Optical properties of dust grains

our view on cosmic dust

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Outline

- Introduction/Importance
- Methods for types of dust grains:
  - Small, homogeneous grains
  - Homogeneos aggregates
  - Large inhomogeneous aggregates
- Conclusions
- Key areas for improvement

The importance of optical properties

- Astronomy is (largely) the study of radiation
- So basically all information on the properties of dust grains in astronomical environments comes from its interaction with radiation

Degenerate inverse problem

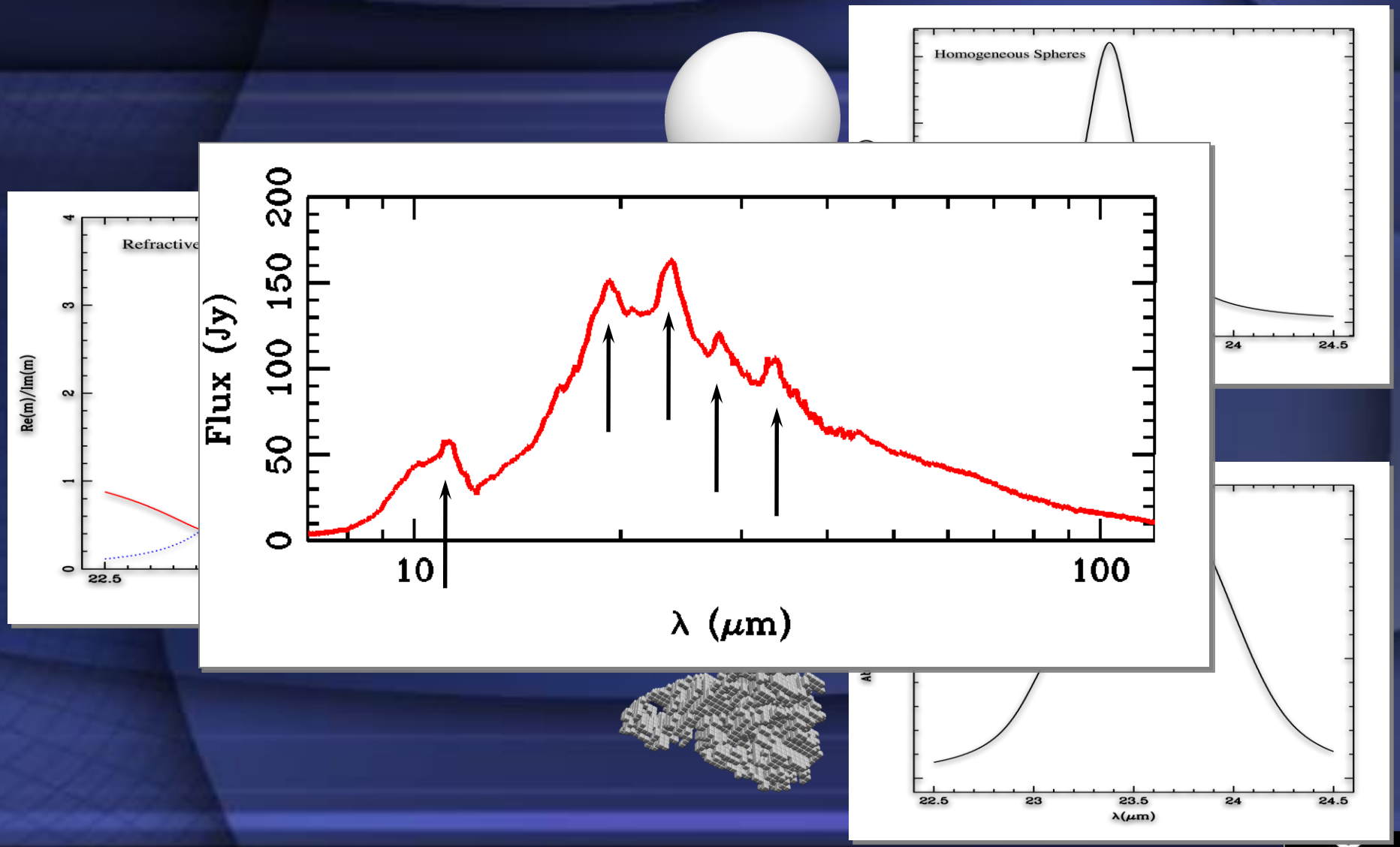
What we want to know

- The composition of the particles
  - (thermal) processing, tracing grain formation
- The size of the particles
  - Grain growth, planet formation
- The structure of the particles
  - Aggregation processes
- The shape of the grains
  - Formation conditions, erosion

What to take away today

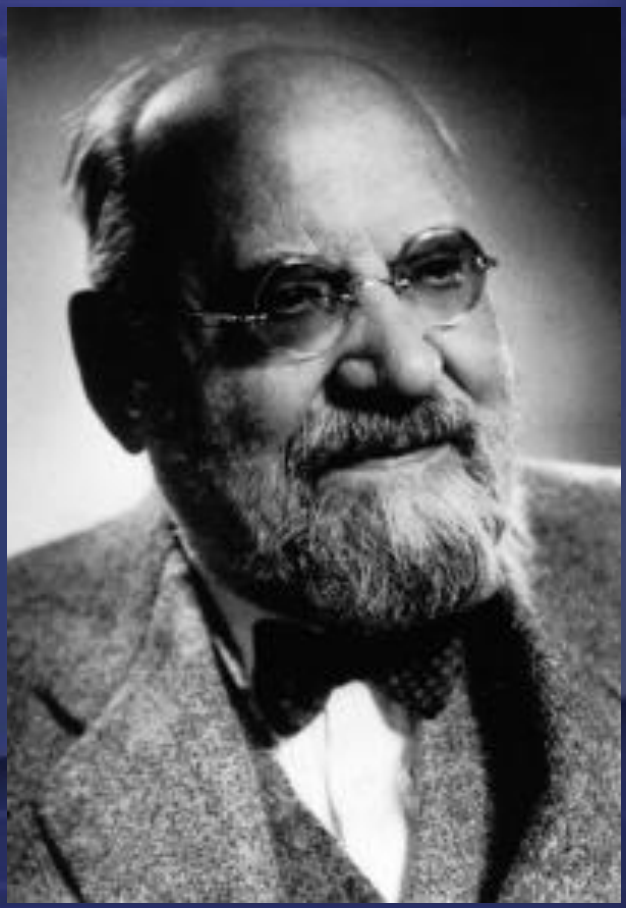
- Think carefully about the dust model you use; it matters!
- It is important to study the effects of your choice on the outcome
- We can do a lot, but we are not there yet...

Infrared spectroscopy



Mie theory 1908-2008

- Solution for a homogeneous sphere
- Provides great insight in the physics
- But in most cases the grains are not spheres...



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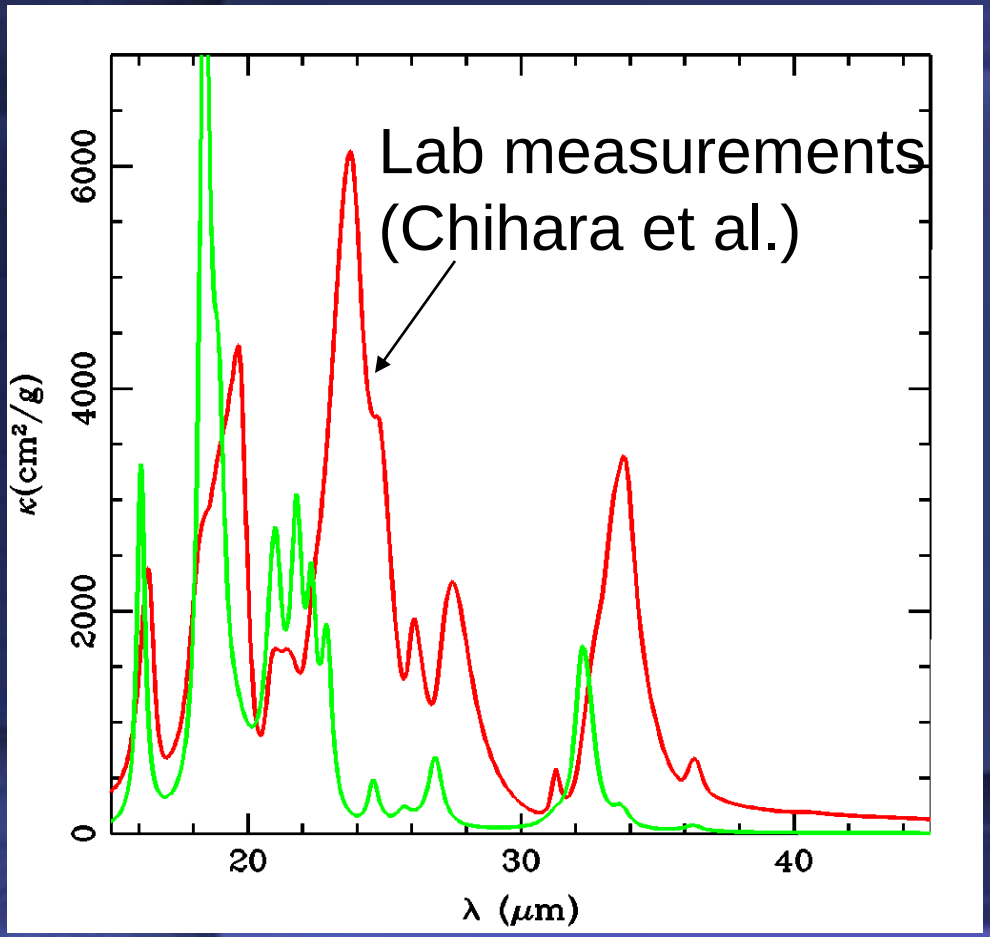
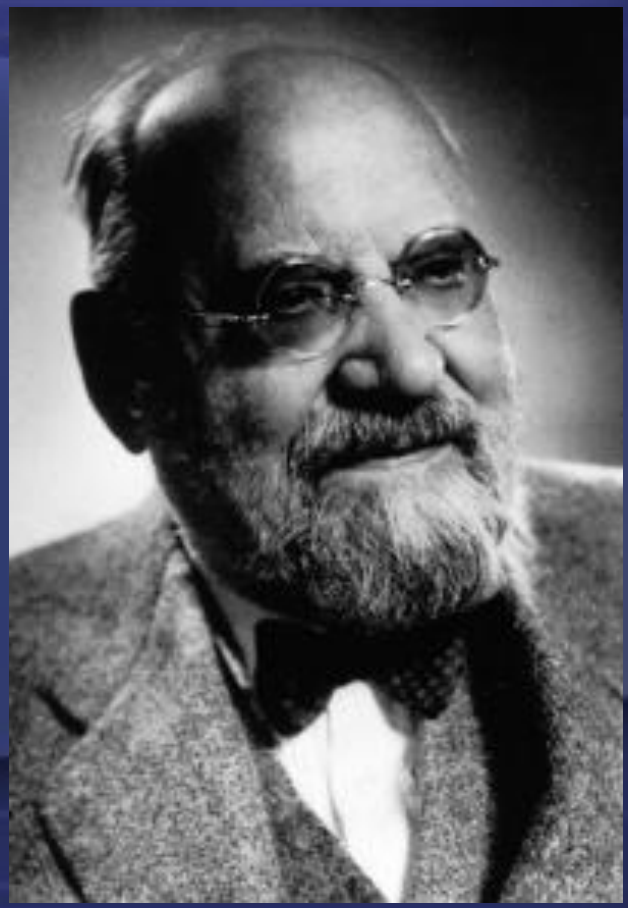
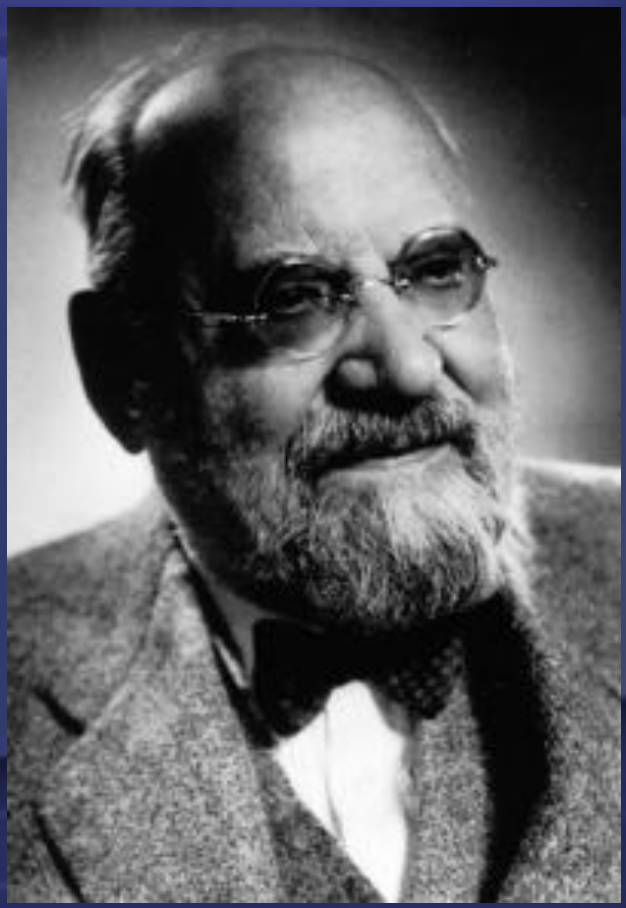


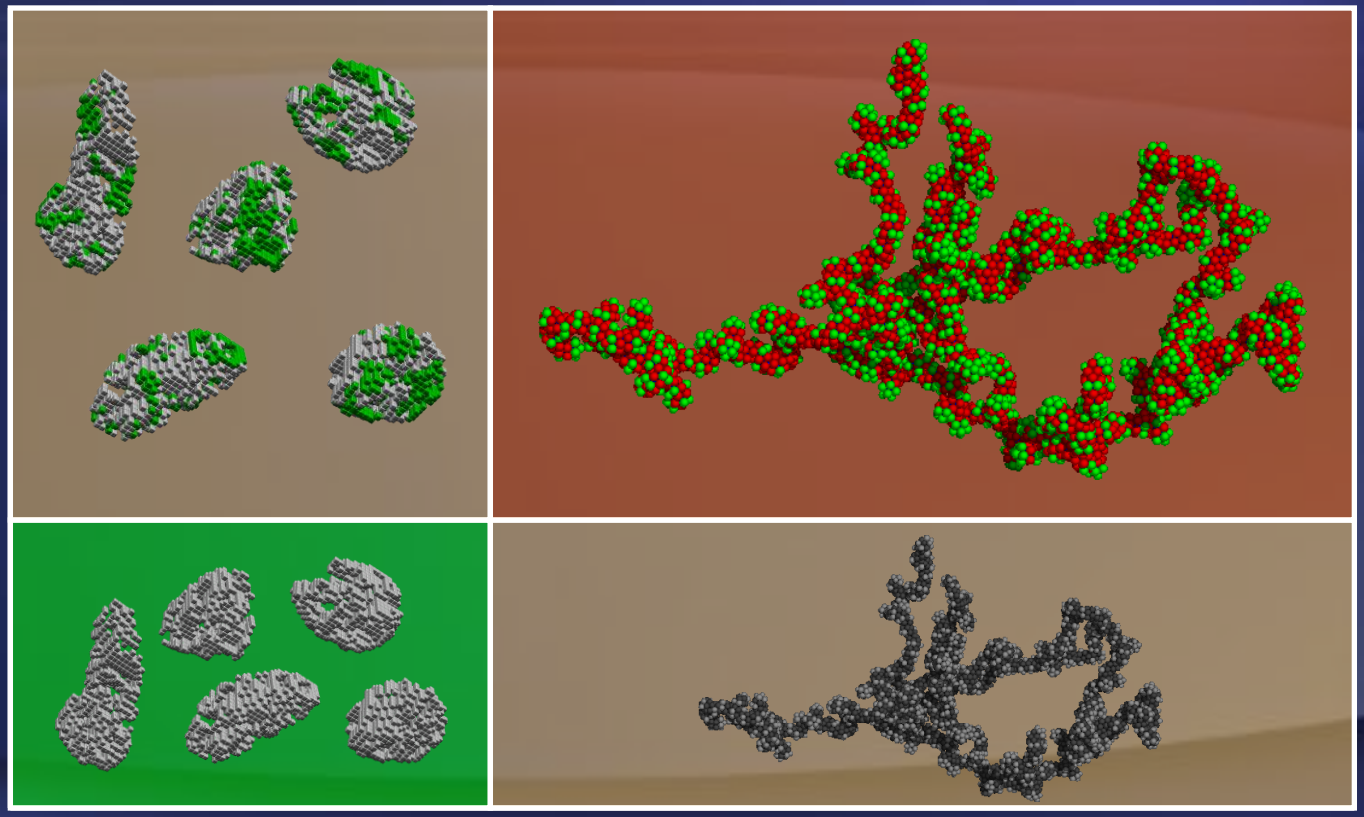


Mie theory 1908-2008

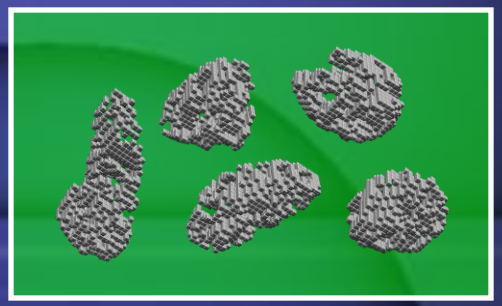
- Scattering properties of large extreme refractive index particles
  (Muñoz et al. 2006)
- In combination with effective medium theory
  (Min et al. In press)



Grain types


Grain composition
Heterogeneous
(Multiple materials)
Homogeneous
(Single material)
'Small' grains
Large (Aggregates)
Grain size ⟶

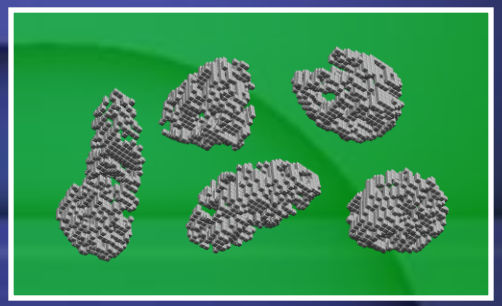
‘Small’ grains: - One particle composed of one material



Several methods:

- Sphere/spheroid:
  - Mie theory (Mie 1908)
  - Seperation of variables (Farafonov, Voshchinnikov)
- Irregularly shaped:
  - Statistical approach (Min, Voshchinnikov)
  - Discrete Dipole Approximation (Purcell, Draine, Yurkin)
  - T-matrix method (Mishchenko, Wriedt)

‘Small’ grains: - One particle composed of one material



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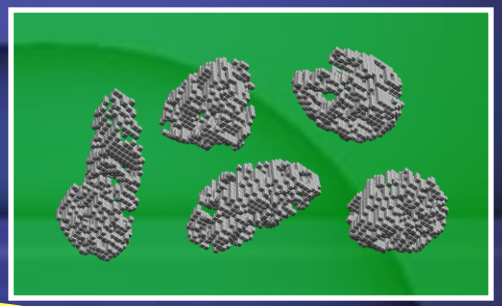


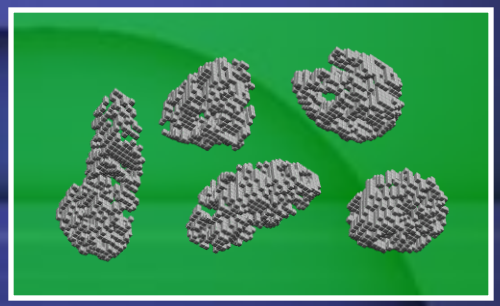
$$C_{\mathrm{abs}} = \sum_{j=1}^{3N} w_j \, kV \, \mathrm{Im}\left(\frac{m^2-1}{1+L_j(m^2-1)}\right)$$

Contains *all* information on particle shape

Ellipsoid with ‘form-factor‘ L_j

Min et al. JQSRT, 2006

‘Small’ grains: - One particle composed of one material

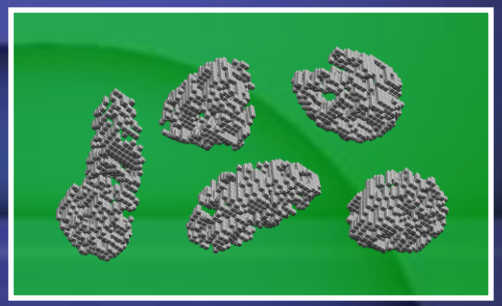


This implies that (in the Rayleigh domain) the optical properties of any arbitrarily shaped particle are identical to those of a distribution of simple shapes.

It is only required that the simple shapes cover the range of form-factors needed.

Examples: CDE (Bohren & Huffman), Hollow Spheres (Min et al.), Multilayered spheres (Voshchinnikov et al.)

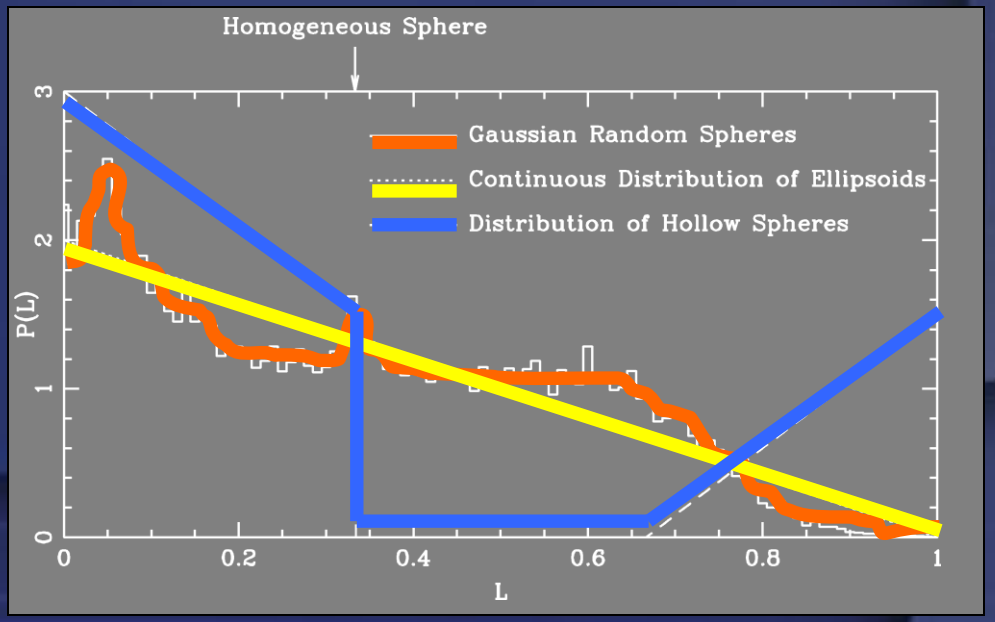
‘Small’ grains: - One particle composed of one material



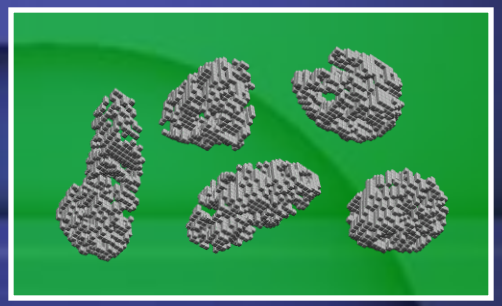
It means that if we find ‘the’ formfactordistribution for an average ‘irregurarly shaped’ particle, we’re done.

This can be obtained:

- From theory
- Experimentally by fitting infrared spectra (see poster by Mutschke et al.)



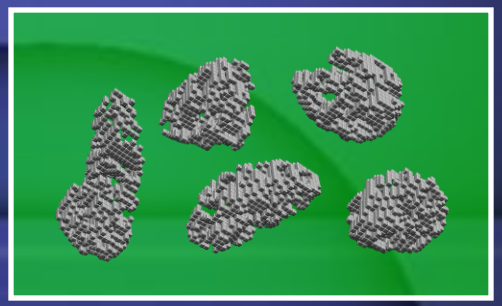
‘Small’ grains: - One particle composed of one material



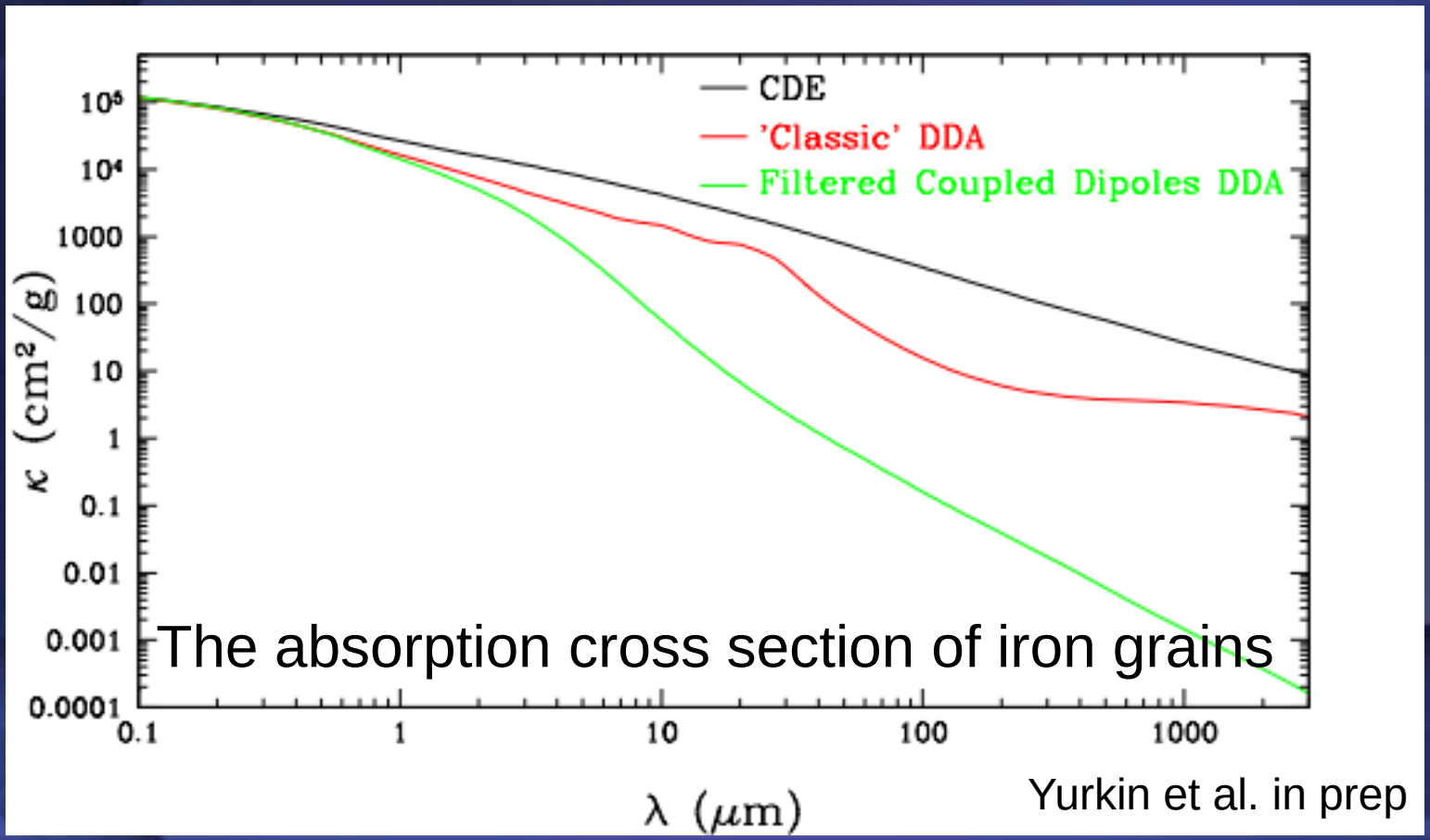
- The Discrete Dipole Approximation (DDA) can be used to compute optical properties of arbitrarily shaped particles.
- Publicaly available codes:
  - DDSCAT (Draine), ADDA (Yurkin)

Be careful when the refractive index is high!!

‘Small’ grains: - One particle composed of one material



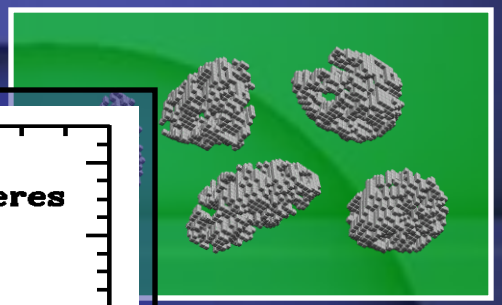
Extreme refractive indices

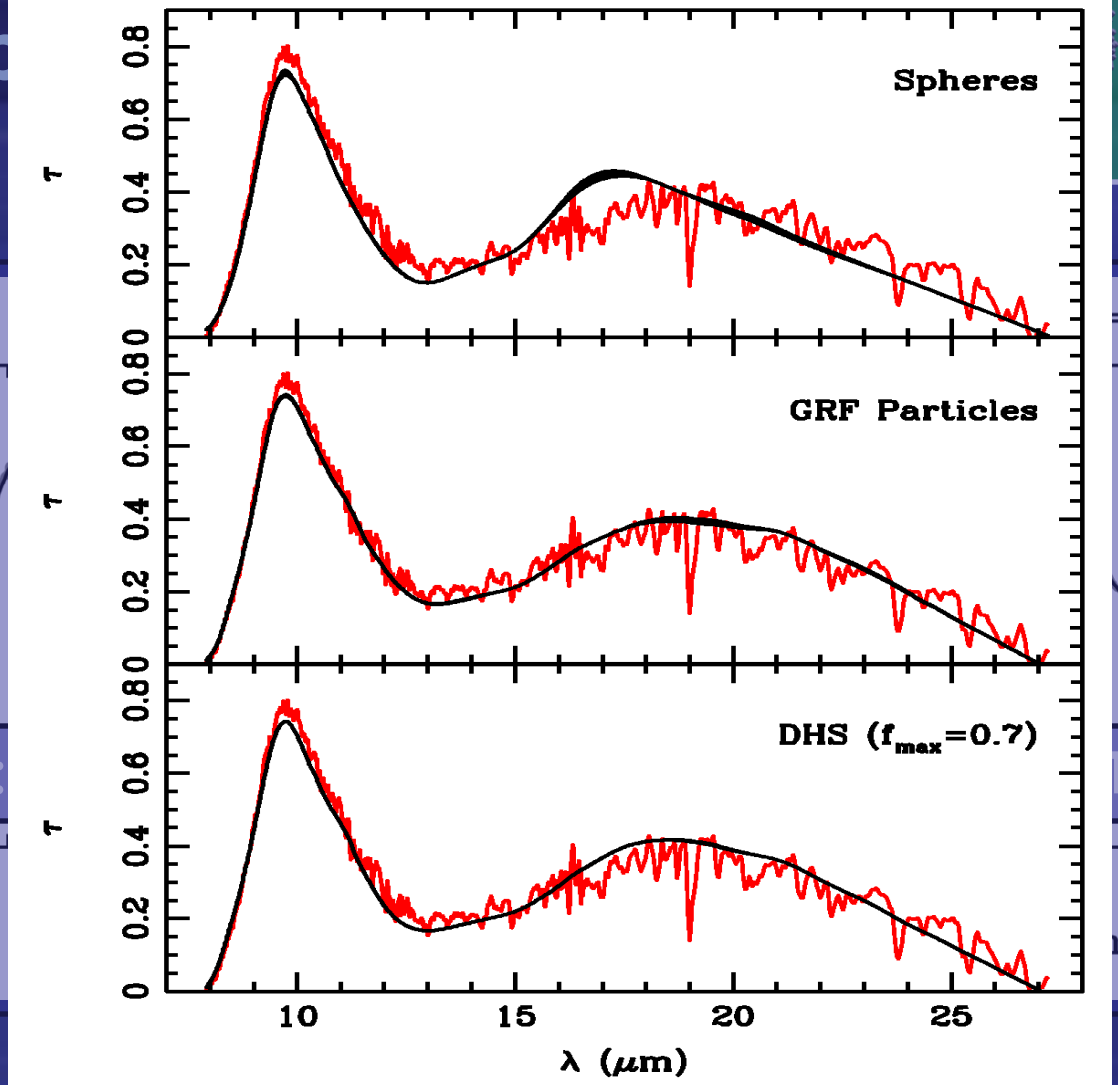


The absorption cross section of iron grains

Yurkin et al. in prep

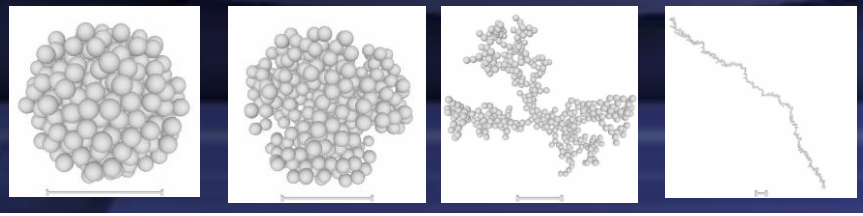
Interstellar silicates: the 10 micron amorp

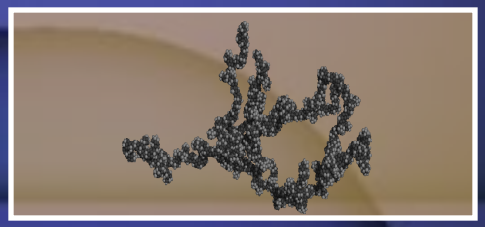


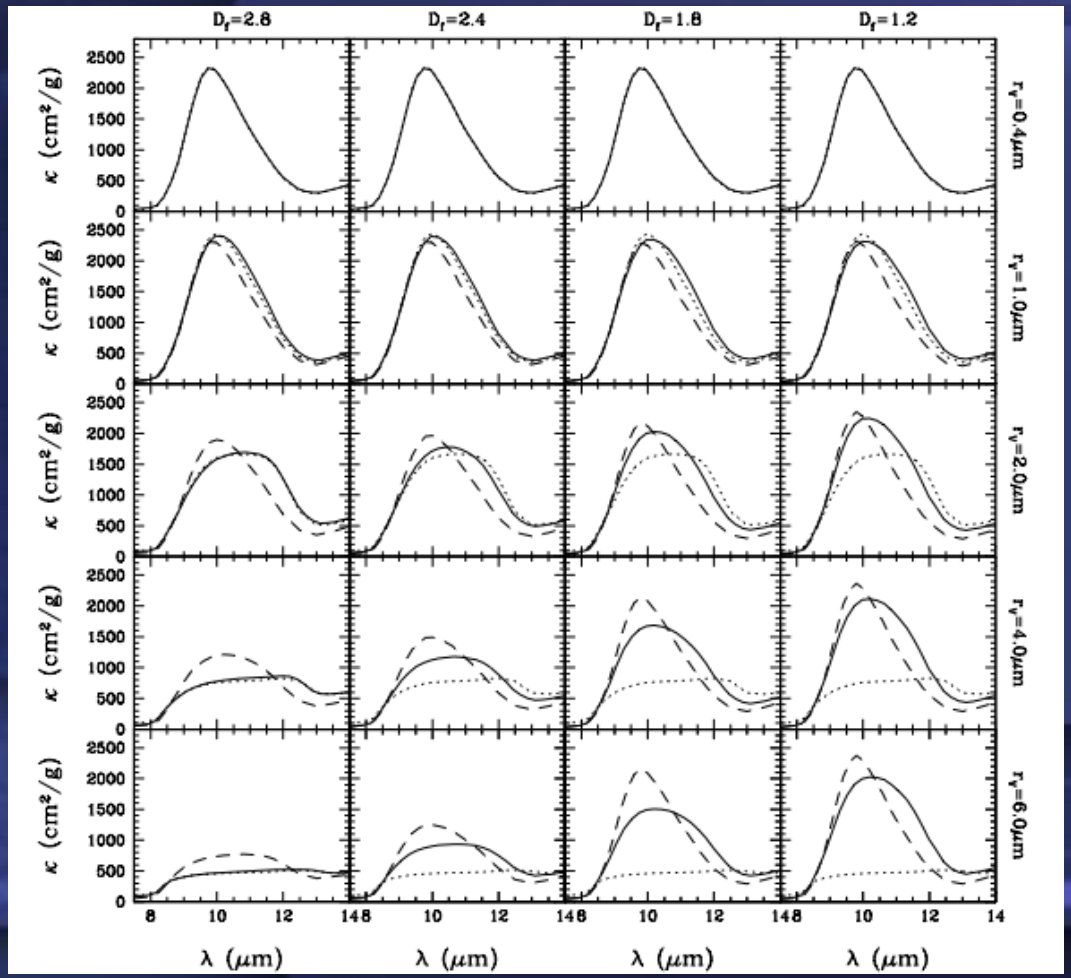


Min et al. 2006

Homogeneous aggregates



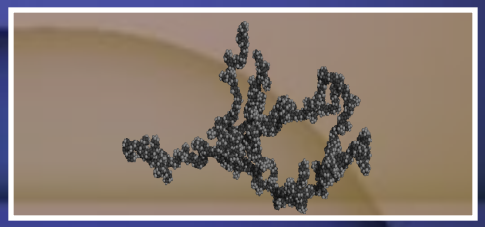




increasing size

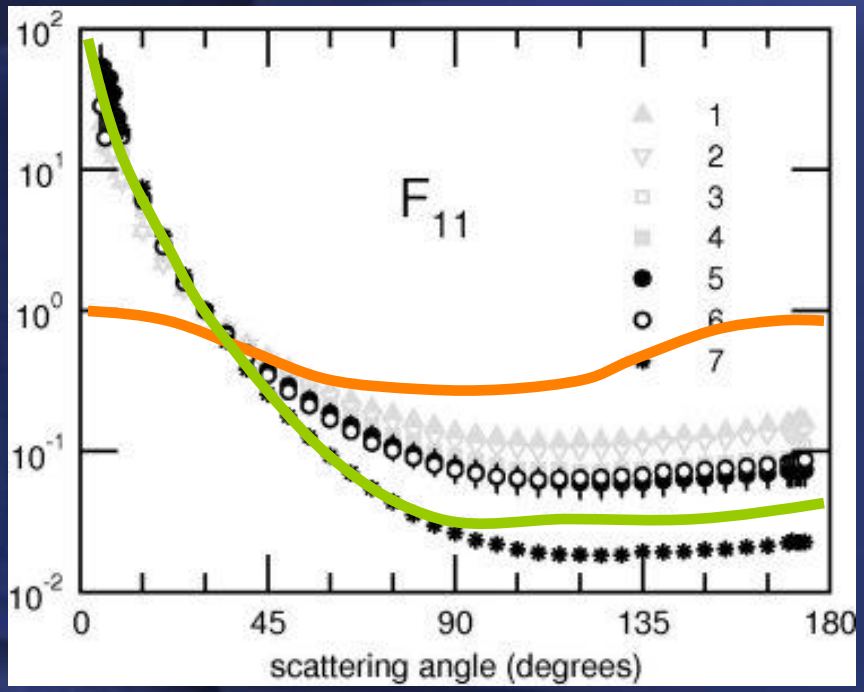
Fluffy aggregates look spectroscopically like small grains

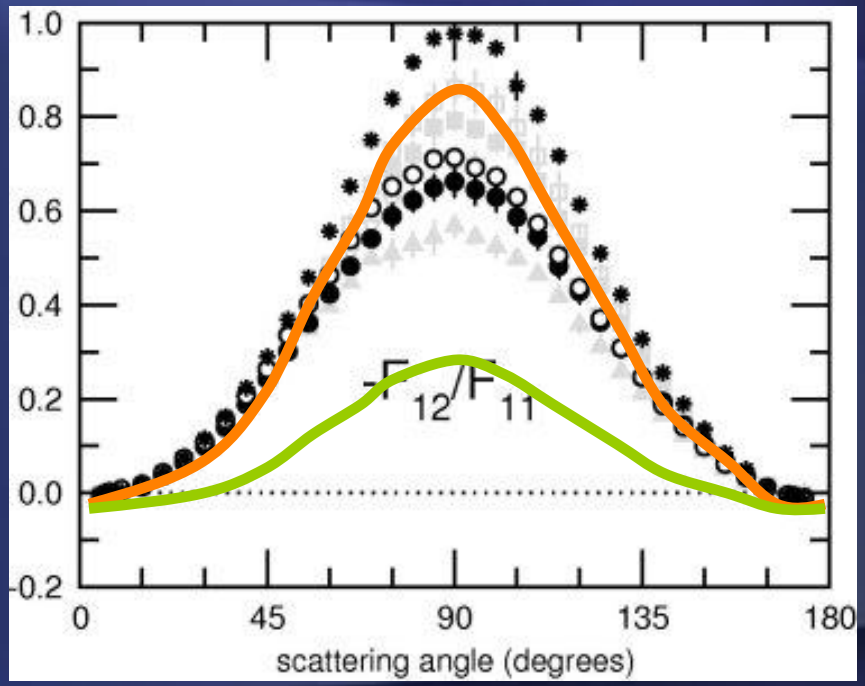
Homogeneous aggregates



Is there a difference between small grains and fluffy aggregates?

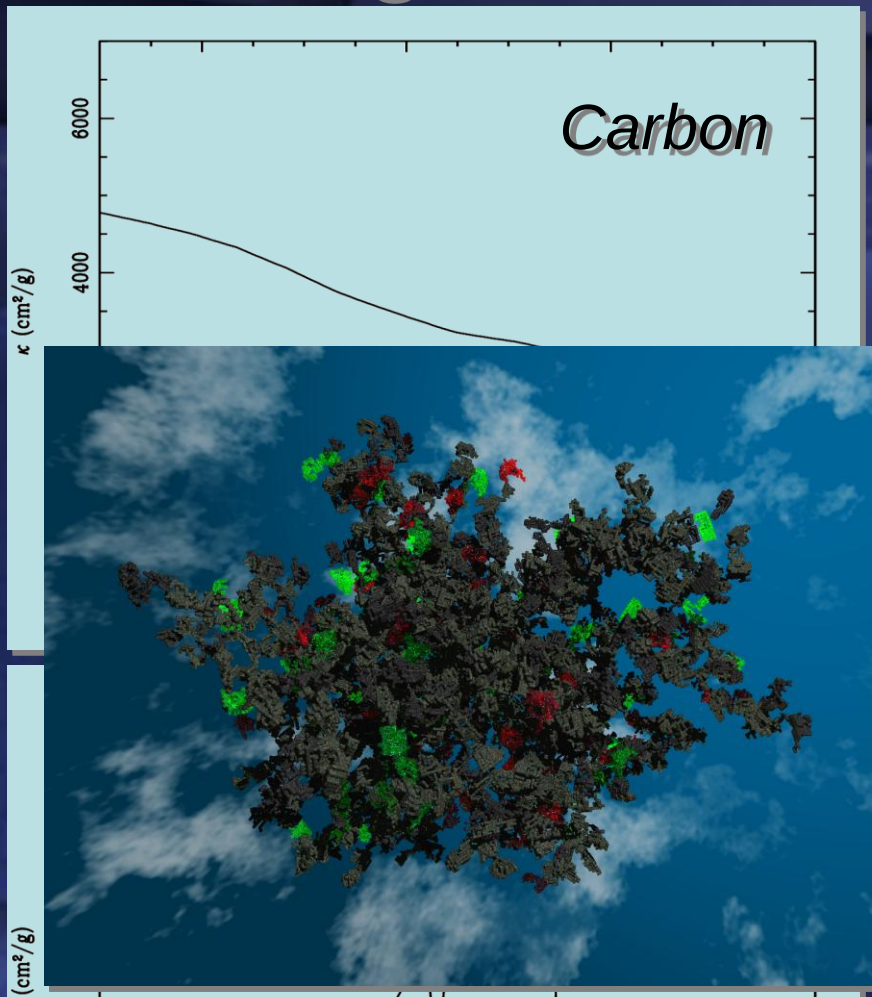
Small grains **Large grains**

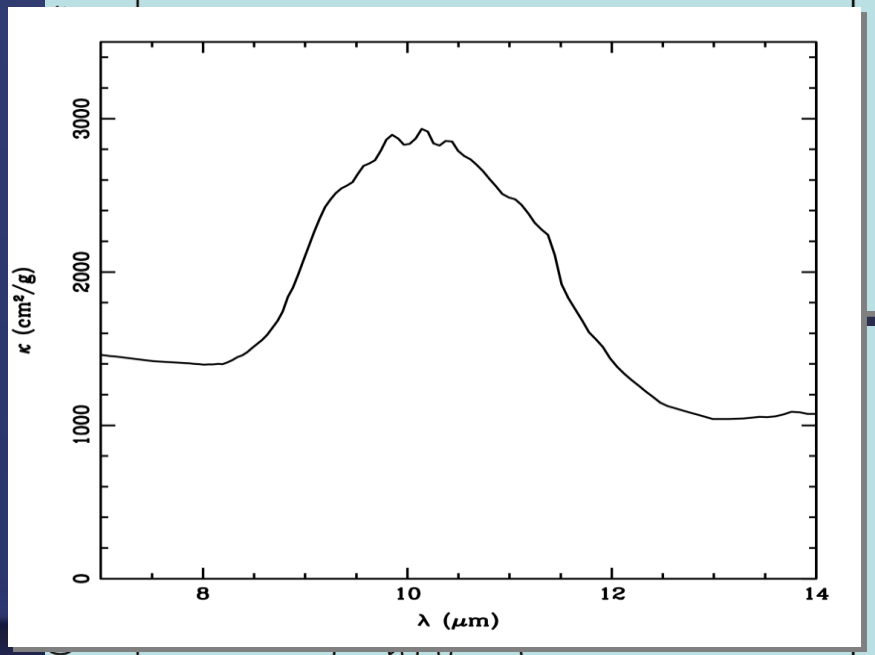




Volten et al. 2007

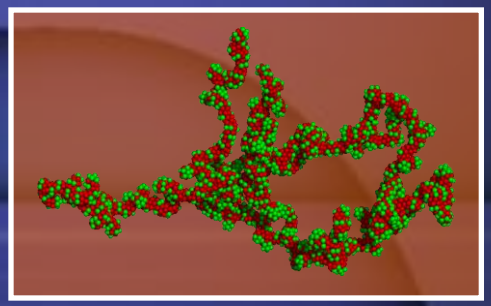
Inhomogeneous aggregates





Dust N

Effective absorption spectra



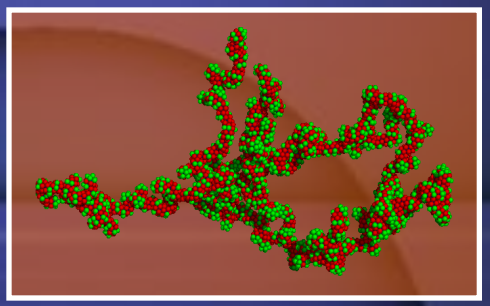
Inhomogeneous aggregate

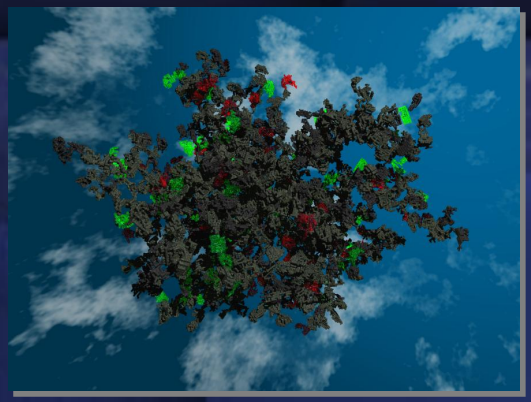
r_V=1 μm

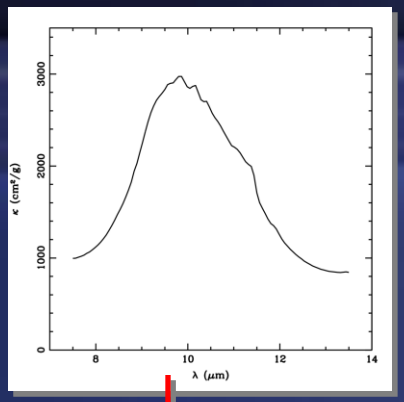
Contributions from different components

Homogeneous aggregates

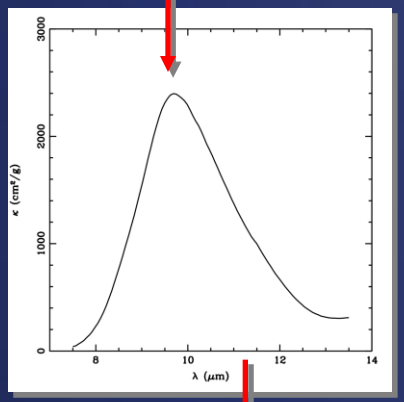
Effective absorption spectra

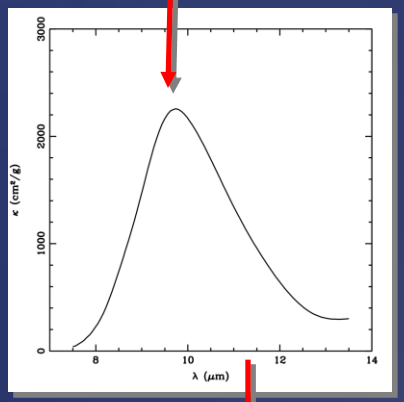


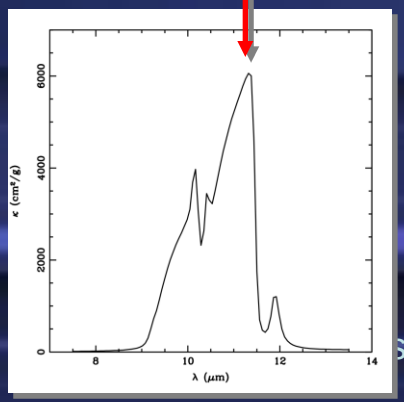


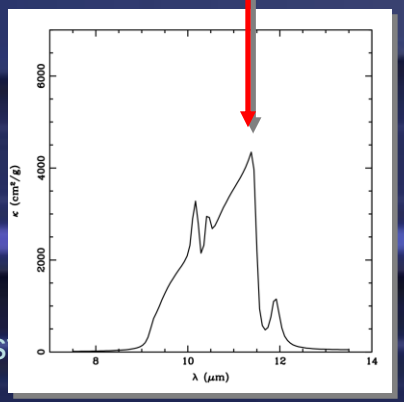


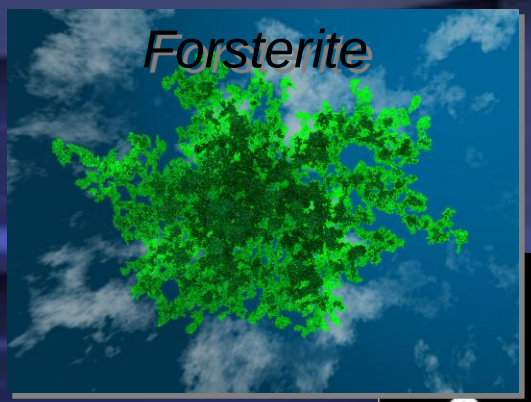
r_V=2 μm



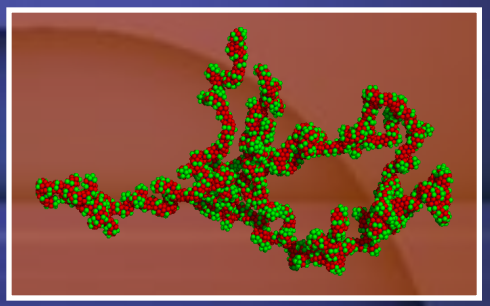


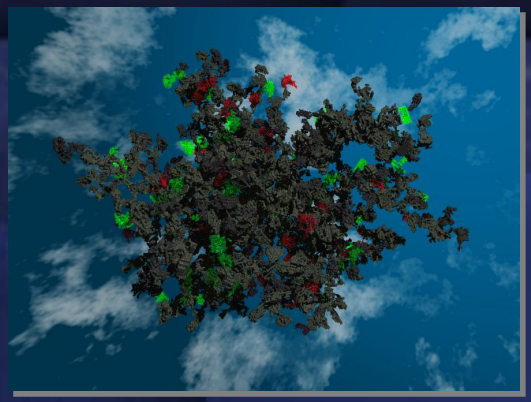


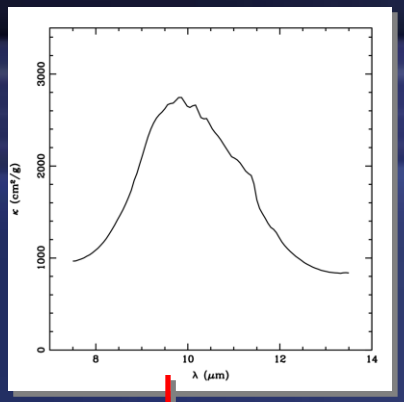




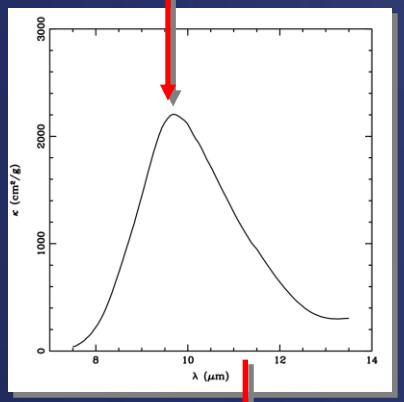
Effective absorption spectra

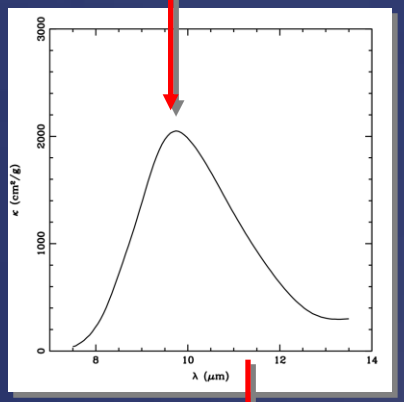


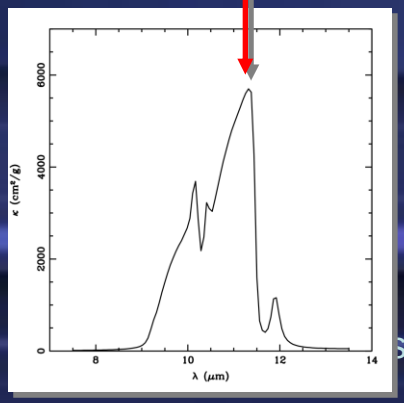


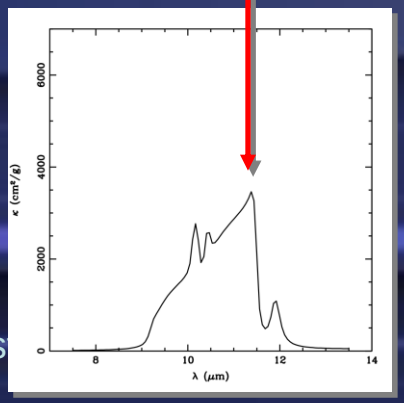


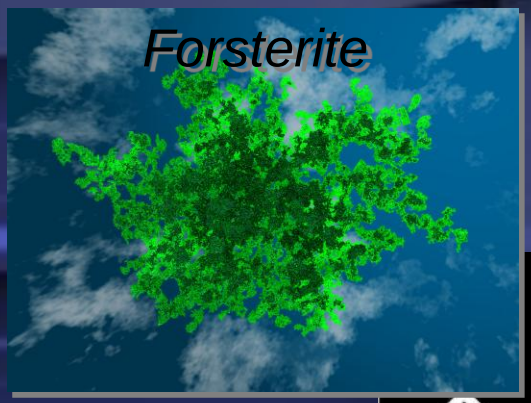
r_V=3 μm



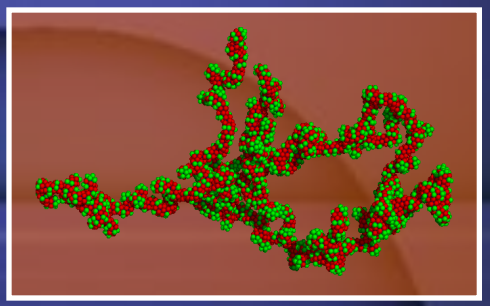


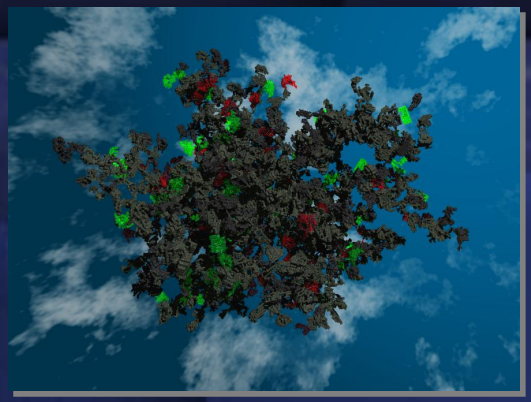


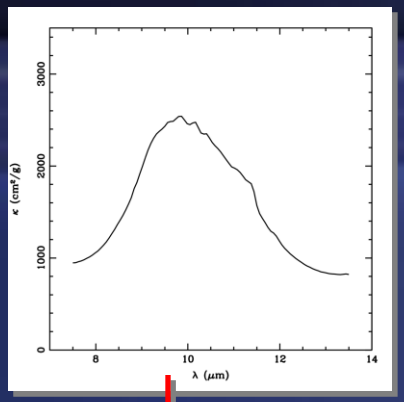




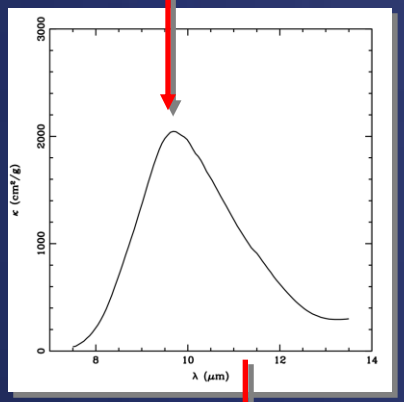
Effective absorption spectra

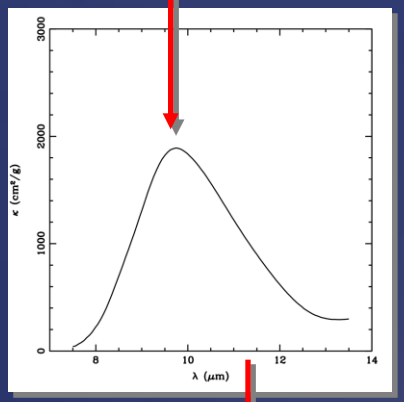


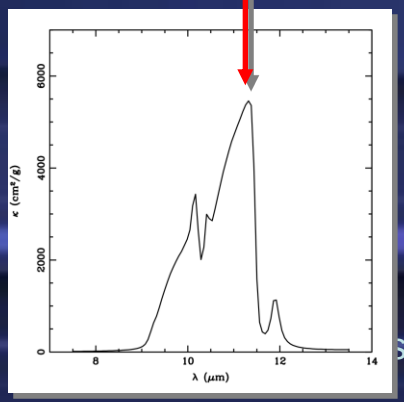


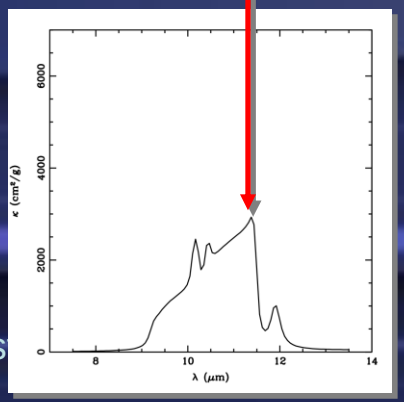


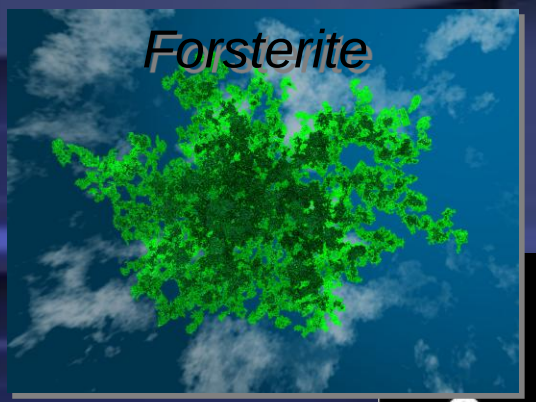
r_V=4 μm



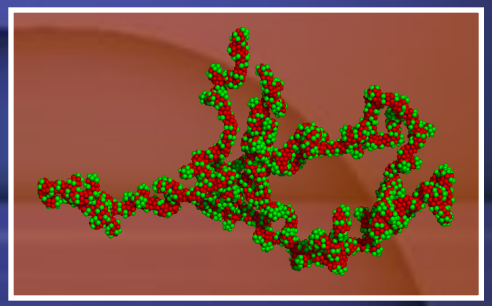


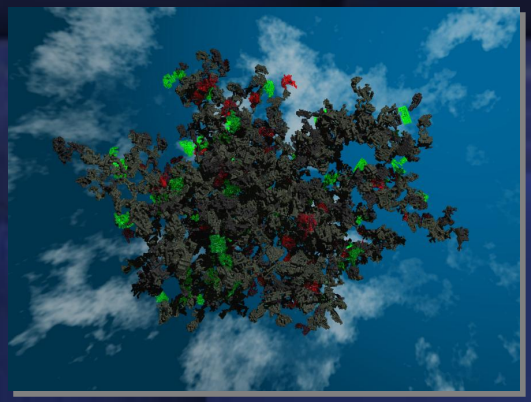


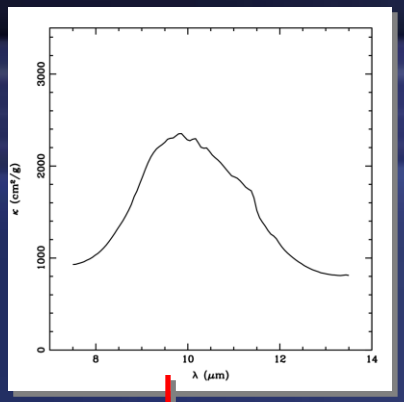




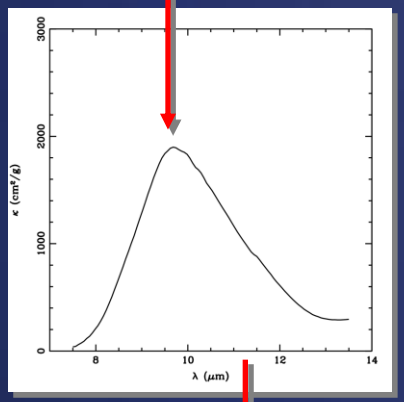
Effective absorption spectra

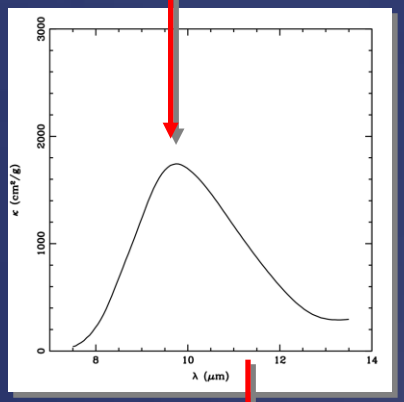


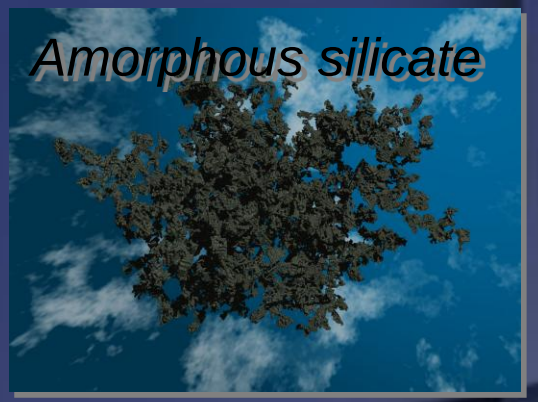


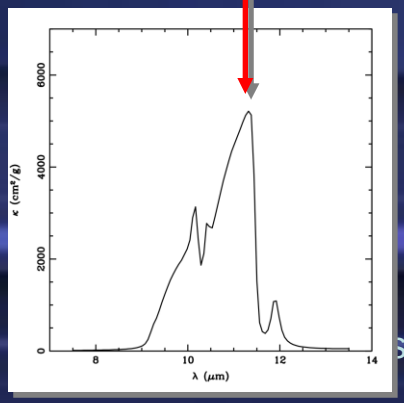


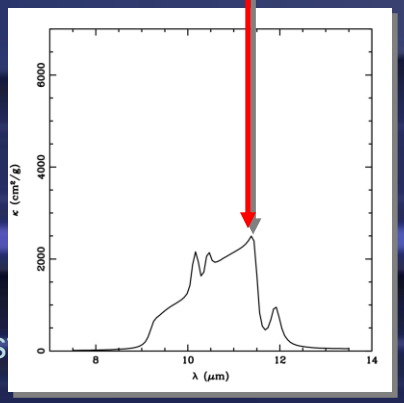
r_V=5 μm



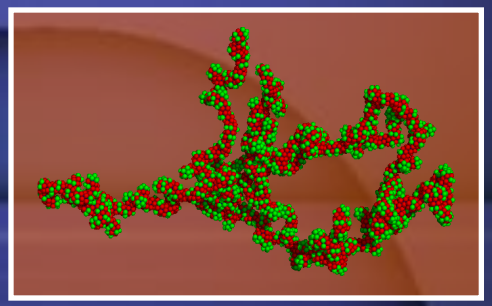


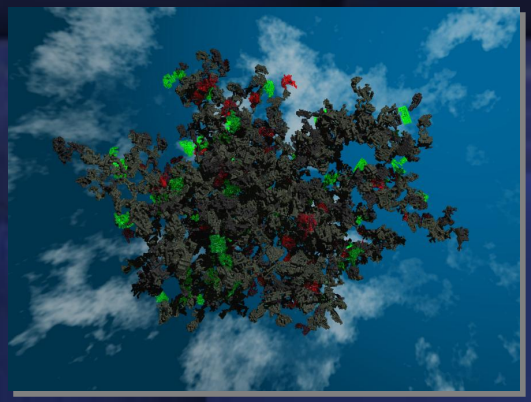


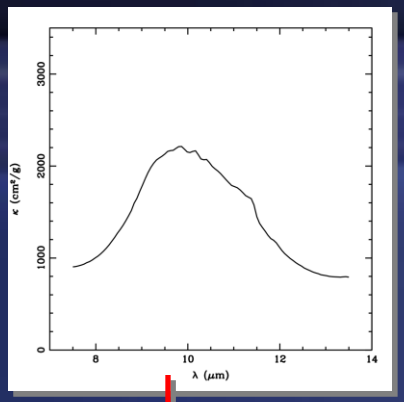




Effective absorption spectra

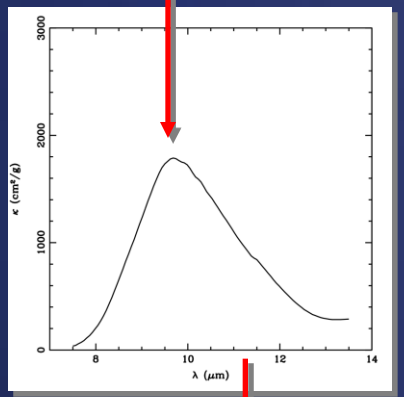


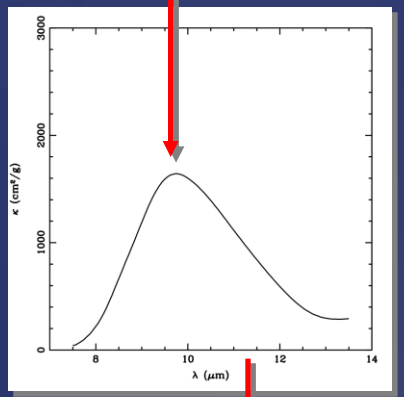




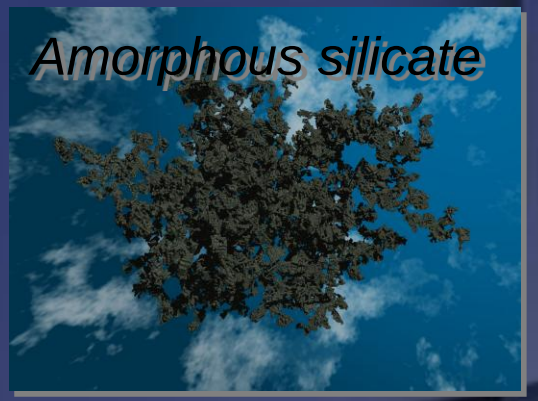
r_V=6 μm

Amorphous silicate

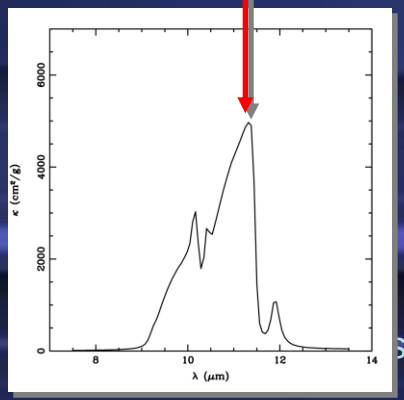


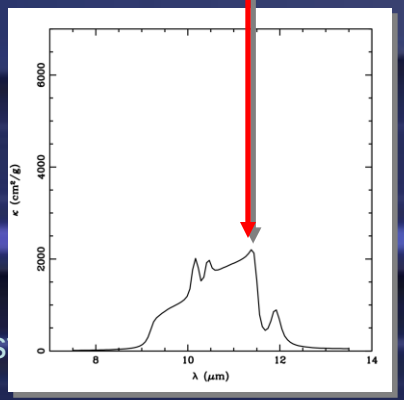


Amorphous silicate



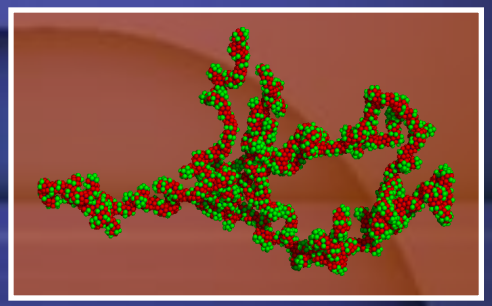
Forsterite





Forsterite

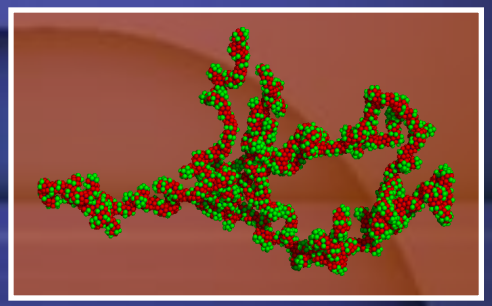
Trends observed



- The feature strengths decrease with increasing aggregate size
- Materials with small abundance stay spectroscopically small for large aggregate sizes

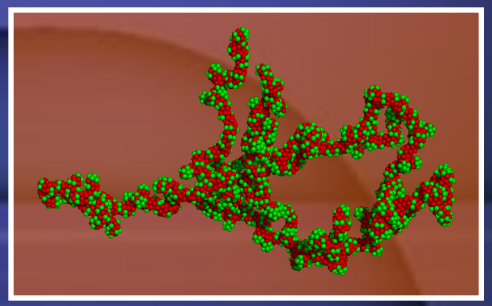
- These effects have to be taken into account when studying aggregates!

Efficient ways to compute aggregates



- Effective medium theory
  - Aggregate Polarizability Mixing Rule (APMR), Min et al. (in press)
  - Bruggemann rule (Voshchinnikov et al., 2007)
- Multilayered spheres (Voshchinnikov & Henning, 2008)

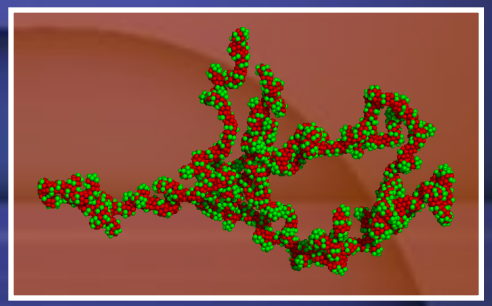
Efficient ways to compute aggregates



QuickTime™ and a
decompressor
are needed to see this picture.

Voshchinnikov & Henning, 2008

Efficient ways to compute aggregates

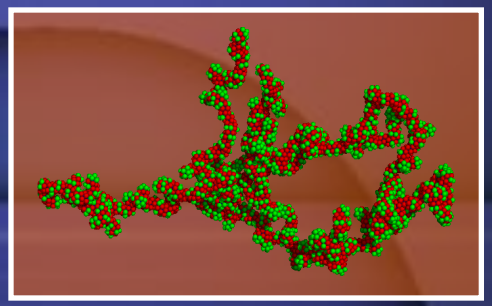


QuickTime™ and a
decompressor
are needed to see this picture.

8	9	10	11	12	13

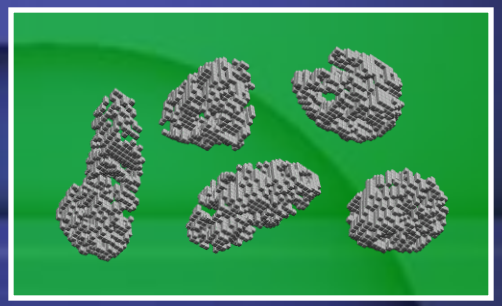
Tamanai et al., 2006

Effective medium theories



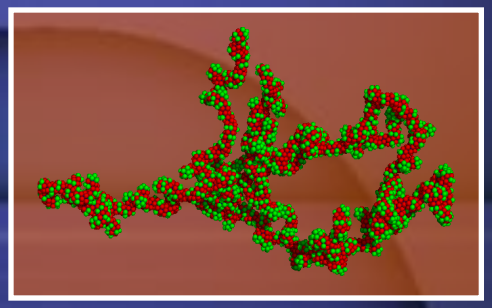
- Most effective medium theories assume the inclusions are spheres
- This is especially tricky for:
  - Iron inclusions
  - Crystalline inclusions
- The APMR circumvents this for very fluffy structures of ‘Rayleigh sized’ monomers

Conclusions



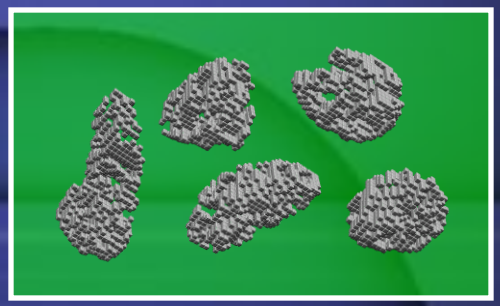
- We can compute the optical properties of solid single grains using the statistical approach quite accurately
  - Small grains: formfactor distributions
  - Larger grains: DDA computations
  - Large grains: statistical approach
- The shape model employed can have a large effect on the outcome

Conclusions



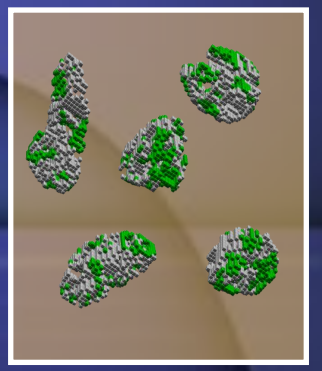
- The structure of the grain matters for its spectral signature
- Low abundance materials appear spectroscopically small
- Effective medium theory (APMR) is an efficient way of taking this into account

Key areas for future research



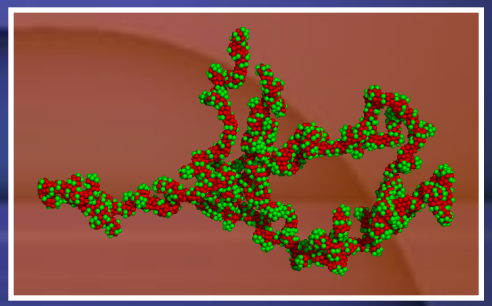
- Opacities of high refractive index materials
  - Iron
  - Carbon
  - Iron-sulfide

Key areas for future research



- Inhomogeneous compact grains
  - Core-mantle structures
  - Iron inclusions
  - Crystalline inclusions

Key areas for future research



- Effects of different aggregate structures on the spectral shapes
  - More compact aggregates
  - Larger constituents
  - Shorter wavelengths
- Models that can also compute the scattering properties correctly
  - Superposition T-matrix
  - Large scale DDA computations

What to take away today

- Think carefully about the dust model you use; it matters!
- It is important to study the effects of your choice on the outcome
- We can do a lot, but we are not there yet...