EXPLORING THE USE OF T-MATRIX/RADIATIVE TRANSFER HYBRID MODELS FOR FINE PLANETARY PARTICULATES IN THE MID-INFRARED. G. Ito[1] and T. D. Glotch[1], [1]Stony Brook University, 255 Earth and Space Sciences Building, Stony Brook, NY 11794-2100 (gen.ito@stonybrook.edu).

Introduction: Remote sensing using mid-infrared (~5-50 μm) wavelengths has been useful in exploring planetary surfaces (e.g. Thermal Emission Spectrometer for Mars). This wavelength range is suited for quantitative analysis of bulk silicate mineralogy. Composition of surface materials can be derived from mid-infrared emissivity spectra with the assumption that spectral endmembers add linearly to produce observed spectra. This assumption is applicable to bulk rocks and particulates large compared to the wavelength of light. A major difficulty occurs for particulate surfaces with particle sizes on the order of the wavelength of light used in remote sensing, which are abundant in the Solar System. Non-linear particle size effects are observed in spectra, and composition cannot be accurately derived unless this effect is well understood and modeled.

Different light scattering models have been proposed to capture the non-linear particle size effect on spectra. Previous models, mainly Mie/radiative transfer hybrid models, have achieved some success, but they are not satisfactory enough to be useful for applications to real remotely sensed data.

More accurate light scattering models are necessary, and we search for better models using a combination of radiative transfer and T-matrix models. The T-matrix method is known to better capture multiple scattering effects for closely packed particles [1]. We couple the two to make hybrid models and evaluate how well T-matrix/radiative transfer hybrid models can capture non-linear multiple scattering due to fine particle sizes.

Methods: We test 3 hybrid models: T-matrix combined with radiative transfer models from Conel (1969) [2], Hapke (1993) [3], and Hapke (1996) [4]. T-matrix computation provides the scattering parameters necessary for these radiative transfer models to calculate emissivity spectra. We use Multiple Sphere T-Matrix (MSTM) code [5] for T-matrix computation.

The T-matrix method requires optical constants of relevant materials and coordinate positions of particles. We start with the simplest case, spherical particles in a spherical cluster with all particles having the same diameter. We use optical constants of enstatite provided by Rucks and Glotch (2014) [6]. Enstatite has three principle indices of refraction, but each particle in the MSTM code can only take one index of refraction, therefore, the 3 indices must be assigned with some proportion to the particles in a cluster. The contributions of each of the 3 indices of refraction to the emissivity spectrum of a particulate mixture were calculated by first measuring emissivity of coarsely ground enstatite (same sample used in [6]) (>500 μm), and then inputting that emissivity into a linear retrieval algorithm [7] with synthetic oriented enstatite spectra calculated from the optical constants used as the library spectra.

Mie/Conel, Mie/Hapke (1993), and Mie/Hapke (1996) hybrid models were also computed. Mie hybrid models have been used widely and provide useful reference to compare and evaluate the outcomes of T-matrix hybrid models.

The enstatite sample used to obtain optical constants by [6] was ground into powders and sieved into particle sizes of <10, 45–63, 63–90, 90–125, and 125–250 μm. The size distributions of these sieved enstatite particles were measured using a laser diffractometer. The means of each of the size ranges measured from laser diffractometry were used to set the diameters of particles in T-matrix and Mie hybrid models.

Results: Computational and laboratory emissivity spectra are plotted in **Figure 1**. Emissivity spectra using 3 T-matrix hybrid models and 3 Mie hybrid models were computed for 4 particle sizes.

In laboratory spectra, the decrease in the strength of major Reststrahlen bands (at ~850−1150 cm^{-1} and at ~500 cm^{-1}) with decrease in particle size is evident. The appearance of a transparency feature at ~800 cm^{-1} is also observable as particle size decreases.

T-matrix hybrid models produced almost featureless spectra for the finest particle size between 400 and 1300 cm^{-1}, which is in relatively satisfactory agreement with the laboratory spectra. Outside of these wavenumber ranges, the modeled spectra are not in good agreements with the laboratory spectra. For larger particle sizes, the general patterns of T-matrix hybrid model spectra are consistent, but the magnitudes differ, particularly observable at Reststrahlen bands and the transparency feature.

Mie hybrid model spectra for the finest particle size contain overestimated transparency feature at ~800 cm^{-1}. The agreement with the laboratory counterpart is slightly less than that of the T-matrix hybrid models, but the trend follows a similar pattern. For larger particle sizes, the general patterns of Mie hybrid models relatively match those of laboratory, and especially good agreements are observed at wavenumbers above 1200 cm^{-1} for Mie/Conel (1969) and Mie/Hapke (1996) models.

Discussions: At this stage, T-matrix hybrid models show advantage over Mie hybrid models for the smallest particle size fraction. T-matrix hybrid models are able to avoid the overestimation of the transparency feature at ~800 cm^{-1} seen in Mie hybrid models.

For larger particle sizes, T-matrix hybrid models are underperforming. The magnitudes of Reststrahlen bands are not as well modeled as the Mie counterpart, and the effect of particle size on spectra are minimally captured.

Out of the 3 radiative transfer models, Conel (1969) and Hapke (1996) models produced the most consistent spectra with laboratory counterparts for all particle sizes. This is likely due to the fact that these two models better approximate laboratory setting than Hapke (1993) model.

We believe that filling factor is playing a major role in T-matrix hybrid models. For this work, filling factor of ~0.6 was chosen somewhat arbitrarily as a test case. Decreasing the filling factor could improve modeling, particularly where emissivity was overestimated, such as Reststrahlen bands.

Conclusions: This work explored the applicability of T-matrix/radiative transfer hybrid models in producing emissivity spectra of ground enstatite. Our initial work showed some advantages over widely used Mie/radiative transfer hybrid models. Spectra from T-matrix hybrid models are potentially being influenced by filling factor, particle size distribution, and particle shapes; we will experiment with these parameters in upcoming works to more fully evaluate the performance of T-matrix hybrid models.

References: [1] Mishchenko M. I. (2008) *Rev. Geophys.*, 46(2). [2] Conel J. E. (1969) *JGR, 74*, 1614–1634. [3] Hapke B. W. (1993) *Cambridge Univ. Press*, New York. [4] Hapke B. W. (1996) *JGR, 101*, 16817–16832. [5] Mackowski D. W. and Mishchenko M. L. (2011) *J. Quant. Spect and. Radiative. Transfer, 112*, 2182–2192. [6] Rucks M. and Glotch T. D. (2014) *AGU Fall Meeting*, Abstract #P23B-3987. [7] Ramsey M. S. and Christensen P. R. (1998) *JGR, 103(B1)*, 577–596.

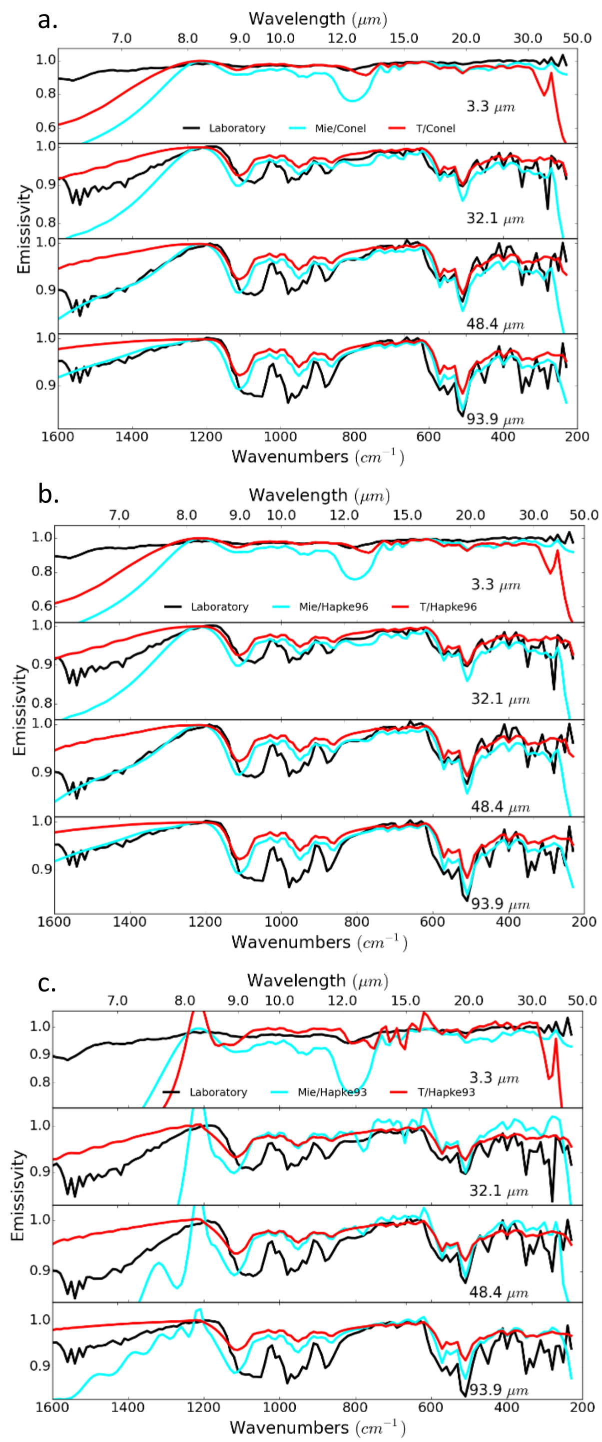

Figure 1. Computational and laboratory emissivity spectra of enstatite particulates. Models used in computation are T-matrix and Mie models coupled with radiative transfer models of a. Conel (1969), b. Hapke (1993), and c. Hapke (1996). Each plot contains spectra for 4 different size fractions where means of each size range, measured in laser diffractometry, are indicated.