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Retrieval of dust-particle refractive index using the phenomenon of negative polarization

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ABSTRACT

We study the phenomenon of negative polarization in irregularly shaped agglomerated debris particles. We find that the location of the negative polarization minimum is unambiguously governed by Re(m). Furthermore, the amplitude of the negative polarization puts a strong constraint on the material absorption in target particles regardless of their real part of refractive index Re(m). The interrelation can be parameterized with a simple formula and it can be utilized in remote sensing. We apply our finding to laboratory optical measurements of Allende meteorite at $\lambda = 0.633\ \mu m$ and estimate its complex refractive index to be $m \approx (1.68–1.83)+(0.01–0.02)i$.

1. Introduction

Optical remote sensing of atmospheric aerosols or cosmic dust is feasible with an analysis of scattering and absorption of sunlight from target particles. One distinctive feature of solar radiation is that it is highly unpolarized. However, scattered solar radiation acquires partial polarization. If scatterers are randomly oriented, this polarization is predominantly linear and can be quantified with the degree of linear polarization P that is defined as follows [1]:

$$P = -\frac{Q}{I} = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}, \tag{1}$$

here I and Q are the first and second Stokes parameters, and $I_\perp$ and $I_\parallel$ are the intensities of the scattered electromagnetic waves whose electric fields vibrate perpendicular to and within the scattering plane. Numerous laboratory measurements of small mineral dust particles ($\sim 1\ \mu m$) systematically reveal negative values (i.e., $I_\parallel > I_\perp$) of the degree of linear polarization near backscattering, e.g., [2,3]. A similar behavior has been observed in cosmic dust, e.g., [4,5], and this phenomenon is referred to as *negative polarization*.

In Fig. 1 we demonstrate the negative polarization measured in red light ($\lambda = 0.633\ \mu m$) for two types of particles suspended in air. They correspond to Allende meteorite [2,6] and feldspar [3,6] materials. Here, P is shown as a function of the phase angle α. Note that phase angle is a supplementary angle to the scattering angle $\alpha = 180^\circ - \theta$, so the case $\alpha = 0^\circ$ corresponds to exact backscattering. As one can see in Fig. 1, both samples reveal negative polarization despite their different origins. However, the shape of the negative polarization branch (NPB) is different. This suggests a potential of the negative polarization for remote-sensing applications.

We choose feldspar and Allende meteorite for comparison because these samples are prepared in a similar way: both are obtained by crushing large pieces of material to a fine-grained powder. This may explain the similar shapes

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of Allende and feldspar particles that are highly irregular in appearance with sharp edges (see SEM images in [2,3]). Furthermore, in both samples, fractions of micron-sized particles, whose half-size r spans the range from 0.75 μm through 2.5 μm, obey a similar size distribution that can be satisfactorily approximated with a power-law distribution r^{-3}. Particles within this range make the dominant contribution toward the light-scattering response from the sample [7]. Therefore, it seems reasonable to suggest that the difference in the NPB seen in Fig. 1 is caused mainly by the difference in refractive index of feldspar and Allende meteorite particles. The samples indeed look dramatically different when they are deposited onto a surface: Allende meteorite is a dark gray powder; whereas, feldspar is a white-pink powder [2,3].

The mechanism governing the negative polarization in single, wavelength-size particles is not well understood, because of the complex interactions of electromagnetic waves in such targets. However, there is some suggestion, e.g., [8,9], that the negative polarization in agglomerate particles can be explained with the coherent-backscattering mechanism (or weak localization) that was initially intended to explain the negative polarization in a discrete particulate medium composed of small particles [10,11]. For non-agglomerated particles, this negative polarization has been tied to the internal fields [12,13]. Despite the lack of a precise understanding of the NPB origin for small particles, the branch can be utilized in remote-sensing applications. We demonstrate here the dependence of the NPB on the complex refractive index m of irregularly shaped target particles.

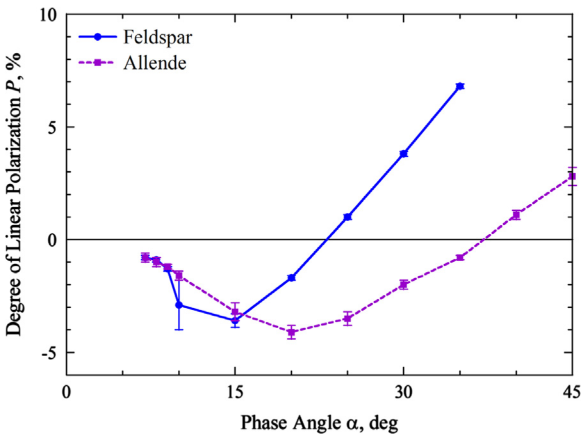

Fig. 1. Degree of linear polarization P versus phase angle α measured near backscattering in the Allende meteorite and feldspar. Data are adapted from [2,3,6]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Model particles and computation of their light scattering

We compute light scattering from micron-sized particles using the discrete dipole approximation (DDA), e.g., [14,15]. We exploit our own implementation of the DDA that provides accurate computations of light scattering. More details on this code, practical issues in the DDA simulation of light scattering from irregularly shaped particles, and control of the computational accuracy can be found in [9,16,17].

We consider *agglomerated debris particles* that have highly irregular, agglomerate morphologies, providing shapes similar to natural sample particles. For a detailed description of the algorithm for the generation of agglomerated debris particles, see, e.g., [7,16]. Most importantly, these particles have been shown to reproduce the scattering characteristics of real feldspar particles having the same size distributions and at multiple wavelengths [7]. However, agglomerated debris particles can also be relevant in application to the Allende meteorite particles because these sample particles were prepared in the same manner as the feldspar particles. Both types of particles indeed reveal somewhat similar shape and nearly the same size distribution of submicron- and micron-sized particles.

Three-sample agglomerated debris particles are shown in Fig. 2. We note that the particles have a fluffy morphology. On average, only 23.6% of the volume of the sphere circumscribed about the particles is occupied by the material (filling factor or packing density). The average geometrical cross section of the particles is equal to 0.61 of the projected area corresponding to the circumscribing sphere.

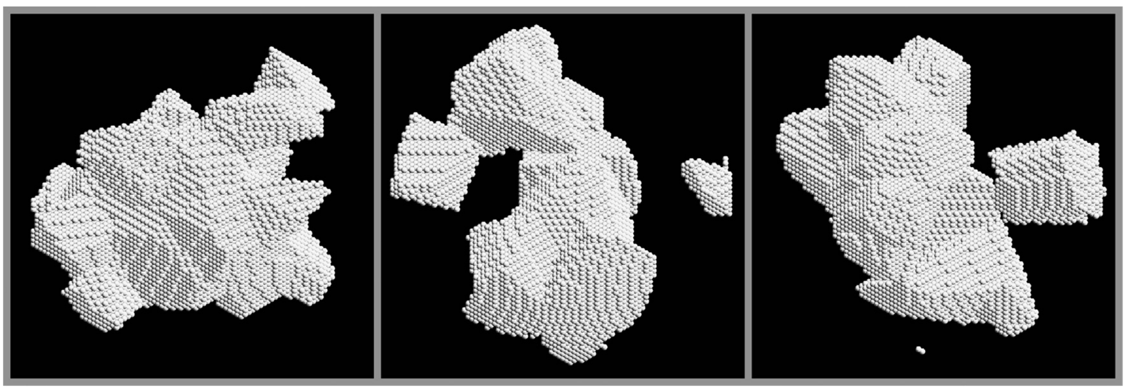

Fig. 2. Three example images of agglomerated debris particles.