

# COORDINATED ANALYSIS OF AN ION IRRADIATED CARBONACEOUS CHONDRITE

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**Introduction and Methods:** Space weathering processes such as micrometeorite bombardment and solar wind irradiation alter the microstructural, compositional, and optical properties of airless body regoliths over time. Space weathering complicates the interpretation of remote sensing data, posing a problem for JAXA Hayabusa2 and NASA OSIRIS-REx data analysis—missions which are returning samples from C-type asteroids Ryugu and Bennu, respectively [1,2,3]. To promote our understanding of the effects of space weathering on hydrated, organic-rich materials, maximize scientific return from remote sensing data, and prepare for the analysis of returned samples from these missions, we simulate solar wind exposure through ion irradiation of CM2 Murchison—a suitable analog for C-complex asteroids [4]. Here, we present coordinated analysis of a dry-cut slice of Murchison before and after 2 keV H<sub>2</sub><sup>+</sup> and 4 keV He<sup>+</sup> ion irradiation up to total fluences of 8.1x10<sup>17</sup> ions/cm<sup>2</sup> and 1.1x10<sup>18</sup> ions/cm<sup>2</sup>, respectively. Analytical techniques include X-ray photoelectron spectroscopy (XPS), visible to near infrared (VNIR; 0.35 – 2.50 μm) reflectance spectroscopy, and two-step laser-desorption mass spectrometry (μL<sup>2</sup>MS).

**Surface Chemistry:** XPS spectra before and after H<sub>2</sub><sup>+</sup> and He<sup>+</sup> irradiation show similar effects on the matrix's surface chemistry. Carbon peaks are significantly lowered after irradiation, suggesting that both ion types cause net removal of carbon-bearing species on the monolayer depth scale (or possibly their re-distribution in the sample by ion mixing). This effect exceeds what would be expected for simple removal of “adventitious” carbon. All other elements—except F, S, and Ni in the H<sub>2</sub><sup>+</sup>-irradiated region—exhibit an increase in peak intensity. Preliminary peak-fitting data indicates reduction of iron from Fe<sup>2+</sup> to Fe<sup>0</sup> and alteration of sulfate to sulfides from both ion irradiations.

**Reflectance Spectroscopy:** He<sup>+</sup> ion irradiation yields darkening shortwards and brightening longwards of the 0.7 μm wavelength. Spectral reddening (i.e., increasing reflectance with increasing wavelength) also occurs in the He<sup>+</sup>-irradiated sample. In contrast, the H<sub>2</sub><sup>+</sup>-irradiated sample is similar in brightness to the unweathered surface. Both irradiated spectra show weakened ~1.0 μm (olivine or Fe<sup>2+</sup> phyllosilicates), ~0.7 μm (Fe<sup>2+</sup>-Fe<sup>3+</sup> phyllosilicates), and ~1.94 μm (water) absorption bands, with He<sup>+</sup> inducing a more significant change [5]. He<sup>+</sup> irradiation also slightly strengthens absorptions at ~0.44, 0.47, and 0.50 μm bands, of which the latter two correspond to Fe-oxides.

**Organics Analysis:** Consistent with the XPS carbon results, μL<sup>2</sup>MS mapping at the 118 nm photoionization wavelength shows a ~30-40% reduction in overall organic abundance after irradiation. Concentrations of aromatic species remain relatively unchanged post-irradiation, suggesting aromatics may be more resistant to irradiation-driven chemical and structural modifications compared to other organics. Subsequent mapping with 266 nm photoionization will highlight the chemistry and evolution of these aromatics.

**Discussion:** Ion irradiation of carbonaceous material yields complex spectral results. XPS and μL<sup>2</sup>MS mapping show a net decrease of carbon associated with alteration and removal of organics. XPS also shows the reduction of iron and creation of sulfides, which may potentially indicate irradiation-induced nanophase Fe<sup>0</sup> and Fe-sulfide production. Reflectance data exhibits attenuation of the 0.7 and 1.0 μm bands after irradiation, reflecting the breakdown of matrix phyllosilicates and possibly olivine, the partial reduction of iron, and/or minor production of nanophase particles [6]. In contrast to XPS, the strengthening of bands near 0.47 and 0.50 μm may reflect the presence of Fe<sup>3+</sup> bearing oxides (e.g., magnetite) in the form of nanophase particles which can be produced in reducing environments containing free OH<sup>-</sup>. Such a process may be further supported by the weakening OH/H<sub>2</sub>O band at 1.94 μm which would provide volatile phases necessary for oxide formation via loss of OH<sup>-</sup> from phyllosilicates during irradiation. Similar trends were observed in Murchison pulsed-laser irradiation experiments conducted by [7]. Minor slope reddening of both irradiated surfaces compared to the unweathered Murchison surface could further suggest the formation of nanophase Fe<sup>0</sup> or sulfides in addition to nanophase oxides e.g., [1]. In contrast, the mechanism behind spectral brightening is uncertain. The decrease in nearly all organic species (except aromatics) suggests volatilization by He<sup>+</sup> irradiation. Compared to organic analyses of pulsed-laser irradiation experiments in [8], He<sup>+</sup> irradiation appears to destroy a variety of organic species while pulsed-laser irradiation breaks down complex refractory hydrocarbons, thus leading to an increased abundance of organic free species. Future chemical and microstructural TEM analyses will help us correlate nanoscale features to the complicated spectral effects mentioned here.

**References:** [1] Pieters, C. & S. Noble (2016) *JGR*, 121(10), 1865-1884. [2] Lauretta, D. *et al.* (2015) *Met. Planet. Sci.*, 50, 834-849. [3] Yoshikawa, M. *et al.* (2015) IAU Gen. Assem. 22, 54481. [4] Clark, B. *et al.* (2011) *Icarus*, 216, 462 – 475. [5] Cloutis E. A. *et al.* (2012) *Icarus*, 220, 586-617. [6] Keller, L. P. *et al.* (2015) LPSC XLVI, Abs. 1913. [7] Thompson, M. S., *et al.* (2018) LPSC XLIX, Abs 2408. [8] Matsuoka M. *et al.* (2017), *Icarus*, 254, 135-143.