A RADIATIVE TRANSFER APPROACH TO CHARACTERIZING THE OPTICALLY THIN DUST SPECTRAL COMPONENT IN MINI-TES OBSERVATIONS OF THE MARTIAN SURFACE. F. Rivera-Hernández[1], J. L. Bandfield[2], S. W. Ruff[3], M. J. Wolff[2], [1]Earth and Space Sciences, University of Washington, Seattle, WA 98195-1310; riveraf@uw.edu, [2] Space Science Institute, [3]School of Earth and Space Exploration, Arizona State University.

Introduction. A spectral contribution different from that observed for thick dust mantles (Fig. 1) has been identified in many of the *in-situ* measurements of rocks and soils acquired by the Miniature Thermal Emission Spectrometer (Mini-TES) instruments on the Mars Exploration Rovers (MER) [1-3]. This spectral contribution is thought to be caused by thin mantles of dust (TMD) and is referred as the optically thin dust contribution by [2,3]. If not corrected, the additional contribution to the spectra caused by TMD can greatly hinder the mineralogical interpretation of rock surfaces [3]. Although these effects have only been recently identified in Mini-TES data, they are likely to be present in thermal infrared spectroscopic measurements (TIR; ~200 to 2000 cm^{-1}) of other Solar System bodies.

The focus of this study is the characterization of key radiative processes that are necessary to understand the spectral features produced by TMD in Mini-TES observations. An understanding of the underlying physics of TMD in TIR spacecraft and laboratory measurements is important to be able to reproduce, predict, and correct their contribution in TIR datasets.

Spectral effects of thick dust mantles. Previous investigations using TIR spectroscopic measurements of dust coated rocks have shown that a decrease in spectral contrast occurs with thicker dust coatings present on a rock surface [3-5]. If sufficiently thick, the dust can obscure the spectral signature of the rock, and the spectral signature of the dust dominates the TIR spectrum. These studies indicate that the dust and substrate spectral signatures mixed in a simple "checkerboard" fashion [4, 5]. Thick mantles of dust can be easily modeled as a linear combination of uniformly clean and dusty surfaces.

Spectral contribution of thin dust mantles. The spectral contributions from TMD are different from the spectral features that are documented for thick accumulations of dust in laboratory and spacecraft TIR spectroscopic measurements. Instead of blocking the radiance emitted from the underlying surface in a checkerboard fashion the dust acts as an absorber and emitter and contributes spectral features at specific wavelengths in which the dust is optically active. Radiatively these spectral features are similar to those produced by atmospheric dust and were initially attributed as such in Mini-TES data by [1]. However, the magnitude of the spectral features can not be accounted for solely by atmospheric dust and they do not display the features of atmospheric CO_2, that should also be present if the spectral features are due to radiance originating from the atmosphere [2,3].

If a dust layer is thin enough so that the dust particles are loosely stacked and sufficiently separated from one another, then the surface dust could behave in a similar manner to atmospheric dust. Furthermore, if the dust is mantling a high conductivity surface, such as a rock, it would be relatively easy to maintain a large temperature difference between the dust (which is mostly in contact with the surrounding air) and the underlying rock. In theory, this temperature contrast may be easier to achieve on Mars where the thermal conductivity of the atmosphere is significantly lower then Earth's.

Regardless, the temperature contrast between TMD and the underlying surface doesn't appear to occur in natural settings or the laboratory on Earth. This makes it difficult to reproduce these effects in the laboratory at Earth's atmospheric pressure, requiring dust to be deposited on thermally isolated mirror surfaces instead of directly on the substrate.

Methodology: Laboratory measurements [6] and radiative transfer modeling are used to reproduce and quantify the spectral effects caused by TMD observed in spacecraft and laboratory measurements. Here we focus on our radiative transfer modeling efforts.

Radiative transfer modeling. Qualitatively, when measuring emitted radiance from a surface in the TIR spectral range, we want to know how the emitted radiance is modified from the source to the detector. If there is a layer of dust, in the field of view of the detector, the dust will interact with the radiance emitted by the underlying surface (either through absorption and/or scattering) and the radiance measured by the detector will now have contributions from both the dust and the underlying surface. The dust can also emit its own radiance. The change in radiance due to these interactions can be calculated using the azimuthally averaged radiative transfer equation (RTE) for a plane parallel medium that is absorbing, scattering and emitting radiance.

Various approximations to the RTE were explored to calculate modeled radiances to test their robustness compared to TIR laboratory measurements of dust coated surfaces [7,8]. The primary difference between these models is how they approximate the scattering component of the RTE. The scattering contribution to the RTE is where most of the complexity in radiative transfer theory lies. Here we present initial results of two of these models; the case were scattering is neglected and a two-stream approximation [7].

Model set-up. We start with a simple model of a thermally isolated layer of spherical particles on or above a basaltic rock surface emitting radiance at a given temperature. Laboratory TIR measurements of a clean basaltic rock were used for the input radiance for the underlying surface. The basaltic rock is broadly similar in composition to Adirondack-class rocks with dust coatings on Mars [1,3]. The dust particles are modeled at a distinct temperature from the underlying rock and assumed to be isolated spheres so that Mie theory can be used to calculate scattering parameters (*e.g.*, single scattering albedo) that are necessary to solve the azimuthally averaged RTE [7-9]. If the thin mantles of dust are indeed behaving in a manner similar to atmospheric dust then this assumption should be adequate and accounting for near-field interactions is not necessary. The scattering parameters can be calculated for either a single particle size or for a particle size distribution.

Preliminary modeling results. Preliminary modeled brightness temperatures of a basaltic rock surface mantled by a thin layer of Montmorillonite dust show spectral behavior similar to that seen in Mini-TES data (Fig. 2). Optical constants for Montmorillonite [10] were used to calculate the scattering parameters and a gamma function with an effective radius of 2 µm and an effective variance of 0.4 were used to describe the particle size distribution of the dust. The optical thickness of the dust layer at ~1000 cm^{-1} is 0.258. Although Montmorillonite is a poor mineralogical match to the martian dust, its spctral features have broad similarities that are useful for our purpose of characterizing the spectral effects of TMD.

One of the main assumptions of our current model is that the dust particles are thermally isolated spheres so that Mie theory can be used to calculate the scattering parameters. However, in reality scattering interactions between the dust and the substrate might have effects that Mie theory does not account for and a more complex scattering theory might need to be employed [11].

Conclusions: Dust coatings can have dramatic and complex effects on TIR spectra. Our model appears to reproduce these effects to a good first order and can quantify the relationship between dust coatings and measured radiance. There is much that is still not understood about how thin mantles of dust effect TIR measurements and our initial investigation is a starting point into understanding these effects.

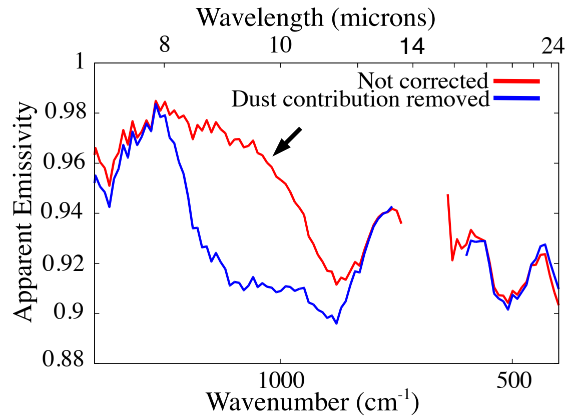

Figure 1. Mini-TES spectra of Adirondack Class olivine-rich basalts. The emission feature at 8-12 µm coincides with an absorption feature of Olivine-rich basalt. Without correction the composition would not be clearly identifiable.

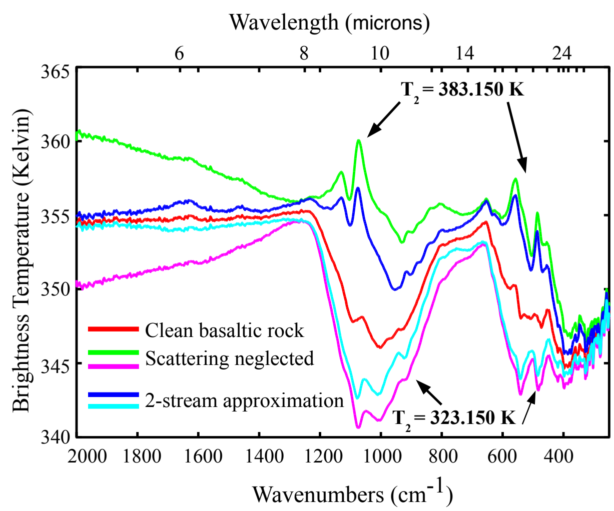

Figure 2. RTE modeling. Arrows point to features similar to those caused by TMD in Mini-TES observations. The average brightness temperature of the rock is 349 K. T_2 is the temperature of the dust.

References: [1] Ruff, S.W., et al. (2006) *JGR*, 111, 1210.1029/2006JE002747. [2] Ruff, S.W. and Bandfield, J.L. (2010) *LPSC,* 41, 2411. [3] Hamilton, V.E. and Ruff, S.W. (2012) *Icarus*, 218, 2, 917-949, 10.1016/j.icarus.2012.01.011. [4] Johnson, J.R., et al. (2002) *JGR*, 107, 503510.1029/2000JE001405. [5] Graff, T. (2003) M.S. thesis, Arizona State University. [6] Rivera-Hernandez, F., et al. (2013) *LPSC*, 44, 2674. [7] Li, J and Fu, Q. (2000) *J. Atmos. Sci.*, 57, 2905–2914. [8] Stamnes, K., et al. (1988) *Applied Optics*, 27, 12, 2502-2509. [9] Maetzler, C., (2002) University of Bern, Research Report No. 2002-08. [10] Glotch, T. D., et al. (2007) *Icarus*, 192, 2, 605-622. [11] Mackowski, D. W. (2008) *J. Quant. Spec. and Rad. Transfer*, 109, 5, 770-788.