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# Collective effects by agglomerated debris particles in the backscatter

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**Abstract**

We present an analysis of backscattered light by agglomerated debris particles whose size is comparable with the wavelength. We consider agglomerates that consist of one or two large central particles and a few relatively small fragments surrounding the particles. We find that for the particles we studied, the attachment of small fragments onto the particles leads to a decrease of the negative polarization branch (NPB) at small phase angles in comparison with the branch produced by the isolated particles. For relatively large agglomerates (with size parameters $x$ about 25) the internal scatter in the agglomerates may produce a secondary minimum of the NPB. In this case the second order of scatter between constituents of aggregates plays the dominant role.


*Keywords:* Backscatter; Agglomerated particles; Negative polarization

## 1. Introduction

There are two persistent features in the intensity and degree of linear polarization in the backscatter of natural light by irregular particles comparable with wavelength. These backscatter (opposition) features are the intensity surge with maximum at zero phase angle (exact backscatter) and the negative polarization branch (NPB). These effects have been seen in numerical calculations of irregularly shaped particles [1–4]. While it is difficult to measure the scatter in this region, experimental measurements in the near-backscatter region up to 8° from exact backscatter suggest these effects exist from natural particles [5,6]. The shape of the backscatter features depends significantly on the particle size, wavelength, refractive index, and structure of particles. Therefore, both effects can be important in the development of optical remote-sensing techniques.

Agglomerate dust particles are ubiquitous in nature, for instance, in cometary atmospheres and planetary surface layers. The case of relatively large irregular particles covered by small irregular fragments is of special

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interest. It has been shown that the presence of particles on a plane interface can lead to a strong NPB [7] and it has been suggested that the presence of small particles agglomerated onto larger particles may be the cause of the NPB seen in dust particles [8]. There are almost no data on how the collective scatter in such agglomerates affects the intensity surge and negative polarization branch at small phase angles. While there are studies of agglomerates of spherical particles [1], this case has little practical applicability as real dust particles have mainly irregular shapes.

In order to study the collective effects at backscatter by the agglomerated particles we use a previously published algorithm for their generation and a well-tested discrete dipole approximation (DDA) code [2–4].

## 2. Model of agglomerated debris particles

In the DDA approach, the scattering volume is discretized, and the individual cells are assigned optical properties. To generate agglomerated debris particles, we consider a number of cells that forms a spherical volume and is the initial matrix of a particle. A portion of randomly chosen cells from a surface layer of the volume is marked as seeds of empty space. No material seeds are placed in the layer. In the space beneath the layer, seeds of material and empty space are randomly located. Then step-by-step each cell other than the seed cells is marked with the same optical properties as the nearest seed cell. This process results in a particle surface layer of complicated structure with an effective thickness greater than the initial layer thickness.

Our conclusions below are based on the investigation of seven examples of agglomerates that were randomly generated using various initial parameters, resulting in different structures. In six cases the agglomerates consist of a central body surrounded by a few (three or four) relatively small pieces. In one case the agglomerate consists of two relatively large bodies accompanied by eight small pieces. The total number of parameters (the size parameter and refractive index) was 12. We present here results only for two agglomerates, since the other studied cases show similar dependencies.

The first agglomerate (sample #1) was generated with 137,376 cells in the initial matrix. The numbers of seed cells of empty space in the surface layer and under it are 100 and 20, respectively. The number of seed cells of material under the surface layer is 21, the thickness of the surface layer is 1% of the initial radius. The resulting agglomerate consists of five separate constituents that contain 20,009, 4385, 1542, 249, and 250 dipoles. Thus, the agglomerate has a central massive body (76% of particle material) surrounded by four relatively small fragments. An image of the agglomerate is presented in the left panel of Fig. 1.

The second agglomerate (sample #2) was generated with 1,099,136 cells in the initial matrix. In this case, the surface layer has zero thickness, i.e. it is absent. The numbers of seed cells of empty space and material inside the initial matrix are 300 and 20, respectively. The resulting agglomerate consists of ten separated constituents that contain 25,204, 17,974, 8870, 8584, 5738, 5167, 4797, 3488, 2142, and 1098 dipoles. The two largest pieces consist of 52% of the material. As one can see in right panel of Fig. 1, the agglomerate has fragments

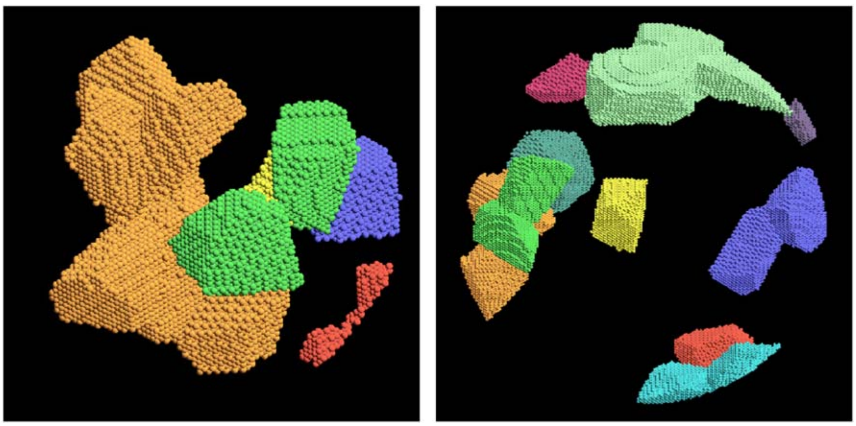

Fig. 1. Colored images of a debris agglomerate. Different fragments are shown by different colors. Left (a) and right (b) panels present the sample #1 and #2, respectively.