (right). On the edge of the pellet, one can see an unirradiated area (corona of 500 µm): the altered region gets darker for the CO and brighter for the CM.

Irradiated pellets of olivine, diopside, CV and CO meteorites show spectral reddening and darkening in the VIS-NIR, while the darker meteorites tend to brighten, as seen in Fig.4, and get bluer spectra after irradiation.

Preliminary results in the MIR range show for all the carbonaceous chondrites and the silicate samples a shift toward longer wavelength of the silicate/phyllosilicate bands as seen in our previous study on Allende and Murchison. The aqueous altered meteorites also suffer a modification of the dedicated 3 µm band.

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