
Modeling of Silicate emission features in Circumstellar Dust

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Abstract

We present a composite grain model to explain the IR emission features at 10 and 18 μm from the circumstellar dust of stars. The IRAS-LRS data from about 700 stars have been analysed and fitted to a set of composite porous dust grains consisting silicate host and graphite/vacuum inclusions. The 10 μm silicate feature shifts with the inclusion volume fraction of graphite grains but not with the changes in porosity. Both 10 and 18 μm features do not broaden with the inclusions of graphite or vacuum. It is also noted that the axial ratio of the dust grain shapes change for various types of circumstellar dust observed in the IRAS data.

Abstract ... contd.

The model uses a composite fluffy dust grain for explaining most of the observed interstellar extinction curves and also polarization. Another parameter which needs to be constrained by the dust models is the interstellar abundances of Carbon and Silicon which is usually overestimated by the solid dust models but our model predicts closer match to the observed ISM abundances. Further, our composite dust model also explains the IR emission from circumstellar dust.

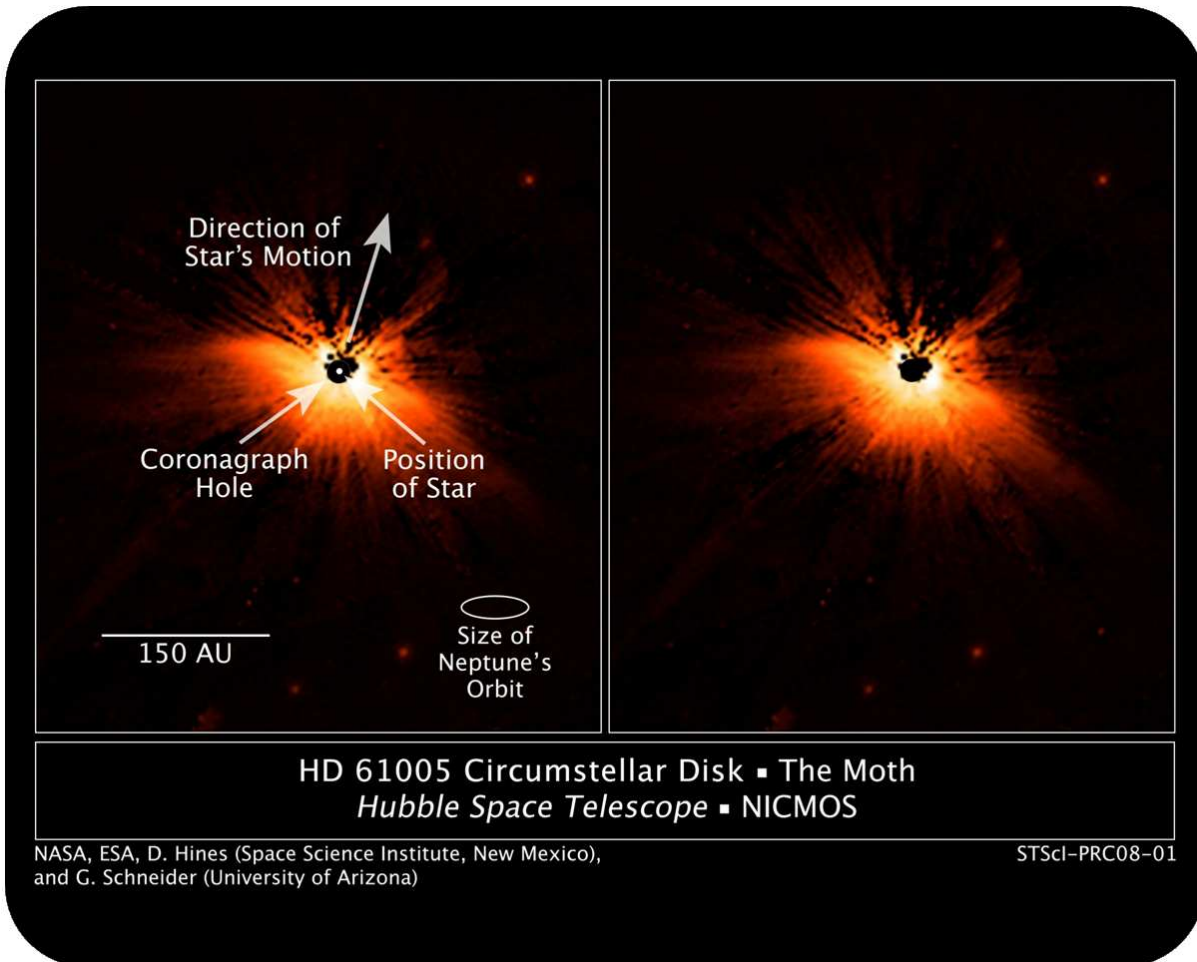
Plan Of The Talk

- Dust around Stars
- Composite Dust Grain Models
- IR emission from dust
- IRAS data base
- Statistics of Model fits to large IRAS data set

Circumstellar Dust

- Dust associated with individual stars - their evolution, physical properties, temperature, etc. are determined by the parent star alone.
- Dust grains can't form in interstellar space, must form in stellar atmospheres, and then ejected out into the interstellar medium where they can evolve and change.
- Dust around young evolving stars – remnant of star and planetary system formation.
- Dust present around evolved stars that are post main-sequence stage - significant sources of new grain material, formed in their winds during extended period of high mass-loss or in isolated cataclysmic events such as nova or supernova outbursts.

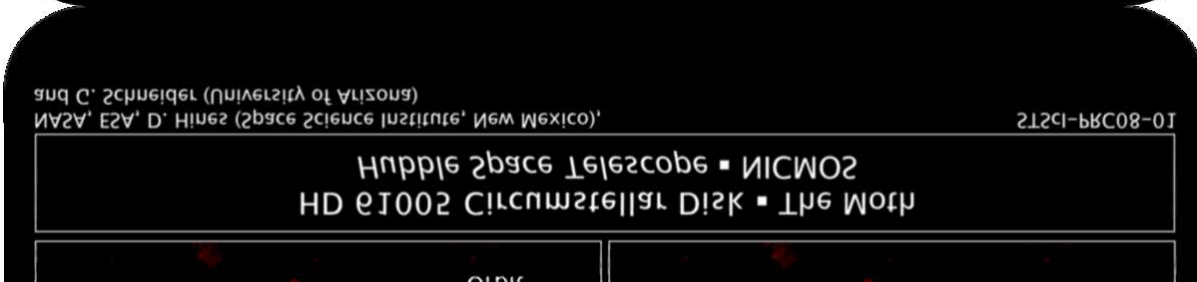
Circumstellar Dust Image



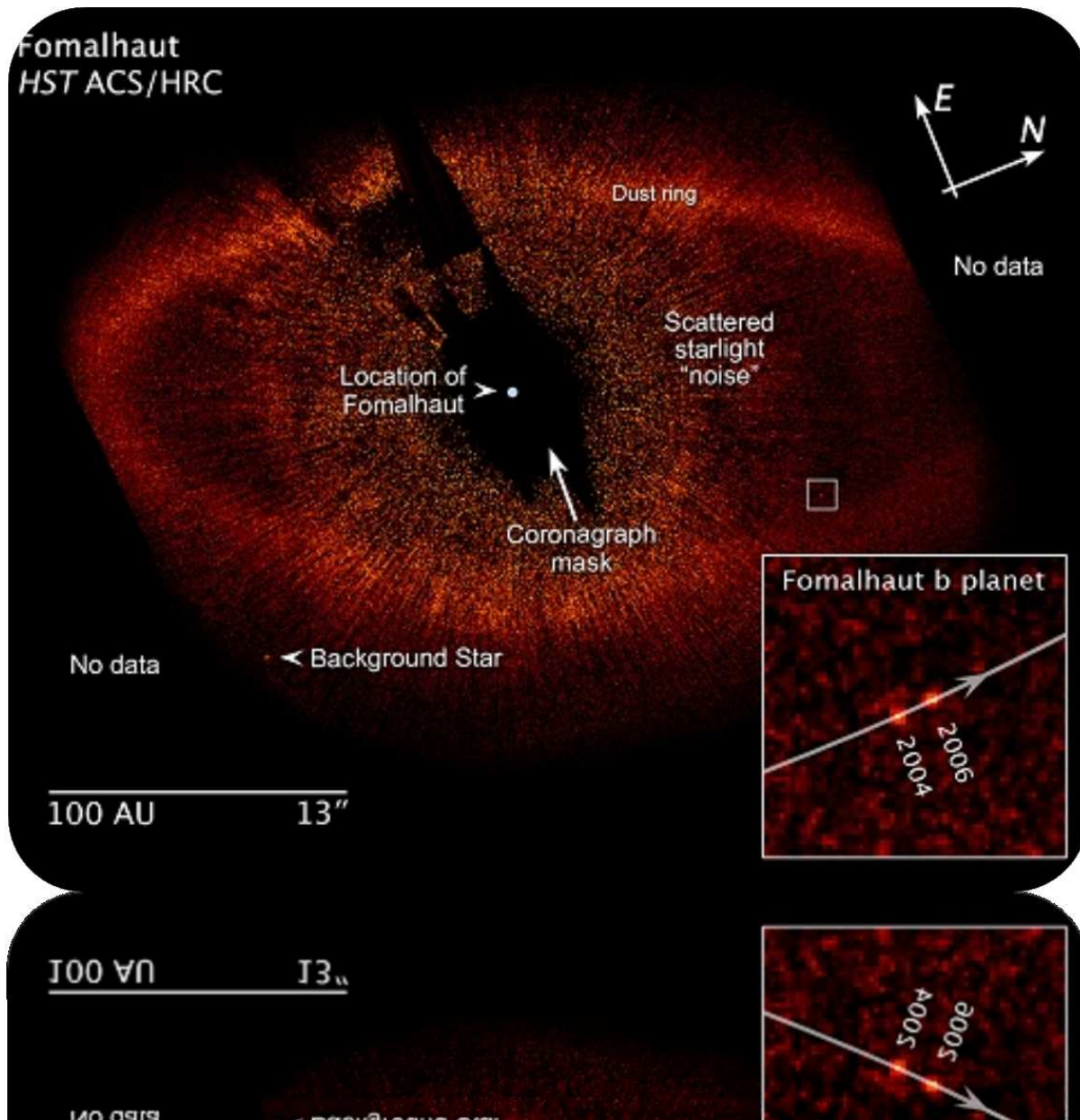
HD 61005 Circumstellar Disk ■ The Moth
Hubble Space Telescope ■ NICMOS

NASA, ESA, D. Hines (Space Science Institute, New Mexico),
 and G. Schneider (University of Arizona)

STScI-PRC08-01



Circumstellar Dust Image



Circumstellar Dust Artist Impres- sion



References on Dust Modeling by our group

- Vaidya & Gupta, A & A, 328, 634 (1997)
- Vaidya & Gupta, A & A, 348, 594 (1999)
- Vaidya, Gupta, Dobbie & Chylek, 375, 584 (2001)
- Gupta, Mukai, Vaidya, Sen & Okada, A & A, 441, 555 (2005)
- Gupta, Vaidya, Dobbie & Chylek, Astrophys. Sp. Sci., 301, 21 (2006)
- Vaidya, Gupta & Snow, MNRAS, 371, 791 (2007)
- Vaidya & Gupta, JQSRT, 110, 1726 (2009)
- Roy, Sharma & Gupta, JQSRT, 110, 1733 (2009)
- Roy, Sharma & Gupta, JQSRT, 111, 795 (2010)
- Vaidya & Gupta, A&A, 528, A57 (2011)

Composite Grains with DDA

It is very unlikely that interstellar grains have regular shapes (spherical/cylindrical/spheroidal) or that they are homogeneous in composition and structure. It has been proven that (from balloon observations and other flyby missions) the real dust grains are porous; fluffy and non-spherical – rather than solid spheres as was assumed in Mie theory for computation of light scattering properties by dust grains.

We use Discrete Dipole Approximation (DDA) to model the dust grains.

Validity Criteria in IR

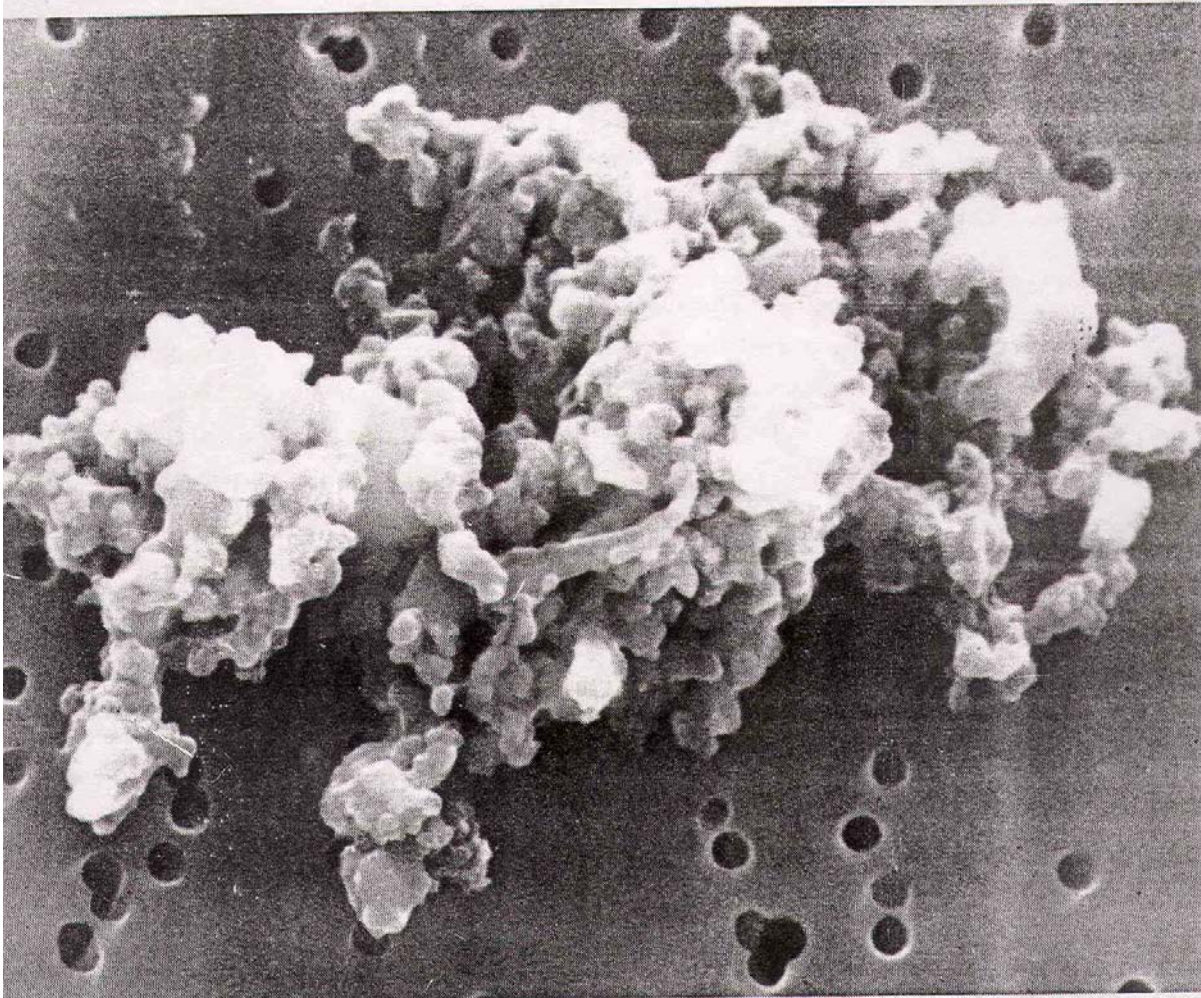
Table 1: DDA validity criteria showing the $|m|kd \leq 1$ values for each model in IR region for maximum grain size of $a=0.250\mu$.

λ (μm)	N=9640	14440	25896
5.0	0.041	0.030	0.022
10.0	0.021	0.014	0.011
15.0	0.015	0.011	0.005
20.0	0.011	0.007	0.003
25.0	0.005	0.002	0.001

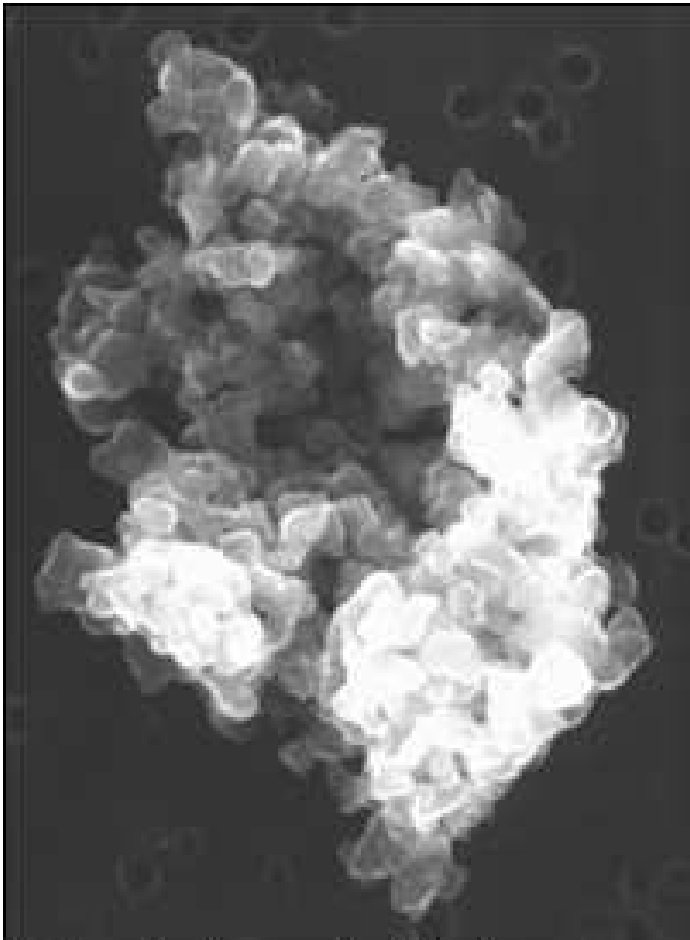
Axial Ratios & No. of Inclusion (no. of dipoles/inclusion)

Inclusions	Inclusion	Fractions	
N=9640	f=0.1	f=0.2	f=0.3
AR=1.33	32/24/24		
16/12/12	1(1184)	2(1184)	
8/6/6	6(152)	11(152)	16(152)
4/3/3	38(16)	76(16)	114(16)
N=25896	f=0.1	f=0.2	f=0.3
AR=1.50	48/32/32		
12/8/8	7(432)	13(432)	19(432)
6/4/4	54(56)	108(56)	162(56)
3/2/2	216(8)	432(8)	648(8)
N=14440	f=0.1	f=0.2	f=0.3
AR=2.00	48/24/24		
16/8/8	3(536)	6(536)	8(536)
12/6/6	6(224)	11(224)	16(224)
8/4/4	23(64)	46(64)	68(64)
3/2/2	23(24)	46(24)	68(24)

Composite Grains .. contd.

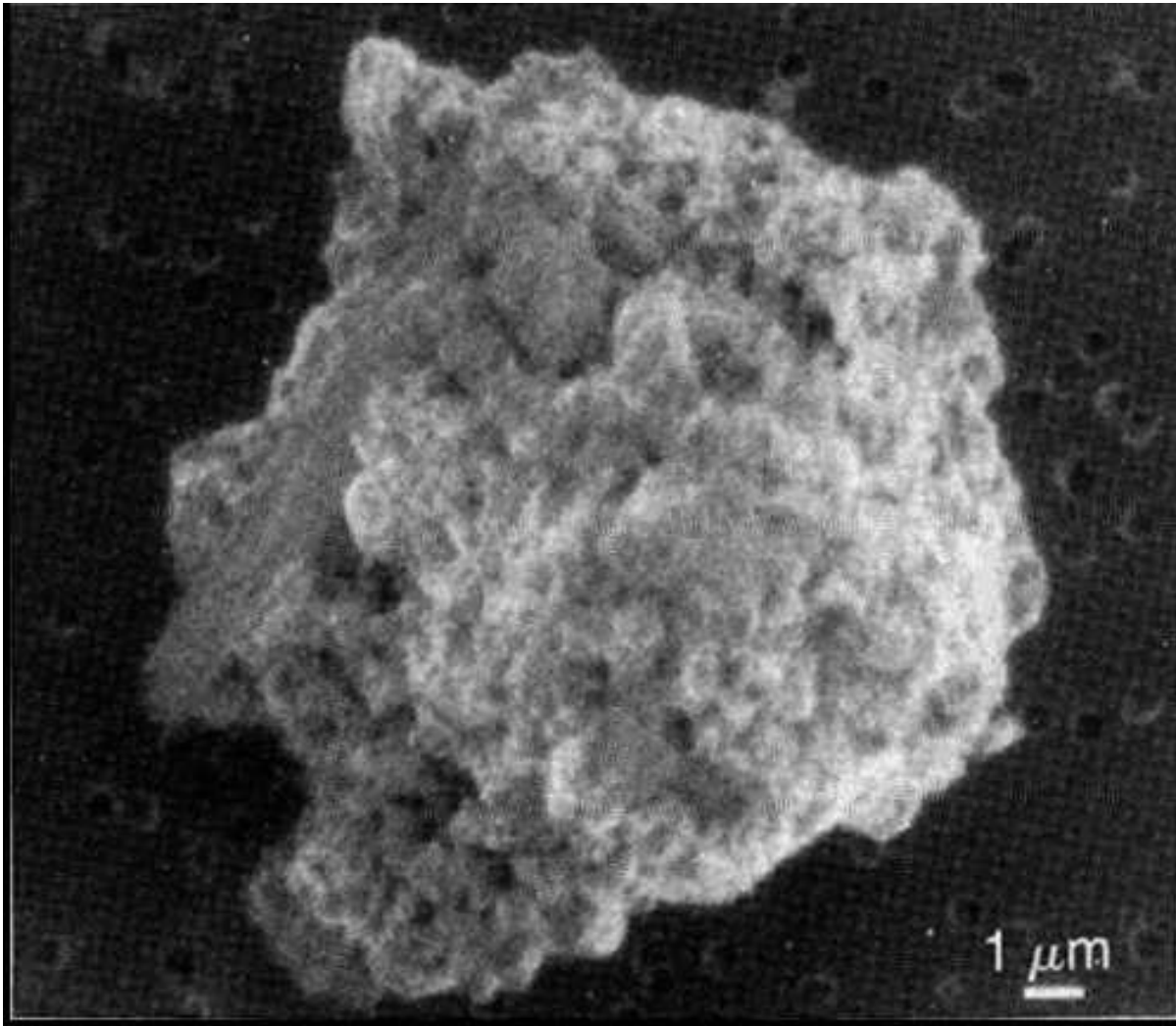


Composite Grains .. contd.

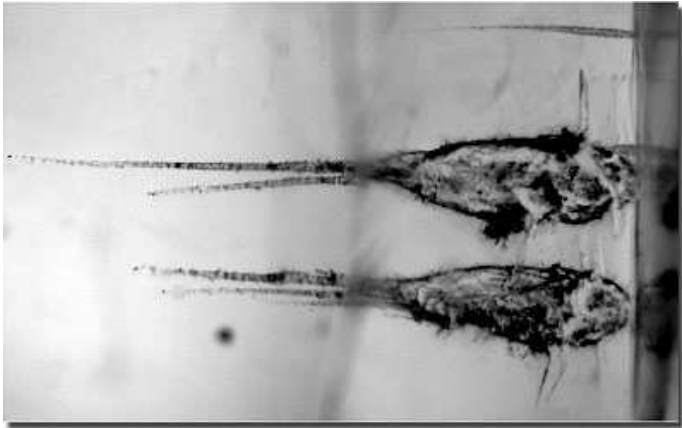


*Cosmic dust grain 11 micrometers
in diameter.*

Composite Grains .. contd.



Aerogel Dust Tracks from Impact mission



Simulated Grains

Multi-component-composite; size distribution and porous etc.

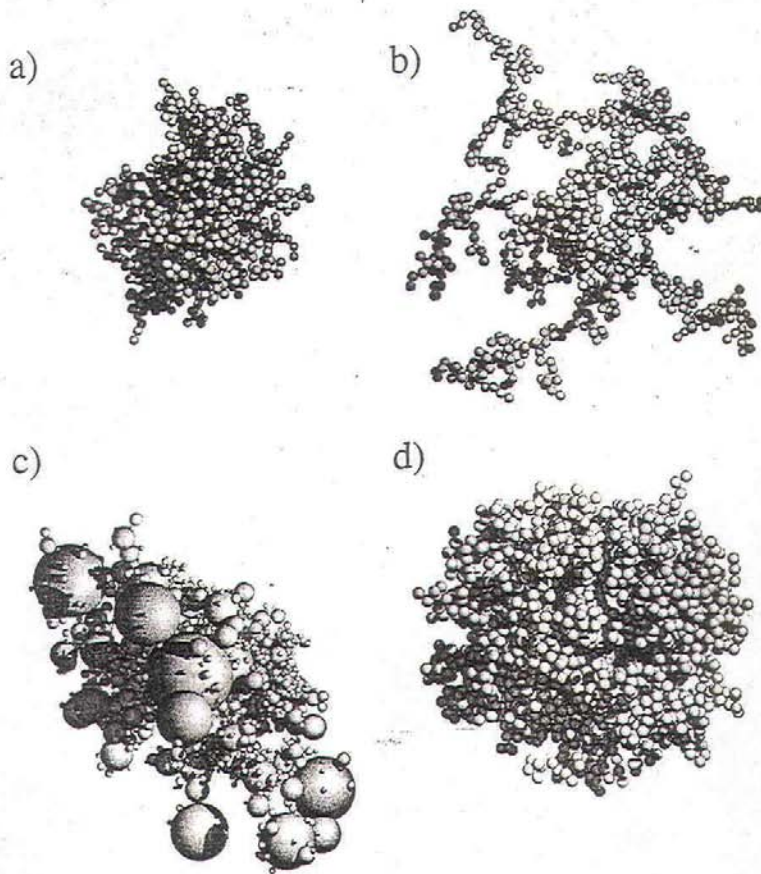


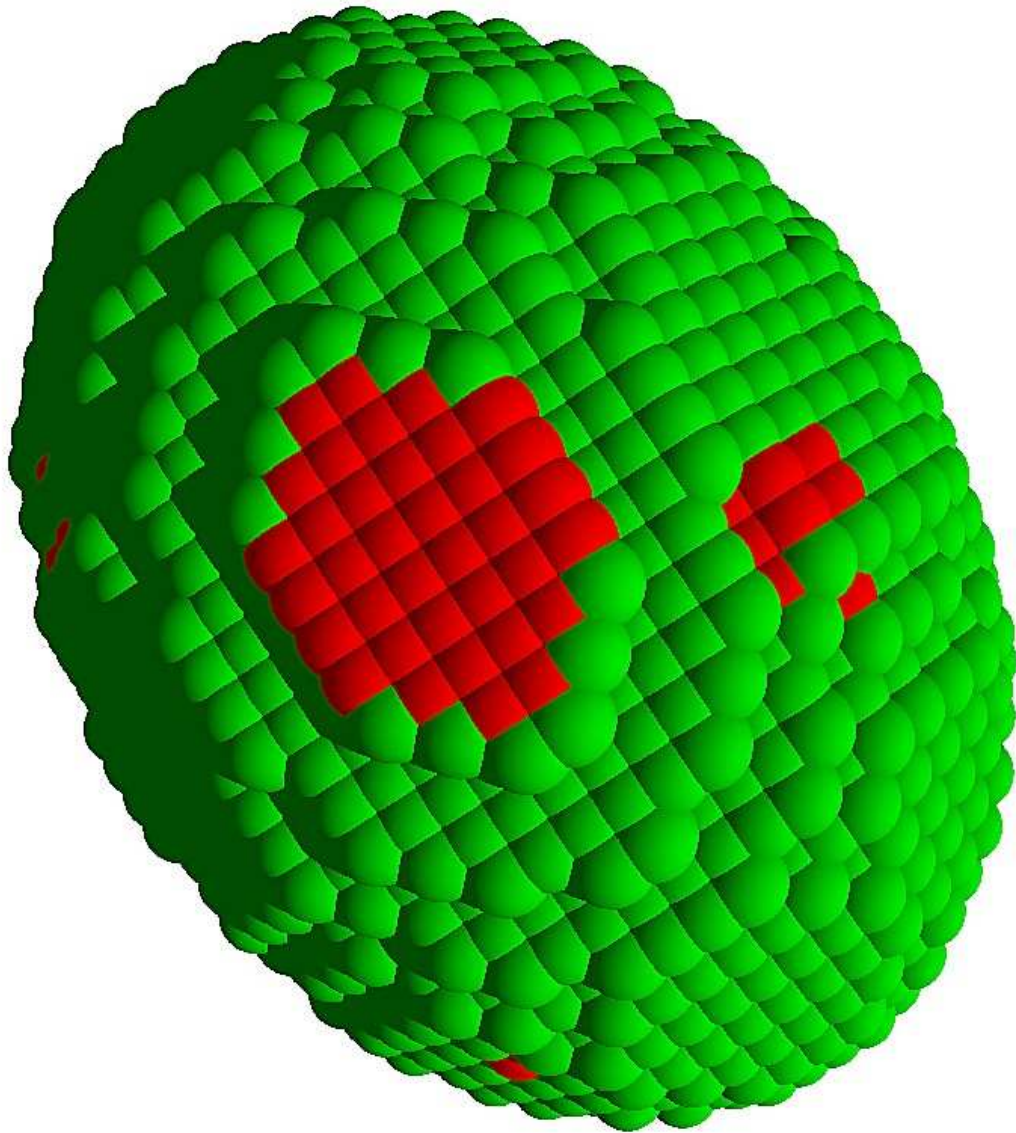
Figure 8.4. Computer simulations showing examples of particles formed by grain-grain coagulation (Dorschner and Henning 1995). (a) A compact particle produced by particle-cluster aggregation of 1024 identical small spheres. (b) A loose fractal particle produced by cluster-cluster aggregation of 1024 identical small spheres. (c) A composite particle produced by particle-cluster aggregation of 2001 spheres with sizes following



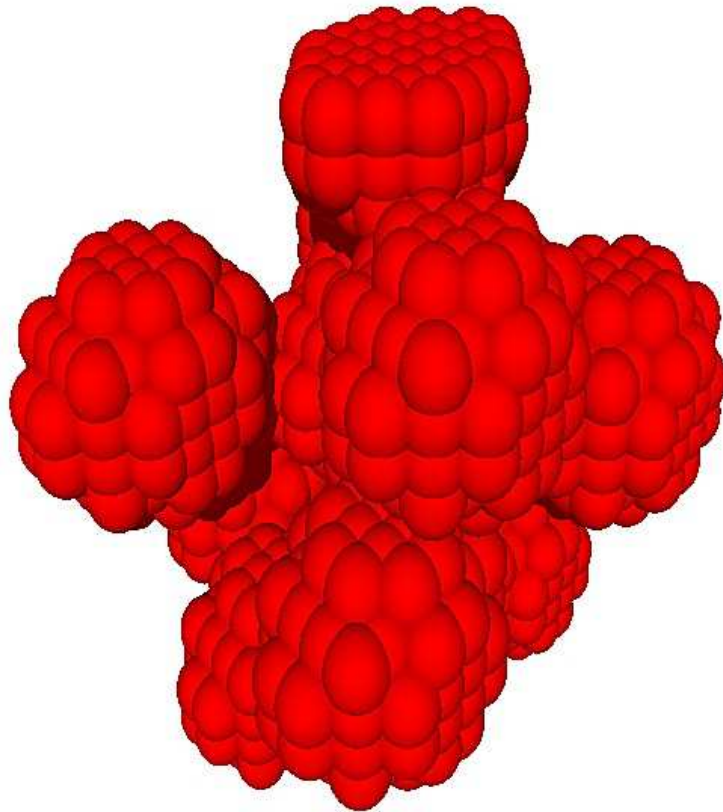
Composite Grains with Inclusions

A typical Non-spherical Composite grain with a total of $N=9640$ dipoles with the inclusions embedded in the host spheroid such that only the ones placed at outer periphery are seen. (Gupta et al., *Astrophys. Space Sci.*, 301, 21 (2006))

Composite Grains with Inclusions .. contd.



Showing the Inclusions



The IRAS Satellite



IRAS Data Set

- A total of 5425 objects with better quality spectra were included in the Atlas of Low-Resolution IRAS Spectra (F. M. Olnon & E. Raimond, A&AS, 1986).
- The Infrared Astronomical Satellite (IRAS) surveyed approximately 96% of the sky in four broad wavelengths centred at about 12, 25, 60 & 100 μm . 2000 bright sources from the Atlas were classified into 17 classes based on spectral morphology (R. Gupta, H. P. Singh, K. Volk, S. Kwok, APJS, 2004).

IRAS Data Set ...contd.

- Class 6 objects which are O rich AGB stars with strong silicate emission feature at $10\mu m$ are considered for this work. A Low Resolution Spectrometer (LRS) measured spectra of the brighter point sources (about 50,000) between 7.7 & $22.6\mu m$, with a resolution varying from 20 to 60.

IR emission from circumstellar dust

The IR Flux F_λ is calculated using the relation:

$$F_\lambda = Q_{abs} \times B_\lambda(T)$$

Composite grain model has been used to compute IR fluxes in the $5-25\mu m$ region at several dust temperatures $T=200-350^\circ K$ and compared with the IRAS-LRS average observed curves and also for several stars which are known to have strong Silicate emission features at 10 and $18\mu m$.

NIR Emission Models Used

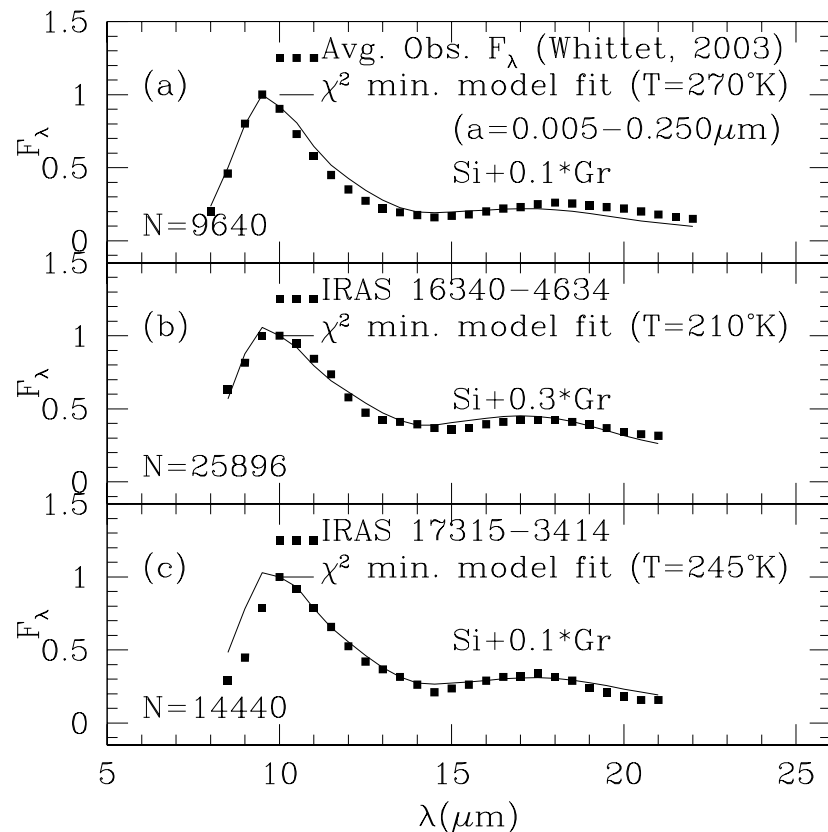
- The absorption efficiencies Q_{abs} of composite grain, made up of a host silicate oblate spheroid and inclusions of graphite or voids, for three axial ratios, in the spectral region $5-25 \mu m$, are computed using the DDA. (Ref. D.B. Vaidya & R. Gupta, 2011, A&A)
- Oblate spheroids are selected based on studies that show that they represent properties of circumstellar dust particles better; in particular it provides a good fit to the observed polarization across the $10 \mu m$ feature. (Ref. Th. Henning & R. Stognienko, 1993, A&A; Kim & Martin, 1995, ApJ)

Emission Models ... contd.

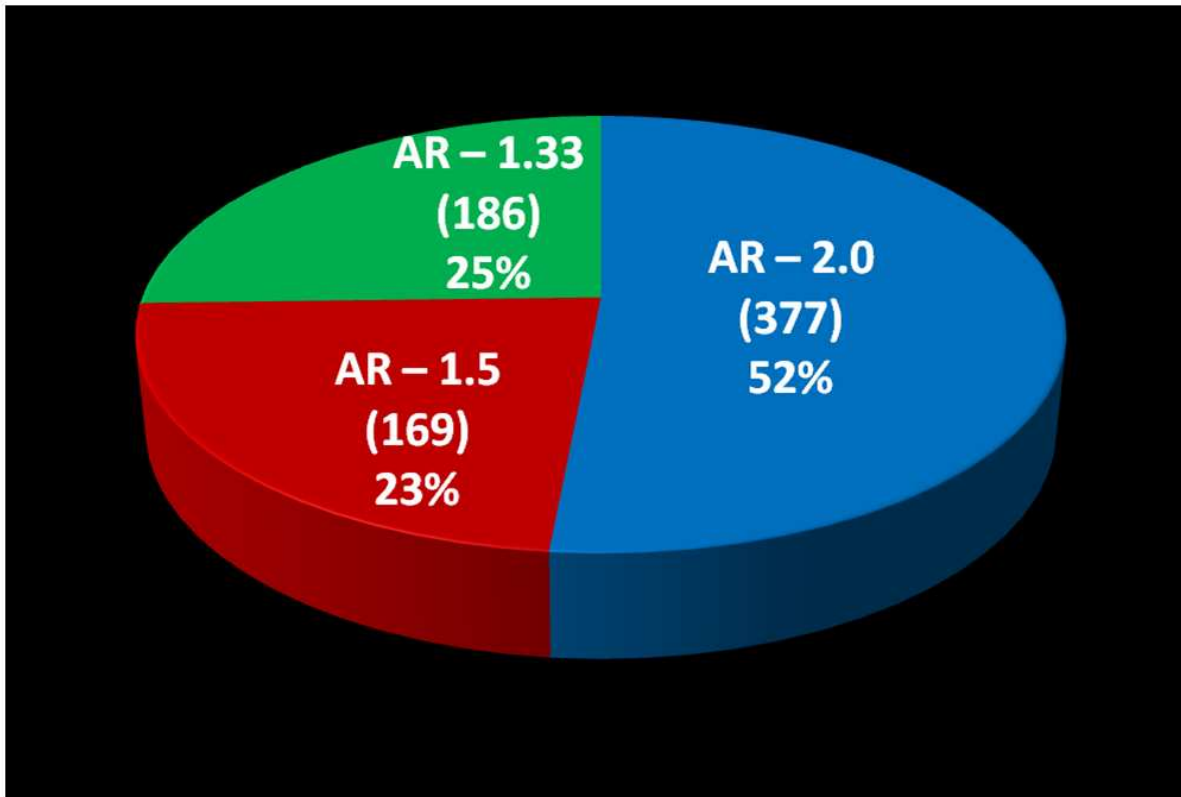
- Graphite inclusion is chosen because it explains the observed bump at 2175\AA in the extinction curve. Porous inclusions are also chosen because studies show that most dust grains are porous and fluffy.

IR flux comparison with composite models and observed fluxes

Best fit χ^2 minimized composite grain models (silicates with graphite inclusions) plotted with the average observed infrared flux for IRAS-LRS curve and two other stars (Vaidya & Gupta, A&A, 528, A57 (2011)).

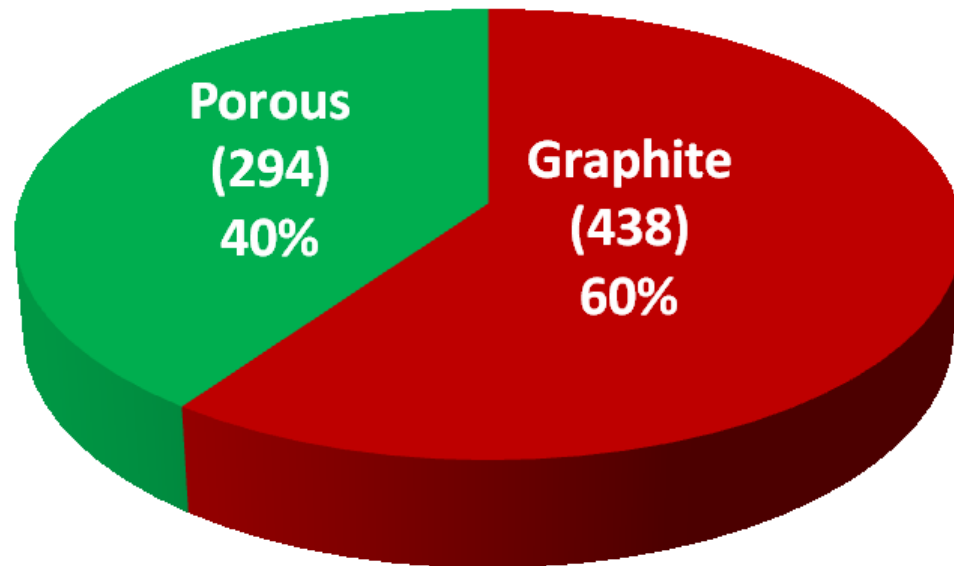


Statistics for Large Set of IRAS objects



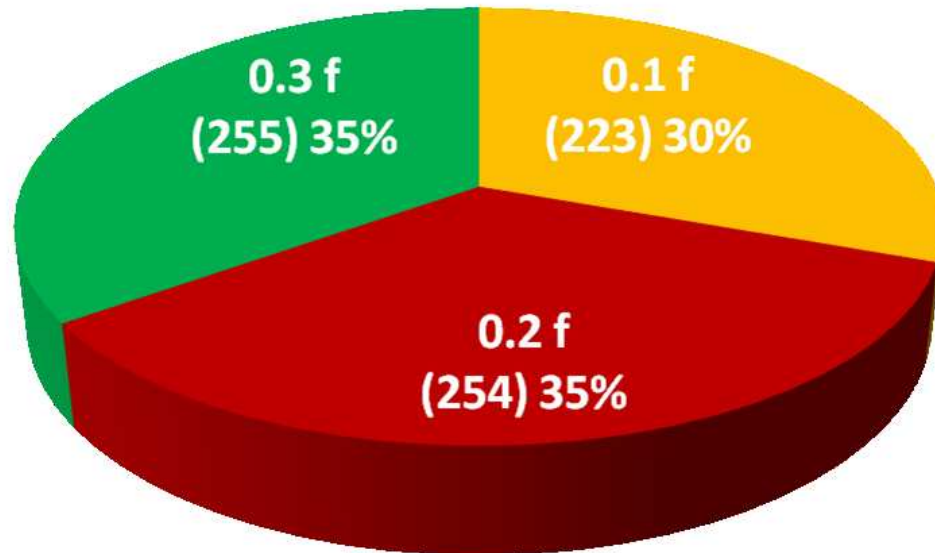
Axial Ratio of Grain Shape

Statistics ... contd.



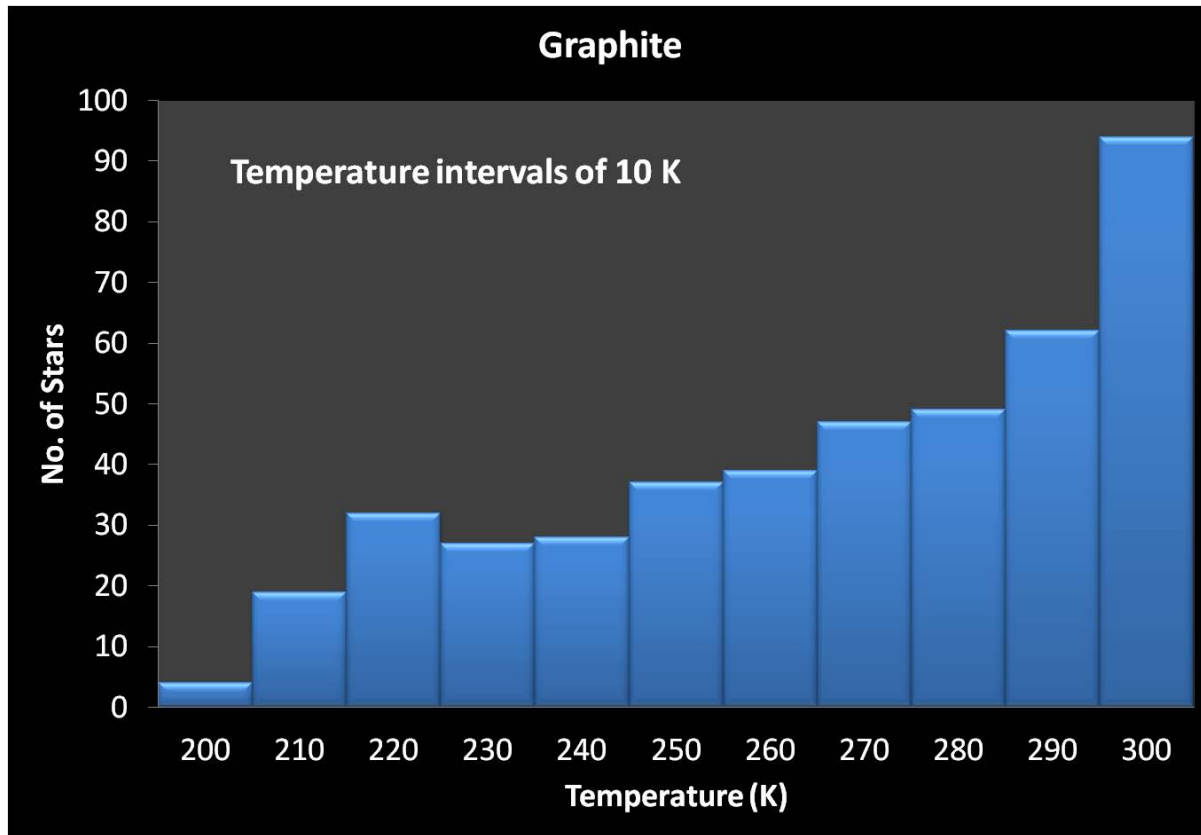
Silicate Grain with Porous v/s Graphite Inclusions

Statistics ... contd.



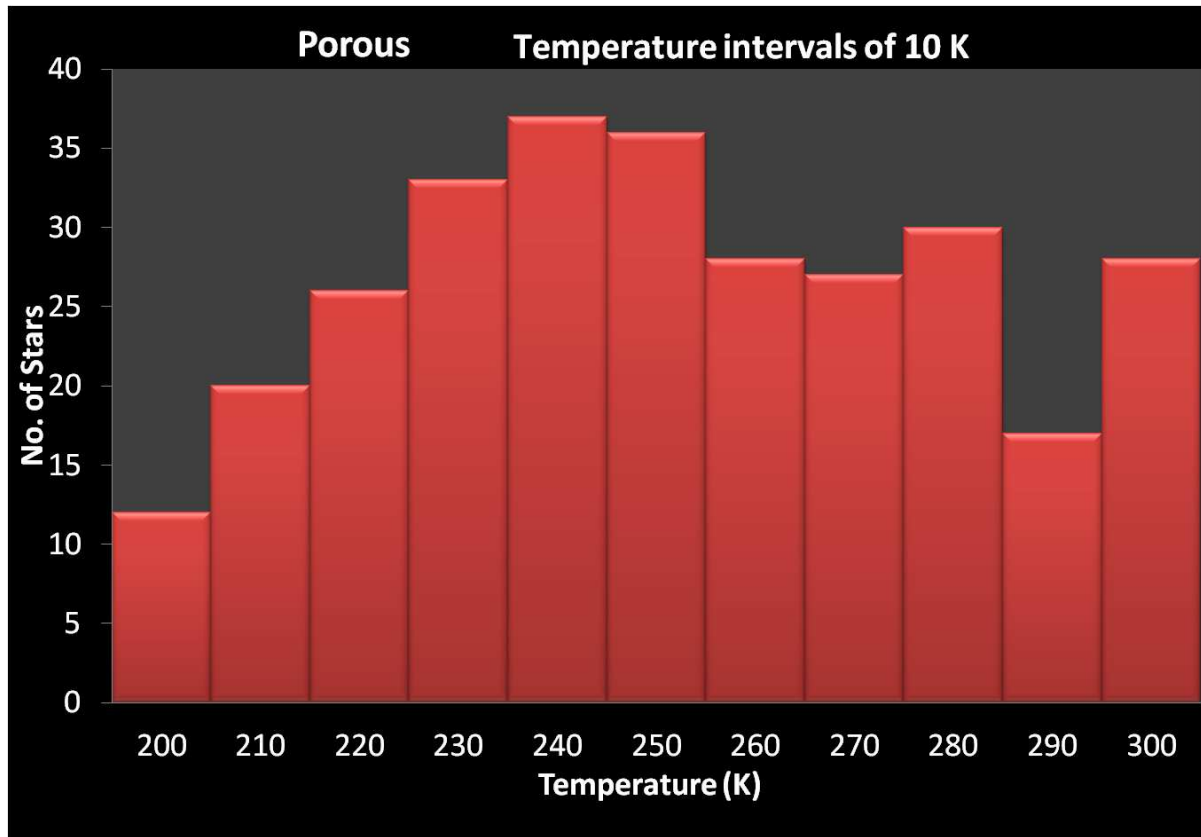
Fraction of Inclusions

Statistics ... contd.



Dust Temperature Estimates for Graphite Inclusions

Statistics ... contd.



Dust Temperature Estimates for Porous Inclusions

Conclusions of the Study

- The composite grain model with no. of dipoles $N=14440$, axial ratio 2.0, and graphite inclusions provides the best fit for infrared flux observed from dust shells around most of the O rich AGB stars.
- The composite grain models give dust temperatures between 200-300 °K which fit with most of the observed IRAS-LRS curves. It is also comparable to the dust temperature range 200-300°K as suggested by Bowey & Adamson (2001); and 200-400°K as suggested by Voshchinnikov & Henning (2008).



Thanks!