Circular polarization of light scattered by randomly built aggregates

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Abstract

We present calculations of the scattering angle dependence of the degree of circular polarization of light singly scattered at 500 nm by randomly oriented randomly built aggregates of optically inactive homogeneous identical spheres. Using the T-matrix method we analyzed the effect of changing the size of the monomers for two different geometries. The values of the computed degree of circular polarization are comparable to the observed ones for light scattered by dust particles in comets P/Halley, C/1995 O1 (Hale-Bopp) and C/1999 S4 (LINEAR).

1 Introduction

A small but non-zero degree of circular polarization (DCP hereafter) has been persistently observed for light scattered by dust grains in comets. A summary of some of the available observations is presented in Table 1.

The measurements for a given comet are highly variable in time. The time scale of the variations have been reported to be of the order of a few days [1, 2] or as short as a few minutes [3]. The precision of the measurements is, in general, quite low, especially for measurements of comet Halley, where the errors are of the order of the mean values, or even larger.

Some systematic errors might be introduced in the observations of Halley by Metz et al. [3], because they present a strong dependence on the diaphragm aperture: DCP values of -1.0%, 0.2% and -1.3% were obtained for apertures of $10''$, $21''$ and again $10''$, respectively.

In a previous work (Guirado et al. [7]) we presented a systematic study of the DCP of light scattered by model asymmetrical particles. There we used two artificially asymmetrical aggregates of identical spheres (monomers) and calculated the DCP curves, i.e., the DCP as a function of the scattering angle for several sizes, refractive indices and numbers of monomers of the aggregates. We obtained a DCP of up to 2%. From the results of that work we inferred the following: when the substructure (monomer or group of monomers) producing the asymmetry of the aggregate is comparable in size to the wavelength, some principal peaks appear in the DCP curve. These peaks reduce their amplitude when the aggregate becomes larger than the wavelength, but always remain at about the same scattering angles. Also the number of principal peaks keeps constant when varying the size of the aggregate. When the size of the aggregate is increased in such a way that the diameter of each monomer becomes of the order of the wavelength, secondary peaks appear in the DCP curve. The number of these peaks increases while increasing the size of the aggregate, and their positions change. Finally, when making an average of the DCP curve over a size distribution the secondary peaks contribution is cancelled out when these peaks are summed up and only principal peaks remain, because they always contribute in the same sense at the same positions. From these conclusions, we derived that aggregates built in a random way may also produce a significant DCP of scattered light if the substructure producing the asymmetry of the particle is comparable in size to the wavelength of scattered light. The main goal of the present work is to study what is the order of magnitude of the DCP of light

Comet	Author	Wavelength (nm)	Aperture	Phase angle (°)	DCP (%)
Halley	Morozhenko [1]	514	$2.7'' \times 81''$	21.1 - 34.8	(-0.76 ± 0.27) - (0.37 ± 0.20)
Halley	Morozhenko [1]	484	$2.7'' \times 81''$	21.1 - 34.8	(-0.05 ± 0.15) - (0.70 ± 0.28)
Halley	Dollfus [2]	visible*	$2.1''$ to $107''$	40.7 - 22.5	(-0.65 ± 0.39) - (1.18 ± 0.48)
Halley	Metz [3]	560	$10''$, $15''$ and $21''$	66.1	(-2.2 ± 0.1) - (-0.7 ± 0.0)
Hale-Bop	Manset [4]	684	15.5“	40 - 47.4	(-0.24 ± 0.02) - (0.20 ± 0.04)
Hale-Bop	Rosenbush [5]	485	10“	46	(-0.26 ± 0.02) - (-0.06 ± 0.06)
LINEAR	Rosenbush [6]	red**	$15''$	60.9 - 122.1	up to 1%

* Wide band filter centered at 500 nm and covering the whole visible spectrum.
** Wide band R filter.

Table 1: Summary of some observations of circular polarization of light scattered by comets.

scattered by randomly built aggregates. If too small, we could directly rule out real asymmetrical aggregates as producing most of the circular polarization in comets, but if it is of the order of the observations, we should proceed with a systematic study of several geometries, sizes and refractive indices.

A previous approach to this problem was made by Kolokolova et al. [8]. These authors found values of the DCP very close to zero for randomly built aggregates of identical optically inactive homogeneous spheres in random orientation. But only two particular sizes were chosen, and now we know that other sizes could give large values of the DCP so that significant values might remain after size-averaging.

2 Numerical methods

For the generation of the aggregates we implemented a cluster-cluster aggregation (CCA) method in a Fortran code. We chose this mechanism instead of particle-cluster aggregation (PCA) because the former produces aggregates with elongated substructures, which is favourable to the asymmetry of the formed particles. Only if the obtained DCP is comparable to the observations, PCA aggregates should be studied. In order to limit the size of the clusters and the whole aggregates, we fixed a limit to the maximum distance between two monomers of the structure.

For all calculations we used the T-matrix superposition method for aggregates made of spherical monomers. We chose the free available double precision version of the code of Mackowski and Mishchenko [9]. The results depend somewhat on the accuracy parameters of the code, and we needed very accurate results because we expected to obtain small values of the DCP. So, we changed the accuracy parameters until the results became stable. The criterion for stability was the following. We defined the relative error for each element of the scattering matrix as $\frac{F_{ij}(parameters1)-F_{ij}(parameters2)}{F_{ij}(parameters2)}$, where $parameters2$ are ten times smaller than $parameters1$. Then we changed the parameters until the error was smaller than 10^{-9} for all scattering angles and all elements of the scattering matrix.

3 Numerical results

We chose aggregates made of identical homogeneous and optically inactive spheres for this preliminary study. The refractive index was $m = 1.5 + i0.001$. We have calculated the degree of circular polarization, as a function of scattering angle, produced by incident unpolarized light scattered at a wavelength $\lambda = 500$ nm by collections of the above described particles in random orientation.

Two different shapes were used for the aggregates (see Fig. 1). We will denote by x the size parameter of the monomers of the particle, and by X the volume equivalent size parameter of the whole aggregate. All results are plotted as a function of the scattering angle, and the phase angle, which simply is 180° minus the

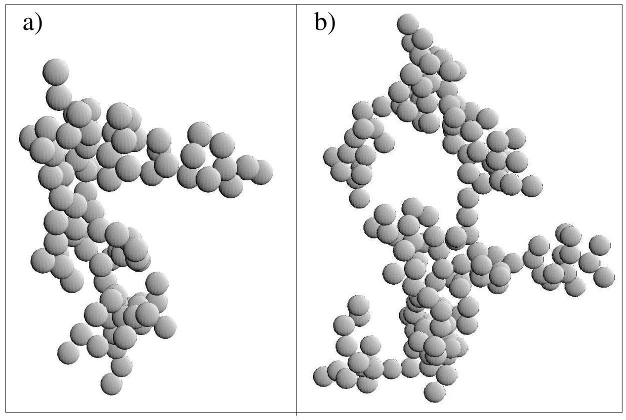

Figure 1: Randomly built asymmetrical aggregates consisting of (a) 93 and (b) 165 identical spherical monomers.

scattering angle.

As seen in Fig. 2 while increasing the size parameter for geometry (a), larger values of the absolute value of the DCP appear, while the substructure producing the asymmetry becomes comparable in size to the wavelength. For geometry (b) even larger values of the absolute value of the DCP are reached.

Secondary peaks are not present in any of the geometries. In our interpretation this is due to the fact that the monomers are much smaller than the wavelength.

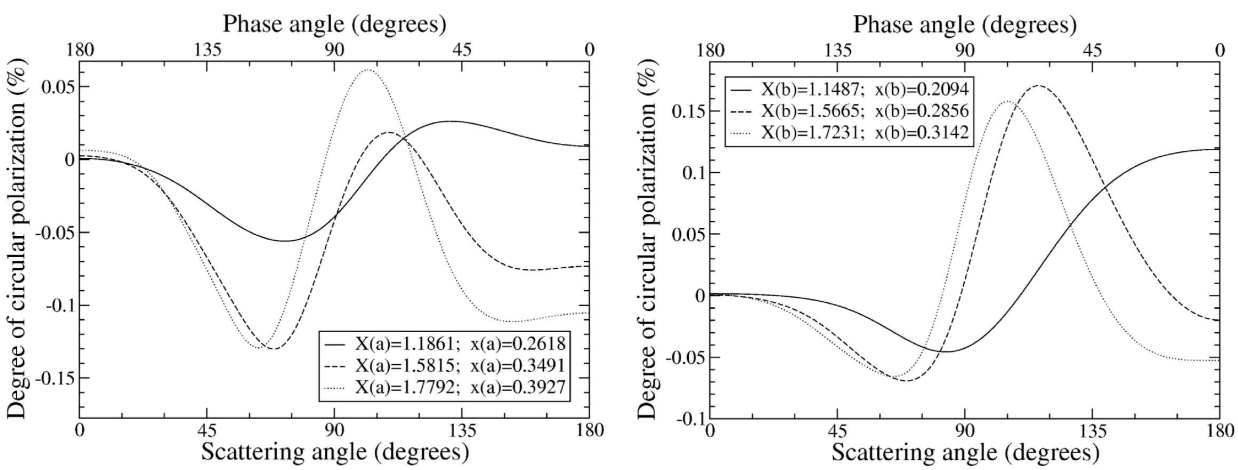

Figure 2: The degree of circular polarization as a function of the scattering angle for three collections of randomly oriented randomly built aggregates differing in volume equivalent size parameter for shape *a* (left) and *b* (right).

4 Conclusions

Single scattering of unpolarized light by randomly built optically inactive particles in random orientation can produce values of the degree of circular polarization comparable to the observed values for light scattered in comets. Further work is in progress.

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