COMPARISON OF THE BIDIRECTIONAL REFLECTANCE OF A WELL-CHARACTERIZED POWDER WITH PREDICTIONS OF MODELS BASED ON THE EQUATION OF RADIATIVE TRANSFER. B. W. Hapke[1], M. K. Shepard[2], R. M. Nelson[3], W. D. Smythe[3] and K. Mannett[3]. [1]Dept. of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260, hapke@pitt.edu, [2]Bloomsburg University, [3]Jet Propulsion Laboratory.

Introduction: Models of the reflectances of planetary regoliths based on the equation of radiative transfer are widely used to interpret spacecraft and telescopic spectrophotometric data. However, the validity of such models has recently been questioned [1] because they neglect coherent and other effects that may be important. To investigate this we have measured the bidirectional reflectance of a well-characterized powder consisting of particles of known scattering properties and compared the data with results of exact numerical solutions of the radiative transfer equation (RTE).

Experimental: The powder sample consisted of spherical particles of soda-lime-silica glass with refractive index n = 1.51+i3.5E-5. The spheres ranged in size from about 2 to 50 μm with a size distribution of number of spheres with radii between r and r+dr proportional to r^{-3}. Their mean single scattering albedo was 0.995 and mean cosine of the scattering angle $\langle\cos\theta\rangle = 0.785$. The porosity was 57%. The powder was poured into the sample holder and gently tapped to distribute it evenly, following which it was gently scraped to insure a smooth, level surface.

The bidirectional reflectance was measured using the photometer in the Bloomsburg University Goniometer Laboratory. It consists of a quartz-halogen source and solid state detector; it has been described in detail in reference [2], and this will not be repeated here. All measurements are relative to the reflectance of a Labsphere® standard, traceable to the National Bureau of Standards, illuminated normally and viewed at 5^o. We report measurements made in the principle plane at angles of incidence $i = 0^o$ and 60^o, and at phase angles between 3^o and 145^o. The data were taken through a narrow bandwidth filter with an effective wavelength of 700 nm. The reflectance was also measured with the long-arm photopolarimeter in the JPL goniometer laboratory; this data will be reported elsewhere. However, the two data sets were generally consistent where they overlapped.

Theoretical Model: The measured data were compared to exact numerical solutions of the radiative transfer equation computed using the code of Mishchenko et al [3] for media of well-separated, noninteracting, spherical particles. The single particle scattering function for the the spheres, calculated from Mie theory is shown as the solid line in figure 1. Note the glory resonance at 1^o, the cloudbow resonance at 20^o, and the diffraction peak at 180^o.

Fig. 1. Single Particle Scattering Function

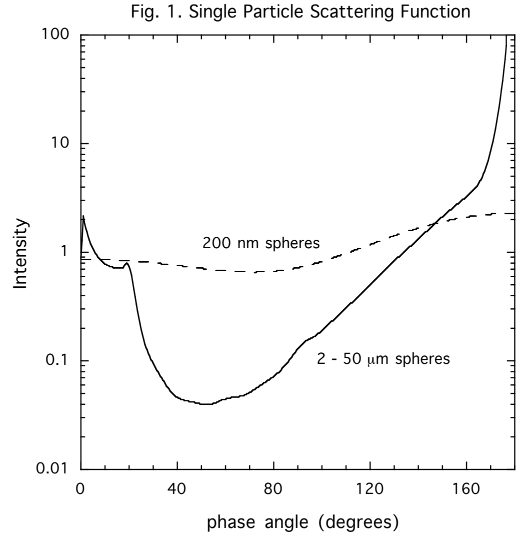
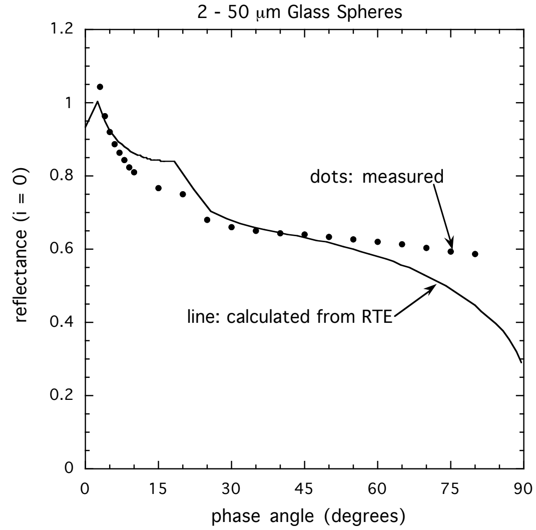


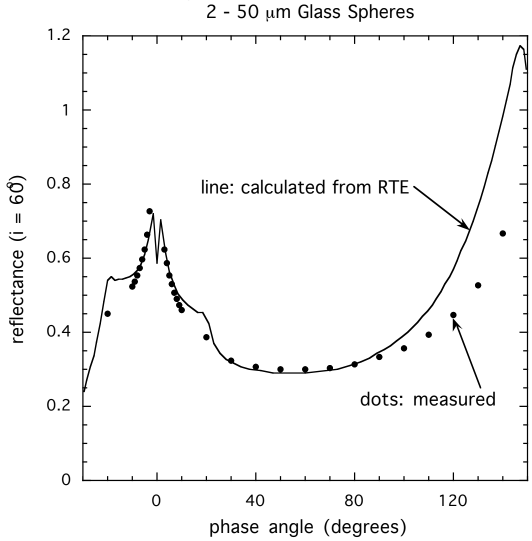
Fig. 2a. Reflectance of Powder of 2 - 50 μm Glass Spheres



Results: The measured and calculated reflectances are shown in figures 2a and 2b, where the dots are the measured data and the lines are the computed reflectances. The agreement is reasonably good at small phase angles, but there are large discrepancies near the limbs and in the amplitude of the cloudbow resonance. The overestimate of the amplitude of the cloudbow at a phase angles near 20^o was expected because the real particles have small departures from a perfect spherical shape, whereas the Mie calculation assumes perfect sphericity. Also, the finite angular sizes of the source and detector tend to smear out the peak and reduce its measured size.

However, the limb discrepancies are more puzzling. A possible explanation is that the powder surface is not perfectly flat, so that when viewed at large phase angles the detector sees mainly surfaces tilted away from the source, causing the measured reflectance to be lower than predicted. However, while roughness explains the discrepancy in the $i = 60^o$ data, it cannot account for the $i = 0^o$ differences, which are in the opposite sense.

Fig. 2b. Reflectance of Powder of 2 - 50 μm Glass Spheres



We suggest that the explanation is that when the particles are close together in a powder they are less forward scattering than when widely separated, as the theoretical model assumes. Hapke [4] has emphasized that the forward scattered diffraction peak does not exist for particles in a close packed powder. To illustrate this we have calculated the theoretical reflectance of powder composed of glass spheres 200 nm in diameter. Their single particle scattering function is shown as the dashed line in figure 1, and the bidirectional reflectances of the powder in figures 3a and 3b. These spheres are much less forward scattering than the large spheres, with $\langle\cos\theta\rangle = 0.200$, and the agreement is much better at the limbs, although, of course, not at small phase angles where the resonances are important for the large spheres but not the small ones.

Conclusions: A particle phase function that is much less forward scattering than an isolated sphere is required to bring the calculated and observed reflectances into agreement. This can be explained by the loss of diffraction scattering when the particles are close together. When this is taken into account the agreement between the measured and predicted reflectances is rerasonably good. These results give increased confidence in the reliability of models based on the equation of radiative transfer.

References: [1] Piatek, J. et al (2004) *Icarus*, 171, 531-545. [2] Shepard M. and Helfenstein P. (2007) *Icarus*, in press. [3] Mishchenko M. et al (1999) *J. Quant. Spectr. Rad. Transf.*, 63, 409-432; http://www.giss.nasa.gov/~crmim/publications/. [4] Hapke B. (1999) *J. Quant. Spectr. Rad. Transf.* 61, 565-581.

Fig. 3a. Measured Reflectance of Powder of Glass Spheres 2 - 50 μm Compared with Calculated Reflectance of Powder of 100nm Spheres

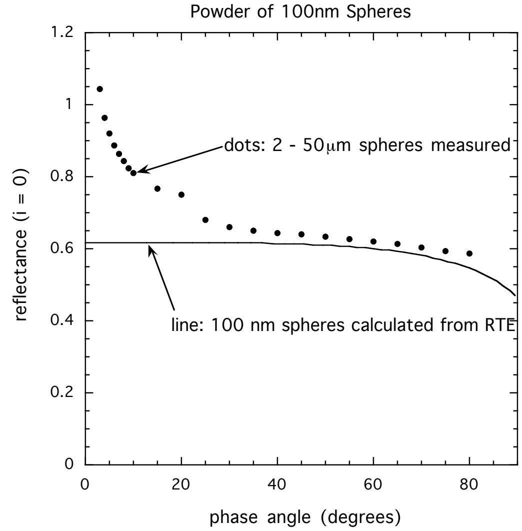


Fig. 3b. Measured Reflectance of Powder of Glass Spheres 2 - 50 μm Compared with Calculated Reflectance of Powder of 100nm Spheres