# The appearance of large aggregates in protoplanetary disks

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Planet formation starts when tiny dust grains in protoplanetary disks aggregate to form larger structures. These large aggregates have observational and dynamical properties that are very different from more compact particles. Understanding the evolution of protoplanetary disks, the planet formation process, and constraining this from observations, require that we understand the observational characteristics of these structures. We present computations of the optical properties and radiative transfer of aggregates in protoplanetary disks. We discuss how we can constrain aggregate size and structure from observations and as such constrain the first step in planet formation.

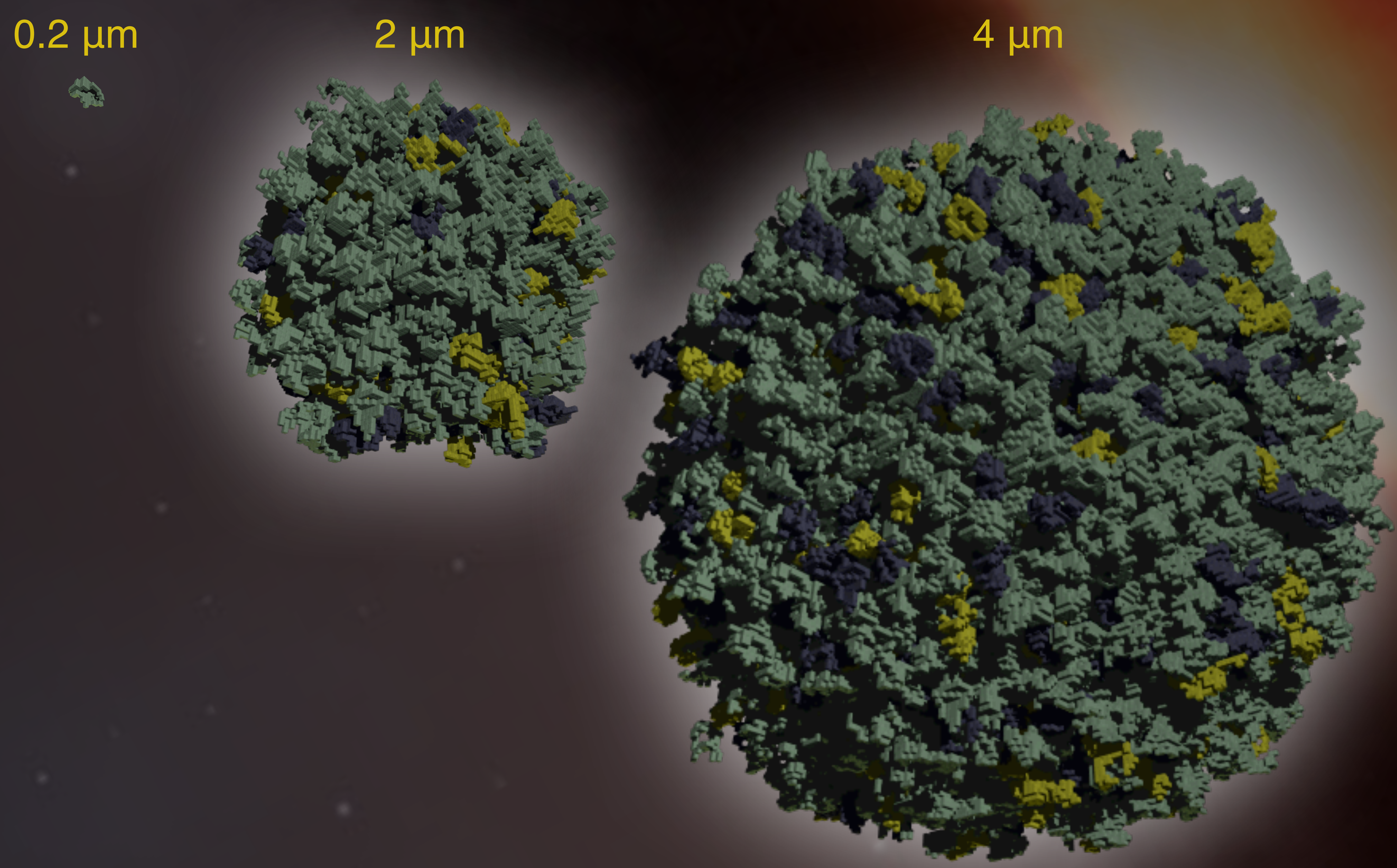
## Method

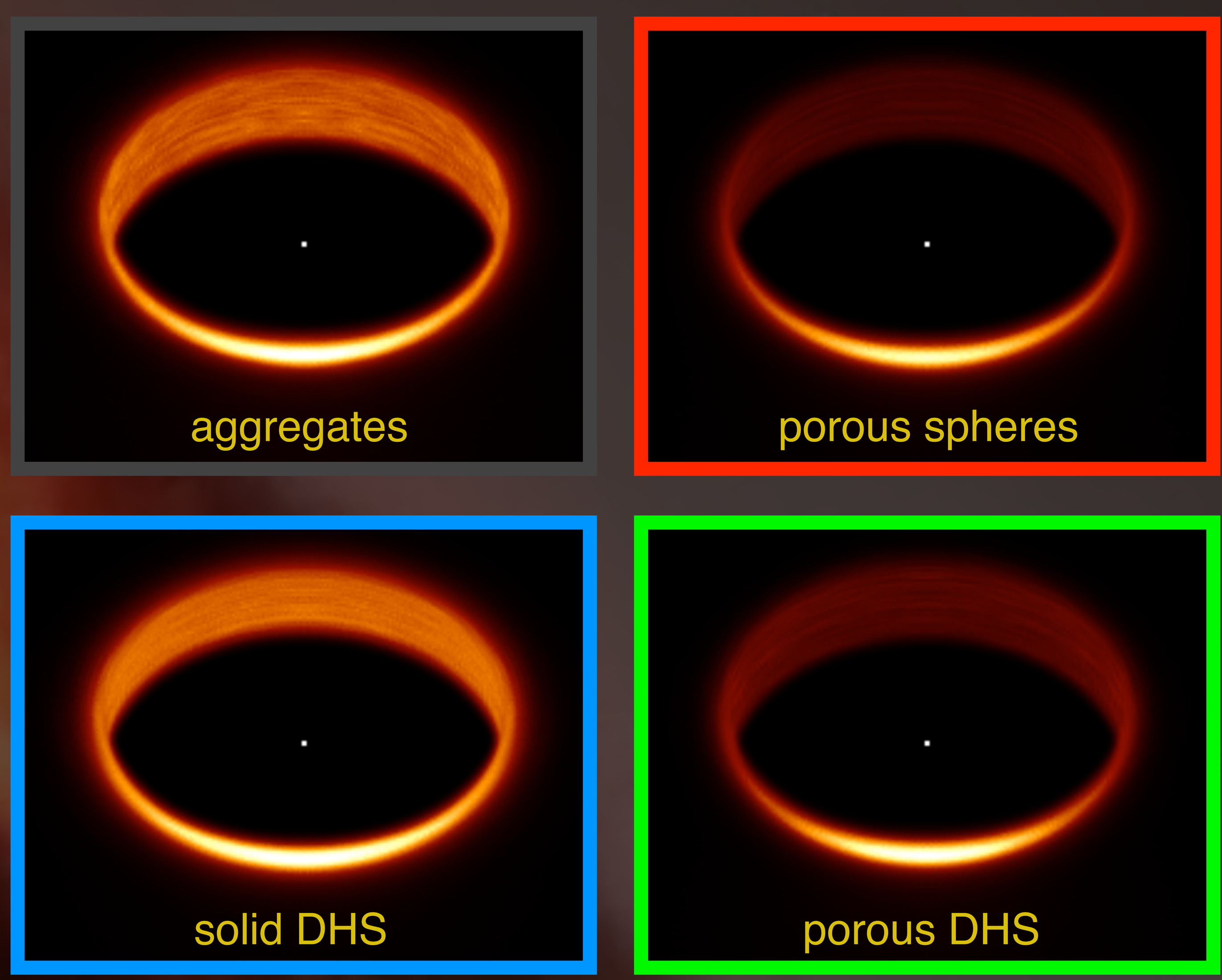
We compute the optical properties of realistic aggregates using the computationally expensive Discrete Dipole Approximation. This method allows for arbitrary particle geometry and composition at a very high computational cost. We compare the resulting optical properties to simplified approximate methods to compute the optical properties of cosmic dust to study how well these methods perform for the different observables (in this poster the colors represent the different approximate methods while computations with the aggregates are presented in black):

**Porous spheres:** Spheres are the easiest particles to get the optical properties for. Unfortunately, it has been shown before that the optical properties of homogeneous spheres represent those of realistic particles poorly. Here we take spheres with a porosity of 25% to include some effects of irregularity.

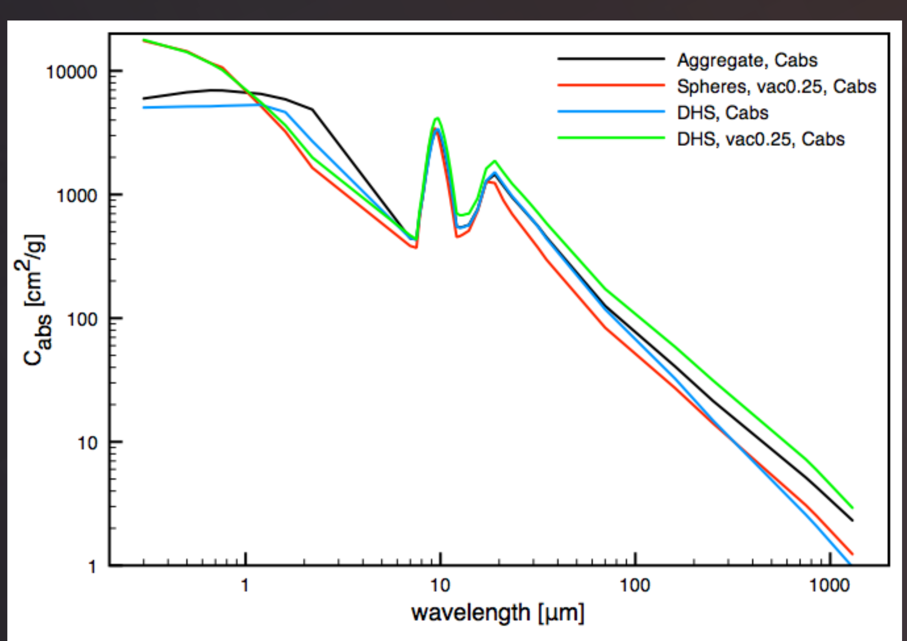
**Solid DHS:** The Distribution of Hollow Spheres (DHS) was invented to overcome the issues with homogeneous spheres. It incorporates simple effects of irregularity.

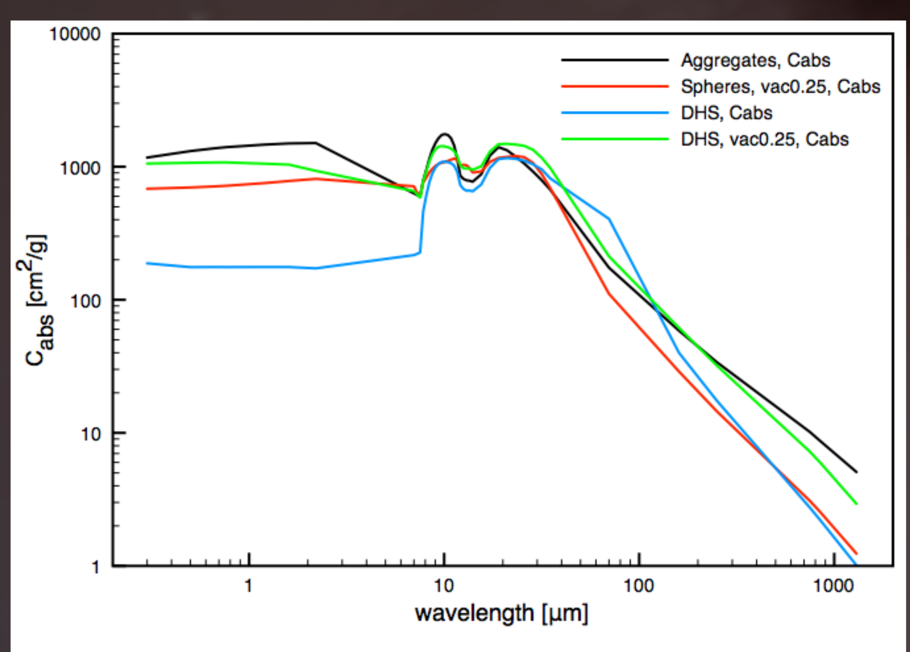
**Porous DHS:** Like the Solid DHS, but now also including 25% porosity.




**Scattering:** The scattered light images of protoplanetary disks with an inner gap often show a brightness asymmetry attributed to anisotropic scattering. We see that the asymmetry of the computed images strongly depends on the partcile shape and structure assumed. The fact that the aggregates display a much milder asymmetry than the porous particles is caused by the irregular surface structure of the aggregates, causing diffuse backscattering.




**Absorption:** The absorption cross section of the dust grains determines the temperature structure and the emerging SED. This is the most crucial optical property to get right when modeling protoplanetary disks.

An important aspect of the opacity curve is the strength of the silicate feature as a function of grain size. This property varies for different approximate methods.

Another important issue is the slope and absolute value of the opacity in the millimeter range. This property of the opacity curve is influenced not only by grain size, as is frequently assumed, but also by grains shape and composition.

**Conclusions:** Comparing detailed computations of irregularly shaped aggregate to approximate computational methods we conclude the following:

- **Correct treatment of optical properties are crucial to disentangle dust properties from disk geometry**
- **There is no method that accurately describes all optical properties.**
- **Overall particle shape and internal structure (porosity) are both important.**
- **The shortcomings of different computational approaches are important to keep in mind when modelling protoplanetary disks, to avoid over-interpretation.**

These conclusions are based on a more extended comparison of which a subset is presented here.