Interrelating angular scattering characteristics to internal electric fields of wavelength-scale Gaussian particles

Jani Tyynelä,[1] Evgenij Zubko,[2,3] Gorden Videen,[4,5] and Karri Muinonen[1]

[1]*Observatory, PO. Box 14, FI-00014 University of Helsinki, Finland (WWW: http://www.astro.helsinki.fi)*
[2]*Institute of Low Temperature Science, Hokkaido University, Kita-ku North 19 West 8, Sapporo060-0819,Japan*
[3]*Astronomical Institute, Kharkov National University, 35 Sumskaya Street, Kharkov, 61022, Ukraine*
[4]*Army Research Laboratory, AMSRL-CI-EM, 2800 Powder Mill Road, Adelphi, Maryland 20783, U.S.A.*
[5]*Astronomical Institue "Anton Pannekoek", Kruislaan 403, NL-1098 SJ Amsterdam, The Netherlands*

Abstract

We study the effect of internal electric field on the scattered field by modifying the electric field components of the discretized internal field of the particle. The internal fields for incident *X*-polarized and *Y*-polarized wave have been computed for a Gaussian-random-sphere particle using Discrete Dipole Approximation. The incident field propagates in the direction of the Z-axis. We show that both the Z- and X-component of the internal field cause negative polarization, the Z-component directly and the X-component through constructive interference between the contributions from different parts of the particle interior. The former component has a more pronounced influence on the overall polarization, while the latter component dominates the negative linear polarization close to the backscattering direction and is additionally seen to be responsible for the backscattering enhancement in intensity.

1 Introduction

Two ubiquitous light-scattering phenomena observed in atmosphereless solar-system bodies near opposition are the backward enhancement in scattered intensity and the negative linear polarization extending to some 20 degrees from the exact backscattering direction. The negative polarization seems to be largely due to single-particle scattering (e.g., [1]) but, close to backscattering, the coherent-backscattering mechanism plays an important role (e.g., [2]). Mechanisms responsible for the negative polarization of single particles have been suggested by, e.g., Muinonen et al. [3]. In the case of spherical particles, they hypothesize that, for a linearly X-polarized incident field propagating in the direction of the Z-axis, negative polarization arises from both the X- and Z-component of the internal field. The negative polarization of the Z-component arises due to non-destructive interference in the scattering plane defined by the wave and polarization vectors of the incident field (Y = 0; Fig. 1b). In the perpendicular plane X = 0 (Fig. 1a), the contribution is canceled. The negative polarization of the X-component arises due to constructive interference in the plane Y = 0 (Fig. 2b) between the cells divided by the planes X = 0 and Y = 0. In the perpendicular plane X = 0 (Fig. 2a), the linear polarization is positive, but the interference typically varies.

2 Computation of the scattered field

The effect of interference in the particle interior on the scattering characteristics is here studied by dividing the interior into equi-spaced cells parallel to the planes X = 0 and Y = 0, first into quadrants and then further into sixteen cells. The contributions from the radiating cells are calculated incoherently. The method described above was applied previously to spherical particles [4] and it was noted that the interference between different parts of the interior were responsible for the negative polarization and the backward enhancement. For the study, we have chosen a Gaussian-random-sphere particle with size parameter for the

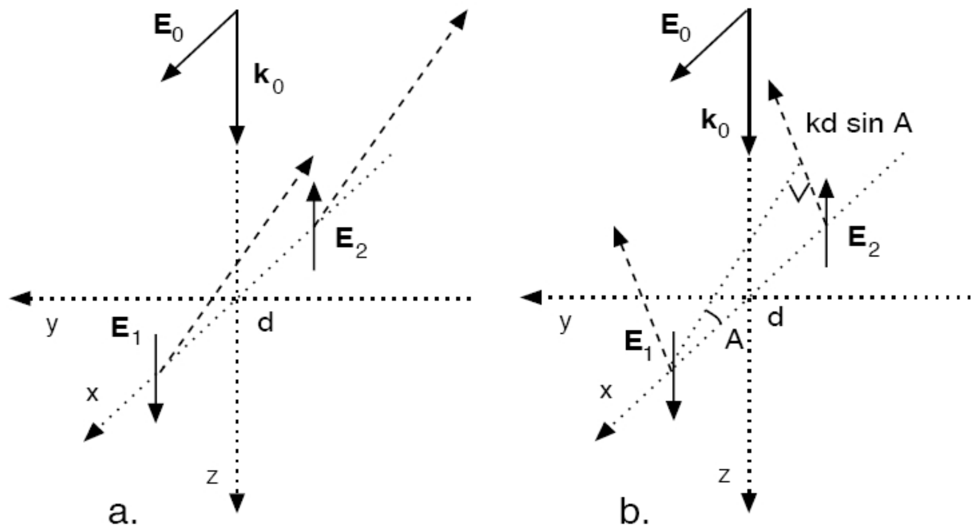

Figure 1: We illustrate the negative-polarization mechanism based on the Z-component of the internal electric field with odd parity: a) in the $X = 0$ plane, the scattered waves from the dipoles interfere destructively (phase difference $\Delta\phi = \pi$);b) in the $Y = 0$ plane, the interference between the waves varies depending on the distance d and phase difference $\Delta\phi = \pi + kd\sin(\pi - \theta)$, giving rise to negative linear polarization (see [3]).

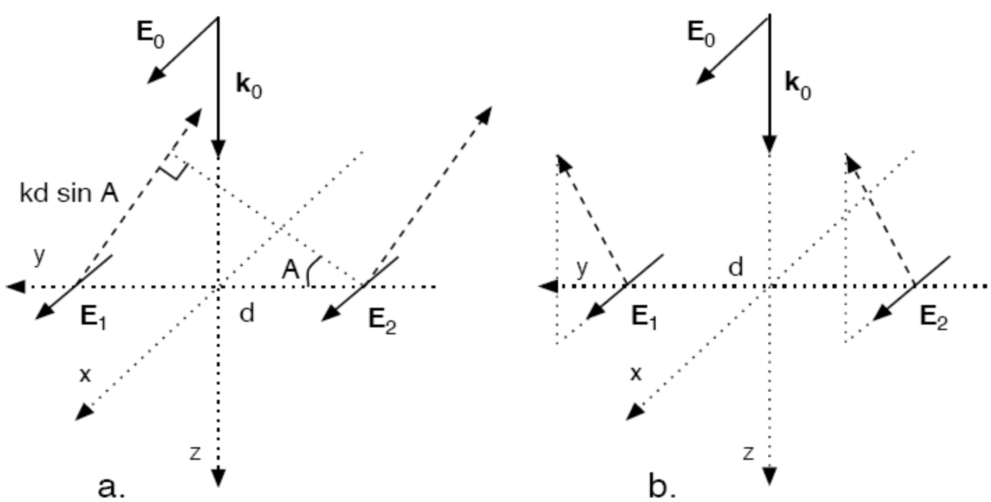

Figure 2: We illustrate the backward enhancement and the negative-polarization mechanism based on the X-component of the internal electric field with even parity: a) in the $X = 0$ plane, the scattered waves from the dipoles interfere destructively with phase difference $\Delta\phi = \pi + kd\sin(\pi - \theta)$; b) in the $Y = 0$ plane, the waves interfere constructively for all scattering angles (see [3]).

circumscribing sphere $x = 12$, the refractive index $m = 1.5 + 0.1i$, the relative standard deviation of radius $\rho = 0.245$ and the power-law index of the covariance function $\nu = 4$.

For the Gaussian-random-sphere particle, the internal fields for X- and Y -polarized incident field are obtained from a DDA simulation using the code by Zubko et al. [5]. The scattered field is calculated in XZ- and YZ-planes and an azimuthal averaging is carried out by rotating the particle with respect to the Z-axis for one hundred evenly distributed orientations. The size parameter grid for the internal field is $\Delta x = 0.375$.

3 Results and discussion

We investigate the effect of the different components of the internal field on the total intensity $I_{\|} + I_{\perp}$ and the linear polarization $P = (I_{\perp} - I_{\|})/(I_{\perp} + I_{\|})$ of the scattered field.

Figures 3a and 3c depict the total intensity normalized to one at $\theta = 0°$ and Figures 3b and 3d depict the linear polarization for the Gaussian-random-sphere particle. For the upper plots, the case of unmodified internal field is shown with thin solid line and the case of omitting the Z-component of the internal field is shown in thick solid line. For the lower plots, the case of unmodified internal field is shown with thin solid lines, the case of both omitting the Z-component of the internal field and dividing the interior into quadrants is shown in dashed line and the case of both omitting the Z-component of the internal field and dividing the interior into sixteen cells is shown in thick solid line.

As can be seen, the effect of omitting the Z-component of the internal field increases the linear polarization dramatically, but does not eliminate the negative polarization near backscattering region. When the interior is divided into quadrants, the polarization becomes positive for all scattering angles. Division further into sixteen cells does not have as profound an effect on polarization in this case, but for the total intensity, the effect is evident. As the interior is divided into four incoherently radiating parts, the relative backward enhancement in intensity diappears. The results reinforce the idea that the mechanisms described above are responsible for the negative polarization also for non-spherical particles. The computations will be extended to larger numbers of Gaussian particles.

References

[1] H. Volten, O. Munoz, E. Rol, J. de Haan, W. Vassen, and J. Hovenier, ’Scattering matrices of mineral aerosol particles at441.6 nm and 632.8 nm,” J. Geophys. Res. 106, 17375-17401 (2000)

[2] K. Muinonen, ’Coherent backscattering of light by complex random media of spherical particles: numerical solution,” Waves in Random Media, 365-388 (2004)

[3] K. Muinonen, E. Zubko, J. Tyynelä, Yu. G. Shkuratov, and G. Videen, ’Light scattering by Gaussian random particles with discrete-dipole approximation,” JQSRT, in press (2007)

[4] J. Tyynelä, E. Zubko, G. Videen, and K. Muinonen, ’Interrelating angular scattering characteristics to internal electric fields for wavelength-scale spherical particles,” JQSRT, in press (2007)

[5] E. Zubko, Y.G. Shkuratov, G. Videen, and K. Muinonen, ’Effects of interference on the backscattering properties of irregularly shaped particles using DDA,” in Proceedins of the 9th Conference on Electromagnetic and Light Scattering by Nonspherical Particles: Theory, Measurements and Applications, 287-290 (2006)

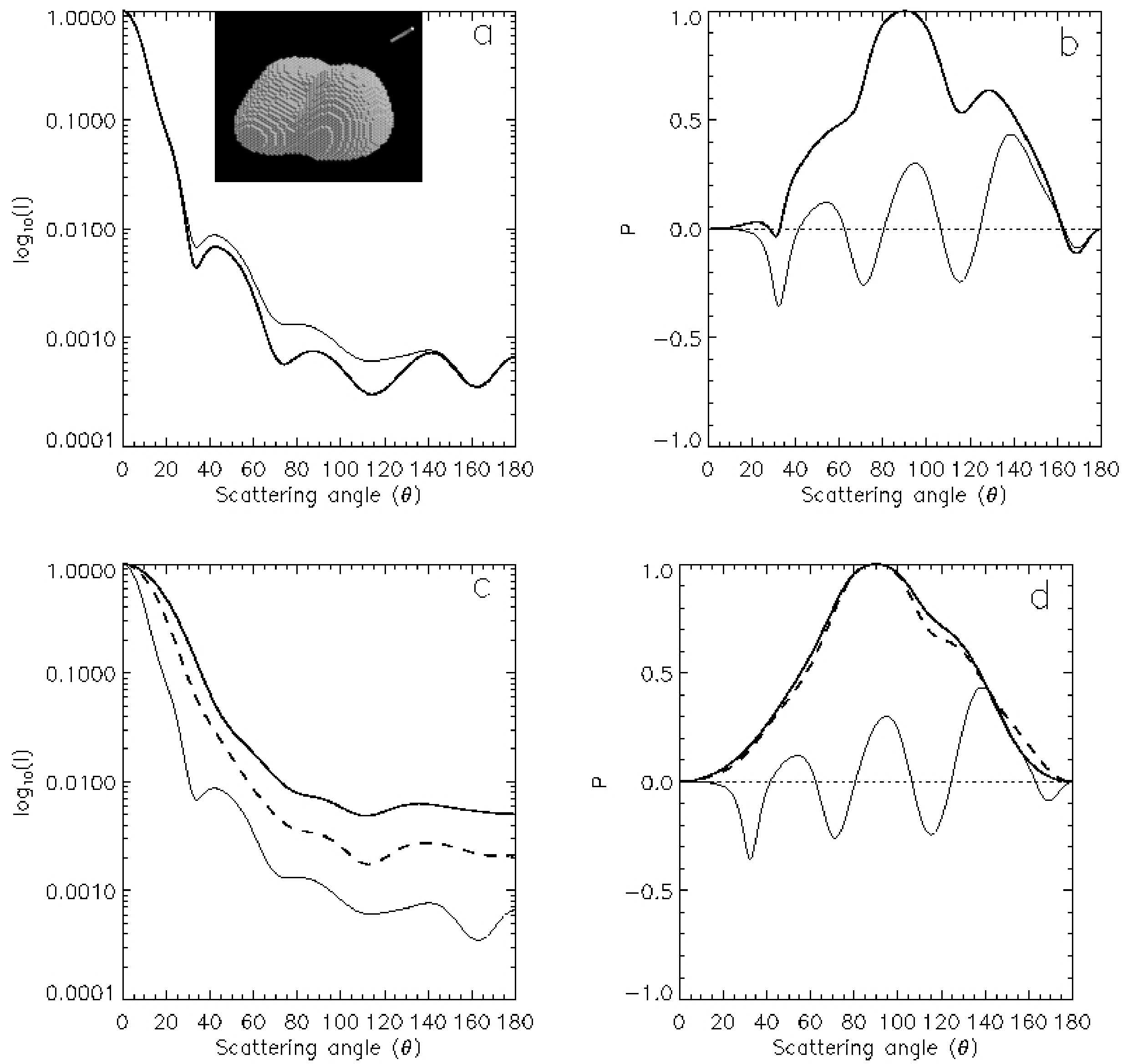

Figure 3: We plot the total intensity $I_{\|} + I_{\perp}$ (a) and $P = (I_{\perp} - I_{\|})/(I_{\perp} + I_{\|})$ (b) in the case of the unmodified internal field (thin solid line) and when $E_Z = 0$ (thick solid line). Also, we plot the total intensity (c) and P (d), when $E_Z = 0$ and the particle interior is divided into quadrants (thick dashed line), sixteen cells (thick solid line), and the unmodified internal field (thin solid line). An image of the sample Gaussian-random-sphere particle is shown in plot a. The parameters for the particle are $x = 12$, $m = 1.5 + 0.1i$, $\rho = 0.245$ and $\nu = 4$.