CHARACTERIZING IRRADIATED SURFACES OF AIRLESS BODIES USING IR SPECTROSCOPY

R. Brunetto[1], C. Lantz[1], R.G. Urso[1], T. Nakamura[2], D. Baklouti[1], T. Le Pivert-Jolivet[1], S. Kobayashi[2], and F. Borondics[3], [1]Université Paris-Saclay, CNRS, Institut d'Astrophysique Spatiale, 91405, Orsay, France (rosario.brunetto@ias.u-psud.fr), [2]Division of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, Japan, [3]SOLEIL synchrotron, Gif-sur-Yvette, France.

Introduction: Irradiation by solar wind and cosmic ions continuously modifies the optical properties of unprotected surfaces in the Solar System [1]. This alteration induces significant biases in the interpretation of the sub-surface pristine bulk composition through remote sensing. However, as the alteration of the surface is a function of time, an in-depth understanding of the phenomenon may provide an original way to estimate the weathering age of a surface. It is mandatory to establish reliable spectral proxies for distinguishing an irradiated from a pristine surface. These criteria must be based on unambiguous and reproducible spectral variations upon irradiation. Laboratory experiments on analogs can help identifying the best spectral proxies of irradiation. Here we report two cases of laboratory measurements showing evidence that the Mid- and Far-IR bands of silicates and the Near-IR bands of methanol can constitute reliable proxies of the time-bound effects of irradiation on primitive asteroids (such as Bennu [2]) and on methanol-rich Centaurs (Pholus [3]) and Trans-Neptunian Objects (Arrokoth [4] and (55638) 2002 VE95 [5]), respectively.

Methods: We report new IR data of ion irradiated carbonaceous chondrite meteorites to simulate of the irradiation of primitive asteroids. We produced pellets of meteorites from different classes (CV, CO, CM, CK, CI, C2). All the samples were irradiated at the SIDONIE implanter of CSNSM-Orsay (France), using He^+ and/or Ar^+ ion beams with 20 keV or 40 keV energies. We monitored the samples in situ under vacuum (INGMAR setup) by visible and Near-IR diffuse reflectance spectroscopy. Mid- and Far-IR spectra of the irradiated meteorites were measured at the SMIS beamline of the SOLEIL synchrotron (France). Details of the irradiation conditions and of the spectral measurements are described in previous studies [6-9].

In order to study the effects of solar wind ion bombardment on methanol-rich surfaces, we performed ion irradiation experiments of H_2O:CH_3OH icy mixtures and we monitored the evolution of their near-IR bands with increasing irradiation dose. These experiments were also performed with the INGMAR setup.

Results: Generally speaking, our laboratory experiments show that IR bands of silicates and methanol are very sensitive to space weathering.

Irradiation of meteorites. Mid- and far-IR bands of irradiated meteorites were significantly modified upon irradiation. We observed the silicate IR bands to shift in peak position upon irradiation. The irradiation-induced spectral shift was always observed towards the longer wavelengths (shorter wavenumbers).

Irradiation of solid methanol. In the laboratory spectra of irradiated methanol and its mixtures with water ice, we detected significant variations of the methanol 2.34/2.27 µm band ratios as a function of the irradiation dose.

Discussion: The IR bands mentioned above can constitute a reliable proxy of the time-bound effects of irradiation on airless bodies. Based on the laboratory evidence of the redshift of IR silicate bands upon irradiation, we explored the possibility of detecting irradiation effects through the remote sensing observations of asteroids, using the bandshift as a proxy. In particular, the notable match of the diagnostic peak positions of Bennu with those of irradiated meteorites suggests that the surface of Bennu may have recorded the effects of space weathering.

Methanol NIR bands can be used as a proxy of the irradiation history of outer Solar System bodies. By comparing the laboratory results of irradiated methanol with the observations of Arrokoth and of Pholus, we estimated the doses accumulated by the surface of these bodies. We found that Arrokoth experienced a lower extent of irradiation than Pholus.

We discuss the detectability of the spectral variations observed in the laboratory with new-generation telescopes, in order to evaluate the exposure timescales of airless bodies. We show that the detection of irradiation effects is within the reach of IR spectral resolution of the OSIRIS-REx mission and of the future James Webb Space Telescope.

Acknowledgments: The irradiations were performed using the INGMAR setup, a joint IAS-CSNSM (Orsay, France) facility funded by the P2IO LabEx (ANR-10-LABX-0038) in the framework Investissements d'Avenir (ANR-11-IDEX-0003-01). The microspectroscopy measurements were supported by grants from Region Ile-de-France (DIM-ACAV) and SOLEIL. This work has been funded by the CNES-France (Hayabusa2 and OSIRIS-REx missions) and by the ANR projects RAHIIA-SSOM and CLASSY (Grants ANR-16-CE29-0015 and ANR-17-CE31-0004-02) of the French Agence Nationale de la Recherche.

References: [1] Brunetto R. et al. (2015) *in Asteroids IV* 597–616. [2] Hamilton V. et al. (2019) *Nat. Astron. 3*, 332–340. [3] Cruikshank D. et al. (1998) *Icarus 135*, 389-407. [4] Stern A. (2019) *Science 364*, 1-12. [5] Barucci M.A. et al. (2006) *A&A 455*, 725-730. [6] Brunetto R. et al. (2014) *Icarus 237*, 278–292. [7] Lantz C. et al. (2015) *A&A 577*, A41. [8] Lantz C. et al. (2017) *Icarus 285*, 43–57. [9] Brunetto R. et al. (2018) *Planet. Space Sci. 158*, 38–45.