INFRARED DARKENING OF OLIVINE FROM SIMULATED MICROMETEOROID IMPACT EXPERIMENTS J. M. Young[1], T. D. Glotch[1], C. Legett[1], and T. Munsat[2] [1]Stony Brook University – Department of Geosciences – 255 Earth and Space Sciences, Stony Brook, NY 11790 (jordan.young@stonybrook.edu) [2]Institute for Modeling Plasma, Atmospheres, and Cosmic Dust, University of Colorado, Boulder, CO

Introduction: It is well understood that surface materials on airless planetary bodies are affected by various astrophysical phenomena. These phenomena and the surface processes they cause are collectively referred to as space-weathering [1]. Space-weathering occurs as result of several processes including the exposure to solar wind and high-frequency radiation. Another important cause of the space-weathering of surfaces is micrometeoroid bombardment.The role of impacts in the context of large-scale events is fairly obvious. For example, large-scale impacts led to the formation of the mare basins on the lunar surface. The effects on surficial materials of airless bodies due to micrometeoroid impacts are less obvious but are still a large factor in surface evolution. Micrometeoroid impact flux near 1 AU has been estimated at a value of F $\simeq 1.5 \times 10^{-15}$ kg/m^2/s, delivering a total mass of on the order of 5 ton/year to the Moon [2]. (Grün et al., 1985) $6.688\text{x}10^{-6}$ g cm^{-2} s^{-1}, adding a mass of $1.8\text{x}10^{6}$ kg per year [2][3]. Micrometeoroids range in radii from submicrom to mm. There are several estimates regarding the mean impact velocity of micrometeoroids striking the Moon, which include 12.75 km s^{-1} [4] and 15.3 km s^{-1} [3] . Through high velocity and therefore high energy impacts, micrometeoroids are known to contribute to the space-weathering of materials via pulverization of existing mineral grains. On the lunar surface, continuous bombardment causes the comminution of larger grains into fine-grained lunar regolith. Due to the high-energy nature of these impacts, surface materials are frequently melted and vaporized as well. The weathering due to processes including micrometeoroid impacts also cause changes to infrared spectra. Spectral effects in the visible/near-infrared caused by space-weathering are well known and are threefold: (1) *darkening*, or the decrease in reflectance values at all wavelengths in a given spectrum, (2) *reddening*, or an increase in reflectance values at longer wavelengths relative to shorter wavelengths in a given spectrum, and (3) *band-dampening* where sharp spectral absorption features become progressively less pronounced. While well known, it is unclear and difficult to discern which space-weathering processes or combinations thereof cause a specific spectral effect. The goal of this work is to conduct simulated micrometeoroid impact experiments in order to understand the specific contribution that micrometeoroid impacts have on space-weathering spectral effects.

Methods: The goal of the impact experiments was to understand the effects that micrometeoroid bombardment has on surface materials of airless bodies. The materials chosen to be impacted were single crystals of olivine. For a first experiment, olivine, $(Fe,Mg)_2SiO_4$, a simple and common mineral phase in the solar system, was chosen. For this study, two thick sections of the same single crystal olivine grain were prepared. Both sections were highly polished as part of preparation. One olivine section was irradiated with 12 kEv protons at the Tandem Van de Graaf generator at Brookhaven National Laboratory and the other section remained unaltered. Infrared spectra were collected before and after proton bombardment and on the unaltered sample as well. Both thick sections were then mounted on aluminum slides to prepare for impact experiments. Impact experiments were conducted using the accelerator at the Dust Accelerator Lab (DAL) in the Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT) at the University of Colorado Boulder. The impactor material used for the experiments was synthetic olivine coated in the organic polymer polypyrrole. Due to experimental time constraints a group of impactors with size on the order of 10^{-7} meters, corresponding with a velocity range between ~1-10 km s^{-1}, were used. The distribution of impactor mass vs. velocity can be seen in Figure 1.

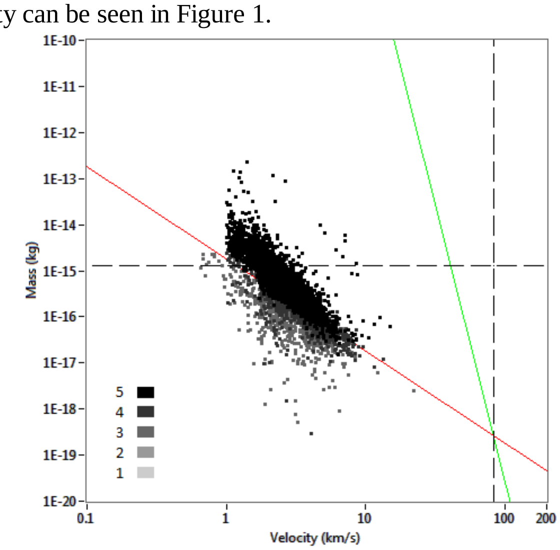

Figure 1. Impactor mass vs. velocity distribution. Darker points indicate multiple impactors with similar properties

For this experiment, accelerated dust particles traveled in a beam with a conic geometry terminating on the target samples in a circular cross-section with a diameter of ~1 cm. Impact density followed a Gaussian distribution profile with the highest density occurring in the center of the circular cross-section. For each experiment, approximately 10,000 dust particles impacted the target sample. As part of the experimental setup, a FieldSpec3 infrared spectrometer was used to collect spectra without removing samples from vacuum. White standards were collected before bombardment and at 5000 shots. Spectra were collected after every 1000 shots for a given experiment. After impact experiments were conducted, surface characterization methods, including Raman and infrared spectroscopy were carried out using a WiTEC alpha300R confocal Raman imaging system and a Nicolet iN10MX FTIR imaging spectrometer, respectively.

Results: Spectra collected from the irradiated olivine section and the unaltered section before micrometeoroid impact show interesting results. The spectra of both samples underwent both darkening and reddening. Several spectral features are less pronounced in the irradiated section spectrum. The most interesting result deals with spectral changes thought to have occurred during impact experiments. Spectra collected from the two olivine sections show major darkening at all wavelengths, save ~1.0-1.4µm. Sharp and pronounced features are seen in the spectra collected before impacts are observed to be broader and dampened in the post-impact spectra. These spectra can be seen in Figure 2.

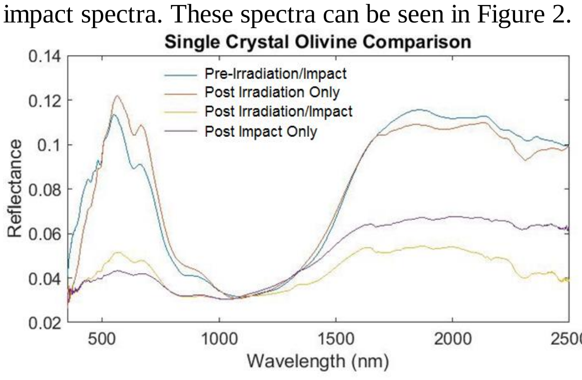

Figure 2. Infrared spectra collected from pre- and post-impact polished olivine sections.

Surface characterization observations via Raman imaging show highly damaged areas consistent with the center of the Gaussian distribution profile of the impact beam. In these areas, olivine spectra are noisy and have a spectral line shape dominated by fluorescence. This spectral signature is consistent with spectra collected from amorphous material. Raman spectra collected from highly damaged areas also identify the presence of carbonaceous materials as shown in Figure 3.

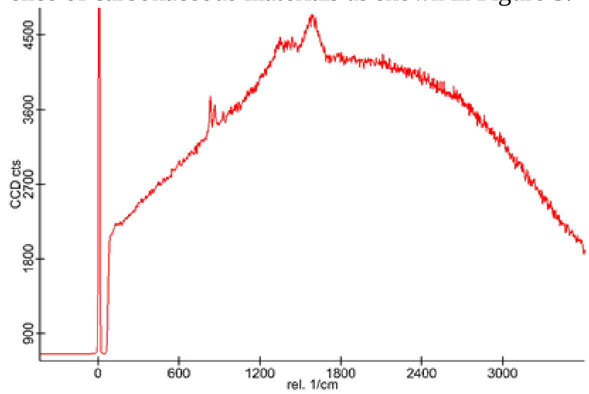

Figure 3. Raman spectrum collected from a highly damaged area of an olivine section. High fluorescence indicates the presence of amorphous material; doublet peaks at ~900 cm^{-1} are characteristic of olivine; peaks at ~1360 and ~1600 cm^{-1} indicate carbonaceous materials.

Discussion: Per the results of the preliminary impact experiments, we have found that high energy impacts have a significant darkening effect regarding the infrared spectra of single crystal olivine. Post-impact surface characterization shows that highly impacted areas on the olivine sections are flush with amorphous material and coated in carbonaceous material. The amorphous phases are likely the result of small-scale melting of the target olivine caused by impacts. The carbonaceous component observed in highly damaged areas is likely a derivative of the polypyrrole coating of the impactor material, deposited on the surface of the thick section after impact. If the carbonaceous material is responsible for the darkening observed, it would suggest that extremely small deposits of certain materials can have profound spectral consequences for surface materials on airless bodies. However, more surface characterization is required before the root cause of the observed darkening can be truly understood. At the time of writing, transmission electron microscopy of the the impacted samples is underway.

References: [1] Hapke (2001) *JGR*, *106*, 10039–10073. [2] Vanzani et al. (1997) *LPSC* [3] Cremonese et al. (2013) *A&A*, *551*[4] Cintala (1992) *JGR*, 97, 947