A PRELIMINARY LOOK AT SPACE WEATHERING ON 101955 BENNU: A RADIATIVE TRANFER MODELING PERSPECTIVE. D. Trang[1], L. P. Keller[2], H. C. Connolly[3], B. E. Clark[4], V. E. Hamilton[5], K. J. Walsh[5], D. S. Lauretta[6] and the OSIRIS-REx team, [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i (dtrang@hawaii.edu), [2]NASA Johnson Space Center, [3]Rowan University, School of Earth and Environment, [4]Ithaca College, [5]Southwest Research Institute, [6] Lunar and Planetary Laboratory, University of Arizona

Introduction: The surfaces of airless bodies, such as 101955 Bennu, are vulnerable to micrometeoroids, high-energy particles, and solar wind particles [1–4]. As a result, material on the surface of these bodies experience physical and chemical changes that are collectively known as space weathering. Space weathering processes result in the production of sub-micron-sized particles called submicroscopic particles. There are two types of submicroscopic particles, nanophase (<33 nm in size) and microphase particles (>33 nm in size) [5,6]. Studies of lunar samples show that nanophase particles occur within the glassy rims that surround grains and agglutinates [7]. In contrast, microphase iron particles occur only within agglutinates. Another important difference between these two particles is that nanophase and microphase particles affect visible to near-infrared reflectance spectra differently [5,6]. From lunar samples, the presence of nanophase particles in a regolith causes the regolith's reflectance spectrum to darken and redden, whereas the presence of microphase particles in a regolith causes it to only darken. In addition, the reflectance spectra of submicroscopic particle-bearing regolith exhibit weakened absorptions and spectral features. Lantz et al. (2018) found that these particles also affect spectral curvature [8]. By taking advantage of these spectral characteristics, with global spectral data, it is possible to model the nanophase and microphase particle abundances across a planetary surface resulting in the production of global space weathering maps [e.g., 9,10].

The composition of the nanophase and microphase particles on the Moon is dominantly native iron due to its mineralogy of the regolith [e.g., 11]. On other airless bodies, the composition of these submicroscopic particles includes other phases (mainly sulfides) because of the differences in regolith mineralogy. The Hayabusa mission returned samples of the S-type asteroid, Itokawa. Analyses of the rims of the grains showed the presence of nanophase iron particles, but also nanophase iron sulfides (troilite) [12,13]. In a spectral modeling study, Trang et al. [9] found that the reflectance spectra of Mercury could not be modeled with only nanophase and microphase iron, but required the addition of nanophase and microphase amorphous carbon, which originated from the presence of graphite on Mercury's surface [9]. Because the composition of Bennu is consistent with carbonaceous chondrites [14] with a mineralogy widely different from the Moon, the effects of space weathering on Bennu likely resulted in the production of nanophase and microphase particles composed of material other than just iron. Thompson et al. (2017) simulated space weathering on a CM2 carbonaceous chondrite, a composition likely to be similar to Bennu, by laser irradiation on a chip of the Murchison meteorite [15]. They found that the nanophase particles also came as troilite, pentlandite, and magnetite.

The goal in this study is to use radiative transfer modeling [i.e., 6,11] to understand the spectral characteristics of nanophase and microphase troilite and magnetite, which will provide insight on how space weathering affects the visible to near-infrared spectra of Bennu. The second goal of is to apply the radiative transfer technique to model the OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) data (only 0.4–1.1 μm due to limitations from optical constants) to obtain the abundance of nanophase and microphase particles on Bennu's surface. From this, we will be able to create a radiative transfer-based space-weathering map. This is similar to the work of [9,10], where they created global space weathering maps of the Moon and Mercury. This work will focus on the first goal.

Methods: We used the radiative transfer model developed by [16,17], which was modified to be able to model nanophase [11] and microphase particles [6]. To use this model, we need to make several assumptions of the surface and regolith. First we assume that the surface consists of 15 μm grains on both the ground and on boulders. These grains, which we will call the host particle, contain nanophase particles on the rims of the grain and microphase particles within agglutinates. We also assume that the host particles are silicates with an FeO abundance of ~20 wt%, based upon the abundances in CM and CI meteorites [18]. Trang and Lucey (2019) created a model to estimate a reflectance of silicate particles based upon its FeO content [10], for this model, our grains will have a reflectance between 5–15% assuming an incidence and emission of 30° and 0°, respectively (**Fig. 1a**). We assume that three different types of nanophase and microphase particles are present on Bennu, iron, troilite, and magnetite, based upon the findings of Thompson et al., (2017). We did not include pentlandite due to the lack of optical constants of this mineral.

Afterward, we create a spectral library containing thousands of model reflectance spectra with different abundances of nanophase and microphase particles. The model spectra represent regolith containing host particles with different combinations and at varying abundances (from 0–1.5 wt% at intervals of 0.1 wt%) of nanophase and microphase iron, troilite, and magnetite abundances.

Results: We examined the effects of 1 wt% nanophase and microphase particles on visible to near-infrared spectra. The spectral effects of nanophase iron exhibit slight reddening and darkening (**Fig. 1a**). In contrast, the microphase iron causes darkening and very slight bluing as there is an increase in darkening at longer wavelengths than at shorter wavelengths. As for troilite, the nanophase and microphase troilite show similar characteristics, more bluing than reddening and the nanophase troilite causes the spectrum to darken more overall than the microphase troilite particle. As for the nanophase and microphase magnetite, they show similar characteristics in the magnitude of bluing and darkening.

Discussion: In this work we observe that the microphase iron particles causes slight bluing. To understand this bluing, we compared it to a spectrum of a bright neutral host (i.e., quartz) containing microphase iron (**Fig. 1b**). We observe that with 0.1 wt% microphase iron, the spectrum is darker with almost unnoticeable bluing. This indicates that the bluing is more obvious with darker hosts because of the smaller range in reflectance. In contrast, microphase troilite shows significant amounts of bluing even when located in a quartz host (**Fig. 1b**) (by about 10% between 0.4–1.1 µm), whereas nanophase troilite still reddens the spectrum. Microphase magnetite with a quartz host shows darkening through the visible and near-infrared, but the nanophase magnetite shows bluing (**Fig 1b**). From these comparisons, we suggest that the continuum slope direction is dependent on the mineral of the submicroscopic particle. Furthermore, it appears from the comparison between nanophase troilite in a 20 wt% FeO silicate host to a quartz host show that the magnitude of the reddening and the direction of the continuum slope (reddening versus bluing) is dependent on the host particle as well.

These findings have implications to both observations of carbonaceous asteroids, such as Bennu, and experimental space weathering in the laboratory. While some studies have reported that asteroid surfaces become bluer with longer exposure to space weathering, others have observed reddening [15,19–21]. From using the radiative transfer model, we find that both reddening and bluing is possible and is dependent on the mineralogy of the host and the nanophase and microphase particles.

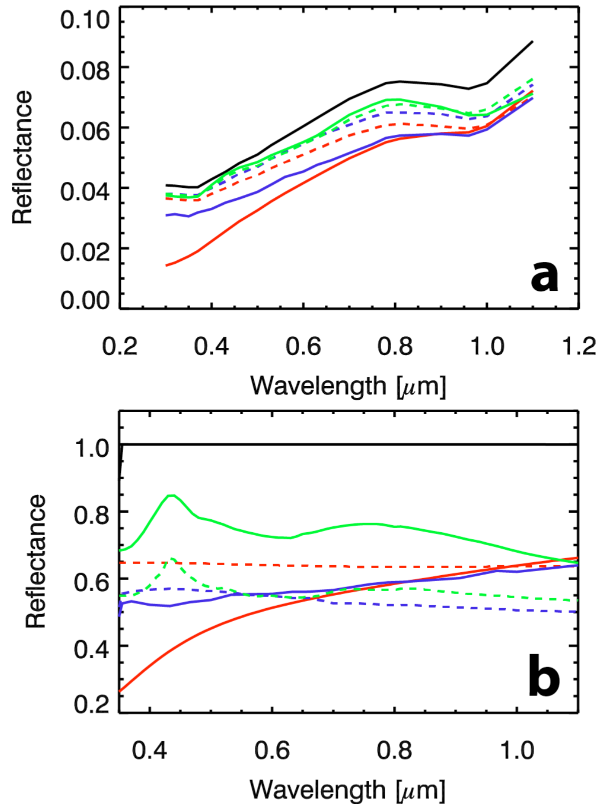

Fig. 1 Model spectra of (a) a silicate host with 20 wt% FeO or (b) quartz (black solid). The color spectra includes nanophase (colored solid) and microphase (colored dotted) iron (red), troilite (blue), and magnetite (green). In (a) the nanophase and microphase particle abundance is 1 wt% and in (b) it is 0.1 wt%

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