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Infrared emission from the composite grains: Application to circumstellar dust

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Abstract. We calculate the absorption efficiency of the composite grain, made up of a host silicate spheroid and inclusions of ice/graphite/or voids, in the spectral region 1.0 - 30.0 μm. The absorption efficiencies of the composite spheroidal grains for three axial ratios are computed using the discrete dipole approximation (DDA). We study the absorption as a function of the volume fraction of the inclusions and porosity. In particular, we study the variation in the 10.0 μm and 18.0 μm absorption features with the volume fraction of the inclusions and porosity. We then calculate the infrared fluxes for these composite grains and compare the model curves with the average observed IRAS - LRS curve, obtained for circumstellar dust shells around several stars.

Keywords : Infrared emission from dust, Circumstellar dust, Composite dust

1. Introduction

Dust grains ejected from stars are more likely to be non-spherical and inhomogeneous, viz. porous,fluffy and composites of many small grains glued together, due to grain-grain collisions, dust-gas interactions and various other processes. Since there is no exact theory to study the scattering properties of these inhomogeneous grains we need approximate methods. We use discrete dipole approximation (DDA) to study the scattering properties of the composite grains (Vaidya et al. 2007). For the description on the DDA see Draine (1988). The

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DDA allows the consideration of irregular shape effects, surface roughness and internal structure within the grain (Wolff et al. 1994, 1998 and Voshchinnikov et al. 2005). For discussion and comparison of DDA and other approximate methods, e.g. effective medium approximations, see Bazell & Dwek (1990), Perrin & Lamy (1990), Perrin & Sivan (1990), Ossenkopf (1991) and Wolff et al (1994). We calculate the absorption efficiency of the composite grains, made up of a host silicate spheroid and inclusions of graphite/ice/voids (Vaidya & Gupta 2009) in the spectral region, 1.0 - 30 μm. We use these absorption efficiencies of the composite grains to calculate the infrared fluxes at various dust temperatures.

In section 2 we give the validity criteria for the DDA and the composite grain models. In section 3 we present the results of our computations and compare the model curves with the observed IR fluxes obtained by IRAS satellite. The main conclusions of our study are given in section 4.

2. Composite grains and DDA

We use the computer code developed by Dobbie (1999) to generate the composite grain models used in the present study. We have studied composite grain models with a host silicate spheroid containing N= 9640, 25896 and 14440 dipoles, each carved out from $32 \times 24 \times 24$, $48 \times 32 \times 32$ and $48 \times 24 \times 24$ dipole sites, respectively; sites outside the spheroid are set to be vacuum and sites inside are assigned to be the host material. It is to be noted that the composite spheroidal grain with N=9640 has an axial ratio of 1.33, whereas N=25896 has an axial ratio of 1.5, and N=14440 has an axial ratio of 2.0. The volume fractions of the graphite inclusions used are 10%, 20% and 30% (denoted as f=0.1, 0.2 and 0.3). Details on the computer code and the corresponding modification to the DDSCAT code (Draine & Flatau 2003) are given in Dobbie (1999), Vaidya et al. (2001, 2007) and Gupta et al. (2006). For an illustrative example of a composite spheroidal grain with N=9640 dipoles, please refer Fig. 1, given in Vaidya et al. (2007). There are two validity criteria for DDA (see e.g. Wolff et al. 1994); viz. (i) $|m|kd \leq 1$, where m is the complex refractive index of the material, $k=\pi/\lambda$ is the wavenumber and d is the lattice dispersion spacing and (ii) d should be small enough (N should be sufficiently large) to describe the shape of the particle satisfactorily. The complex refractive indices for silicates and graphite are obtained from Draine (1985, 1987) and that for ice is from Irvine & Pollack (1968).

3. Results

3.1 Absorption efficiency of composite spheroidal grains

We study the absorption properties of the composite spheroidal grains for three grain models with the number of dipoles N=9640, 14440 and 25896, for three

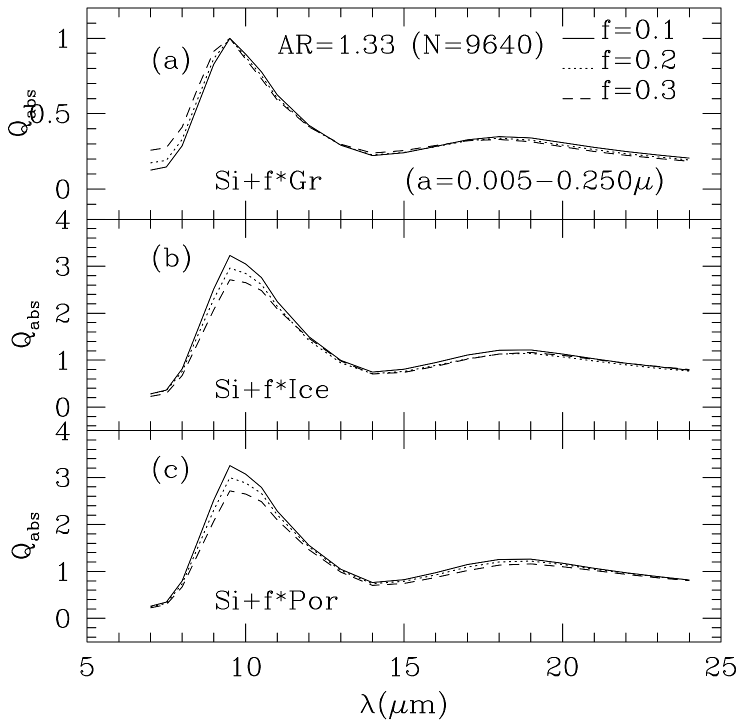

Figure 1. Absorption Efficiencies for the composite grains with host spheroids containing dipoles N=9640 and (a) graphite, (b) ice and (c) void inclusions.

volume fractions of inclusions; viz. 10%, 20% and 30%, in the wavelength region 1.0-30.0μm. The inclusions, selected are graphite/ices/or voids.

Fig. 1(a-c) show the Absorption efficiencies (Q_{abs}) for the composite grains with the host silicate spheroids containing 9640 dipoles with inclusions of graphites, ice and voids respectively. The three volume fractions, viz. 10%, 20% and 30%, of inclusions are listed in the top (a) panel.

The effect of the variation of volume fraction of inclusions is clearly seen for all the models. The other two composite grain models with N = 25896 and 14440 also showed the variation in absorption efficiency with volume fractions of inclusions (see Vaidya & Gupta 2009).

It is seen from Fig. 1(a), that the absorption efficiency increases with the volume fractions of graphite inclusions for the wavelengths shortward of 10 μm. It is to be noted that the wavelength of peak absorption shifts towards shorter wavelengths i.e. the peak shifts from 9.7 μm for f=0.1 to 9.5 μm for f=0.2 and to 9.2 μm for f=0.3. It is also to be noted that there is no significant variation in the absorption efficiency with the volume fraction of graphite inclusions longward of 10 μm. Fig. 1(b) shows the variation of absorption efficiency with ice inclusions. It is seen that the absorpton efficiency at the peak decreases with the volume fraction of ice. Moreover, these results with ice inclusions do not show any significant shift in the wavelength of peak absorption. Fig. 1(c) also indicates that the peak absorption decreases with the variation in the porosity of the grains and there is no significant shift in the wavelength of peak absorption.

Fig. 1(c) indicates that the wavelength of peak absorption shifts with the variation in the porosity of the grains.

Using the absorption efficiencies of the composite grains, we calculate the infrared flux, F_λ at various temperatures of the dust, and for a power law MRN dust grain size distribution (Mathis et al. 1977). We compare the model curves with the average observed LRS-IRAS curve, obtained for circumstellar dust shells around $\sim$ 20 oxygen rich M-type stars (Whittet 2003).

In Figs 2 (a) and (b), we have shown the average observed IRAS-LRS curve (Whittet 2003) and its best fitted temperatures to the Graphite and Voids inclusions models with N=9640.

These results on the composite grains, with host spheroid containing small axial ratio, i.e. N=9640 dipoles and the volume fraction of graphite and void inclusions f=0.1 fit the observed infrared flux reasonably well at the shorter wavelength range of 7.0-10.0 μm and dust temperatures ranging from T=270-290°K. However, at longer wavelengths, i.e. $> 10.0\mu m$, the fit is not satisfactory. These results indicate that composite grain models with other inclusions (e.g. amorphous carbon, silicon carbide, PAHs) and porosities may be required for better fit to the observed data and such calculations are planned in the future.

4. Summary and conclusions

Using the discrete dipole approximation (DDA), we have studied the variation of the absorption efficiency for the composite spheroidal grains, with the volume fractions of the inclusions in the wavelength region of 1.0-30.0μm. These results clearly show the variation in the absorption efficiency for the composite grains with the volume fractions of the inclusions. The results on the composite grains with graphite inclusions also show the shift in the peak absorption wavelength '9.7 μm' with the volume fraction of the inclusions. These results on the composite grains clearly indicate that the inhomogeneities (porosity,

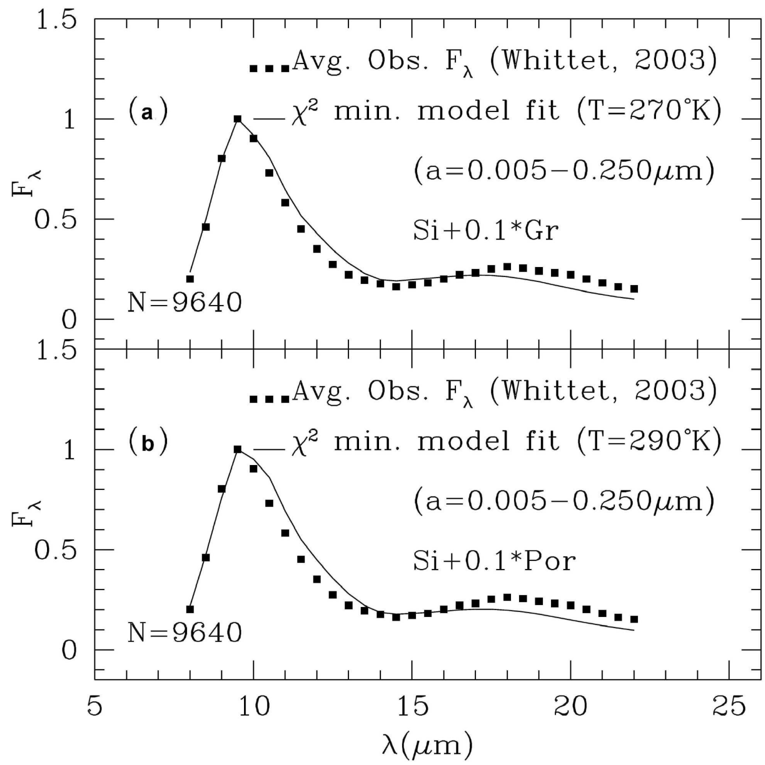

Figure 2. Infrared Flux for composite dust grain models best fitted to the average observed IRAS-LRS curve (Whittet 2003) and corresponding temperatures for the N=9640 models and (a) graphite and (b) voids inclusions.

fluffyness, composites) within the grains play an important role in modifying the absorption/emission properties of the grains.

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