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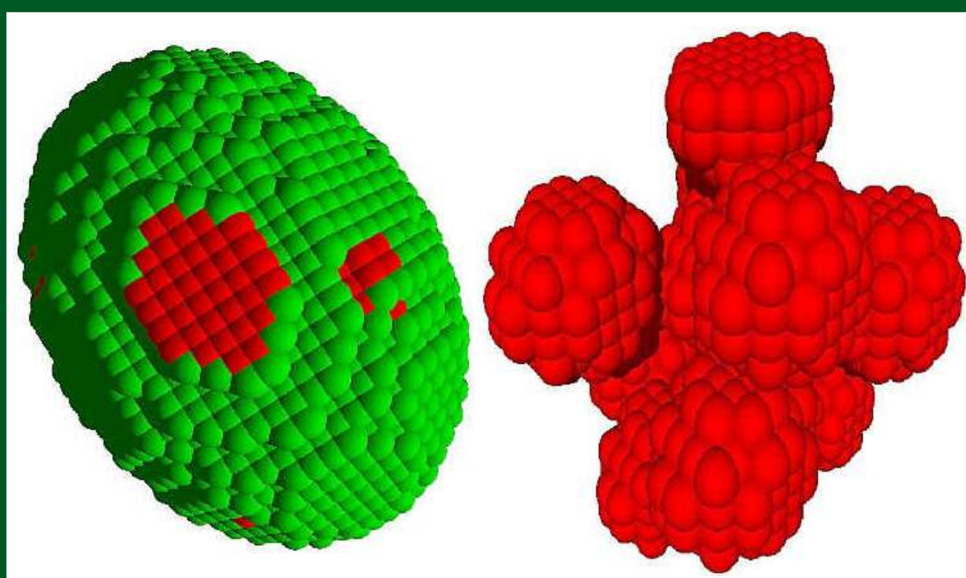

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Light scattering models and their intercomparison

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Light Scattering of dust (of various types) is an important probe to understand the composition, size, shape etc of the dust. Several light scattering models are now available to study the properties of dust which provide ways to understand the observed phenomena viz. extinction, polarization etc in the area of astrophysics, atmospheric, life sciences and other applications. This paper reviews the relevant models which are now increasingly used in these applications but the primary focus will be for astrophysical situations.

Keywords: Light Scattering, Mie theory, Microwave scattering, Discrete Dipole Approximation (DDA)

1 Introduction

The interaction of light with dust (and other material) creates many observed phenomena like atmospheric effects, astrophysical dust related extinction and polarization, medical applications e.g study of cancerous cells in blood samples, underground mines with microwave scattering etc. The oldest light scattering model to understand these observations is Mie theory [1] which assumes solid spheres. This model has been subsequently modified to incorporate non-spheres and additional mixture of material compositions using Effective Medium Approximation (EMA), [2]). T-Matrix [3] is another powerful tool which can handle large dust particles. Discrete Dipole Approximation (DDA) was developed much later than Mie by Purcell & Pennypacker [4] and is more useful since it can replicate the real shapes of dust grains which are highly porous, non-spherical and possibly fractal in nature. The only major limitation of DDA is computational efficiency which has been partially addressed by running the DDA codes on multi-CPU cluster machines which greatly reduce the computation times. More recently fractal shapes of dust grains is gaining importance since these shapes are closest to the real dust grains (as seen in impact mission and other balloon experiments) and thus reproduce several observed phenomena e.g. the negative branch of cometary polarization.

2 Mie theory

The Mie theory was proposed by G Mie [1] and assumes the dust grains to be made of solid spherical shape. Such grains are not realistic since recent studies of interplanetary, cometary and interstellar dust indicate that the cosmic dust grains are inhomogeneous viz. porous, fluffy and composite in nature [5- 9]. Although Mie theory has its limitations, but it is still very useful since when one tries to use a new model, the results need to be compared with the Mie calculations by making the grain shape as sphere.

3 Effective Medium Approximation

Effective Medium Approximation (EMA) assumes that the inhomogeneous grain is replaced by a homogeneous one with some "average effective dielectric function". The effects related to the fluctuations of the dielectric function within the inhomogeneous structure of the grain cannot be treated by EMA. The inhomogeneities within the grain viz. internal structure, surface roughness, voids etc.[10,11], are not accounted for and the material interfaces and shapes are smeared out into a homogeneous "average mixture" [12]. In EMA, one takes the optical constants of two materials and uses mixing rules like Maxwell-Garnet or Bruggman etc (see Bohren & Huffman [2]) and obtains a mixed refractive index of the composite material.

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4 T-Matrix and EMA-T-Matrix

The T-Matrix method has been reviewed by Mishchenko *et al* [3] and directly solves the Maxwell's equations to obtain the extinction efficiencies and polarization values for non-spherical grains with large size parameters $x = 2\pi a/\lambda > 20$. It also provides a superposition approach for computing light scattering by composite/aggregated grains. This method has the advantage of orientation averaging of the grain geometry and is very computationally fast. Recently Vaidya & Gupta [13] have evolved a method of using EMA to generate a mixed refractive index (as described above) and then use it with T-Matrix to obtain the light scattering results for applications to IR emission from composite grains.

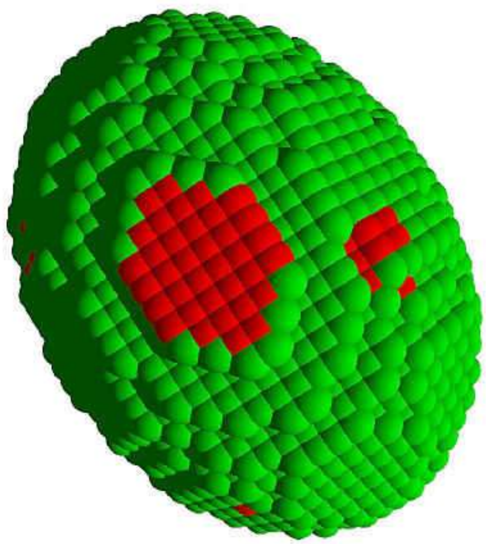

Fig 1. A non-spherical composite dust grain consisting of host (in green) and inclusion (in red) with a total of N = 9640 dipoles where the inclusions embedded in the host spheroid are shown such that only the ones placed at the outer periphery are seen.

5 Discrete Dipole Approximation

The basic idea of Discrete Dipole Approximation (DDA) is that the overall scattering and absorption behavior of a collection of point dipoles, arranged on a lattice with spacing considerably smaller than the incident radiation wavelength, will be equivalent to the scattering and absorption of a homogeneous grain having the same shape as that of the dipole collection. There are two validity criteria for DDA (see e.g. Wolff *et al* [10]). (i) $|m|\, kd \leq 1$, where m is the complex refractive index of the material, $k = \pi/\lambda$ the wave number, and d the lattice dispersion spacing; and (ii) d should be small enough (N should be sufficiently large) to describe the shape of the particle satisfactorily. This method allows one to generate a set of dipole positions for an arbitrarily shaped grain and this can reproduce the real shape for various grain shapes. Further the dipole positions of the main host material can be removed in a random fashion and replaced with either voids (making it porous) or other materials as inclusions (see Vaidya *et al* [14]).

5.1 Non-spherical composite grains

As described above, Fig 1 and Fig 2 show a typical representation of a non-spherical dust grain where the host dipoles could be of say silicate material and the inclusions (in red) could be of graphite material. Such grains have been used in several publications by Vaidya & Gupta [13].

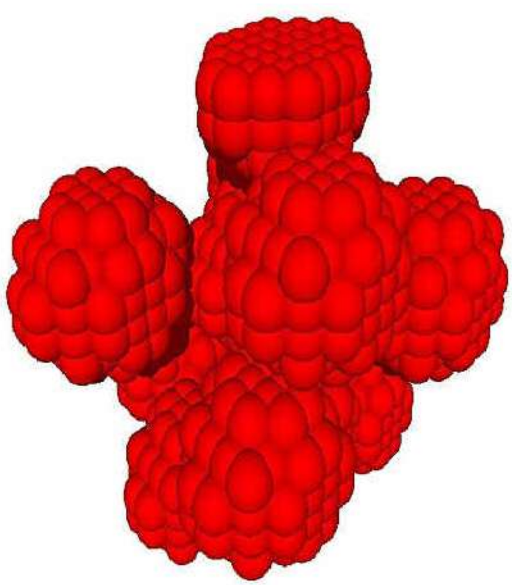

Fig 2. This figure shows the inclusions of the composite grain. The volume fraction f of graphite inclusions is 0.2. The number of inclusions is 11 with 152 dipoles per inclusions.

5.2 Fractal grains

In various applications such as cemetary dust and its polarization observations, it has been noticed that the negative branch of polarization can be reproduced only when one considers the grains to be of fractal shape. A typical grain of this type is shown in Fig 3 which was produced by code developed by Botet & Julien [15].

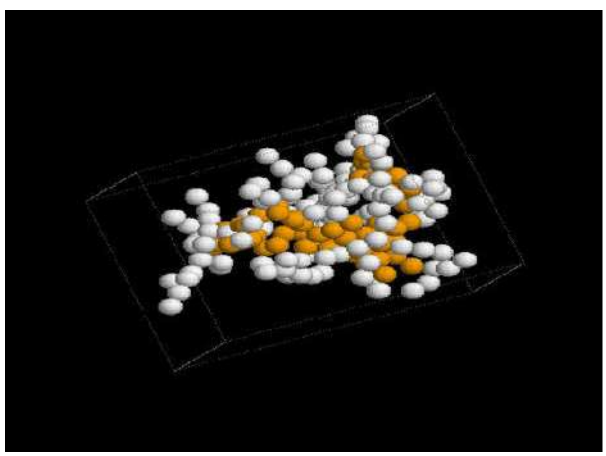

Fig 3. Similar to Fig 1 but grain shape is of fractal nature.

6 Intercomparison between various models

The intercomparisons of DDA and EMT have been discussed in details by Bazell & Dwek [16], Perrin & Lamy [17], Ossenkpof [18] and Wolff *et al* [10]. Vaidya & Gupta [13] have compared DDA and EMA-T-Matrix as shown in Fig 4, where the ratio of absorption efficiency in the NIR region of 5 – 25 μm is carried out. It is seen that the absorption curves obtained using the EMA-T matrix calculations deviate from the absorption curves obtained using the DDA, as the volume fraction of inclusions increases. The results based on the EMA-T-matrix calculations and DDA results do not agree because the EMA does not take the inhomogeneities within the grain into account as was mentioned earlier.

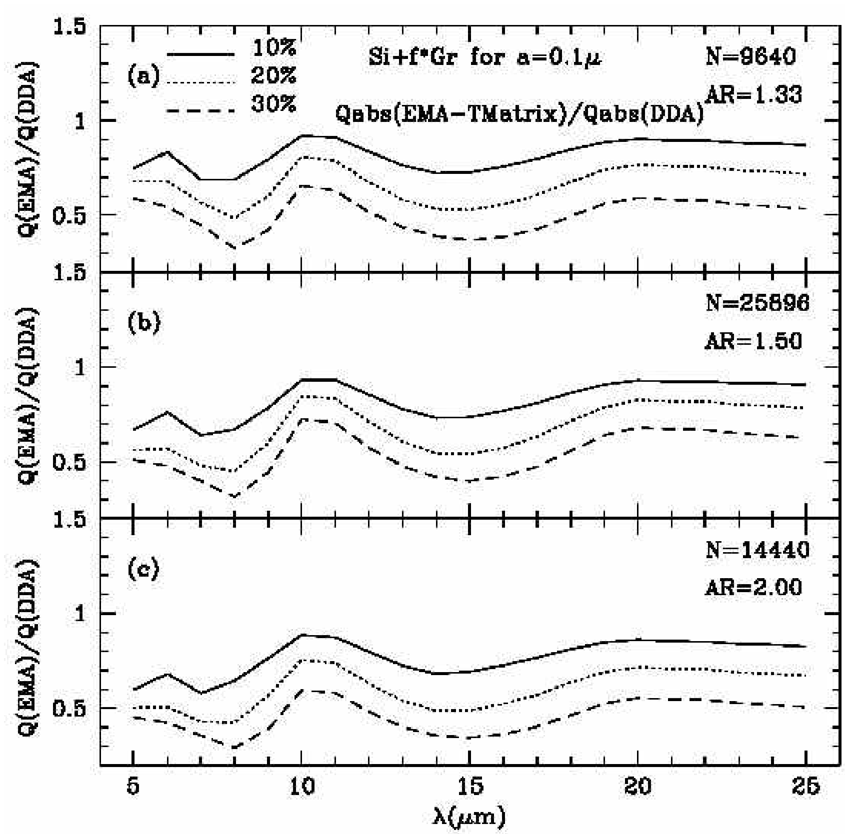

Fig 4. Ratio for absorption efficiency using DDA and EMA.

7 Conclusions

1. Various light scattering methods have been described as applicable to astrophysical situations.
2. The need for more realistic grains with fractal shapes is stressed.
3. Intercomparison between various light scattering methods are discussed.

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