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Cometary dust dynamics and polarization in electromagnetic radiation fields

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Abstract

In this work, we study the polarization of aligned dust particles. The alignment is determined as the stable solution of dynamics due to scattering interactions. The alignment is found to affect on the linear polarization particularly in the 90° scattering angle and backscattering regimes and also induce a measurable circular polarization.

1. Introduction

The observed polarization of cometary comae is due to scattering from asymmetrical dust particles. The alignment of the dust particles is known to alter the polarization. In the context of interstellar dust, it has been firmly established that the dominant alignment method in many situations is by radiative torques.

Due to the modern advancements of different scattering solutions, mainly of the integral equation methods, a complete dynamical scattering solution for arbitrary geometries without orientation averaging is possible with tolerable computational efforts. Computing the T-matrix of scattering with these methods allows the study of dynamical effects of scattering for arbitrary geometries.

In this work, we analyse the polarization of several oriented dust particles. The orientation of the particles is assumed to be due to scattering interactions. Oriented states are found by explicitly integrating the dynamical state of a stationary particle.

2. Methods

We use the electric-current-volume-integral-equation method [2] to calculate the T-matrix of an arbitrary inhomogeneous test geometry [3]. The chosen method provides numerically robust solutions for strongly inhomogeneous scatterers.

The forces and torques due to scattering interactions are calculated from the total electric and magnetic fields, which are presented as vector spherical wavefunction (VSWF) expansions. The fields are related to a mechanical force and torque via the Maxwell stress tensor. The integrals involved can be solved analytically in terms of VSWFs, speeding the force calculations considerably [1].

We model the radiation environment as a discrete blackbody spectrum, with $T_{bb} = 5800$ K. The cometary dust is modelled as a layered Gaussian random sphere (GRS) [4]. The permittivity of the outer shell is $\varepsilon_r = 1.95 + i0.786$ and of the cores $\varepsilon_r = 1.69 + i1.04 \cdot 10^{-4}$, modelling silicate cores covered with a carbon layer.

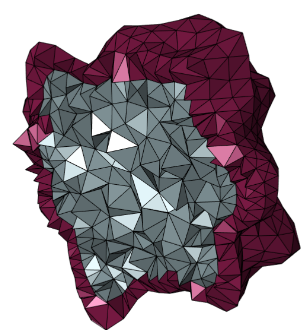

Figure 1: Layered GRS geometry, used to model small solid dust particle.

3. Results

We determined the dynamical evolution of the test geometry, illustrated in Fig. 1, under the radiation of the Sun. The volume equivalent radius of the particle was $a = 200$ nm. The radiation spectrum was a 10-point discretization of the blackbody spectrum between $200 - 2000$ nm. The energy flux of the radiation corresponds to solar irradiance of $330\,\mathrm{Wm}^{-2}$.

The scattering rapidly changes the dynamical state of the particle. Aligned orientation is taken from the state, where the particles angular velocity direction oscillates in a stable manner. The aligned average is then taken as the average about the angular velocity vector over a single rotation. Polarization results for unpolarized incident light over the discrete wavelength spectrum are illustrated in Fig. 2 for the randomly oriented case, and for two scattering planes in the aligned case. The first scattering plane contains the major principal axis of the particle, and the second scattering plane is perpendicular to the first.

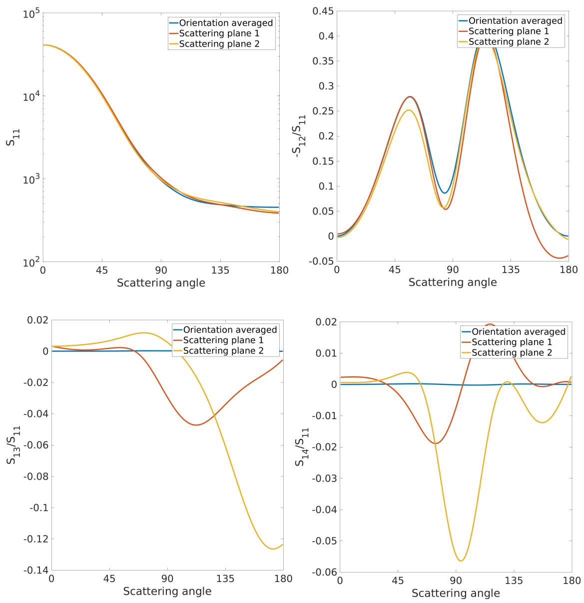

Figure 2: Polarization of randomly oriented and aligned particles. Alignment measurably affects both linear polarization and circular polarization.

4. Conclusions

The scattering forces and torques are significant on the modeled dust particle, leading to rapid alignment. The polarization results of a single test geometry imply encourage systematic study of differently shaped and sized dust particles. Combining the force and torque calculations can also be used to model particle drift in the coma. In the future, this can be used to dynamically model the coma polarization.

Acknowledgements

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