MICRO-FTIR IMAGING AND SPECTROSOCPY OF EXPERIMENTALLY SPACE WEATHERED CM2 CHONDRITE MURCHISON. T. D. Glotch[1], M. S. Thompson[2], C. A. Dukes[3], and M. J. Loeffler. [1]Department of Geosciences, Stony Brook University (timothy.glotch@stonybrook.edu), [2]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, [3]Laboratory for Atomic and Surface Physics, University of Virginia, and [4]Department of Astronomy and Planetary Sciences, Northern Arizona University.

Introduction: Space weathering is the collection of processes, dominated by micrometeoroid bombardment and solar wind sputtering and implantation, that act to alter the physical, chemical, and optical properties of airless body surfaces [1]. Space weathering processes lead to the formation of amorphous rims, vapor-deposited coatings, and nano- and micro-phase Fe^0 on mineral grains on airless body surfaces. The optical effects of space weathering have been well-studied at visible/near-infrared (VNIR) wavelengths for lunar and chondritic samples, but less is understood about the changes seen in mid-infrared spectra as a result of space weathering. In this work, we use micro-FTIR hyperspectral imaging to demonstrate the effects of space weathering at mid-IR wavelengths for the Murchison CM2 chondrite.

Methods: Three chips of the Murchison CM2 meteorite were experimentally space weathered using either nanosecond pulse laser irradiation, 1 keV H^+, or 4 keV He^+ irradiation [2]. Laser irradiation was conducted at Northern Arizona University by rastering a Nd-YAG nanosecond pulsed laser (λ=1064 nm, ~6 ns pulse duration, 48 mJ/pulse) over the sample one or two times). H^+/He^+ irradiation was conducted at the University of Virginia by exposing one side of the sample to 1 keV H^+ to a total fluence of 8.1×10^{17} ions/cm^2 using a flux of 1.9×10^{13} ions/cm^2/s. The other side of the sample was irradiated with 4 keV He^+ to a total fluence of 1.1×10^{18} ions/cm^2 using a flux of 1.0×10^{13} ions/cm^2/s.

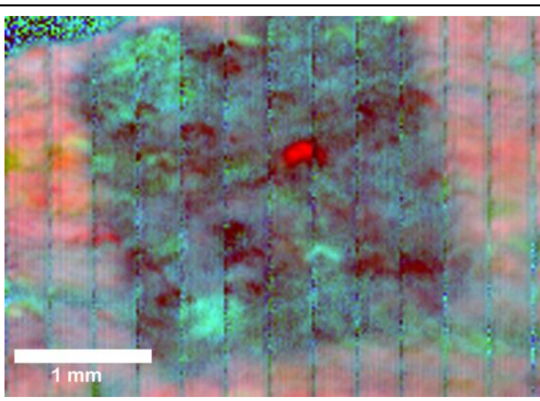

Figure 1. Composite micro-FTIR image of the 2x laser irradiated sample. The dark square in the center of the image denotes the portion of the sample that was irradiated.

Hyperspectral micro-FTIR images were acquired using a Nicolet iN10MX instrument equipped with a KBr beamsplitter and a 16 pixel MCT linear array detector. This instrument provides hyperspectral images over the ~650-4000 cm^{-1} spectral range at 25 µm/pixel spatial resolution. We acquired between 4 and 10 micro-FTIR images per sample and mosaicked them using the ENVI geospatial analysis software suite.

Results: A false color composite image of the 2x laser irradiated sample is shown in Figure 1. In this image, the red channel is the reflectance at 964 cm^{-1}, the approximate peak of the main silicate Reststrahlen band in the sample, although the center position of that band varies. The blue and green channels are band strength parameters for the main Reststrahlen band meant to show the variability in the position of that peak.

Clear spectral differences are apparent from this image. Overall, the experimentally space weathered portion of the sample is less red in this representation of the data. This indicates that that the laser space weathering reduces the overall IR reflectance of the sample. This is consistent with the results of [3], who demonstrated substantial reductions in Reststrahlen band strength for several experimentally space weathered carbonaceous chondrites. Figure 1 also demonstrates substantial spectral variability within the space weathered portion of the sample, suggesting a variable reaction to the laser space weathering treatment.

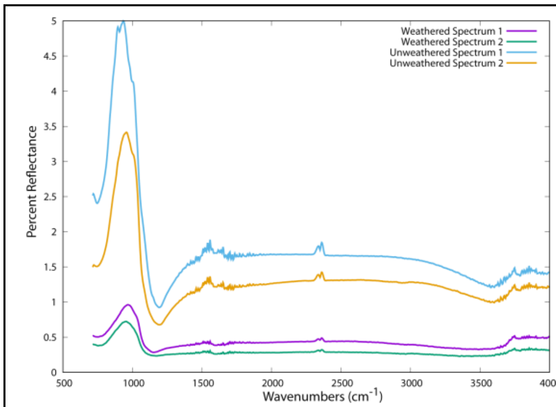

Figure 2. Representative Micro-FTIR spectra from inside and outside the weathered portion of the sample shown in Figure 1.

Figure 2 shows two spectra from inside and outside the weathered portion of the laser-irradiated sample. They are generally representative of the spectral variability of the sample. As suggested by the composite image in Figure 1, there is a strong difference in overall reflectance between the weathered and unweathered spectra, with the reflectance of the weathered spectra reduced by a factor of ~ 5x with respect to the unweathered spectra.

Figure 3 shows the same four spectra scaled to have about the same overall reflectance in the Reststrahlen band region. Several differences between the weathered and unweathered spectra become more apparent when viewing the scaled spectra: (1) The Christiansen feature positions (reflectance minima) for the unweathered spectra are nearly identical and occur at 1196 cm^{-1}. The CF positions for the weathered spectra are shifted to longer wavelengths/lower wavenumbers and occur at ~1174 and ~1150 cm^{-1}. This is consistent, for instance, with observations of CF shifting to longer wavelengths with increased maturity on the Moon [4-5]. (2) The Reststrahlen band maxima for the weathered spectra occur at shorter wavelengths/higher wavenumbers (962 and 969 cm^{-1}) than the unweathered spectra (934 and 956 cm^{-1}). This change is consistent with the shifts in Reststrahlen band position observed by [3]. (3) The shape of the 3-micron band changes dramatically upon weathering.

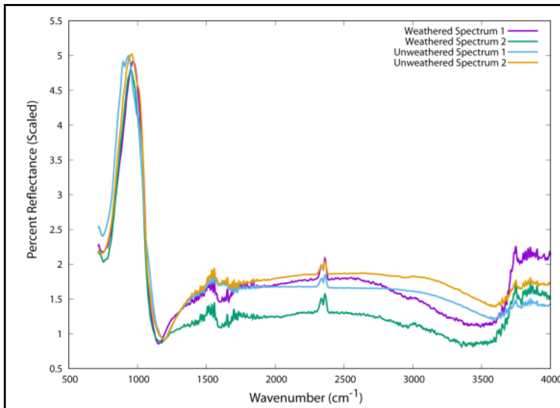

Figure 3. The same spectra as shown in Figure 2, scaled to have similar reflectance values at the silicate Reststrahlen band.

The absolute strength of the 3-micron band is reduced upon weathering (Figure 2), but it is clear that the feature is considerably broader in the weathered samples when viewing the scaled spectra (Figure 3). In both the weathered and unweathered spectra an aliphatic carbon band centered at ~2950 cm^{-1} is present, although its strength relative to the 3-micron band is greater in the weathered spectra.

Discussion and Future Work: Nanosecond pulse laser irradiation has long been used to simulate space weathering processes [e.g., 6]. This process has been shown to reproduce the visible/near-infrared (VNIR) spectral trends associated with natural space weathering processes. Here, we show that for a carbonaceous chondritic sample, clear spectral changes occur at near-to-mid-IR wavelengths upon simulated space weathering. These include the shifting of the CF to longer wavelengths, the shifting of Reststrahlen band center positions to shorter wavelengths, and dampening and broadening of 3-micron band.

These results show the effects of nano-second pulse laser irradiation of the Murchison CM2 carbonaceous chondrite. The weathered portion of this sample was irradiated twice with the laser. In future work, we will compare the spectral changes seen in this sample with any changes found in the laser irradiated (1x) sample and the H^+/He^+ irradiated sample. These results will provide new insights into the structural, physical, and optical effects of space weathering, and provide guidance in the interpretation of mid-infrared remote sensing measurements of carbonaceous chondrite asteroids [e.g., 7], and laboratory infrared analyses of returned samples from the Hayabusa2 and OSIRIS-REx missions.

References:[1] Pieters, C. M. & S. K. Noble (2016), *JGR Planets*, 121, 1865-1884. [2] Thompson M. S. et al. (2019) *LPS L*, Abstract 2045. [3] Brunetto, R. et al. (2020), *Icarus*, 345, 113772. [4] Glotch, T. D. et al. (2015), *Nature Comms.*, 6, 6189. [5] Lucey, P. G. et al. (2017), *Icarus*, 283, 343-351. [6] Sasaki, S. et al. (2001), *Nature*, 410, 555-557. [7] Hamilton et al. (2019), *Nature Astron.*, 3, 332-340.