EXPERIMENTAL SPACE WEATHERING OF CARBONACEOUS CHONDRITE MATRIX. L. P. Keller¹, R. Christoffersen², C. A. Dukes³, R. A. Baragiola³, and Z. Rahman³. ¹ARES, Code XI3, NASA/JSC, Houston, TX 77058 (Lindsay.P.Keller@nasa.gov). ²Jacobs, NASA/JSC, Code XI, Houston, TX, 77058. ³Laboratory for Atomic and Surface Physics, University of Virginia, Charlottesville, VA 22904.

Introduction: Space weathering effects are widely recognized to have altered the optical, chemical, and physical properties of regolith materials exposed on airless bodies. Their effects on primitive carbonaceous asteroids however, are poorly understood and will be critical for interpreting the nature of regolith materials returned by future missions (Hayabusa 2 and OSIRIS-REx) that are targeting primitive, dark, organic-rich near-Earth asteroids.

We performed an irradiation experiment on the Murchison CM2 carbonaceous chondrite to simulate space weathering by solar wind exposure and characterized the irradiated material with infrared spectroscopy and transmission electron microscopy techniques [1,2]. Helium ion irradiation of Murchison matrix resulted in amorphization of the matrix phyllosilicates, loss of OH, surface vesiculation, and a significant reduction of the Fe²⁺/Fe³⁺ ratio in fine-grained phyllosilicates.

Materials and Methods: A polished thin section of Murchison was irradiated with 4 kV He⁺ (normal incidence) to a total dose of 1x10¹⁸ He⁺/cm². We obtained ex situ Fourier-transform infrared (FTIR) reflectance spectra from multiple areas of matrix, ~150 μm² in size, using a Hyperion microscope on a Vertex Bruker FTIR bench. A JEOL 7600F field emission scanning electron microscope (SEM) was used to study the morphological effects of the irradiation. We extracted thin sections from both irradiated and unirradiated regions in matrix using focused ion beam (FIB) techniques with electron beam deposition for the protective carbon strap to minimize surface damage artifacts from the FIB milling. The FIB sections were analyzed using a JEOL 2500SE scanning and transmission electron microscope (STEM) equipped with a Gatan Tridiem imaging filter. Electron energy-loss spectroscopy (EELS) data were collected from 50 nm diameter regions at low electron doses to minimize possible artifacts from electron-beam irradiation damage [2, 3].

Results and Discussion: The irradiated matrix showed lower reflectance in the near-IR and a red-sloped continuum compared to the un-irradiated matrix spectra. The depth of the 3 μm OH/H₂O feature (relative to the 10 μm silicate feature) is decreased in the irradiated regions. SEM imaging shows that the irradiated matrix regions have a “bubbly” or “frothy” texture, with numerous sub-μm rounded holes and voids relative to the un-irradiated material. TEM analysis of the FIB sections show that the frothy texture in the irradiated matrix results from the formation of irregularly-shaped 50-100 nm voids at the sample surface. High-resolution TEM imaging shows that the phyllosilicates (mainly serpentine group minerals) have been rendered amorphous from the irradiation to a depth of ~150-200 nm. There is excellent agreement between the total thickness of the amorphized layer and the He⁺ ion damage depth obtained from SRIM calculations [5].

Fe L₂,₃ EELS spectra from fine-grained matrix phyllosilicates in CM chondrites show mixed Fe²⁺/Fe³⁺ oxidation states with abundant Fe²⁺/ΣFe ~0.7 [4]. Fe L₂,₃ spectra from the irradiated/amorphized matrix phyllosilicates show higher Fe²⁺/Fe³⁺ ratios (Fe²⁺/Fe³⁺ ~0.52) compared to spectra obtained from pristine material at depths beyond the implantation/amorphization layer (Fe²⁺/Fe³⁺ ~0.28). Fe metal was not detected in the EELS spectra from the irradiated material.

We also obtained O K spectra from phyllosilicates in both regions of the sample. The O K spectra show a pre-edge feature at ~530.5 eV that is related to O 2p states hybridized with Fe 3d states. The intensity ratio of the O K pre-edge peak relative to the main part of the O K edge (that results from transitions of O 1s to 2p states) is lower in the irradiated layer compared to the pristine material and may reflect the loss of O (as OH) as was observed by IR spectroscopy.

Conclusions: Irradiation of Murchison matrix with 4 keV He⁺ produced several changes including: the amorphization of the phyllosilicates to a depth of ~200 nm, blistering and void/vesicle development at the surface, a loss of OH from the hydrated silicates, and partial reduction of Fe³⁺ to Fe²⁺ in fine-grained phyllosilicates. The lack of nanophase Fe metal in the irradiated materials suggests that the darkening and reddening observed in the near-IR is likely due to the surface roughness changes or possibly to Fe²⁺-Fe³⁺ charge transfer effects.