Dust models for cometary grains to explain optical polarization

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The observed optical polarizations for comets have been explained in the past by assuming the cometary grains to be compact spheres, such that Mie theory could be applied to simulate the observed polarizations. However, from a realistic point of view, recently other shapes like spheroids and aggregates of monomers have been considered for cometary grains. For this purpose, *T*-matrix or DDA based light scattering techniques have mostly been used to simulate the observed polarizations. Such polarizations, as observed by the authors for comets Halley and Austin, have been explained earlier using Mie theory to understand the composition and size distribution of cometary grains. Recently, the authors have used *T*-matrix technique and aggregate grain model to explain the polarizations of comets like Hale-Bopp, Levy, and Hyakutake. The simulated polarization values, with the aggregate model, were found to match the observed values much better as compared to compact spherical or spheroidal models. However, difficulties have been noted in a simple aggregate model of grains and some possibilities are discussed here.

INTRODUCTION

Comets are known to exhibit high amount of polarization, caused due to scattering of sunlight by dust grains present in the coma of comets. The polarizations observed through ground based or space borne telescopes largely depend on the scattering angle. As the scattering angle becomes very high (> 160 degrees), almost all the comets exhibit negative polarization. It has been found that the observed cometary polarization data can be explained fairly well by assuming the grains to be Mie spheres with a specific dust size distribution and compositions characterized by complex refractive indices. Following this procedure, the authors had in the past explained the observed polarization values of various comets with reasonable accuracy [1-3]. For this calculation, a power-law grain size distribution was assumed from space-craft observations [4] and the complex refractive index was used as a free parameter for modeling. This procedure of fitting the observed polarization data using Mie theory, for various sizes and compositions, was applied to several comets and it was found that the grains of the comets increase in their sizes as they grow dynamically older with successive revolutions around the Sun [3].

ASPHERICAL GRAINS AS COMPARED TO THE SPHERICAL GRAINS IN COMETS

It seems quite reasonable to expect that the naturally-occurring cometary grains cannot be ideal compact spheres, as required by Mie theory. However, until recently, cometary scientists have been using such Mie particles to explain the observed polarization data, as it is more convenient and direct, with a fewer number of free parameters required for modeling.

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In an attempt to explain the observed polarization data of comet Levy (1990XX), we noticed that the polarization can be simulated more accurately if we assume the grains to be prolate (with aspect ratio of 0.48) rather than Mie's ideal spheres [5]. This model calculation also successfully reproduced the observed negative polarization values for comet Levy, which was earlier not possible for similar comets [6]. A Chi-square minimization technique was followed for model fitting. We considered particles with different sizes and compositions, and a *T*-matrix based scattering code was executed. It was found that the sum of squares of difference between the observed and calculated values of polarization becomes minimum if we assume that the grains are prolate instead of spheres. And there was complete uniqueness in the model fitting of data. Thus, one could conclude that the cometary grains are more likely to be prolates rather than spheres (at least for comet Levy).

THE AGGREGATES OF MONOMERS AS THE GRAINS OF THE COMETS

With the fact that the prolate grains gave a better fit to the observed polarization data, as was seen for comet Levy, we extended these calculations to other comets, for which fits using Mie theory were already available. But no significant progress could be made.

It has been long believed that cometary grains are fluffy aggregates [7]. Xing and Hanner [8] carried out calculations with porous aggregates using DDA techniques for comets and got good results. Assuming an individual cometary grain to be an aggregate of several monomers, we performed calculations by superposition *T*-matrix method [9]. To begin with, one can assume that all the monomers are of same size and composition. Aggregates are built by using either Ballistic Particle Cluster Aggregate (BPCA) or Ballistic Cluster Cluster Aggregate (BCCA) method [10]. BPCA is more compact than BCCA. We took several test cases of aggregate grains containing 32 and 1024 monomers (with BPCA and BCCA structures) and it was observed that, as we increase the number of monomers, the calculated polarization values are not very sensitive to the structure or the size of the aggregate. However, the polarization value depends strongly on the radius of the monomers. Since we considered 32 to 1024 monomers in our calculations with monomer radii between 0.10 to 0.13 μm, the effective aggregate size considered was within the range of 0.1 to 1.3 μm (see [11] and references therein). With the polarization data of comet Levy at 0.485 μm [12], a theoretical fit was made by choosing N (number of monomers)=128 and initially taking a refractive index value close to that of olivine (1.771, 0.108; linearly interpolated value of the refractive index: details in [13]) . The monomer radius a was also varied within the range of 0.10 to 0.13 μm. A chi-square minimization technique was applied for obtaining the best fit. By this technique, we could fit the observed data with a refractive index of (1.783, 0.052) and a = 0.12 μm very well and the fit was better than that with prolates obtained earlier [5].

With the success for comet Levy, a similar approach was followed for comet Hale Bopp [13]. Lasue & Levasseur-Regourd [14] used aggregate dust model to study Hale Bopp. The comet exhibited high polarization and grains were believed to be rich in silicates. Data from various authors at λ = 0.485 μm and 0.684 μm were considered for modeling. Monomer radius a was varied within a range of 0.10–0.18 μm. To begin with, calculations were done by taking the refractive index for amorphous olivine, pyroxene, and carbonaceous materials, but none of them could produce good fit to the observed data well. It was observed that the data can be fitted with two different values of monomer radius *a*, at two different values of wavelength, however, the size parameters remained the same as 1.56.

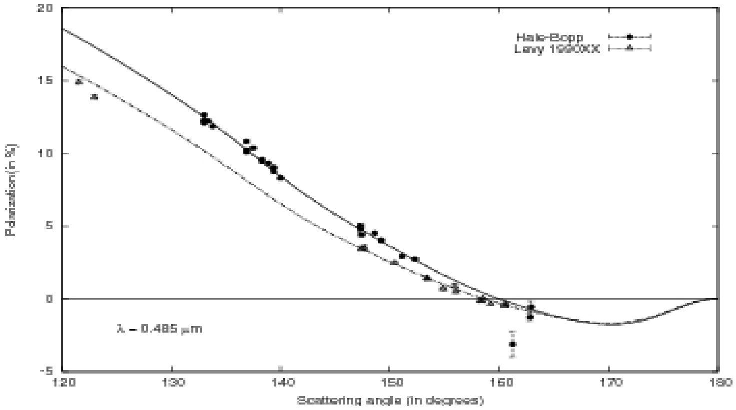

Figure 1. The polarization characteristics of comets Levy and Hale Bopp at 0.485 μm are compared .The solid curves represent simulated polarization values using aggregate model.

At wavelength 0.485 μm, the simulated value of *a* was 0.12 μm, which was the same as that obtained for Levy, but with a different refractive index value (1.778, 0.059). For Levy, the corresponding value was (1.783, 0.052). However, at 0.684 μm, the best fit value of *a* was 0.17 μm, with the refractive index value (1.755, 0.080). Figure 1 shows the observed polarization values of comets Levy and Hale Bopp, along with the theoretical scattering angle versus polarization curve simulated assuming the aggregate model of grains.

More recently, by applying the similar technique, the polarization data of comet Hyakutake at three distinct wavelengths 0.365 μm, 0.485 μm, and 0.684 μm were fitted by assuming an aggregate model of grains by the authors [15]. It was again found that the monomer radius had to be varied to obtain the best fit at different wavelengths, but the size parameter almost remained the same. Since this represents an unrealistic situation, it can be indicative of a situation which is more complex than just having one single aggregate composed of one single size of monomers with identical composition. A grain model containing compact spheroids and aggregates together may be able to explain the situation better. The work on this is under progress.

CONCLUSIONS

Any model for cometary grain, in addition to explaining the observed polarization, should also explain in general all the observed dust features: the scattered intensity, especially backscattering enhancement, polarimetric color as a function of wavelength, etc. However, in the present case, we are limiting ourselves to polarization data only, which have been observed only at certain specific wavelengths and phase angle ranges. With these limitations and based on our analysis above one can conclude that: i) Cometary polarization can be best explained by the aggregate model of dust, as compared to other shapes like Mie spheres and spheroids (prolate, oblate etc.); ii) The polarization values are not very sensitive to the structure or size of the aggregate. Instead, size of a monomer plays an important role; iii) It is interesting to note that the three different comets Levy, Hale Bopp and Hyakutake require almost the same monomer size at same wavelength to simulate the observed polarization curve; iv) At different wavelengths, the best fit conditions can be obtained by varying the monomer radius but the size parameter almost remains the same; v) Other grain models containing compact spheroids and aggregates together [16] may explain the situation in a better way.

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