An experimental approach to thermal and solar weathering of Mercury's crust. S. M. Brown[1] and L. T. Elkins-Tanton[2], [1]Massachusetts Institute of Technology (brownsm@mit.edu, 77 Massachusetts Avenue 54-825 Cambridge MA 02139), [21]Massachusetts Institute of Technology (ltelkins@mit.edu, 77 Massachusetts Avenue 54-824 Cambridge MA 02139).

Introduction: Mercury MESSENGER aims to map the composition of the crust. This composition has direct implications for the formation and evolution of the planet [1]. The instruments that will compositionally map the surface are calibrated with materials in an Earth environment. However, minerals on the surface of Mercury are periodically exposed to the solar wind (radiation) while being heated to over 700K and cooled to below 100K daily [2]. This extreme environment may have various effects, including creating differences in the spectral signature from that of a mineral taken in an Earth-environment, and provoking processes that form the Mercurian surface-bounded exosphere.

To understand how these effects will change interpretations of spectra taken from MESSENGER and to understand interactions between the space environment and the crust we are simulating the space-weathering environment on minerals we expect to find on the surface of Mercury.

We are analyzing our experiments compositionally, structurally, and spectrally. Here we present preliminary results from our compositional studies of grains irradiated for 12 hours. We will next characterize the effects of heat and irradiation on Mercurian crustal minerals.

The Mercurian exosphere is known to be composed of H, He, O, Na, K, Ca, Mg. There are various processes proposed to explain their presence, but we are most closely simulating the thermal evaporation and ion sputtering processes. Most likely, all these proposed processes work towards creating the exosphere (however, various models prefer specific processes (e.g. Burger et al. [3])). Photon-stimulated desorption (PSD) and thermal evaporation can release Na and K while ion sputtering and micrometeoroid impacts can release Na, K, Ca, and Mg. PSD and thermal evaporation are limited by diffusion, while micrometeoroid impacts and ion sputtering is limited by the flux of bombarding particles [4, and references therein]. These processes may interact with each other, i.e. defects generated by ion bombardment may be annealed out by high temperatures.

Samples: We use natural mineral samples that may reasonably be expected to mimic those on the surface of Mercury. We use an anorthoclase feldspar ($Ab_{73}Or_{22}An_{05}$) from Mt. Franklin, Daylesford, Victoria, Australia, a diopside clinopyroxene (Mg #= 63) from Gilgit-Baltistan, Pakistan, an enstatite orthopyroxene (Mg # = 99) from the Chandrika Wewa Reservoir, Sabaragamuwa, Sri Lanka. All of our grains have been reduced to a grain size of 0.85 – 1.18mm.

Irradiation: We use high-energy fast neutrons at the MIT Nuclear Reactor to simulate accelerated solar wind irradiation on Mercury. The larger flux and higher energy particles of the nuclear reaction allows us to accelerate sample radiation compared to Mercury surface conditions, simulating longer surface residence times on Mercury. The accelerated radiation in the reactor, however, may have different physical effects than what occurs on Mercury. Considering that the size of a proton (which is 99% of the solar wind [4, and references therein]) is comparable to the size of a neutron (used in the MIT Nuclear Reactor) and that neutron irradiation is thought to create proton irradiation and is also ionizing like proton irradiation, we believe that fast neutron irradiation is a good approximation for solar wind irradiation [5]. We can determine the relative amount of time on Mercury by using the energy parameter below, using a mean solar wind flux determined by Massetti et al. [6]:

$$E = \phi \cdot t \cdot e \quad , \qquad (1)$$

where E is the energy parameter, Φ is the flux of the energetic particle, t is the amount of time exposed to the flux, and e is the energy of the energetic particle. We equate energy parameters for Mercury and for the nuclear reactor to calculate the residence time on the surface of Mercury of one of our sample minerals. The nuclear reactor uses fast neutrons with an e of 1.4 MeV at an average flux (Φ) of 4×10^{12} cm^{-2}s^{-1}. The energy (e) of a proton is 1.3 keV, with a constant mean solar wind flux (Φ) of 4×10^{8} cm^{-2}s^{-1}. Twelve hours' irradiation in the nuclear reactor simulates about 10,000 Earth-years on the surface of Mercury.

Direct radiation on the surface of Mercury does not occur constantly or efficiently, and is thought to only effect the northern and southern latitudes, about 10% - 25% of the surface [4, and references therein]. For that reason, our estimate for the simulated irradiated time on Mercury is a minimum, as we assume a constant mean flux of solar wind. For example, if the solar wind only reaches the surface half the time (at the mean flux), then a 12 hr irradiation at the MIT Nuclear Reactor would be equivalent to roughly 20,000 years on the surface of Mercury.

Heating: We simulate the high temperatures on the surface of Mercury by heating up unirradiated and irradiated grains to temperatures hotter than those on Mercury, allowing us to accelerate thermal damage. We can determine the relative amount of time on Mercury by using the non-dimensional diffusion parameter γ and using parameters taken from Freer [7]:

$$\gamma = D_0 \exp(\frac{-Ea}{RT}) \cdot \frac{t}{a^2}, \quad (2)$$

Where D_0 is the maximum diffusion coefficient, Ea is the activation energy, R is the gas constant, T is the temperature, t is the time, and a is the radius of the grain. We equate γ for Mercury and for the furnace to calculate the residence time on the surface of Mercury of one of our sample minerals. For example, a 0.5 mm radius grain held at 1520 C for 1 day in our furnace equates to a 1μm radius grain on the surface of Mercury at 400 K for about 20 years.

Discussion and Conclusion: Data presented here is preliminary; this is an ongoing experimental study.

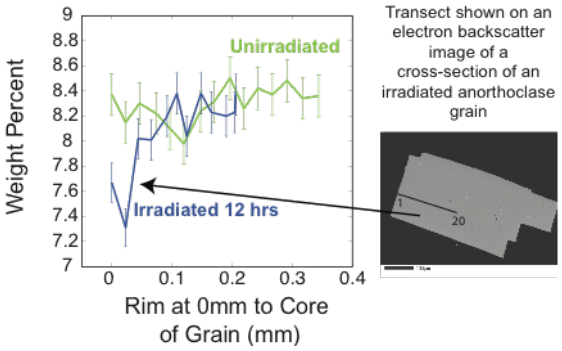

Figure 1 Example transect of Na_2O in an irradiated anorthoclase grain

Figure 1 shows data from minerals that have been irradiated for 12 hours in the MIT Nuclear Reactor. Using the MIT Electron Microprobe, we measure the composition of irradiated and unirradiated grains. To track the movement of species within the grains, we measure multiple transects from the rim to the core of each grain. The errors shown are 1 sigma uncertainty from the microprobe counting statistics.

To calibrate the damage of the irradiated grains, we need to characterize the distribution of species within the unirradiated grains (as they are natural samples, not synthesized). To illustrate this, Figure 1 shows a typical unirradiated grain that does not have constant sodium content from rim to core.

For each transect we calculate the difference of each oxide (in weight percent) between the average core composition and the average rim composition. Averaging all the differences of each transect results in the Table 1. Comparing the change in the difference allows us to see the effects of the radiation. We expect the rims to lose more species as they are exposed to radiation, so a positive increase in the Table 1 indicates a loss of that element from the rim.

Table 1 Average core minus rim (wt %). Important species are highlighted in yellow.

Anorthoclase	SiO_3	Al_2O_3	FeO	CaO	Na_2O	K_2O
Irradiated	-1.62	-0.45	-0.02	-0.01	0.25	0.03
Unirradiated	0.60	0.07	0.01	-0.01	-0.17	0.00
error	0.231	0.113	0.033	0.023	0.173	0.043

Enstatite	SiO_2	Al_2O_3	FeO	MgO
Irradiated	1.24	1.28	0.00	-2.61
Unirradiated	-0.02	-0.38	0.01	0.79
error	0.199	0.086	0.045	0.214

Diopside	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O
Irradiated	0.09	0.00	0.11	0.03	-0.07	-0.13	-0.03
Unirradiated	0.38	0.27	0.27	-0.05	-0.37	-0.45	0.14
error	0.177	0.019	0.185	0.050	0.084	0.131	0.041

From Table 1, our preliminary conclusions are (1) sodium is released during feldspar irradiation, which may be causing a relative increase in silica and alumina in the remaining grain (2) orthopyroxene retains its magnesium during irradiation and (3) calcium and magnesium are released during clinopyroxene irradiation, as the unirradiated grains show a high concentration of calcium and magnesium near the rim, and the irradiation process reduces this concentration significantly.

While these experiments do not simulate photon-stimulated desorption or micrometeoroid impacts, these conclusions may still apply to the formation of the Mercurian exosphere. Feldspars may provide much of the volatiles in the exosphere, such as sodium and potassium, while clinopyroxene may provide the more refractory species, such as calcium and magnesium.

Continuing Work: We are currently in the process of heating and irradiating (for 4 days) the remaining mineral grains. We will continue to compositionally map the damaged grains. We will also analyze the structures and the spectra of the damaged grains.

References: [1] Solomon S.C. (2003) *EPSL, 216*, 441-55. [2] Madey T.E. et al. (1998) *JGR, 103,* 5873-5887. [3] Burger M.H. et al. (2010) *Icarus, 209,* 63-74. [4] Killen R.M. et al. (2007) *Mercury, 433-509*. [5] Was G.S. et al. (2002) *J. of Nuclear Materials, 300,* 198-216 [6] Massetti S. et al. (2003) *Icarus, 166*, 229-237. [7] Freer R. (1981) *Contributions To Mineralogy and Petrology, 76,* 440-454.