INVESTIGATING SPACE WEATHERING OF CARBONACEOUS ASTEROIDS THROUGH LOW-FLUX AND HIGH-FLUX H^+ AND HE^+ IRRADIATION OF THE MURCHISON METEORITE

D. L. Laczniak[1], M. S. Thompson[1], R. Christoffersen[2], C. A. Dukes[3], S. J. Clemett[2], R. V. Morris[4], and L. P. Keller[4], [1]Earth, Atmospheric, and Planetary Sciences Department, Purdue University, West Lafayette, IN (dlacznia@purdue.edu), [2]Jacobs, NASA Johnson Space Center, Mail Code XI3, Houston, TX, [3] Laboratory for Astrophysics and Surface Physics (LASP), Materials Science and Engineering, University of Virginia, Charlottesville, VA, [4] ARES, NASA Johnson Space Center, Houston, TX.

Introduction: Airless planetary bodies are continuously altered by space weathering processes such as solar wind irradiation and micrometeoroid bombardment. These processes modify the microstructural, chemical, and optical properties of planetary regoliths [1]. Although space weathering effects on the Moon and silicate-rich asteroids are well-understood, our understanding of space weathering of carbon-rich asteroids is an early stage. To prepare for the analysis of returned samples from the Hayabusa2 and OSIRIS-REx missions [2-3], laboratory experiments can be used to constrain the effects of space weathering on primitive, hydrated, organic-rich materials. To date, ion irradiation experiments simulating solar wind space weathering have used ion fluxes ~4-5 orders of magnitude higher than the ion flux of bulk solar wind [e.g., 4-6]. This increased ion flux may explain the crystallinity discrepancy between experimentally-irradiated olivine grains, which exhibit amorphous solar-wind damaged rims, and naturally-irradiated lunar and Itokawa olivine particles, which exhibit predominantly nanocrystalline rims [7]. We performed both high-flux and low-flux H^+ and He^+ irradiation experiments on chips of the Murchison CM2 carbonaceous chondrite to investigate the effect of ion flux on olivine amorphization and better understand the microstructural, chemical, and optical effects induced by solar wind space weathering of carbonaceous regoliths.

Methods: Separate 1 keV H^+ and 4 keV He^+ irradiations were performed on dry-cut Murchison slabs. In the high-flux experiments (~1.0×10^{13} ions/cm^2/s), fluences of 8.1×10^{17} H^+/cm^2 (~700 yrs exposure at Bennu) and 1.1×10^{18} He^+/cm^2 (~23,000 yrs at Bennu) were used. In the low-flux experiments (6.6×10^{11} H^+/cm^2/s and 3.6×10^{11} He^+/cm^2/s), fluences of 4.0×10^{16} H^+/cm^2 (~20 yrs at Bennu) and 2.1×10^{16} He^+/cm^2 (~400 yrs at Bennu) were used for H^+ and He^+-irradiation, respectively. A suite of coordinated analytical techniques are used to characterize and compare unirradiated and irradiated surfaces: X-ray photoelectron spectroscopy (XPS) examines changes in surface chemistry, visible to near-infrared spectroscopy (VNIR; 0.35 – 2.50 µm) identifies changes in spectral slope, albedo, and absorption band strength, scanning electron microscopy (SEM) evaluates morphological differences, and, finally, transmission electron microscopy (TEM) and energy dispersive X-ray spectroscopy (EDX) reveal modifications to nanoscale structure and chemistry. For TEM analysis, electron transparent thin sections are extracted from olivine and matrix material using a Thermo Fisher Helios 4G Dual Beam focused ion beam (FIB) SEM.

Results and Discussion: XPS results from high-flux H^+ and He^+ and low-flux He^+ irradiations show the removal of surface carbon and chemical reduction of Fe. VNIR analyses suggest that high-flux He^+ irradiation and low-flux H^+ irradiation induce greater spectral change than high-flux H^+ irradiation and and low-flux He^+ irradiation. Relative to the unirradiated surface, high-flux He^+ irradiation causes brightening longward of 0.75 µm and overall reddening, while low-flux H^+ irradiation causes brightening over the full wavelength range. Both the high-flux H^+-irradiated and low-flux He^+-irradiated spectra are very similar to the unirradiated spectrum. SEM imaging shows similar surface morphologies in the unirradiated, high-flux irradiated, and low-flux matrix surfaces. Some high-flux He^+-irradiated chondrules exhibit blistered surface textures indicative of vesiculaton, however, similar textures have not yet been identified in the low-flux He^+irradiated slab. TEM and EDS analyses of matrix and olivine FIB sections from the high-flux H^+- and He^+-irradiated experiments show varying degrees of vesiculation, structural disorder, and chemical heterogeneity in their ion-processed surfaces. Ion-damaged regions of the He^+- and H^+-irradiated matrix FIB-sections are highly vesiculated and characterized by complete phyllosilicate amorphization. The He^+- and H^+-irradiated Mg-rich olivine FIB-sections as well as the H^+-irradiated Fe-rich olivine FIB-section have ion-damaged zones <100 nm thick that exhibit polycrystalline domains and minor-to-moderate vesiculation. Interestingly, the He^+-irradiated Fe-rich olivine FIB-section differs significantly from the other olivine samples; reaching up to 180 nm thick, its ion-affected surface is highly vesiculated and completely amorphous. TEM and EDS analyses of the low-flux experiments are currently underway. Results, thus, far suggest that solar wind space weathering of carbon-rich regolith is a complex process and comparing high-flux and low-flux results will contribute to a comprehensive understanding of solar wind irradiation on carbon-rich asteroid surfaces.

References: [1] Pieters, C. & S. Noble (2016) *JGR* 121(10):1865-1884. [2] Watanabe S. et al. (2017) *SSRv* 208: 3-16. [3] Lauretta D. S. et al. (2017) *SSRv* 212:925-984. [4] Dukes, C. A. et al. (1999) *JGR* 104:1865-1872. [5] Loeffler, M. J. et al. (2009) *JGR* 114:E03003. [6] Laczniak, D. L. et al. (2021) Icarus 364:114479. [7] Christoffersen, R. et al. (2020) *LPSC LI*, Abstract #2147.