

NANOPHASE IRON THAT DARKENS BUT DOES NOT REDDEN: A MIE-HAPKE MODEL. Paul G Lucey¹, ¹ Hawaii Inst Geophys & Planetology, 1680 East-West Road, University of Hawaii, Honolulu, HI, USA, lucey@higp.hawaii.edu.

Introduction: The optical effects of exposure of lunar materials to space are well-characterized (e.g [1]) and similar effects are expected on Mercury and proposed for asteroids. In the lunar case perhaps the most notable effect is strong reddening of lunar materials relative to powdered lunar rocks. There is consensus that this is due to the optical effect of extremely fine grained (10's of nm) nearly spherical particles of iron that occur in rims on mineral grains generated during micrometeorite impact and sputtering [2]. Noble et al. 2007 [3] did an experimental study of the effect of very fine grained iron metal by preparing silica gel samples infused with fine grained iron and showed lunar-like optical effects of under some ranges of iron particle size and abundance. Hapke 2001 [4] used Maxwell-Garnett equivalent theory to combine the optical properties of iron metal with the optical properties of the host lunar material to successfully produce the reddening and darkening effects observed using the optical influence of the fine-grained iron. Lucey and Noble 2008 [5] tested the Hapke 2001 formulation against the Noble et al. (2007) data and found good agreement when particles were small with respect to the wavelength. However, particles that were larger than about 50 nm showed sharp deviations from the predictions of the Hapke 2001 treatment.

Subwavelength iron particles are clearly important in understanding space weathering on the Moon and by extrapolation elsewhere, but by mass the major products of lunar space weathering are glass-welded aggregates of minerals called agglutinates. Agglutinates, formed by local melting of lunar soil during micrometeorite bombardment, can comprise up to 60 percent of lunar soil, and about half of each agglutinate is composed of dark, relatively spectrally neutral impact melt glass. Agglutinate glass is rich in tiny iron grains, but TEM imaging shows these particles to be much larger than those in the vapor/sputtering rims; presumably the agglutinate glass iron spheres are formed from the iron metal in the vapor deposited rims that have aggregated during the melting process. This darkening without reddening is consistent with the darkening due to iron particles in shocked chondrites [6].

In a variety of efforts to model the spectra of lunar and asteroidal regoliths, (e.g. [4],[7]) all included empirical parameters to represent the darkening effect of agglutinates that is required to match both the red slope of a spectrum as well as the albedo of the soil. At present there is no theoretical treatment of iron metal inclu-

sions that darken, but do not redden. That is the subject of this abstract.

Model: The Hapke 2001 formulation for modeling the optical effect of iron particles within grains relates the complex index of refraction of the host mineral, iron and particle size of the host to the single scattering albedo to account for absorption due to subwavelength particle inclusions, and adds this to his previously defined absorption coefficient. This absorbing effect, based on equivalent medium Maxwell-Garnett theory, assumes the particles are much smaller than the wavelength, and hence has no particle size dependence. While [5] showed Hapke's model for space weathering works well for very small particles, the larger particles in the Noble et al. 2007 experiments did not conform well to predictions.

To introduce a wavelength dependent term I replace Hapke's term that captures small absorbing inclusion effects (t_g) with absorption computed from Mie Theory.

$$(1) \ a_s = q_a \sigma N$$

where a_s is the absorption due to nanophase iron, q_a is the extinction coefficient computed from Mie theory (and is size dependent), σ is the cross section of each particle, and N is the number density.

Results: Using the Noble et al. 2007 I show that this model better reproduces experimental results than Hapke's treatment when particles approach the wavelength. Figures 1 and 2 contrasts the ability of the Hapke 2001 model and this work to reproduce the spectra of nanophase iron particles in silica gel (data from [3]). The assumption of small particles works well at longer wavelengths, but breaks down at shorter wavelengths where the particles are closer to the wavelength.

Figure 3 shows the same data at two wavelengths versus abundance of iron. At long wavelengths the two treatments give similar results, but at shorter wavelengths the current method more closely matches the data.

Conclusion: This work, a simple modification to Hapke's 2001 model for space weathering, enables modeling of the larger iron particle present in

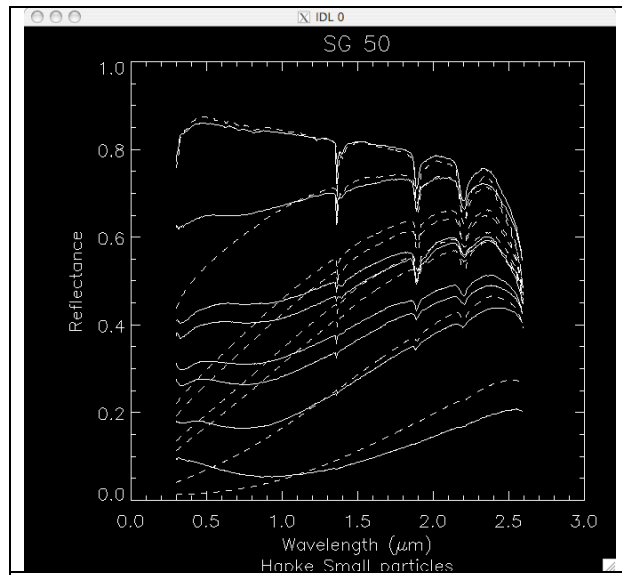


Figure 1. Solid line: Noble et al. 2007 data; Dashed line prediction from Hapke 2001. Note strong short wavelength deviation from prediction.

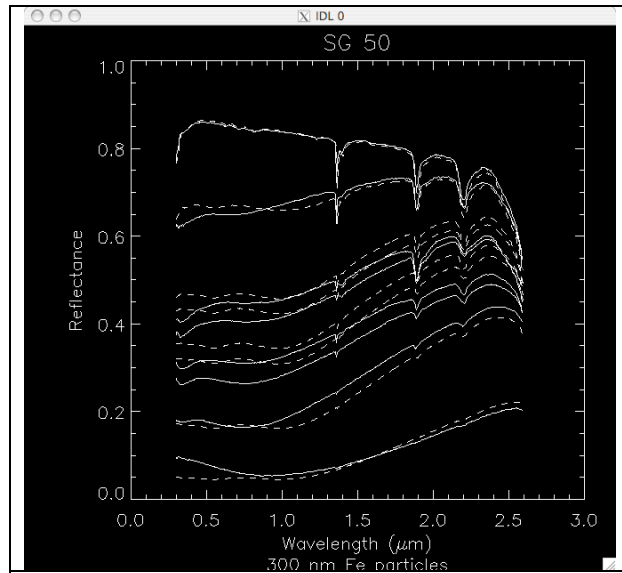


Figure 2. Solid line: Noble et al. 2007 data; Dashed line prediction from this work. Note much better agreement at short wavelengths.

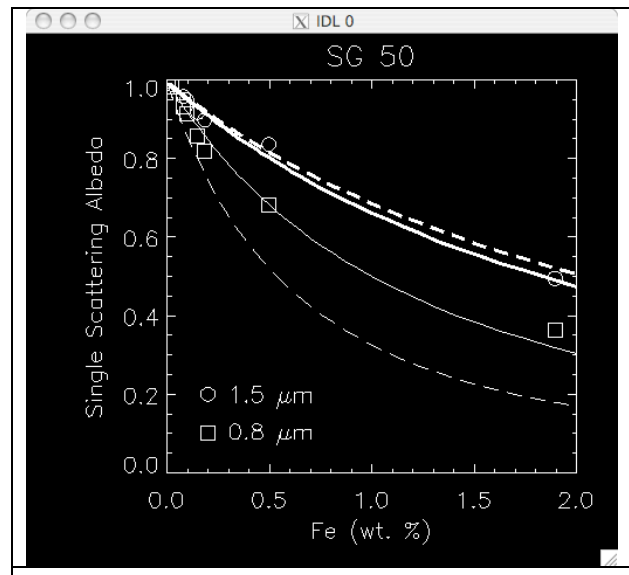


Figure 3. This work (solid lines) versus Hapke (dashed lines). At longer wavelengths (here 1.5 microns, circles) the two models make similar predictions, but at short wavelengths (0.8 microns, squares) the present model is superior.

agglutinates and that may be important on Mercury and asteroids.

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