Scattering by cometary dust using the volume-integral-equation method

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Numerical computations of light scattering by nonspherical particles are of great importance when deriving physical properties of cometary dust, such as the size distribution, structure, and composition, from the characteristics of scattered light. Optical observations of scattering by cometary dust are most consistent with particle models composed of aggregates of submicron monomers [1] or irregularly shaped particles [2]. These models can reproduce, at least to an extent, the typical scattering features of cometary dust, e.g., the negative polarization near the backscattering direction and the weak increase of the backscattering intensity.

To simulate light scattering by aggregates of particles with sizes comparable to the wavelength, a full numerical solution for the Maxwell equations is required. For the simulations of light scattering by cometary dust, the most commonly applied numerical tool is the superposition T-matrix method which is applicable to scattering problems involving aggregates of spherical particles. If constituents are inhomogeneous or non-spherical, the discrete-dipole-approximation (DDA) technique is usually applied. In the DDA solution, however, some accuracy problems have been reported, especially, near the backscattering direction. Here, we present a novel discretization scheme for the volume integral equation of electromagnetic scattering.

The numerical method is based on the electric polarization current volume-integral-equation formulation (JVIE) [3]. The JVIE equation is bounded from L^2 (the vector space of the square integrable functions) to itself, hence the Galerkin method together with L^2-conforming basis functions provides an optimal convergence of the solution [4]. The integral equation is discretized with piecewise linear basis functions associated with tetrahedral elements, and an FFT-based fast algorithm is used for accelerating the matrix-vector multiplication in the solution process. Thus, the computational complexity is the same as in the DDA, i.e., $\mathcal{O}(N \log N)$ for the computation time and $\mathcal{O}(N)$ for the memory consumption.

To validate the method, we consider scattering by an aggregate of equal-sized spheres. The aggregate contains 500 spheres of sizes $ka = 1.5$, and the refractive index $m = 1.88 + i0.47$. The figure shows the aggregate, S_{11}, and $-S_{12}/S_{11}$ computed using the JVIE, DDA, and the exact T-matrix code MSTM. Since the accuracy of the JVIE is slightly better than the accuracy of the DDA, we use the JVIE to analyse scattering properties of more complicated particles, such as Gaussian random ellipsoids [5], with application to cometary dust.

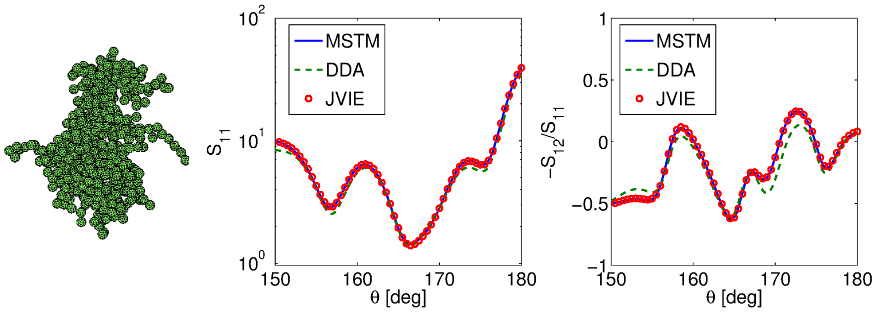

Figure: Comparison of the JVIE, DDA, and MSTM solutions for an aggregate of equal-sized spheres.

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