EPSC Abstracts
Vol. 11, EPSC2017-424-1, 2017
European Planetary Science Congress 2017

Multiple light scattering in planetary regoliths: Numerical methods and their validation

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Abstract

We devise numerical methods for the computation of light-scattering characteristics for planetary regoliths of airless Solar System objects. Using microscopic systems of small particles, we validate the numerical methods through a detailed comparison to the results obtained using exact electromagnetic methods. We conclude that the novel numerical methods allow for a quantitative interpretation of the spectroscopy, polarimetry, and photometry of asteroids and other airless Solar System objects.

1. Introduction

In asteroid photometry and polarimetry, two striking phenomena are observed at small solar phase angles (the Sun-Object-Observer angle). First, a nonlinear increase of brightness is observed towards zero phase in the magnitude scale (the opposition effect). Second, the scattered light is observed to be partially linearly polarized parallel to the Sun-Object-Observer plane (the negative polarization surge). Asteroid UV-Vis-NIR spectra show varying trends and absorption bands due to, for example, olivine and pyroxene minerals, as well as carbon and iron compounds. Generally, these spectra are functions of the phase angle.

Electromagnetic scattering (or light scattering) in a macroscopic particulate medium composed of microscopic particles is an unsolved computational problem. This results in the absence of quantitative direct and related inverse methods to interpret fundamental astronomical observations of asteroids. We report advances in the theoretical understanding of light scattering by macroscopic particulate media. We aim at distributing open software for the computation of UV-Vis-NIR spectra as well as photometric and polarimetric characteristics for asteroids, cometary nuclei, and other small Solar System objects.

2. Numerical methods

We have generalized the numerical method of radiative transfer and coherent backscattering (RT-CB, [1,2]) for densely packed discrete random media of scattering and absorbing particles [3]. Starting from the approach followed by Zurk et al. [4], we incorporate, into RT-CB, incoherent extinction, scattering, and absorption properties of a volume element. That allows us to remove the shortcomings due to the assumption of independent scattering in a sparse random medium. In its most general order-of-scattering form entitled R^2T^2 ("RT squared", radiative transfer with reciprocal transactions, [3]), interactions among the volume elements are computed exactly using FaSTMM, the fast superposition T-matrix method [5]. We have developed efficient software for both RT-CB entailing incoherent interactions as well as R^2T^2. Finally, we have generalized the open-source SIRIS geometric-optics software for specular and diffuse interactions [6] to incorporate incoherent volume-element scattering characteristics.

3. Results and discussion

Our framework allows for a quantitative end-to-end analysis spanning from modeling the single-particle scattering measurements to modeling multiple scattering in macroscopic media of particles (Penttilä et al., this meeting).

We point out that the modeling framework is already utilized for analyzing space-weathering effects (Markkanen et al., this meeting) and meteorite spectrometry (Martikainen et al., this meeting), as well as in modeling multiple scattering by high-albedo planetary-regolith analog samples of silica spheres measured in the laboratory (Väisänen et al., this meeting). In the present work, we offer a detailed comparison of computations using the R^2T^2 and RT-CB methods and the exact FaSTMM method. We show one example comparison in Figs. 1 and 2 for a close-packed spherical medium of small ice particles.

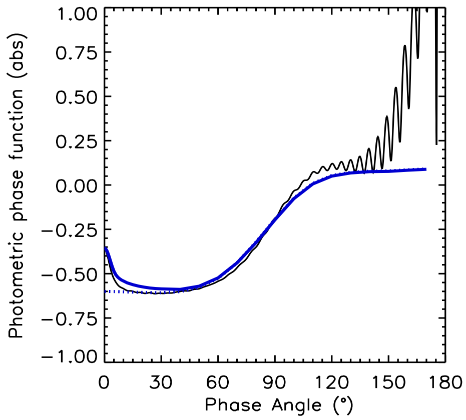

Figure 1: Scattering by a spherical particulate medium of radius 4 μm with 25% volume fraction of 0.2-μm spherical particles with refractive index 1.31. The wavelength is 0.6283 μm. The black solid curves depict the exact Superposition T-matrix results [5], and the blue solid curves depict our new R^2T^2 results (radiative transfer with reciprocal transactions; [3]). The intensity comparison is in absolute units.

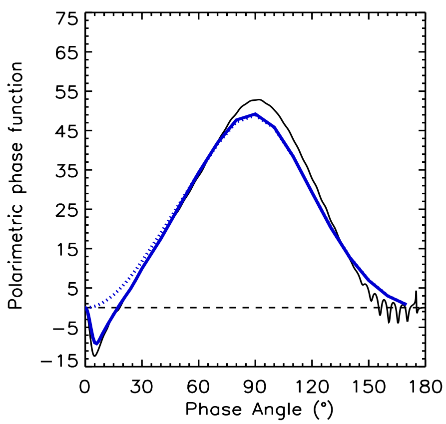

Figure 2: As in Fig. 1 for the degree of linear polarization for incident unpolarized light (in %).

4. Conclusion

We have developed advanced numerical methods for electromagnetic scattering in planetary regoliths and make them openly available. In the near future, we expect major advances in synoptic modeling of asteroid UV-Vis-NIR spectra, photometry, and polarimetry.

5. Acknowledgements

Research supported, in part, by the ERC Advanced Grant 320773.

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