SPACE WEATHERING OF GRAPHITE: APPLICATION TO MERCURY. D. Trang[1], P. J. Gasda[2], L. M. Corley[1], J. J. Gillis-Davis[1], and P. G. Lucey[1], [1]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Mānoa (dtrang@higp.hawaii.edu), [2]Los Alamos National Laboratory.

Introduction: The presence of carbon in Mercury's regolith and the intense space weathering across the surface may be a major contributor of Mercury's low surface reflectance [1–5]. Space weathering consists of various processes acting on the surface of an airless body such as micrometeoroid bombardment, diurnal heating, sputtering from solar wind and cosmic ray particles, and implantation of solar wind particles [e.g., 6,7]. In the lunar regolith, some of these processes create submicroscopic iron particles [8], which are a dominant optically active phase. The presence of these particles within agglutinates and glassy rims on mineral grains causes decreased reflectance, spectral reddening, and weakened absorption bands in the visible and near infrared [9]. The chemical nature of these particles is dependent on the mineralogy of the parent material. In contrast to the Moon, Mercury's surface has more carbon. The global estimated average graphite abundance on the surface is ~1 wt% [3] and up to 3 wt% in the Low Reflectance Material [4]. Exactly how carbon phases respond physically, chemically, and spectrally to space weathering is not well-understood.

Recent reported experiments, which mimic micrometeoroid bombardment with laser irradiation, simulated space weathering of pure graphite and showed that the graphite initially becomes nanocrystalline graphite. Further irradiation resulted in glassy carbon (3-coordinate carbon) and eventually amorphous carbon (4-coordinate carbon)—as confirmed by Raman spectroscopy [10]. These results may suggest that Mercury's regolith contains various forms of submicroscopic carbon particles. Another study, which did radiative transfer modeling of MESSENGER Visible-Infrared Spectrograph (VIRS) data, found that the data could not be modeled with only submicroscopic iron particles added to a bright neutral reflectance material [5]. Instead, they needed to include submicroscopic amorphous carbon in order to fit the VIRS data. This finding may support that with exposure to space weathering, graphite converts to submicroscopic amorphous carbon particles.

The purpose of this study is to use space weathering experiments to understand the physical and chemical changes of graphite when it is exposed to space weathering, to characterize space weathering related phase changes of graphite and to describe how these phase changes affect visible to near-infrared reflectance.

Methods: We used the space-weathering laboratory at the University of Hawai‘i featuring a 20 Hz, 1064-nm Nd:YAG pulse laser. The pulse duration is 6 ns (30 mJ/pulse) with a spot size of 200 µm. Our samples consisted of a loose powder that comprise of quartz and graphite mixtures (1, 3, and 5 wt% graphite) and pure graphite. We irradiated each sample for 20 minutes at 1-minute intervals in a vacuum with pressures between 10^{-5}–10^{-7} mbar at room temperature.

We measured the visible to near-infrared reflectance of each sample before irradiation and after irradiation using an Analytical Spectral Devices FieldSpec 4 spectrometer: with a spectral range of 0.35–2.5 µm with a spectral resolution of 3 nm for wavelengths <1 µm and 10 nm for wavelengths >1 µm. We acquired the spectra at standard viewing geometries — an incidence angle of 30° and an emergence angle of 0°.

Results: Before irradiation, the reflectance spectra of the quartz-graphite mixtures are flat with a slight blue slope (decreasing in reflectance with longer wavelengths) (Fig 1). After 20 minutes of irradiating the samples, we noted three spectral changes: 1) the reflectance decreases at all wavelengths by approximately 50%, 2) the reflectance becomes redder (increasing in reflectance with longer wavelengths), and 3) the appearance of a downturn or a steeper slope in the ultraviolet shortward of 0.40 µm (Fig. 1).

In contrast, after 20 minutes of irradiation, the pure graphite sample showed minimal changes. The reflectance increased at all wavelengths by ~1–2%, the continuum slope is nearly unchanged relative to the spectrum of the unweathered graphite, and the spectral contrast is similar to before irradiation (Fig. 2).

Discussion: From known effects of space weathering lunar regolith [e.g., 6,7,9], the results from our irradiation of the quartz-graphite mixtures agree with current understanding of space weathering effects on visible and near-infrared spectra such that the experimental spectra decreased in reflectance and became redder.

In the preliminary work by [10] of pure graphite, they suggest that the carbon phases transition from graphite, nano-crystalline graphite, and then glassy carbon. However, these transitions may be applicable to the graphite coatings, but not the phase of the submicroscopic particles embedded in glassy rims around silicate particles, such as our quartz-graphite mixture. It is possible that irradiating mixtures with graphite (e.g., quartz-graphite mixture) would only produce submicroscopic amorphous carbon particles [e.g., 5], but not any other carbon phase, such as submicroscopic graphite.

We tested if these phase transitions may be occurring within our samples by applying the radiative transfer technique similar to [5,11] to our spectra of irradiated quartz-graphite mixtures. We assumed a quartz host with either solely submicroscopic graphite, solely submicroscopic amorphous carbon, or a combination of submicroscopic graphite and submicroscopic amorphous carbon. We were not able to produce a satisfactory fit with only submicroscopic graphite or submicroscopic amorphous carbon, but the model spectra based upon a combination of the two carbon phases consistently fit the irradiated quartz-graphite spectra (Fig. 3). These model results suggest that laser weathering graphite produces multiple submicroscopic carbon phases. Therefore, the submicroscopic particles within Mercury's regolith may be present in various carbon phases.

In contrast to the quartz-graphite mixtures, the reflectance spectrum of the irradiated sample of pure graphite is nearly unchanged. The lack of darkening and reddening is because the irradiation either did not produce submicroscopic particles (i.e., submicroscopic particles consists of the same material as the medium) or the submicroscopic particles are not suspended in a transparent medium. In contrast to the quartz-graphite mixtures, the irradiation may have resulted in glassy silicate rims around quartz with the carbon embedded within the glass rims as submicroscopic particles.

Conclusions/Future Work: Our space weathering experiments indicate that irradiating graphite produced submicroscopic graphite and amorphous carbon, suggesting more than one carbon phase occurs on Mercury. We will need to perform more experiments at longer irradiation times and examine the samples using Transmission Electron Microscopy (TEM). The TEM will also be used to confirm the presence of glassy rims with submicroscopic graphite and amorphous carbon as well as their abundance.

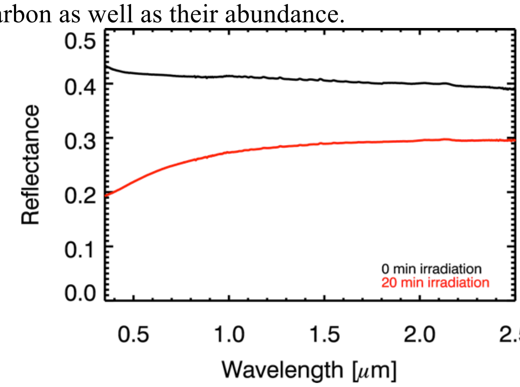

Fig. 1: Spectra of a quartz-graphite mixture (5 wt% graphite) where the black spectrum is the sample before irradiation and the red spectrum is the sample after 20 minutes of irradiation.

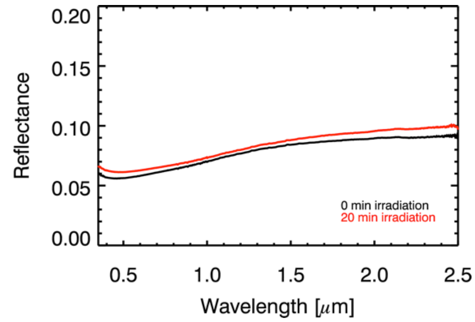

Fig. 2: The black spectrum is the unirradiated pure graphite and the red spectrum is the irradiated graphite.

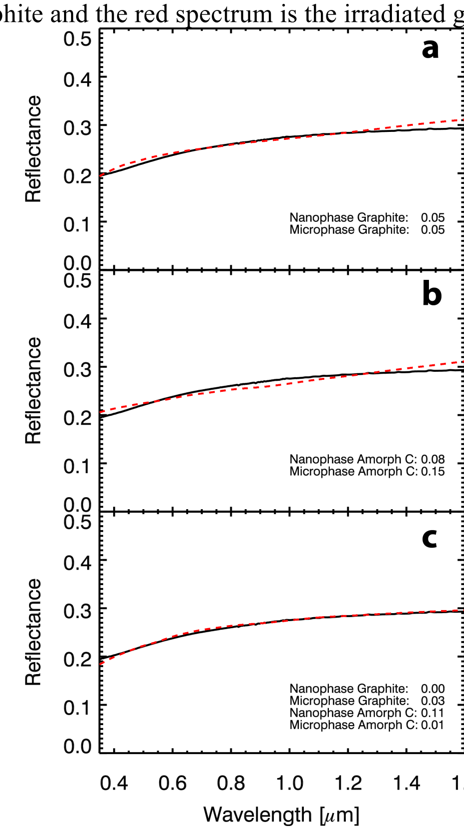

Fig. 3: Spectral models to a spectrum of an irradiated quartz-graphite sample (5 wt% graphite). a) model with submicroscopic graphite, b) model with submicroscopic amorphous carbon, c) model with submicroscopic graphite and amorphous carbon

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