NIR Silicate features and Statistics from IRAS data

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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.

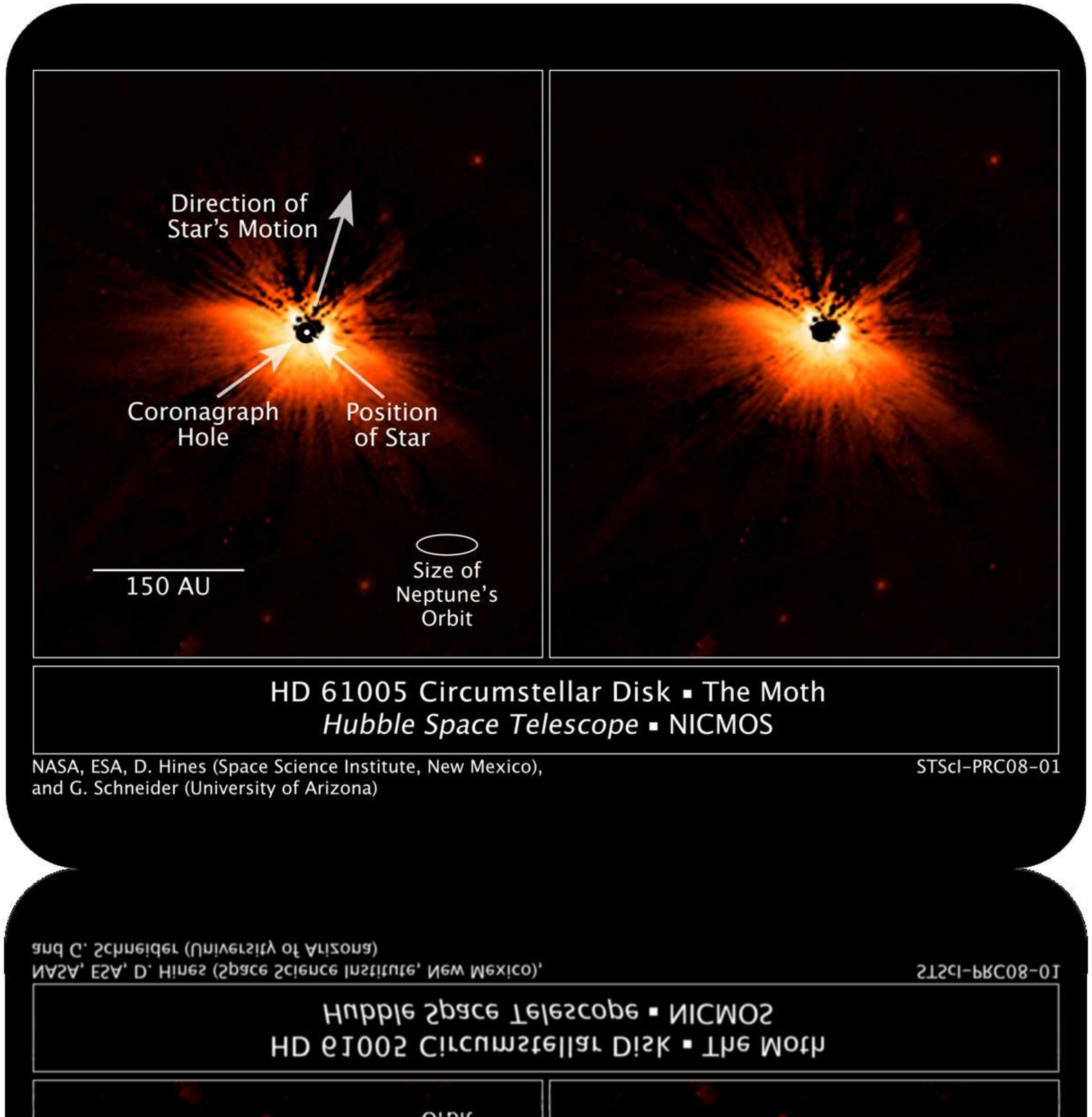
Plan Of The Talk

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

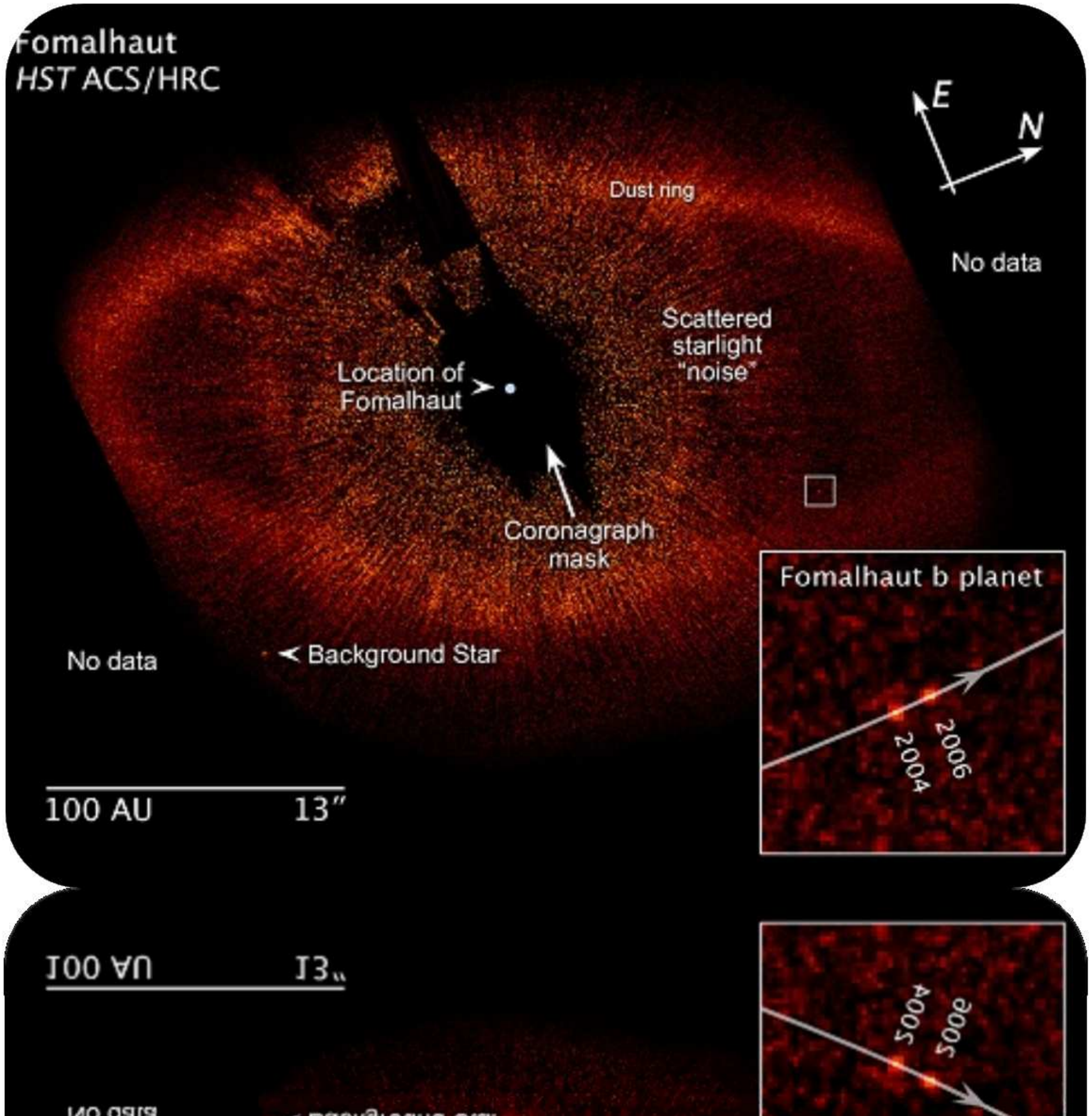
Circumstellar Dust

- 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.

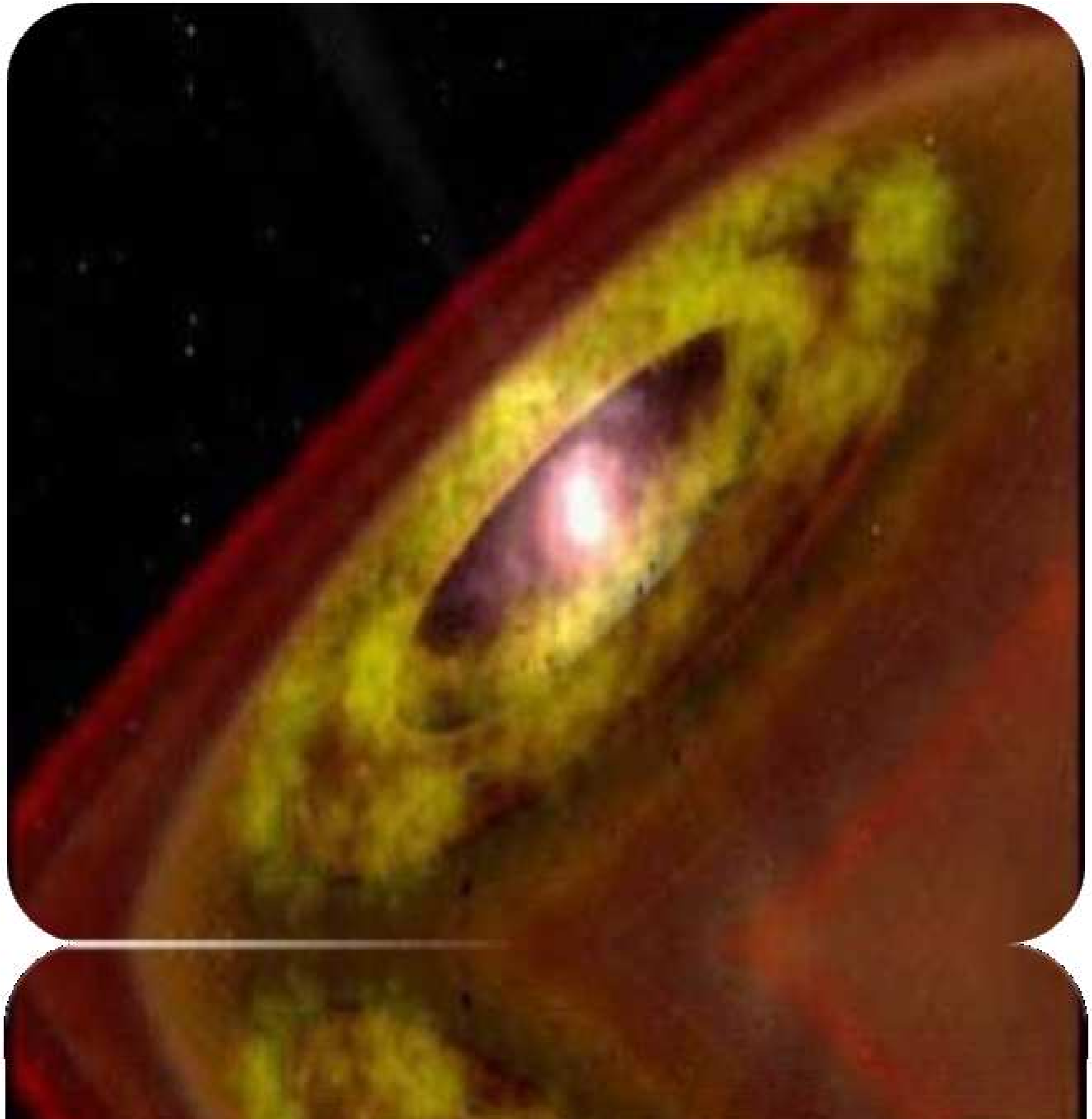
Circumstellar Dust Image



Circumstellar Dust Image



Circumstellar Dust Artist Impression



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/cylinderical/spheroidal) or that they are homogeneous in compostion 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

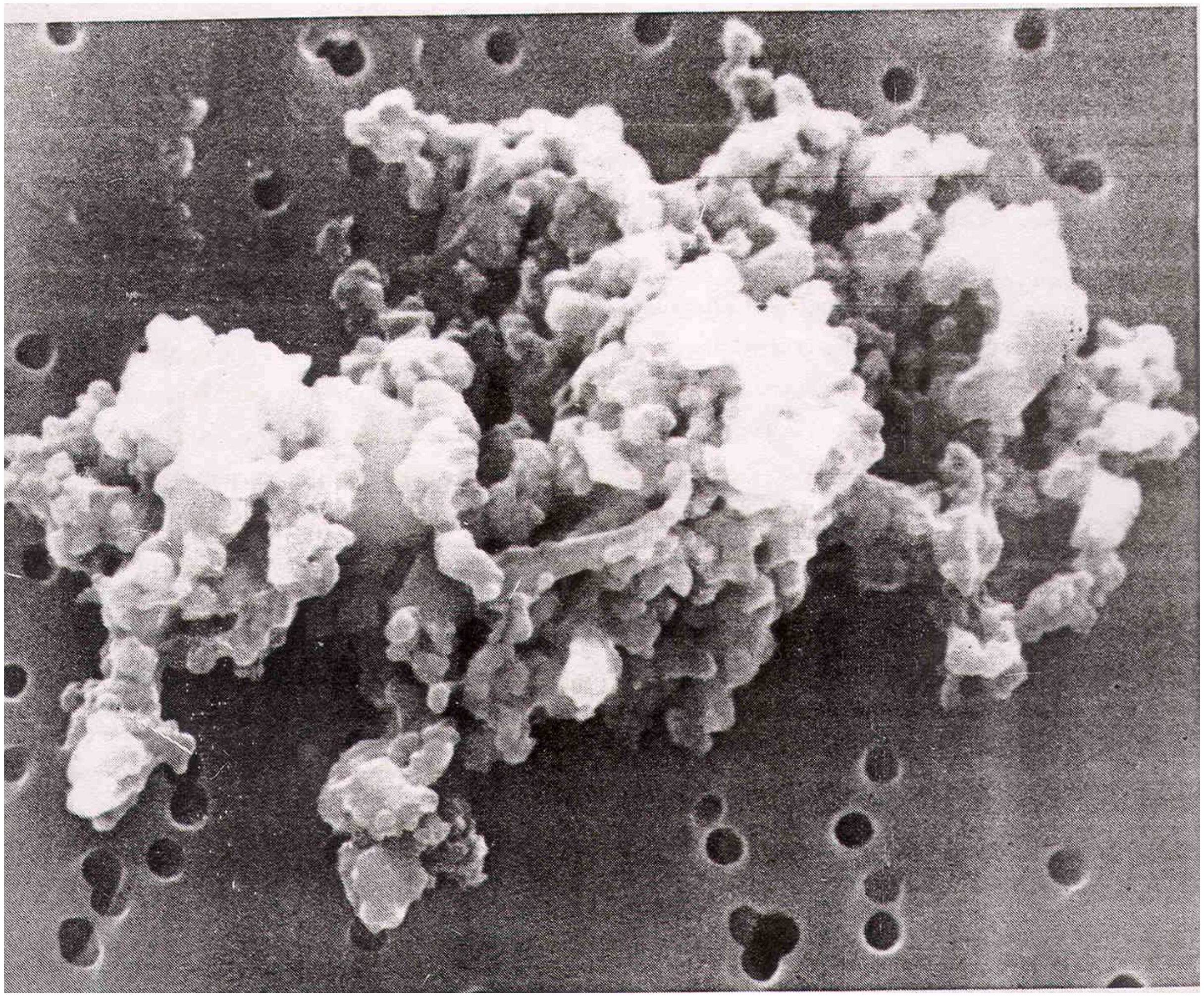
Table 1: DDA validity criteria showing the $|\mathrm{m}|\mathrm{kd} \leq 1$ values for each model in IR region for maximum grain size of a=0.250μ.

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

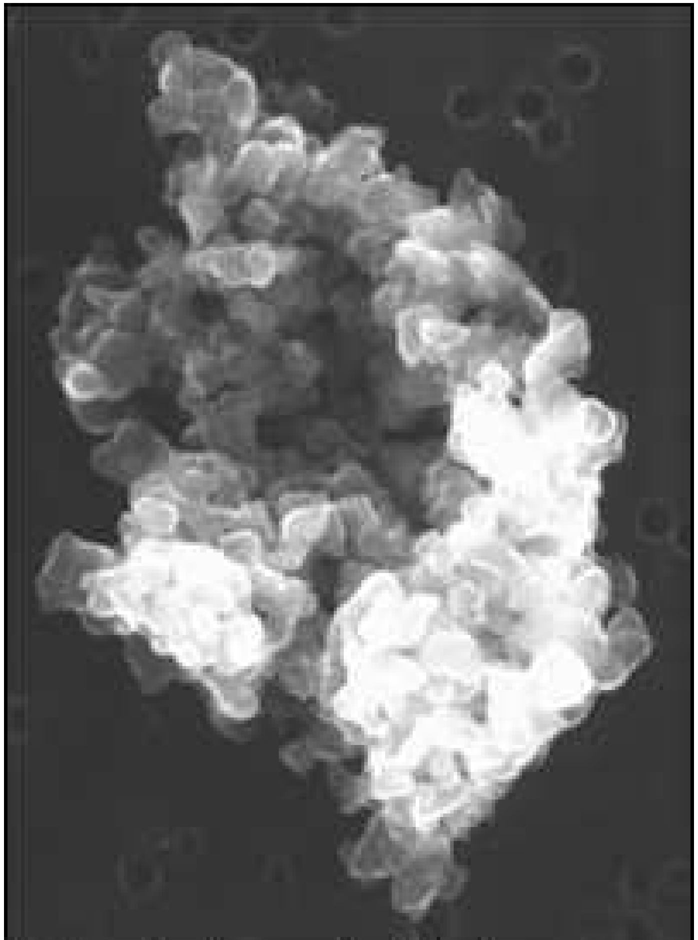
Axial Ratios & No. of Inclusion (no. of dipoles/inclusion)

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)
[illegible]	[illegible]	[illegible]	[illegible]

Composite Grains .. contd.

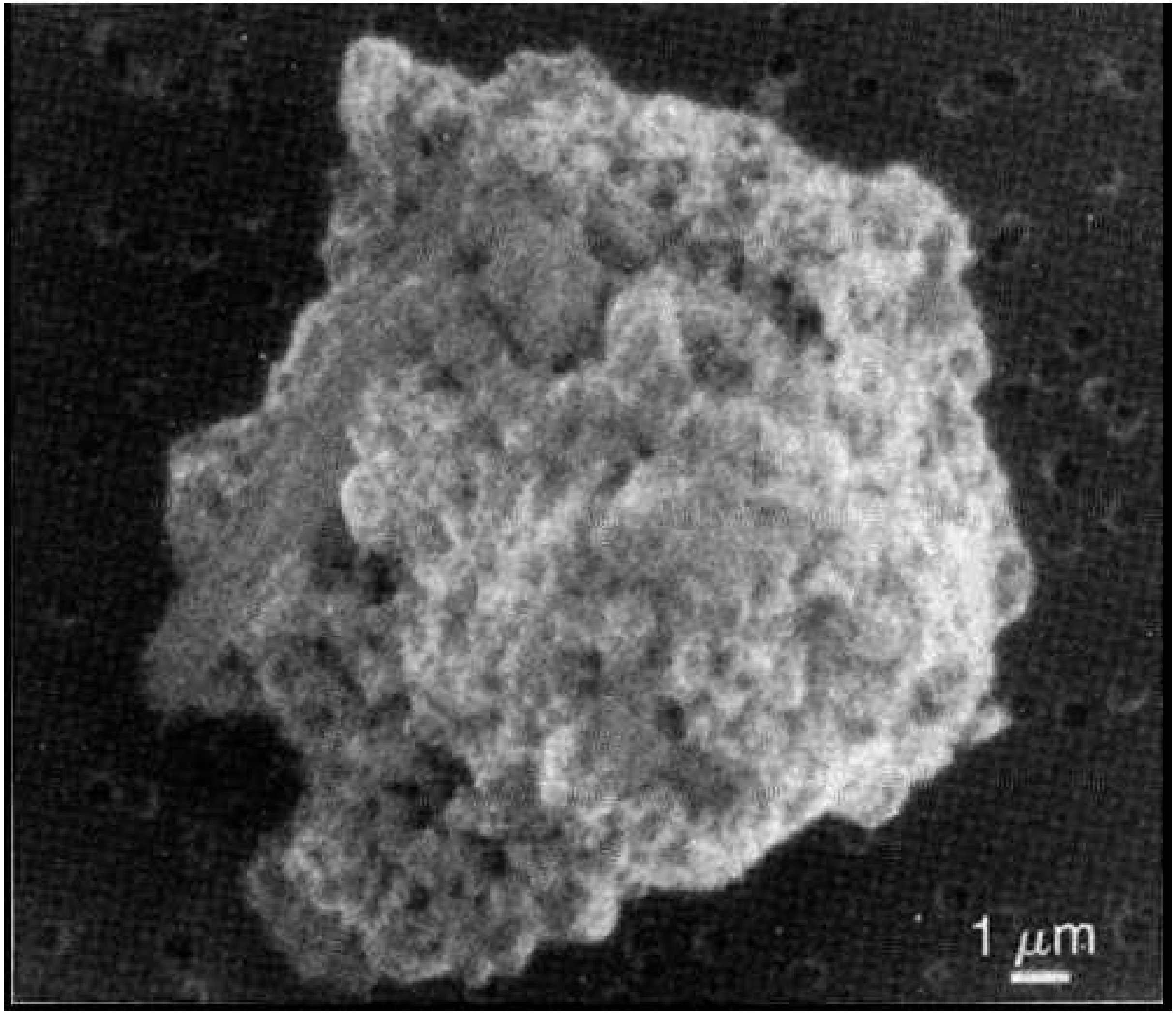


Composite Grains .. contd.

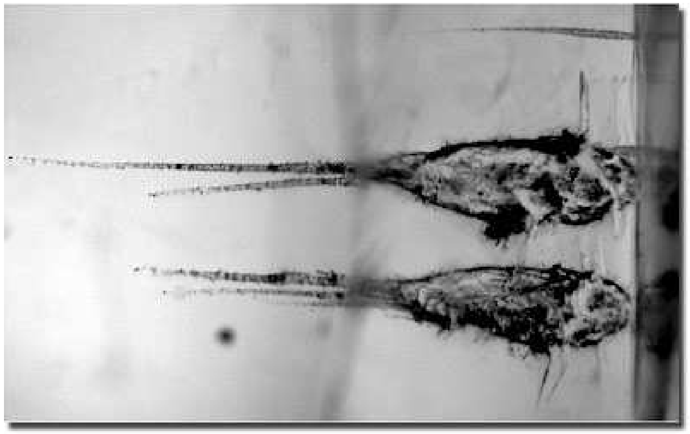


Cosmic dust grain 11 micrometers in diameter.

Composite Grains .. contd.



Aerogel Dust Tracks from Impact mission



Simulated Grains

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

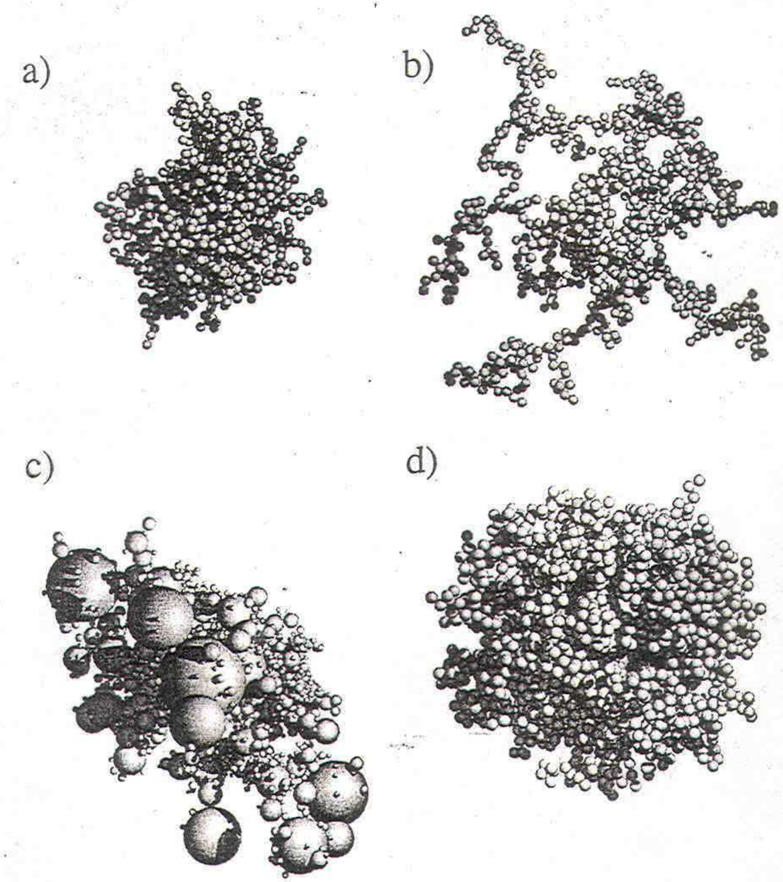
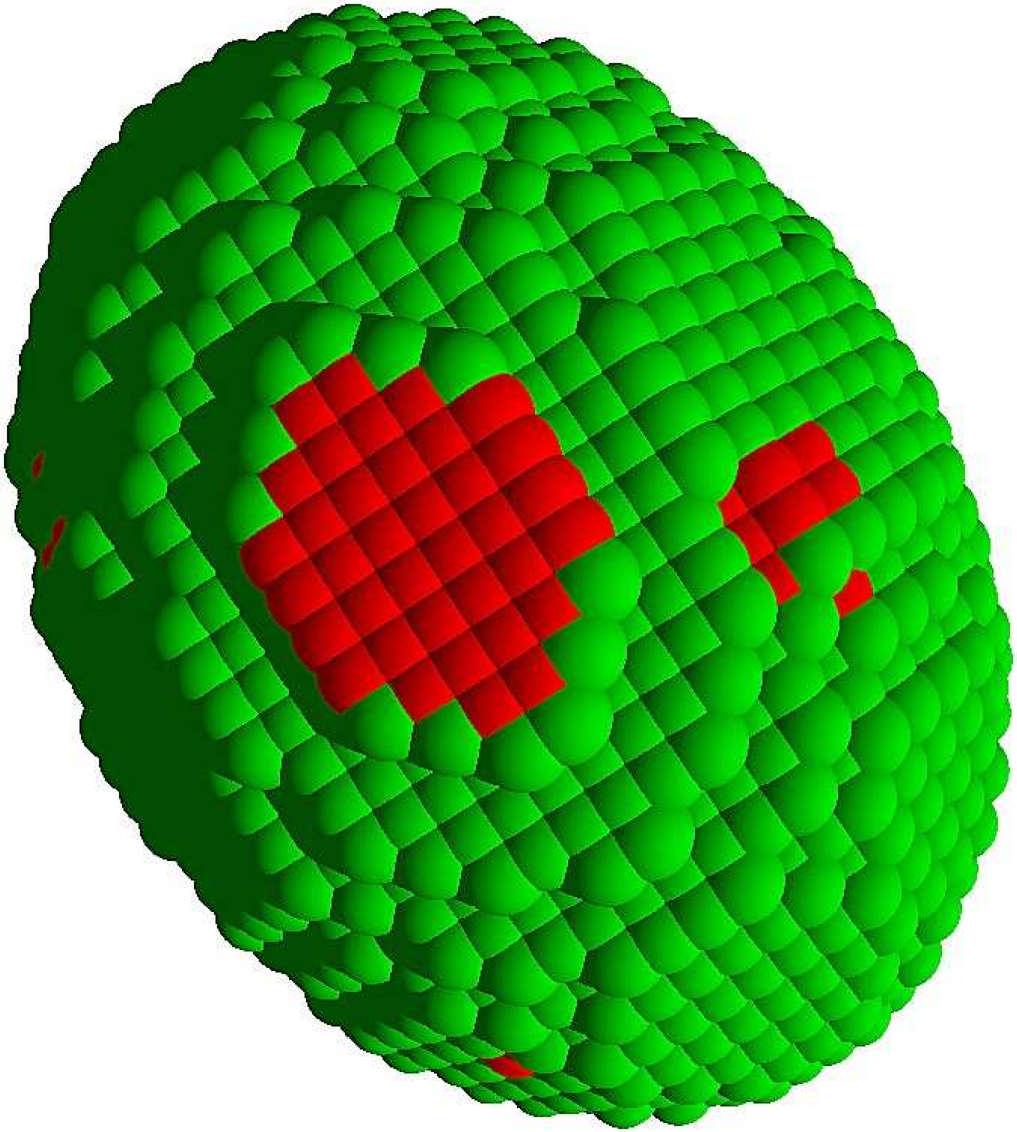


Figure 8.4. Computer simulations showing examples of particles formed by grain–grain coagulation (Dorschner and Henning 1995). (*a*) A compact particle produced by particle–cluster aggregation of 1024 identical small spheres. (*b*) A loose fractal particle produced by cluster–cluster aggregation of 1024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

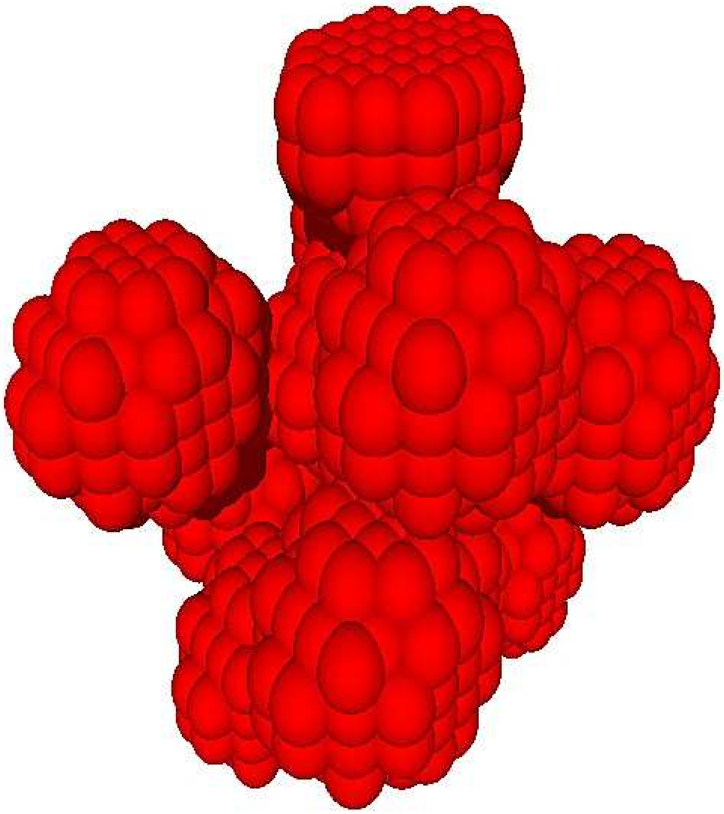
Composite Grains with Inclusions

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 10μm 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 μm, 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 5-25μm region at several dust temperatures T=200-350°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 μm.

NIR Emission Models Used

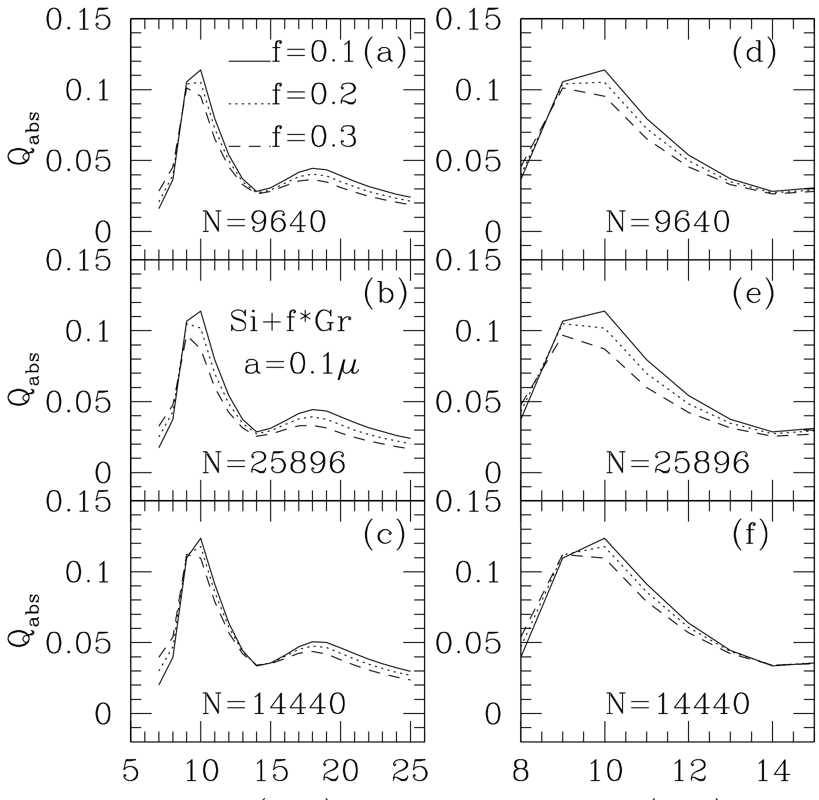
- The absorption efficiencies Q_{abs} of composite grain, made up of a host silicate oblate spheroid and inclusions of graphite or voids, for three axial ratios, in the spectral region 5-25 μm, are computed using the DDA. (Ref. D.B. Vaidya & R. Gupta, 2011, A&A)
- Oblate spheroids are selected based 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 μm 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 2175Å in the extinction curve. Porous inclusions are also chosen because studies show that most dust grains are porous and fluffy.

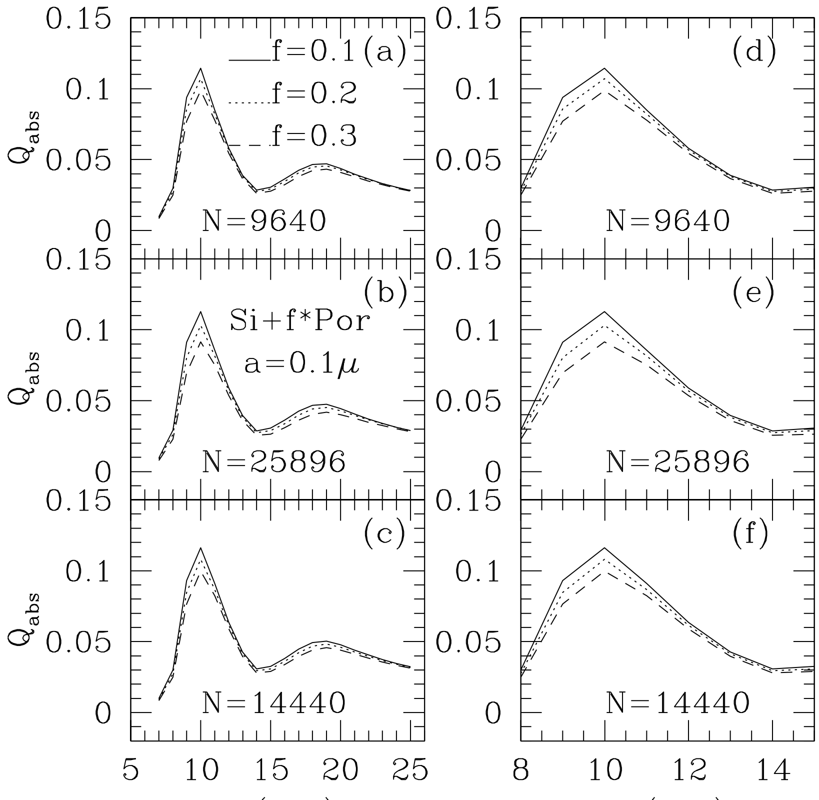
Absorption efficiencies

Absorption efficiencies for the composite grains with host silicate spheroids and graphites as inclusions for all three axial ratios N=9640 (AR=1.33), N=25896 (AR=1.50), and N=14440 (AR=2.00). The 10μ feature is highlighted in the right side panels (d-f).



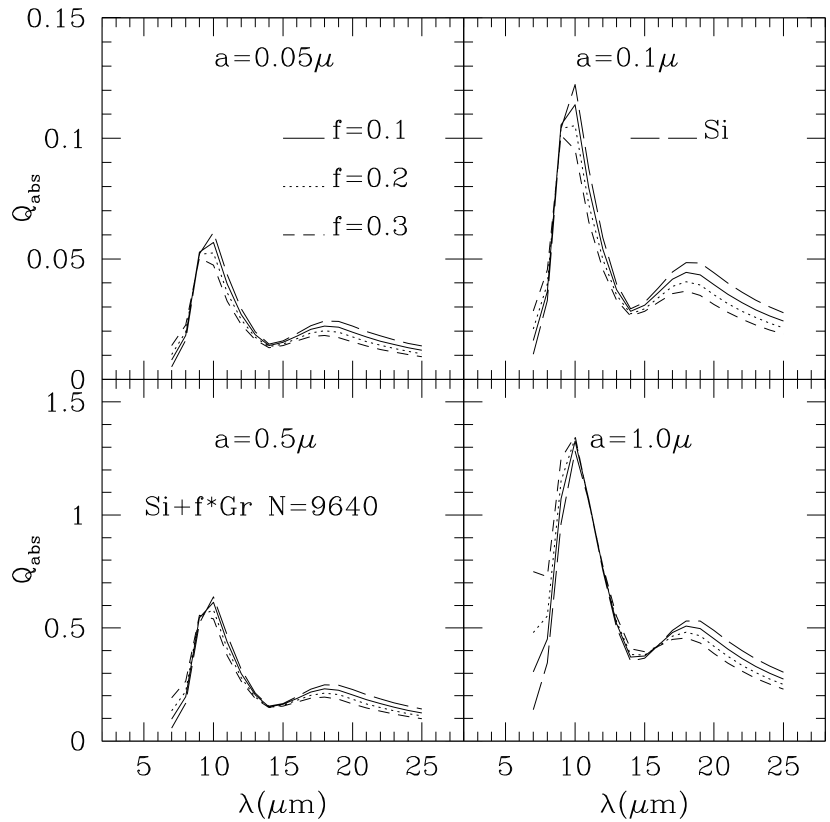
Absorption efficiencies ...contd

Absorption efficiencies for the composite grains with host silicate spheroids and voids (vacuum) as inclusions for all three axial ratios N=9640 (AR=1.33), N=25896 (AR=1.50), and N=14440 (AR=2.00). The 10μ feature is highlighted in the right side panels (d-f).



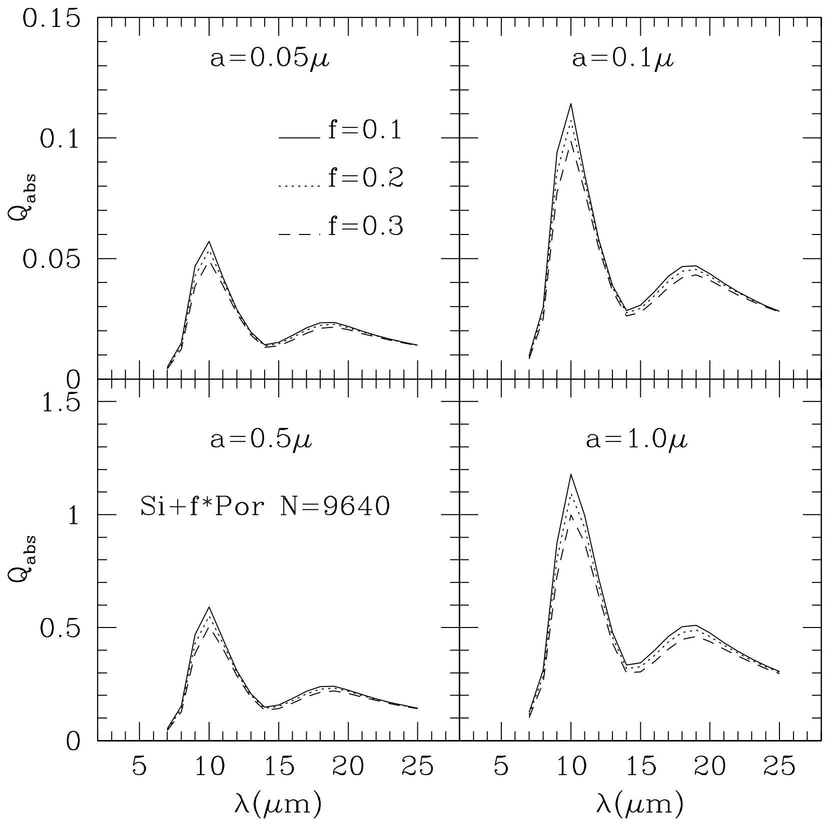
Absorption efficiencies ...contd

Variation in absorption efficiencies with grain sizes. Host silicate spheroids contain dipoles, N=9640, and graphites as inclusions. Also shown is the Q_{abs} for the silicate grain (f=0.0) for all the sizes.



Absorption efficiencies ...contd

Variation in absorption efficiencies with composite grain sizes. Host silicate spheroids contain dipoles N=9640 and voids (vacuum) as inclusions.

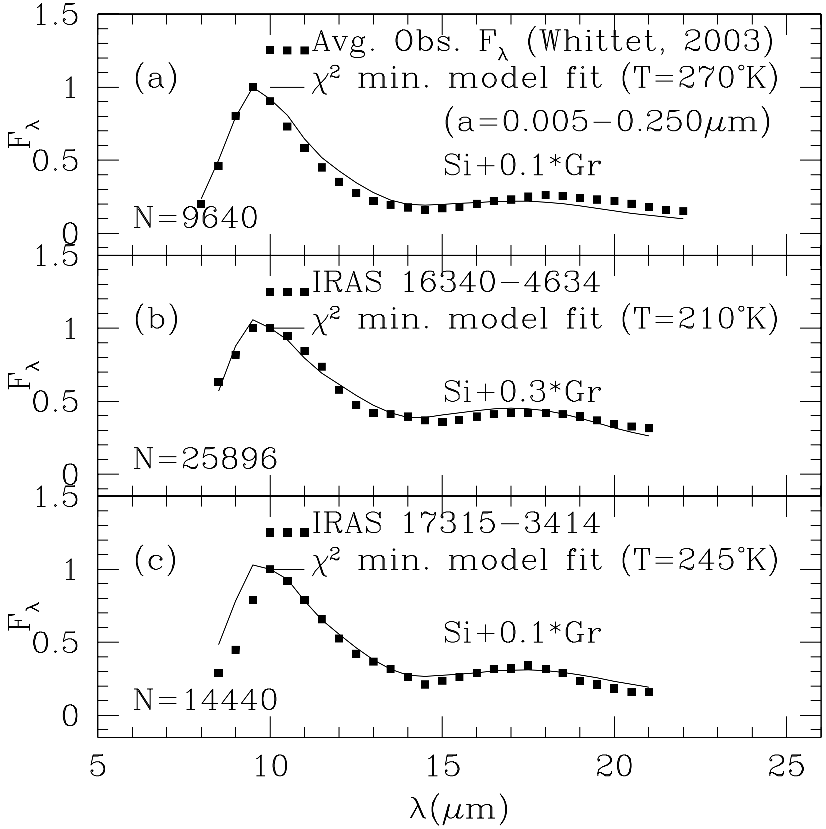


Characteristics of 10 and 18μm features

- It is seen that the 10μ feature shifts towards shorter wavelengths as the volume fraction of the graphite inclusions increases.
- We did not find any shift in the absorption feature at 18μm with the change in the volume fraction of the graphite inclusions.
- For porous inclusions, it is seen that as the porosity increases i.e., as the volume fraction ’f’ of the voids increases, the peak strength decreases. However, we did not find any shift in the 10μm and 18μm features with porosity.

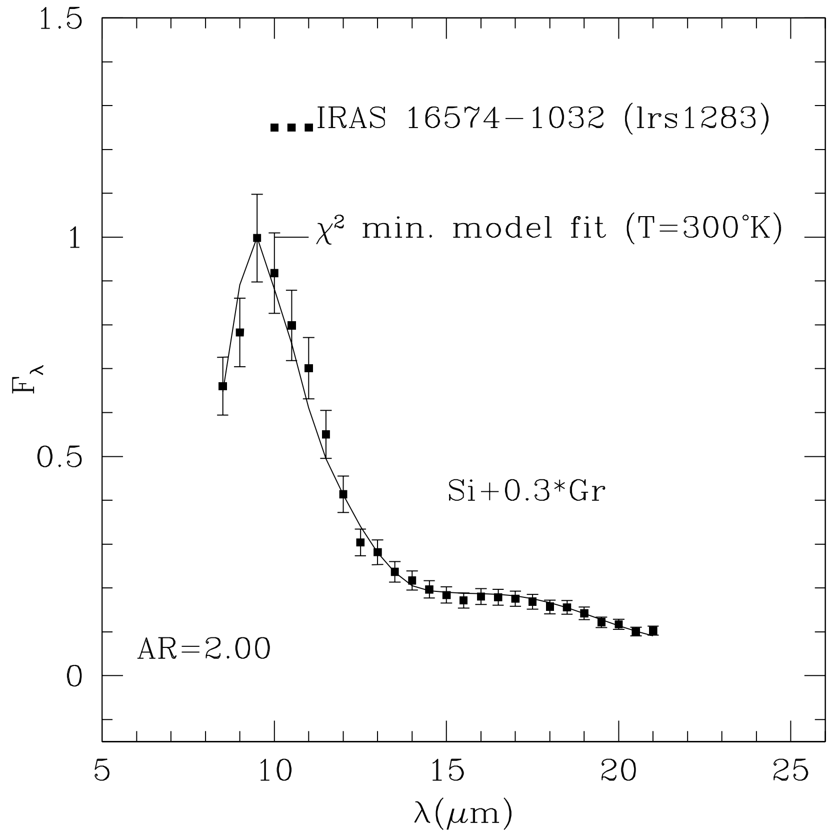
IR flux comparison with composite models and observed fluxes

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)).



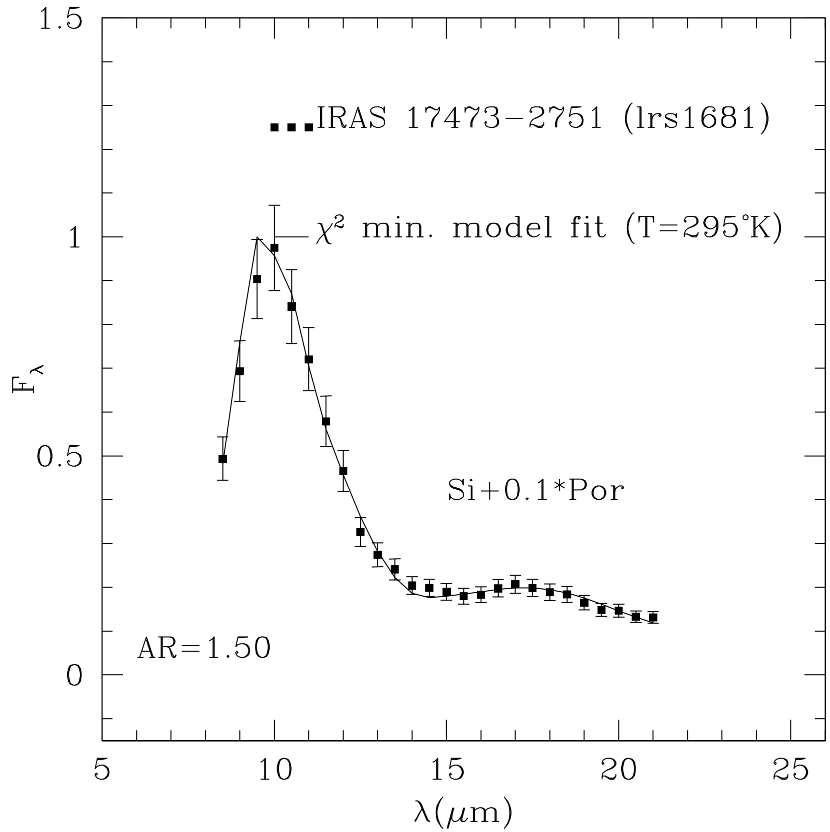
Model fitting to IRAS stars

Best & χ^2 minimized fit of Si+f*Gr composite dust model to an IRAS star



Model fitting to IRAS stars

Best & χ^2 minimized fit of Si+f*Por composite dust model to an IRAS star



Statistics for Large Set of IRAS objects

GENERAL TRENDS FOR MODEL FITS

N (AR)	0.1 f Gr	0.2 f Gr	0.3 f Gr	Total
14440 (2.0)	56	138	345	**539**
25896 (1.5)	26	10	9	**45**
9640 (1.33)	5	1	25	**31**
Total	**87**	**149**	**379**	**615**

N (AR)	0.1 f Por	0.2 f Por	0.3 f Por	Total
14440 (2.0)	7	5	23	**35**
25896 (1.5)	36	14	4	**54**
9640 (1.33)	2	9	17	**28**
Total	**45**	**28**	**44**	**117**

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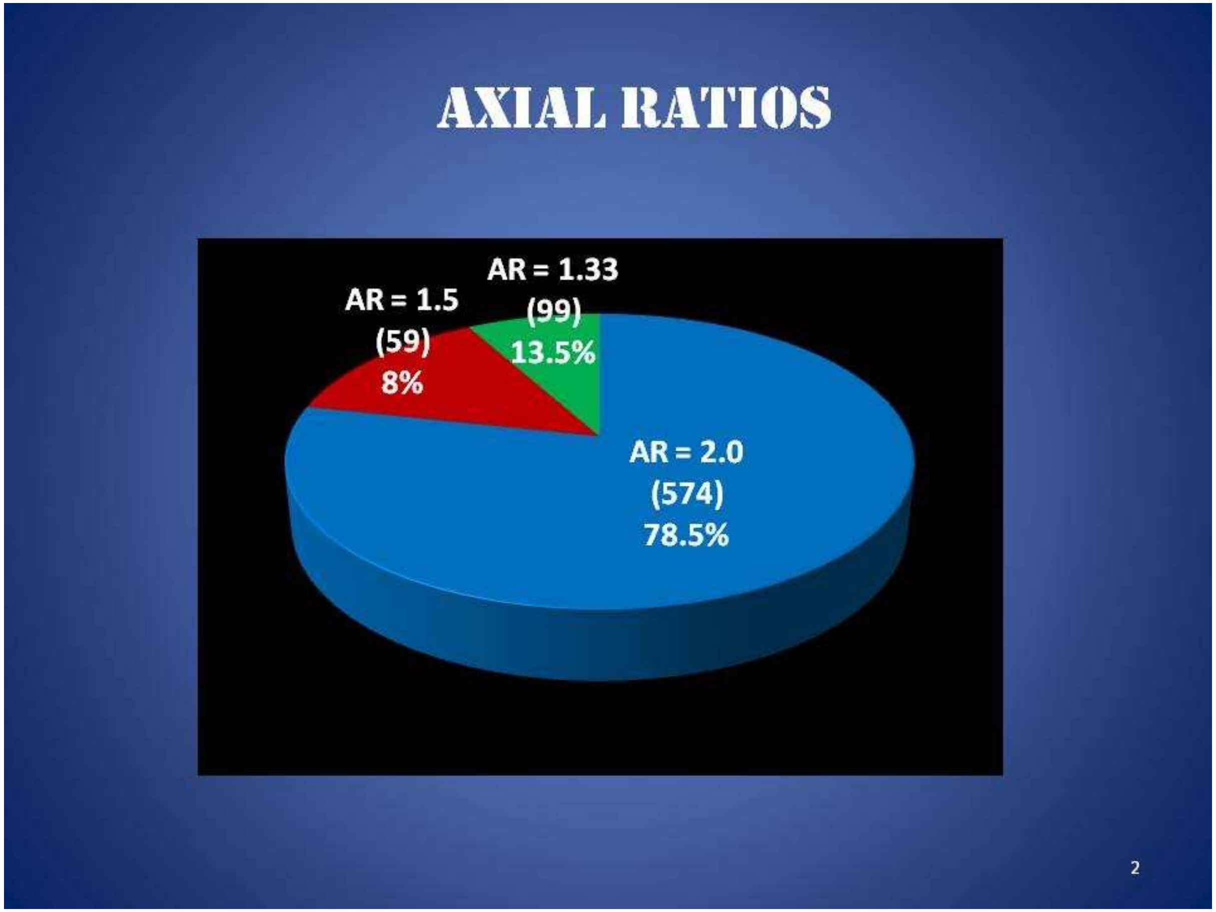
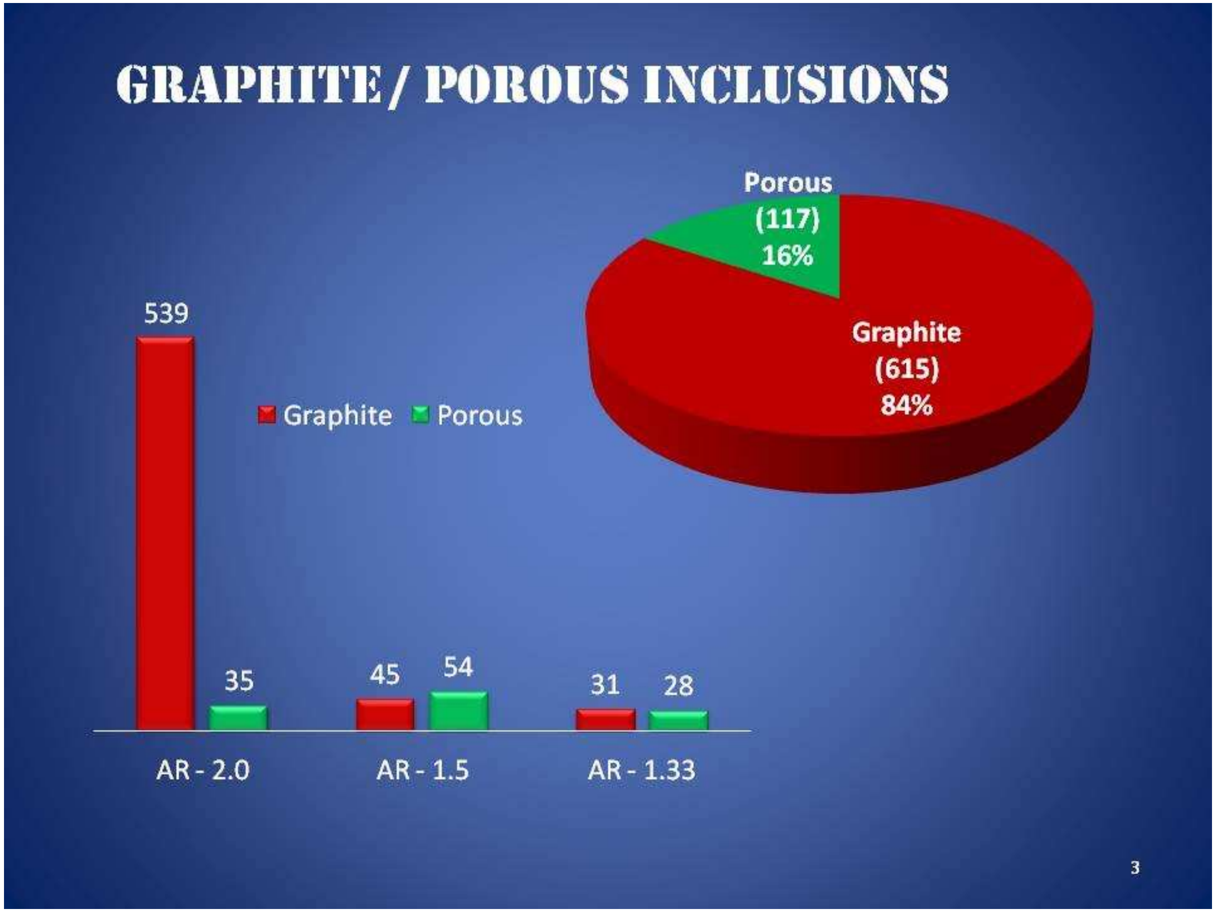
Inclusion Fractions & Axial Ratio of Grain Shape

Statistics ... contd.



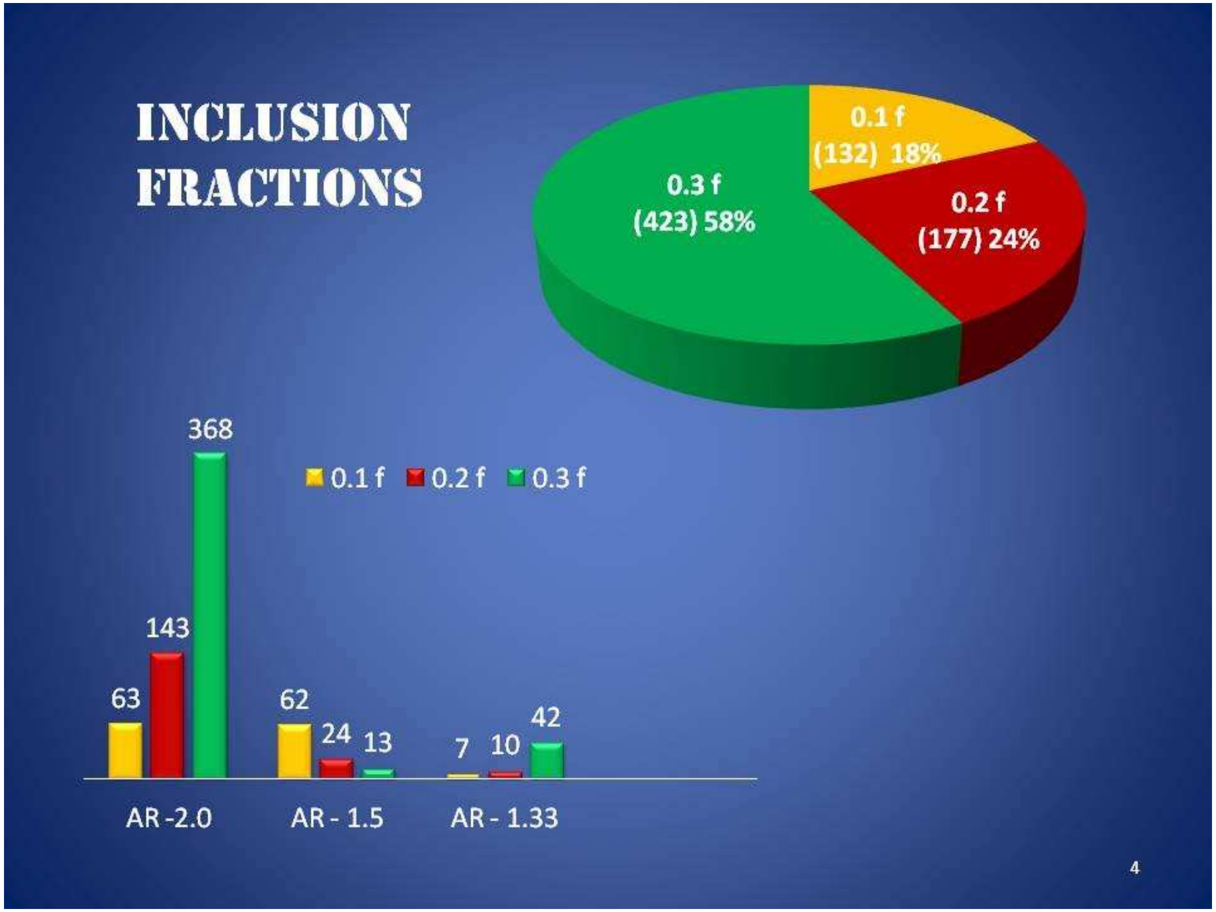
Axial Ratios

Statistics ... contd.



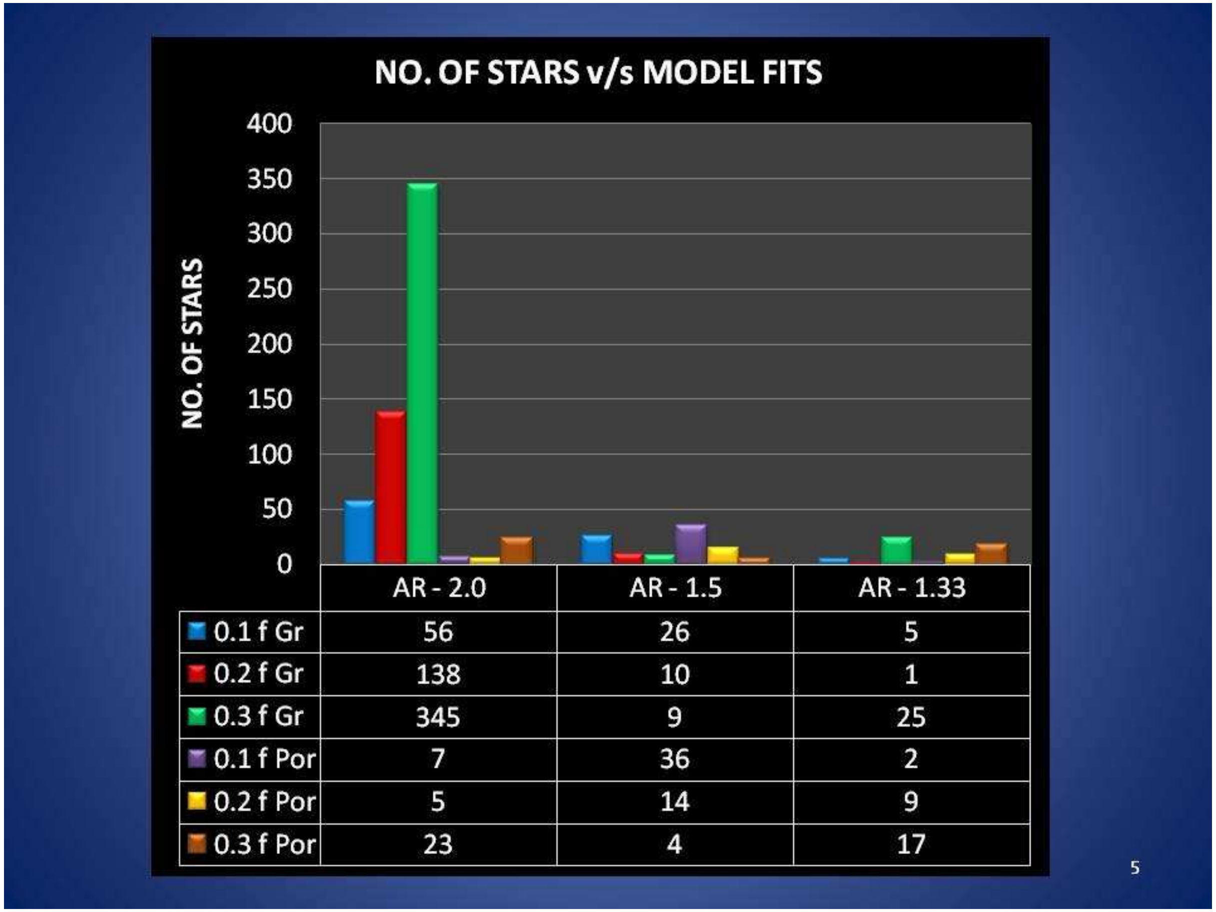
Inclusion Statistics

Statistics ... contd.



Inclusion Fractions

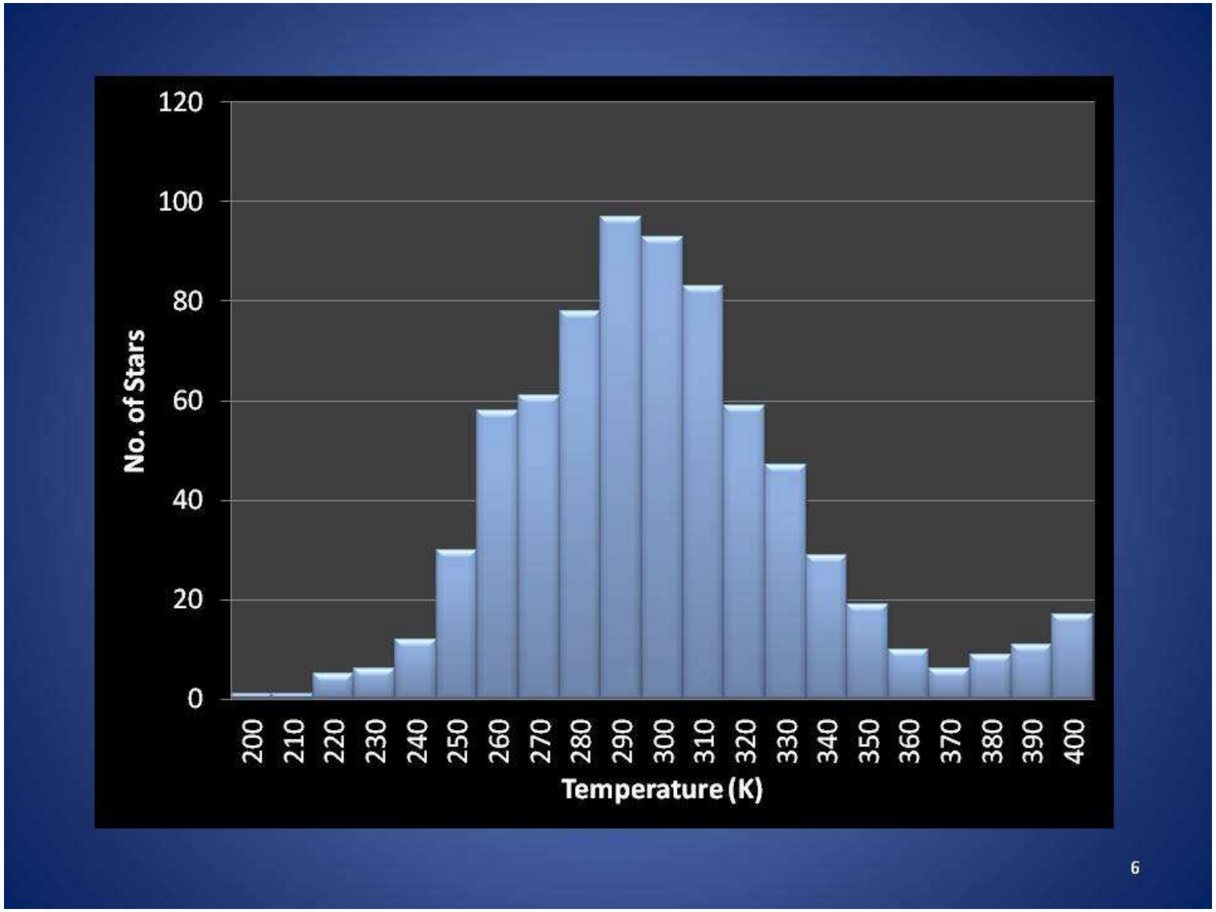
Statistics ... contd.



	AR - 2.0	AR - 1.5	AR - 1.33
0.1 f Gr	56	26	5
0.2 f Gr	138	10	1
0.3 f Gr	345	9	25
0.1 f Por	7	36	2
0.2 f Por	5	14	9
0.3 f Por	23	4	17

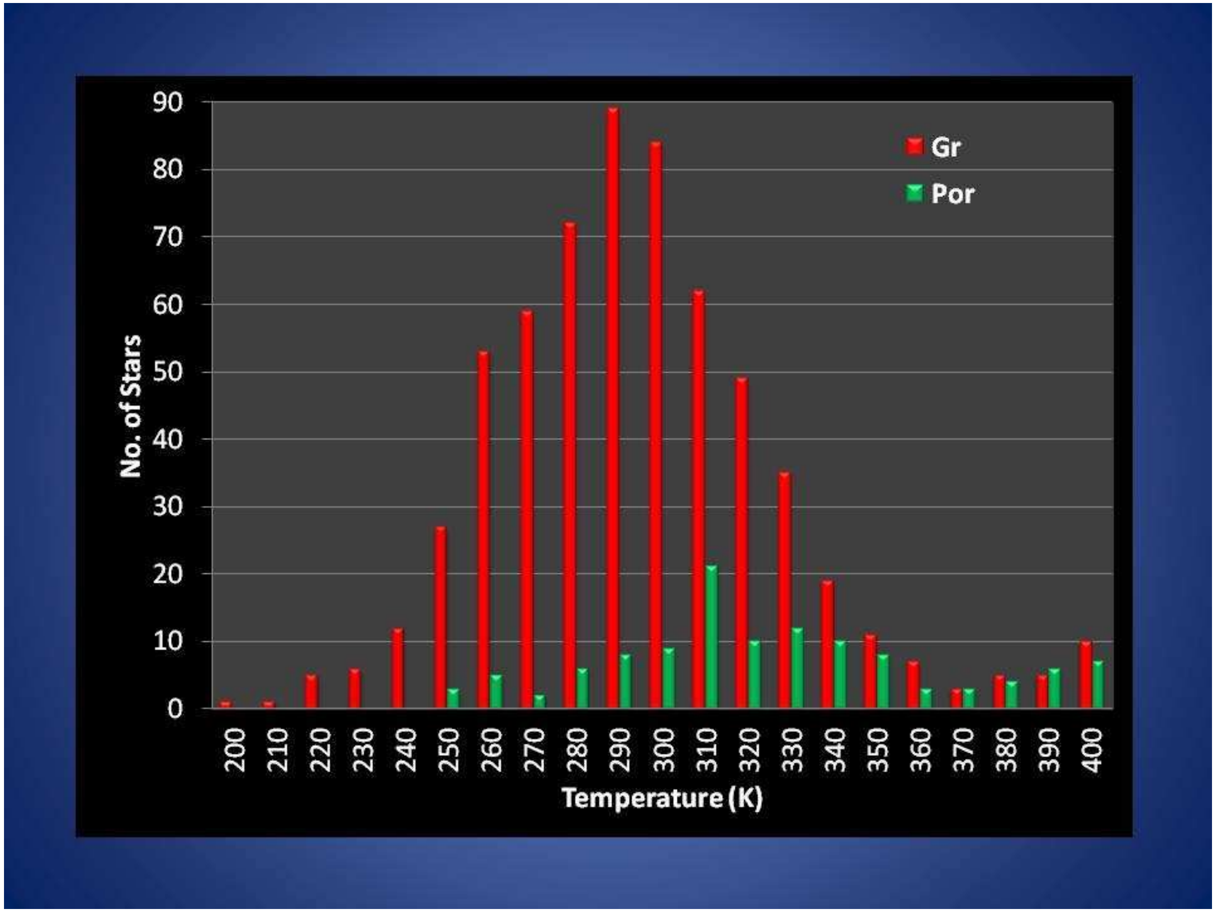
Inclusion Fractions ... contd.

Statistics ... contd.



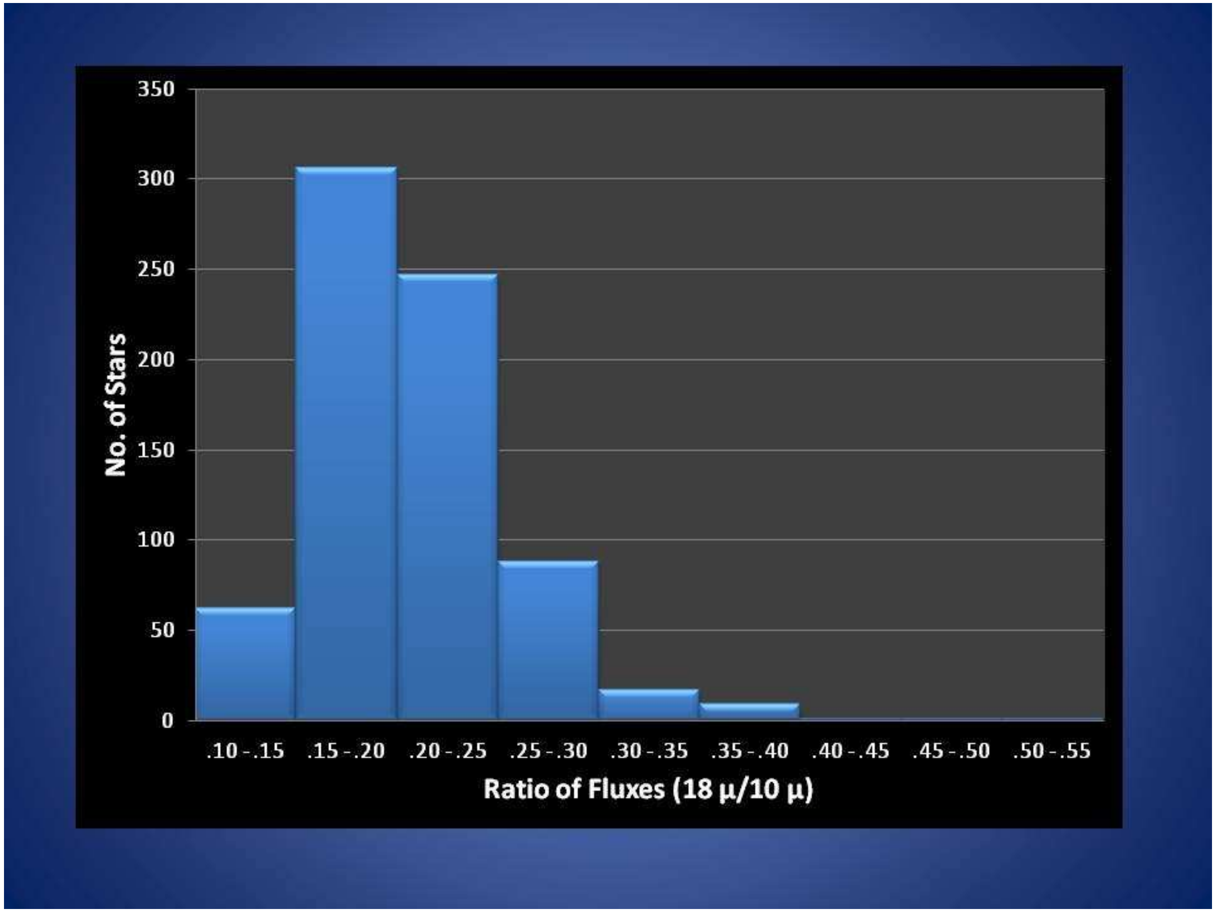
Dust Temperature Estimates

Statistics ... contd.



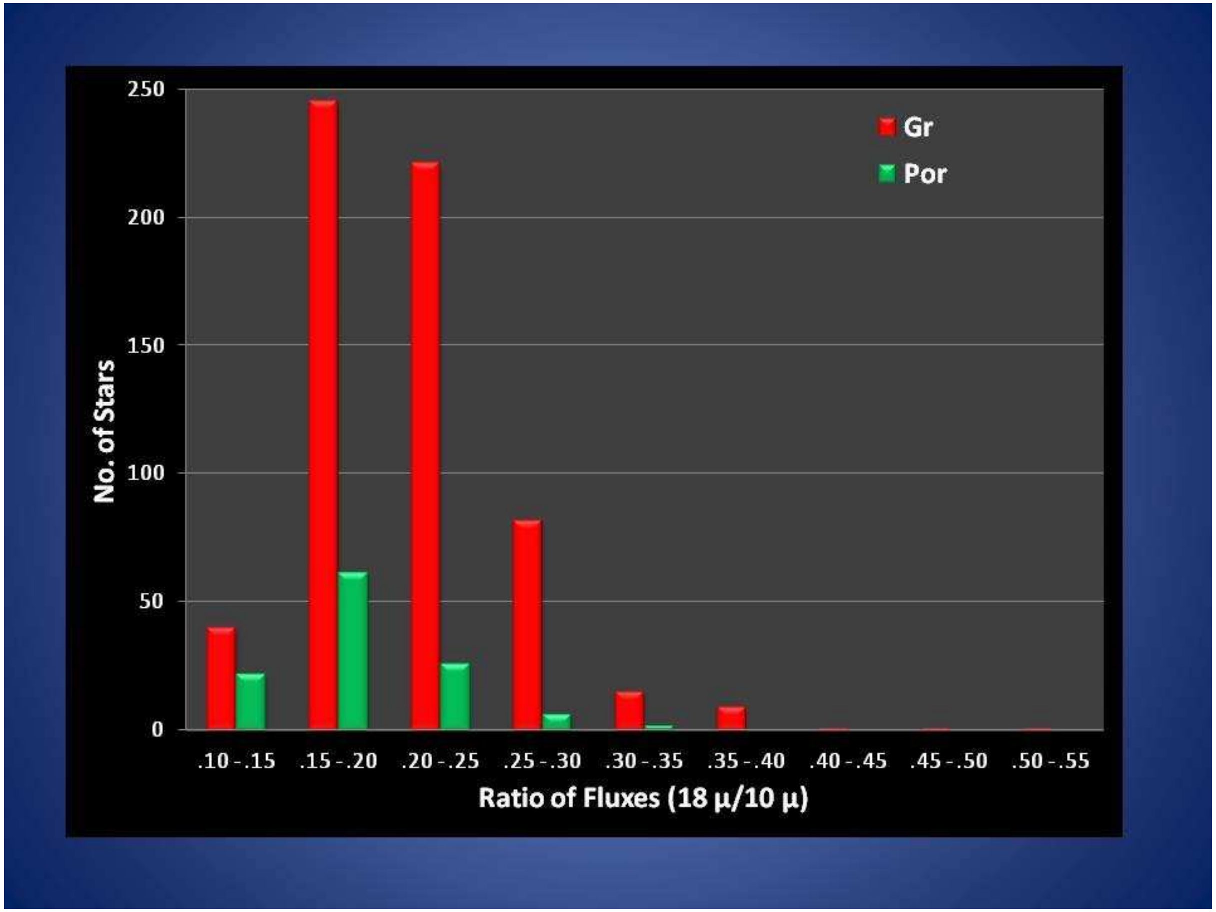
Temperature Estimates for Graphite and Porous Inclusions separately

Statistics ... contd.



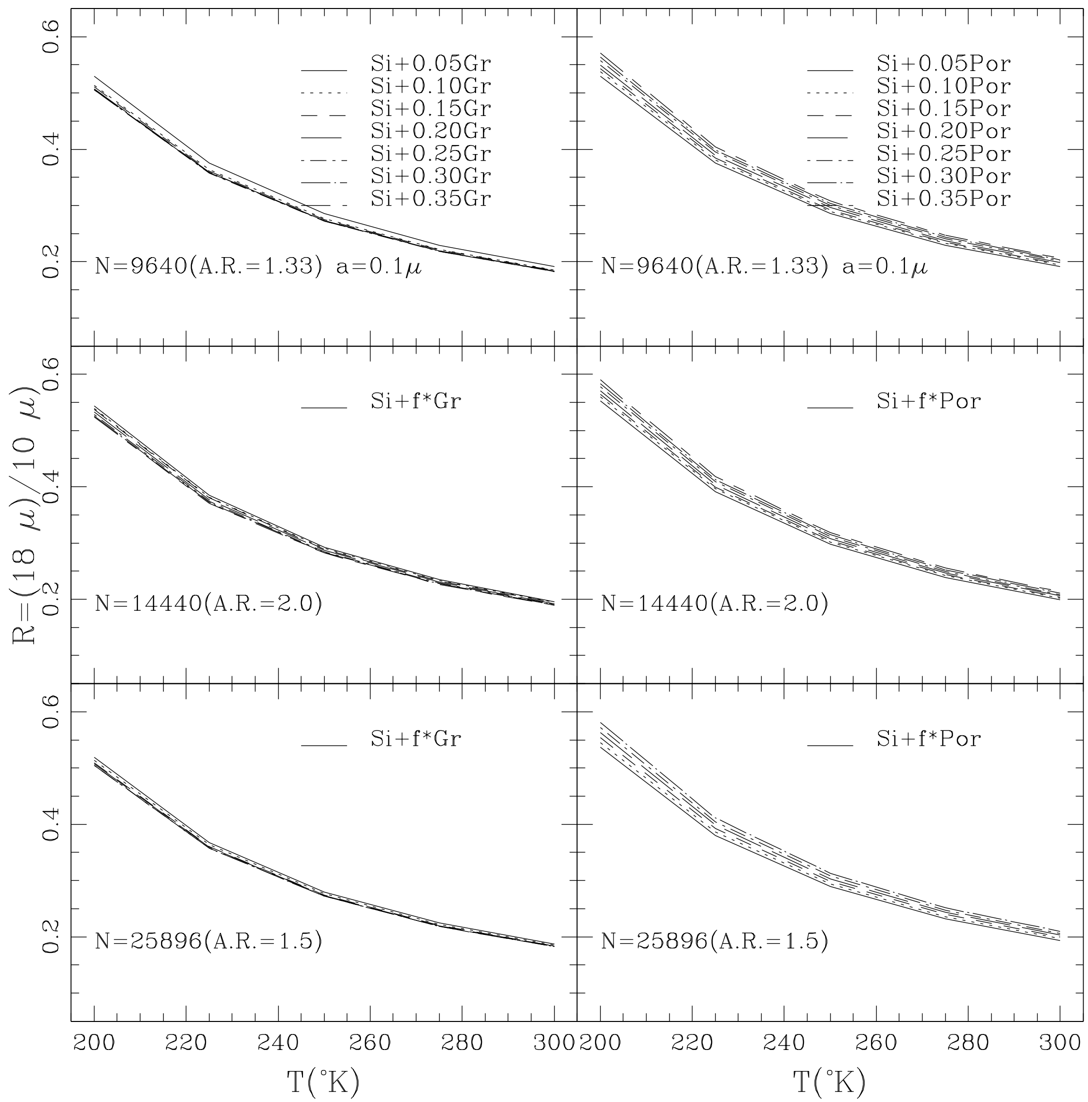
Flux Ratios

Statistics ... contd.



Flux Ratios for Graphite and Porous Inclusions separately

Ratio R=Flux(18μ)/Flux(10μ)



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 280-300 $^\circ$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!