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RESEARCH ARTICLE

INTERSTELLAR EXTINCTION MODELLING BY AGGREGATE DUST

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Abstract

Extinction generally ours whenever electromagnetic radiation propagates through a medium containing small particles. The spectral dependence of extinction, or extinction curve, is a function of the composition, structure and size distribution of the particles. The study of interstellar extinction is important because they provide essential information for understanding the properties of the dust. In this work we have considered the aggregate dust model to interpret the extinction efficiency (Qext) of interstellar dust in the wavelength range 0.11µm to 3.4µm. Using Superposition T-matrix code with Ballistic Cluster-Cluster Aggregate (BCCA) aggregate having 64 number of monomers with graphite, astronomical silicates and amorphous carbon, the normalized extinction efficiency has been calculated for a well designed size distribution within a size range 0.001 to 0.077 micron of extinction near wavelength 0.2175µm. It is seen that for large grain size distribution the well pronounced UV-bump almost disappear. Moreover the nature of variation of extinction curve with increasing size of the grain has also been shown.

Introduction:-

The studies of interplanetary and cometary dust indicate that cosmic grains are likely to be porous, fluffy and composites of many small grains coalesced together, due to grain- grain collisions, dust-gas interactions and various other processes (Krueger & Kissel 1989; Greenberg & Hage 1990; Wolf et al. 1994). Porous, composite aggregates are often modelled as luster of small spheres (\monomers"), assembled under various aggregation rules with typical sizes 0.1-10 µm. Here grain aggregates are assumed to be fluffy substructure collections of very small particles loosely attached to one another. Each particle is assumed to consist of a single material, such as silicates or carbon, as formed in the various separate sources of cosmic dust. Extinction generally ours whenever electromagnetic radiation propagates through a medium containing small particles. The spectral dependence of extinction, or extinction curve, is a function of the composition, structure and size distribution of the particles. The study of interstellar extinction is important be because they provide essential information for understanding the properties of the dust.

Das & Sen (2006) studied the non-spherical dust grain characteristics of comet Levy 1990XX using Spheroidal Grain Model. They found that compact prolate grains as compared to spherical grains an better explain the observed linear polarization data. Using Spheroidal Grain Model, at- tempt has been made to study the extinction properties of interstellar dust (Gupta et al. 2005, Das et al. 2010b). But it

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is now well accepted that cosmic dust grains are fluffy aggregates or porous with irregular shapes (Mathis & Whi en 1989; Dors hner & Henning 1995; Greenberg & Hage 1990). Using Discrete Dipole Approximation (DDA), several investigators studied the the extinction properties of the composite grains (Wolf et al. 1994, 1998; Vosh chinnikov et al. 2005; Vaidya et al. 2007, 2009 et .). Iati et al. (2004) have studied optical properties of composite grains as grain aggregates of amorphous arbon and astronomical silicates, using the Superposition transition matrix approach. Using aggregate dust model, several investigators successfully modelled the light scattering properties of cometary dust (Kimura et al. 2006; Das et al. 2008a, b; Das et al. 2010a; Paul et al. 2010et.).

In our present study, we use more realistic aggregate dust model and calculate the extinction efficiencies in the extended wavelength region, 3.40.10 m using Superposition T-matrix code. Using these extinction efficiencies of the aggregate grains with a power law type grain size distribution we compute the average interstellar extinction curves for graphite, amorphous carbon and astronomical silicate.

Aggregate Dust Model

Building of aggregates

We build the aggregates using ballistic aggregation procedure (Meakin 1983, 1984). Two different models of cluster growth are taken: first via single-particle aggregation and then through cluster- cluster aggregation. These aggregates are built by random hitting and sticking particles together. The first one is called Ballistic Particle-Cluster Aggregate (BPCA) when the procedure allows only single particles to join the luster of particles. If the procedure allows clusters of particles to stick together, the aggregate is called Ballistic Cluster-Cluster Aggregate (BCCA). Actually, the BPCA clusters are more compact than BCCA clusters (Mukai et al. 1992). The porosity of BPCA and BCCA particles of 128 monomers has the values 0.90 and 0.94, respectively. A systematic explanation on dust aggregate model is already discussed in our previous work (Das et al. 2008a). It is to be noted that the structure of these aggregates are similar to those of Interplanetary Dust Particles (IDP), often get collected at high altitudes of the Earths atmosphere (Brownlee 1985). Laboratory diagnosis of particle coagulation in the solar nebula suggests that the particles grow under BCCA process (Wurm & Blum 1998).

The radius of an aggregate particle an besides ribbed by the radius of a sphere of equal volume given by a = a $N^{1/3}$, where N is the number of monomers in the aggregate.

The number of monomers

The number of the monomers in the present study are taken to be N = 8, 16, 32 and 64, respectively. It is seen that the increase of number of monomer does not change the extinction efficiency value appreciably if one consider the large number of monomers (Iati et al. 2005) and moreover increasing number of monomer put restriction in computing as it takes more RAM and time. Also the computer memory restricts the limitations on the size parameters, therefore we have restricted our al calculation of extinction efficiency 64 number of monomers.

The size of monomers

The size of the individual monomer in a luster plays an im- portant role in scattering calculations (Kimura et al. 2003, 2006; Petrova et al. 2004; Bertini et al. 2007; Das et al. 2008a). It is reported that the most of the work relatedto interstellar extinction considered a normal size range of 0.001to 0.250µm, with size distribution (Jones 1988, Vaidya et al. 2006, Das et al. 2010b). They found an `optimum' for the range of the luster size generally used. The above size range of the monomer is more or less capable of evaluating average observed interstellar extinction curve. To study the effect of monomer we ran simulations with $0.001 \leq a_m \leq 0.077$µm i.e., $0.004 \leq a \leq 0.308$µm, this size range is almost comparable to the size range used by Vaidya et al.(2006)

Composition

Interstellar dust mainly consist of very heavy elements C, O, Mg, Si, Fe (Jones 2000, Draine2009, Das et al. 2010b). The carbonaceous and silicate particles are likely materials to contain the above mentioned elements. Therefore we consider submicron particles of amorphous carbon, graphite and astronomical silicates to be the most likely composition to explain the nature of average extinction curve

(Mathis 1989). In our computation we take the refractive indices of graphite and astronomical silicate grains from Drain (1985)and amorphous carbon from Rouleau & Martin (1991).

Numerical Computation

The main objectives of the paper is to study the extinction efficiencies of the graphite, amorphous and silicate grains with various sizes which are typical to interstellar grain sizes. These materials (i.e. silicate, graphite and amorphous carbon) have been the ingredients for most of the models used in the previous work (Mathis et al. 1977; Draine & Lee 1984; Weingartner & Draine 2001, Gupta et al. 2005, Vaidya et al. 2007 et .). Iati et al(2004) took aggregate model to explain interstellar extin tion in general. They did not consider the size distribution of cluster. They calculated extinction cross-section and normalized with mass, moreover they calculated radiation pressure cross section (Cpr), albedo, asymmetry parameter et . They concluded that the extinction, scattering and radiation cross-section only slightly depend upon the morphology i.e. whether the aggregate is BCCA or BPCA consisting of equal number of monomers. Their approach was not based upon to explain the average extinction curve using a suitable size distribution as in our paper we tried to explain it. In the present work, we are not attempting to mat h the observed interstellar extinction curve. The average extinction curves will be generated considering astronomical silicate, graphite and amorphous carbon grains in a wide wavelength range 0.10 μm to 3.4μ m.

The calculations are performed by the SUPERPOSI- TION T-MATRIX CODE, which gives rigorous solutions for ensembles of spheres (Mackowski &Mishchenko 1996). We present the results for the aggregate dust model; i.e. the extinction efficiencies Q_{ext} as a function of wavelength in the spectral range (3.4 to 0.10 μm). The numerical computation in the present work has been done with BCCA aggregates.
We use the power law grain size distribution, i.e., n(a)~ $a^{-3:5}$ (Mathis, Rumpl & Nordsieck (MRN) size distribution; see Mathis et al. 1977) to generate the average interstellar extinction curves for graphite, amorphous carbon and silicate grains where a lower to around 0.004 μm and an upper cut off up to of about 0.31 μm are taken. The complex refractive indices of graphite and astronomical silicate are taken from Draine (1985) and amorphous carbon is taken from Rouleau& Martin (1991).

The general extinction A_λ is given by (Spitzer 1978)

$$A_\lambda = -2.5\log\left[\frac{F(\lambda)}{F_0(\lambda)}\right] = 1.086 N_d Q_{ext} \sigma_d \qquad (1)$$

Where $F(\lambda)$ and $F_0(\lambda)$ are the expected fluxes and N_d is the dust column density and Q_{ext} is the extinction efficiency factor determined from Superposition T-matrix code,

and σ_d is the geometrical cross section of a single particle.

The observational determination of the general extinction, A ,
is very difficult result and it is therefore general practice to normalize extinction data at B and V photometric bands (Jones 1988), e.g.

$$\frac{E(\lambda - V)}{E(B-V)} = \frac{A_\lambda - A_V}{A_B - A_V} = \frac{A_\lambda}{E(B-V)} - R \qquad (2)$$

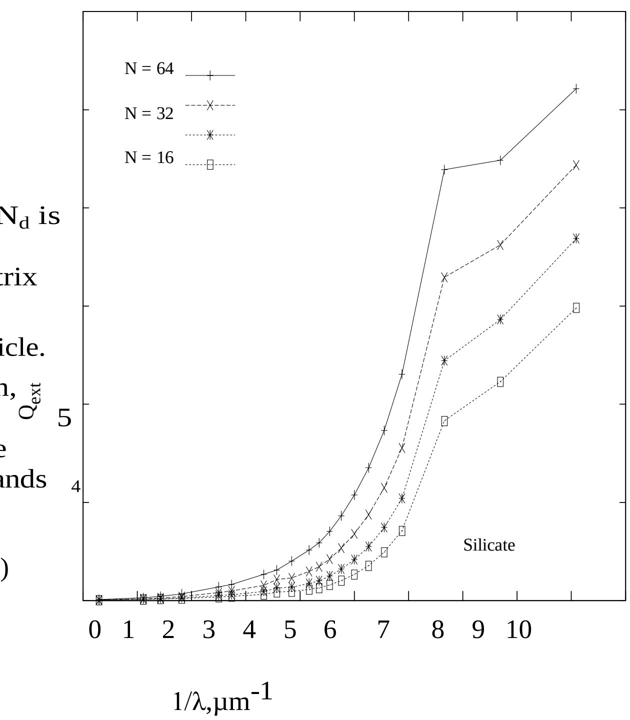

Figure 1. Effect of N on extinction efficiency (Q_{ext}). The simulated extinction efficiency curves obtained for BCCA silicate aggregates are drawn with N = 8, 16, 32 and 64. Here, the size of the monomer(a_m) is 0.013 μm.

For `normal' extinction E (B -V) = 0.6 mag kpc^{-1} and R=3.1 .In general the number density of the dust particles, $n_d(a)$, is assumed to follow a power law size distribution, n(a) a^{-n} with limiting minimum and maximum grain radii a_1 and a_2 respectively. Thus the column density of dust along a path length, L, is given by

$$N_d = A_i n_H a^{-n} L = N_H A_i a^{-n}, \qquad (3)$$

where n_H and N_H are the hydrogen nucleus number density and column density : $N_H = 5.8\times10^{21} E(V-B)$ Bohlin,Savage & Drake 1978, A_i is determined by the elemental depletions, limiting grain radii and the index in the power law. Since we consider MRN size distribution, n=3.5.

Now the extinction for a given grain size distribution is given by (Jones 1988):

$$\frac{A_\lambda}{E(B-V)} = 1.086\times5.8\times10^{21} A_i \int_{a_1}^{a_2} a^{-n}\sigma_d Q_{ext}\, da \qquad (4)$$

Where Q_{ext} extinction efficiency parameter which depends on particle radius (a), wavelength (λ) and dielectric function (ε).

$$A_i = \frac{M}{f\rho n_H}\left[\int_{a_1}^{a_2} a^{-n} v(a)\, da\right]^{-1} \qquad (5)$$

where M is the mass of material in the grains, is the density of the solid, v(a) is the grain volume and f is the fraction of the total grain volume occupied by solid matter. Therefore (1-f) is a measure of the porosity. We have taken densitiesof astronomical silicate, graphite and amorphous carbon as 2.5 g /cm^3, 2.2 g / cm^3 and 1.85 g / cm^3 respectively.

Result:-

Figures 1 to 3 show the extinction efficiencies (Q_{ext}) for silicate, graphite and amorphous carbon for N = 8, 16, 32 and64 in the wavelength range 0.11 μm 3.4μm. The radius of the monomer is taken as 0.013 μm. It can be seen from the figures that Q_{ext} increases with the increase of number of monomers, i.e., with the increase of luster size. We now fix the number of monomers to 64 as N> 64 will restricted thelimitation on computation. In Fig. 4, the variation of Q_{ext} with size parameter of monomer (x= 2πa_m/λ) for silicate, graphite and amorphous carbon at = 0.15 μm are plotted. Figures 5 to 7 show the plot of the extinction efficiencyxt vs 1/ λ for the silicate, graphite and amorphous carbongrains in the wavelength range 0.11 μm to 3.4μm for the grain sizes a = 0.004, 0.5, 0.1 and 0.2 μm. The extinction efficiency of the size ofthe cluster is clearly shown. In Fig. 5, the well pronounced UV bump can be noticed for graphite grains. It is well established fact that the very small sub micron unit of graphite grain (a<<λ) is capable of producing pronounced UV peak at 2175A^0 (Whittet 2002, Gupta et al 2005). It can be seen from Fig. 6 that a well pronounced UV peak can be observed at 0.22 μm (i.e. 4.54 μm^{-1}) up to cluster size 0.5 μm. If we increase the size of the cluster to 2.5 m, the Visible range (0.38 to 0.76 m) and the UV range (the last part of violet in visible spectrum to 0.100 m, in our paper). Using equation (4), we now compute the average interstellar extinction curves for silicate, graphite and amorphous carbon in the wavelength range 0.11μ m to 3.4μ m, where MRN size distribution (i.e., n(a) a$^{-3.5}$, Mathis et al. 1977) with 0.004 ≤a ≤ 0.31 m is taken. The average extinction curves are shown in Fig. 8. The most pronounced extinction peak at wavelength near 2175A in the UV range can be reproduced in our work with graphite grains.

The nature of interstellar extinction curves for visible and IR region is also consistent with the observed average extinction curve. Thus with a suitable mixing between silicate, graphite and amorphous carbon grains, it is possible to reproduce the observed extinction curve Actually the mixing can be achieved in many ways which is beyond the scope of the present work, But in future follow up paper we have a plan to match the observed interstellar extinction curve by suitable mixing of silicates, graphite and amorphous carbon.

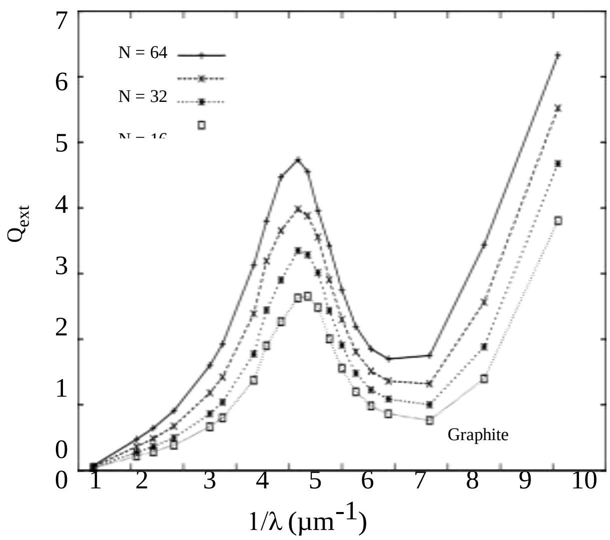

Figure 2:- Effect of N on extinction efficiencies y (Q_{ext}). The simulated extinction efficiency curves obtained for BCCA graphite aggregates are drawn with N = 8, 16, 32 and 64. Here, the size of the monomer (a_m) is 0.013 μm

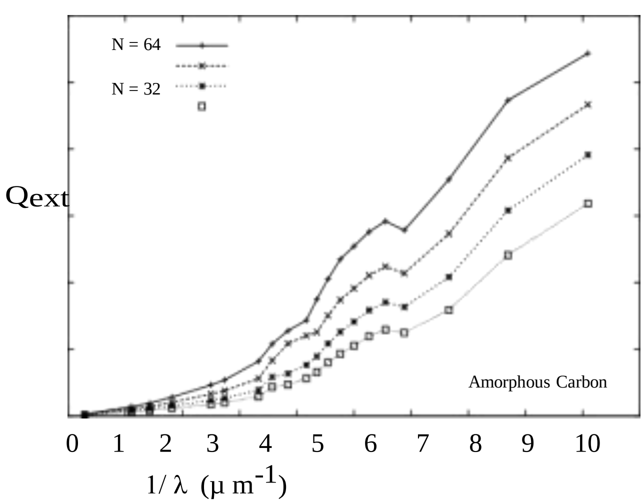

Figure 3:- Effect of N on extinction efficiency (Q_{ext}). The simulated extinction efficiency curves obtained for BCCA amorphous carbon aggregates are drawn with N = 8, 16, 32 and 64. Here, the size of the monomer (a_m) is 0.013μm.

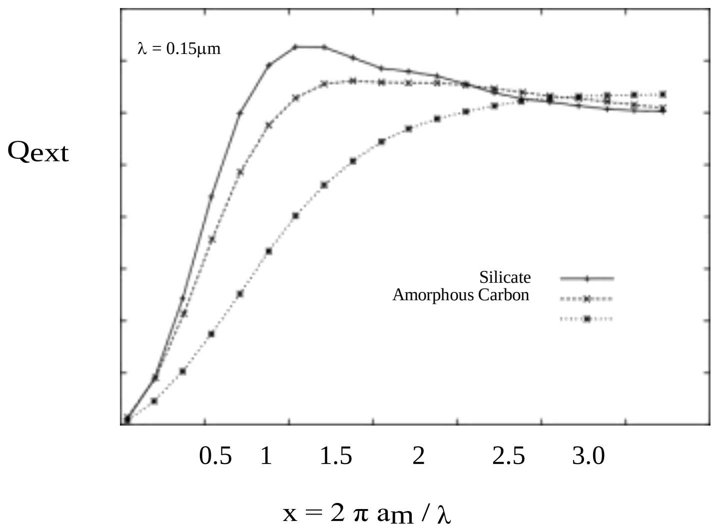

Figure 4:- The variation of Extinction efficiency (Q_{ext}) with size parameter of the monomer ($x = 2\pi a_m / \lambda$) for silicate, graphite and amorphous carbon at $\lambda = 0.15\mu m$.

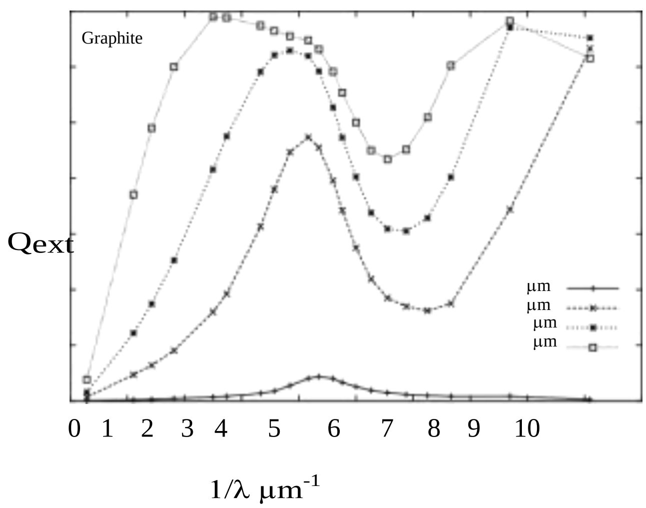

Figure 5:- Extinction efficiencies Q_{ext} versus $1/\lambda$ for randomly oriented graphite grains of sizes a = 0.004, 0.05, 0.1 and 0.2μ m in the wavelength range 3.4 to 0.11 μm.

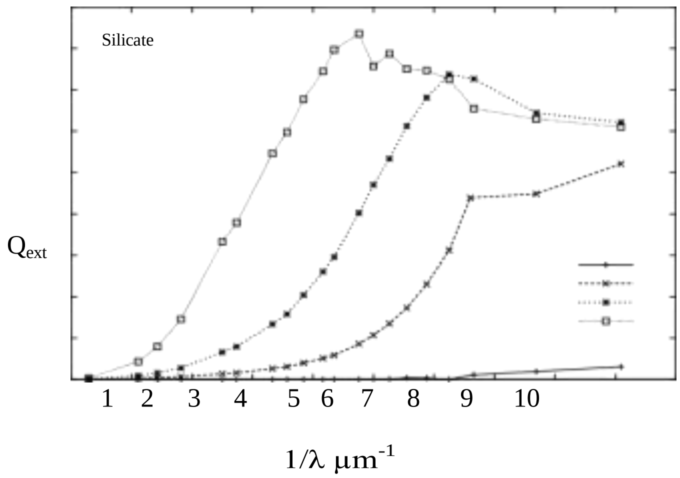

Figure 6:- Extinction efficiencies Q_{ext} versus $1/\lambda$ for randomly oriented silicate grains of sizes a = 0.004, 0.05, 0.1 and 0.2μ m in the wavelength range 3.4 to 0.11 μm.

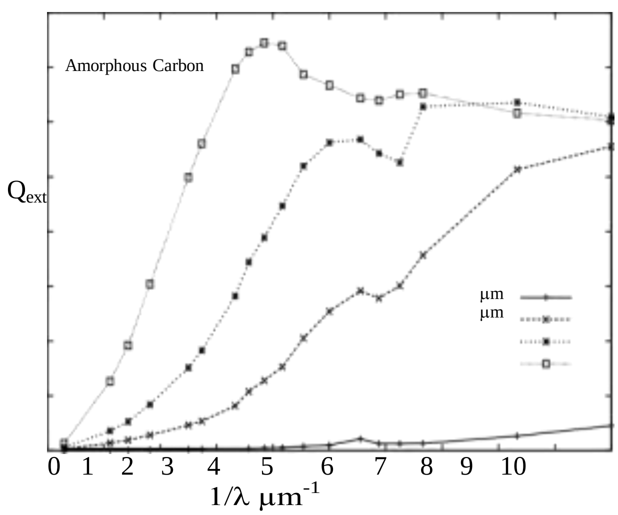

Figure 7:- Extinction efficiency Q_{ext} versus $1/\lambda\ \mu m^{-1}$ for randomly oriented amorphous carbon grains of sizes a = 0.004, 0.05, 0.1 and 0.2μm in the wavelength range 3.4 to 0.10μm.

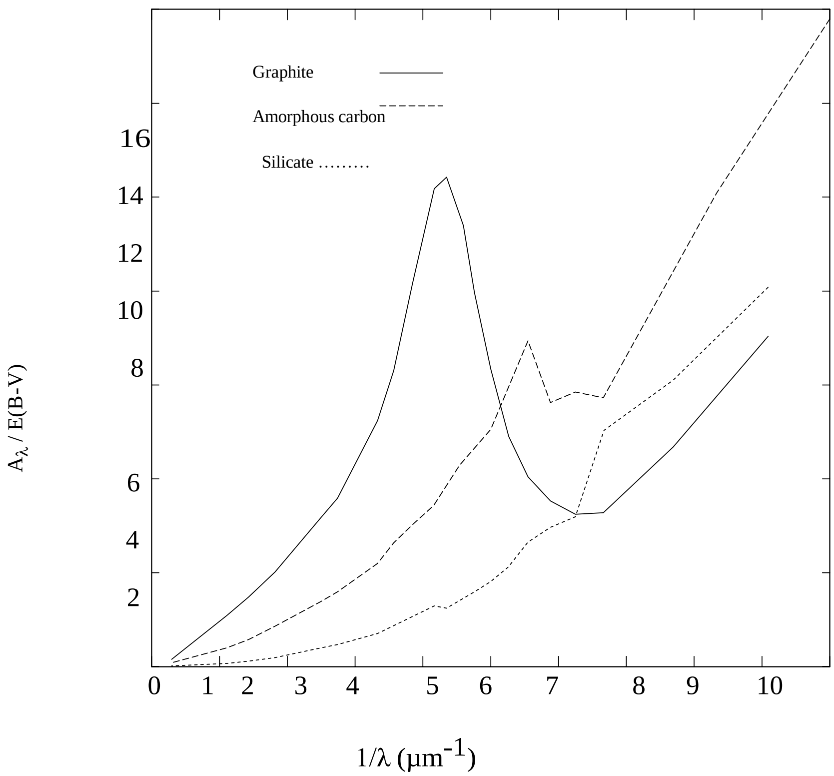

Figure 8. Extinction curves for silicate, graphite and amorphous carbon. The size range of the cluster is taken in the range0.004μm to 0.308 μm.

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