TOOLBOX FOR RESEARCH AND EXPLORATION (TREX): FACILITY FOR THE INVESTIGATION OF SPACE WEATHERING EFFECTS ON REGOLITH-LIKE LOOSE POWDERS. C. Jaramillo[1]*, J. P. Allain[1], D. Savin[2], N. Pearson[3], D. L. Domingue[3], and A. R. Hendrix[3], [1]Penn State University, Department of Nuclear Engineering (University Park, PA, *cxj5289@psu.edu), [2]Columbia University (New York, NY), [3]Planetary Science Institute, (Tucson, AZ).

Introduction: The Toolbox for Research and Exploration (TREX) is a node of NASA Solar System Exploration Research Virtual Institute (SSERVI). TREX (trex.psi.edu) aims to decrease risk to future missions, specifically to the Moon, the Martian moons, and near-Earth asteroids, by improving mission success and assuring the safety of astronauts, their instruments and spacecraft. TREX studies focus on characteristics of the fine grains that cover the surfaces of these target bodies – their spectral characteristics, the potential resources they may harbor, and the hazards they may pose to instrumentation and life-support. TREX studies are organized into four Themes: (1) lab studies, (2) lunar studies, (3) small-bodies studies, and (4) field work. As part of the third Theme, we focus on the instrumentation setup to carry out studies of solar wind-like ion bombardment on materials relevant to small-bodies, especially near-Earth asteroids (NEAs). The setup covers the preparation, irradiation, study and analysis of loose powders under inert conditions to limit the influence of air contamination on the surface of the samples. X-ray photoelectron spectroscopy (XPS) and reflectance studies of the ion-bombarded samples are used to evaluate the influence on the surface chemistry and the effects on reflectance spectra of the sample materials.

Background: The study of airless bodies highly relies on remote-sensing, especially examinations of reflected sunlight in the ultraviolet (UV), visible (vis), and infrared (IR) wavelengths. The surfaces being examined are also subject to space weathering processes, dominated by solar radiation and micrometeoric impacts. These processes induce changes in the chemical and physical properties of the surface with respect to the bulk properties of the airless body. Such changes include erosion, alteration of chemical bonds and modification of elemental composition by ion implantation or preferential sputtering [1].

Space weathering modifies the optical properties (alteration of bonds, modification of extinction coefficients, implantation of helium and hydrogen which induce chemical reactions, etc.) of materials that can result in the alteration of reflectance spectral properties. This oftentimes hinders the ability to properly identify the mineralogy (composition and relative abundance) of the surface of such bodies [2]. Space weathering can also produce some of the resources needed to further space exploration, such as producing OH through H implantation. Laboratory simulations of space weathering processes are essential in order to understand the nature of these modifications, to accurately interpret remote sensing observations, and identify regions of possible resources.

The solar wind, considered to be one of the two main agents of space weathering, mostly comprises hydrogen and helium ions. Its properties vary based on the distance from the sun. At the Earth orbit (1 astronomical unit (AU)), the solar wind has an average flow velocity of 440 km s^{-1} with typical proton densities of 8 cm^{-3} [3]. These conditions correspond to particle energies of ~1 eV amu^{-1} and fluxes of $0.4x10^{9}$ cm^{-2} s^{-1}. Laboratory space weathering simulations have been performed with 4 keV He ions [2], while other studies have focused on simulation of space weathering using light (H^+, He^+) and heavy ions (e.g. O^+, Ar^+, Fe^+) at higher energies (ranging from 20 eV to 600 eV) [4,5].

To conduct reliable laboratory simulations of space weathering by solar wind ions, the following are required: (1) regolith-like loose powders, (2) sample generation in an inert environment to avoid atmospheric contamination, (3) irradiation using solar wind-like conditions, and (4) *in situ* diagnostics to prevent atmospheric contamination of the irradiated materials.

Facility: The IGNIS (Ion-Gas-Neutrals Interaction with Surface) facility has the capability to meet the requirements listed above. A render image of this facility is shown in Fig. 1. IGNIS is a high vacuum facility, operating with nominal pressure values of ~10^{-9} Torr. It has a set of ion guns covering a wide range of fluxes (10^{13}–10^{16} cm^{-2} s) and energies (50-3000 eV). The guns can be operated with noble and reactive gas species (including hydrogen and helium). IGNIS is also an *in situ* characterization facility. The diagnostics tools include an XPS system. The XPS setup uses a soft X-ray source using aluminum K_α (1486 eV) or magnesium K_α (1253 eV) emission for excitation; and a hemispherical energy analyzer capable of performing angle-resolved energy and momentum analysis of electrons and ions. This surface sensitive technique is a powerful tool to study the elemental composition and chemistry state of the surface of materials exposed to ion bombardment.

IGNIS has also been adapted to perform *in situ* measurements of spectral reflectance on fine-grained loose powders . The reflectance spectroscopy setup uses a deuterium lamp (for the UV-vis spectrum) or a tungsten halogen lamp (for the near-infrared (NIR) spectrum) to illuminate the samples. The lamps are external to the irradiation chamber and illuminate the sample through a sapphire window. A spectrometer installed outside of the vacuum chamber is used to collect the reflected spectra through a fiber optic. For the UV-vis range, a spectrometer from Ocean Optics is used, whereas for the NIR region, a spectrometer from Analytical Spectral Devices is used. The setup enables studies of the reflected spectra on samples exposed to solar wind-like ion bombardment, while limiting the effect of air contamination on the sample surface.

A vacuum transfer protocol was established to prepare, transport, irradiate and study regolith-like loose powders while retaining inert conditions throughout these steps. The samples are prepared in a glove box under an inert environment, then transferred to a vacuum suitcase, where they are transported in high vacuum (10^{-7} Torr) to the irradiation facility. The vacuum suitcase was designed to be integrated with IGNIS, so that samples are transferred from the suitcase to the irradiation chamber *in vacuo*, protecting the samples from air contamination.

Preliminary results: The effect of hydrogen ion bombardment on the surface chemistry of olivine powders was studied. The ion beam characteristics were adapted to produce solar wind-like conditions (1 keV ions). The fluence was used as a control parameter. Irradiations with fluences in the range from 10^{18} to 10^{19} cm^{-2} were studied. XPS and reflectance spectra of the samples were recorded *in situ*. Ion bombardment and spectroscopy steps were alternated to assess the evolution of the surface chemistry and the reflectance spectra of the treated samples. These complementary *in situ* measurements allowed us to identify any existing correlation between the surface chemistry evolution–in the first 10-100 nm–and the reflected spectra of materials exposed to solar wind-like ion bombardment.

For the XPS measurements, full range spectra were obtained to monitor the presence of different chemical species on the samples, and to assess their elemental composition. Additionally, high resolution scans were performed on the region corresponding to the elements present in olivine (oxygen, magnesium, silicon and iron). Shifting and broadening of the photoelectron peaks vs. electron energy were an indication of the alteration of the chemical nature of the surface upon energetic ion bombardment. Figure 2 shows the peak evolution after ion irradiation of olivine powders performed in IGNIS. Peak deconvolution was performed to further analyze the changes in the surface chemistry.

References: [1] C.R. Chapman, Annu. Rev. Earth Planet. Sci. 32 (2004) 539–567. [2] M.J. Loeffler, C.A. Dukes, R.A. Baragiola, J. Geophys. Res. E Planets 114 (2009) E03003. [3] J.T. Gosling, Encycl. Sol. Syst. (2014) 261–279. [4] Z. Kaňuchová, R. Brunetto, M. Melita, G. Strazzulla, Icarus 221 (2012) 12–19. [5] J.M. Young, S. Singh, T.A. Byers, D.C. Jones, B. Rout, Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms 443 (2019) 79–83.

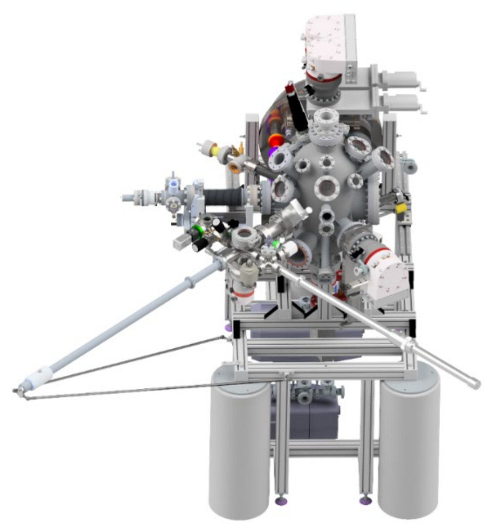

Figure 1: Rendering of the IGNIS facility with the vacuum suitcase integration system

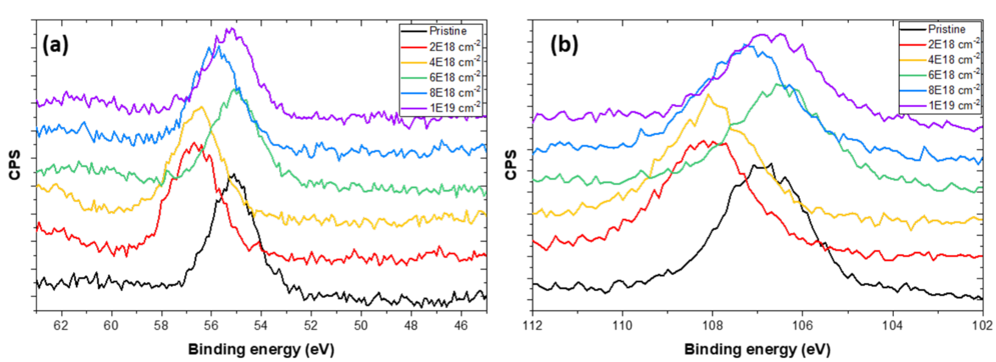

Figure 2: Evolution of surface chemistry shown by high resolution region XPS scans on ion irradiated olivine powder: (a) Magnesium 2p and (b) Si 2p peaks