The chemical composition and location of crystalline forsterite in the disk of HD100546

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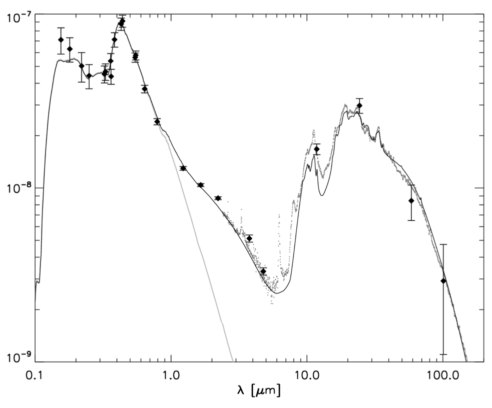
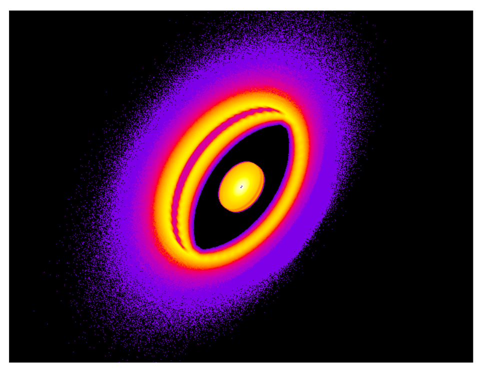


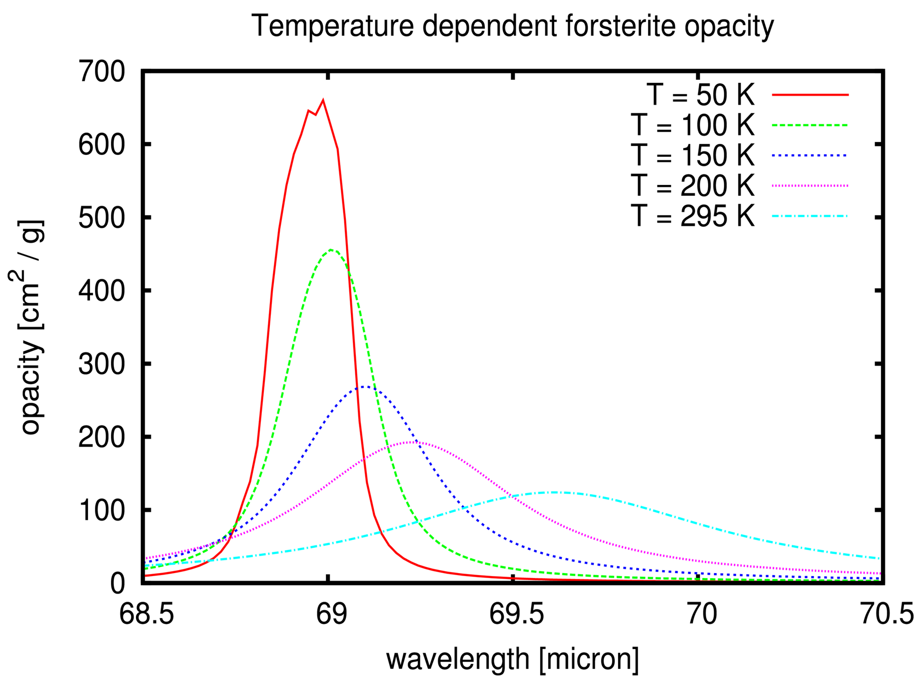
Introduction

HD 100546 is one of a few isolated nearby Herbig stars which has been used in the past as a prototype object for studying protoplanetary disks around intermediate mass stars. At an age of 10 Myr it is one of the oldest stars with a massive, gas rich disk. Mineralogical studies of the dust surrounding HD100546 show strong contributions of crystalline silicates, in particular forsterite. These features make the mid infrared spectrum very similiar to solar system comets like Hale Bopp (Malfait et al. 1998).



The 69µm feature as a temperature proxy

Unlike forsterite features at shorter wavelengths, the shape of the emission feature at 69 µm has a strong dependence on temperature. Increasing the temperature shifts the feature to longer wavelengths.

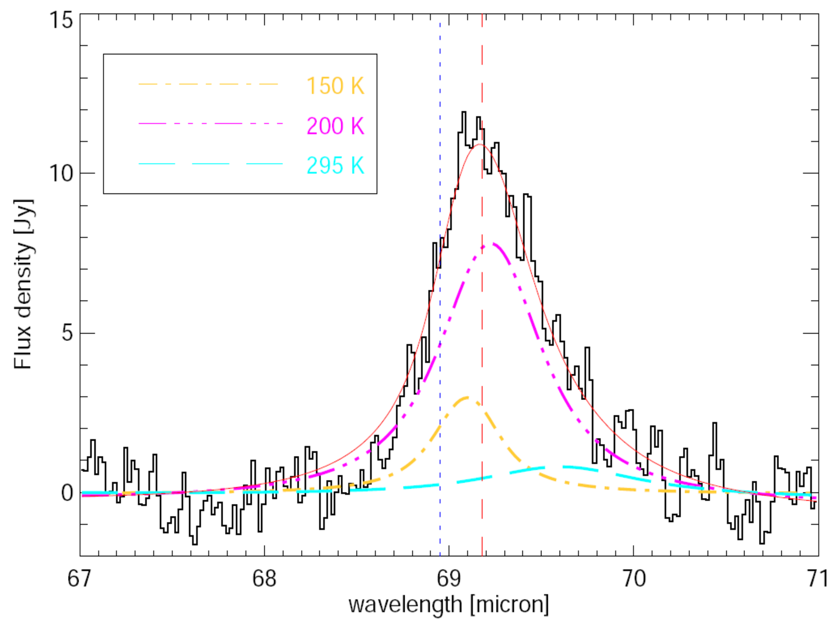


There is a degeneracy in the feature analysis: adding a small percentage of iron also shifts the feature towards longer wavelengths. The 69 µm feature can therefore only serve as a temperature indicator if the forsterite is iron-free, or if the iron content is well-constrained, and vice versa. Both temperature and chemical composition can give important constraints on the origin of the forsterite.

PACS observations

HD100546 was observed with PACS as part of the Science Demonstration Phase in the DIGIT (Dust, Ice, Gas in Time) key programme. A compositional analysis by Sturm et al. (in prep, see also poster P2.25) shows that the 69 µm feature is dominated by a warm component (150 and 200K), if the forsterite is iron-free.

Assuming optically thin emission, such warm forsterite overpredicts the feature strength in the shorter wavelength bands observed with ISO. Colder forsterite (50-100K) provides a better fit to these feature strengths, but requires a few percent iron to shift the 69 µm feature towards the right wavelength.

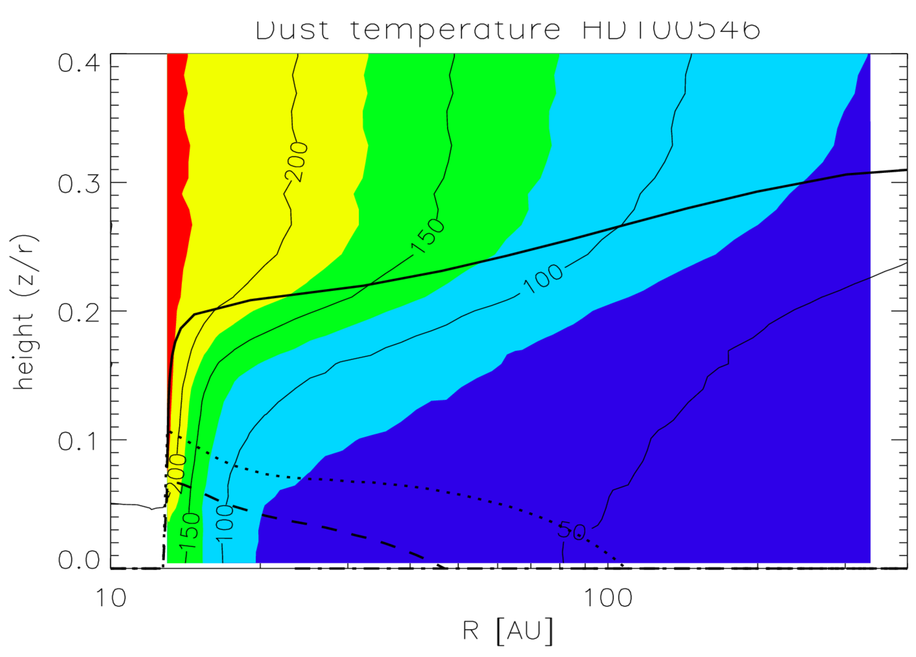


Can forsterite in HD100546 be iron-free?

Optical depth effects

To fit the 69 µm feature with pure forsterite, we need to suppress the shorter wavelength features using optical depth effects. This requires a detailed model of the disk geometry (see Disk Geometry)

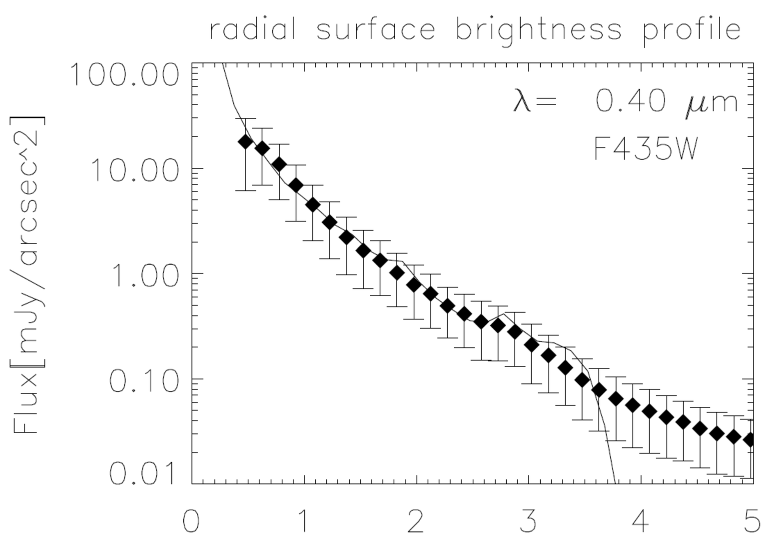
The short wavelength features arise in the disk wall at 13 AU. Because the wall is directly illuminated, regions close to the midplane reach 150 to 200 K. As large parts of these regions are below the vertical τ=1 surface at 24 and 33 µm (dotted and dashed line) they do not contribute to the short wavelength features. They do contribute to the 69 µm feature, as the τ=1 surface at this wavelength lies below the disk midplane.

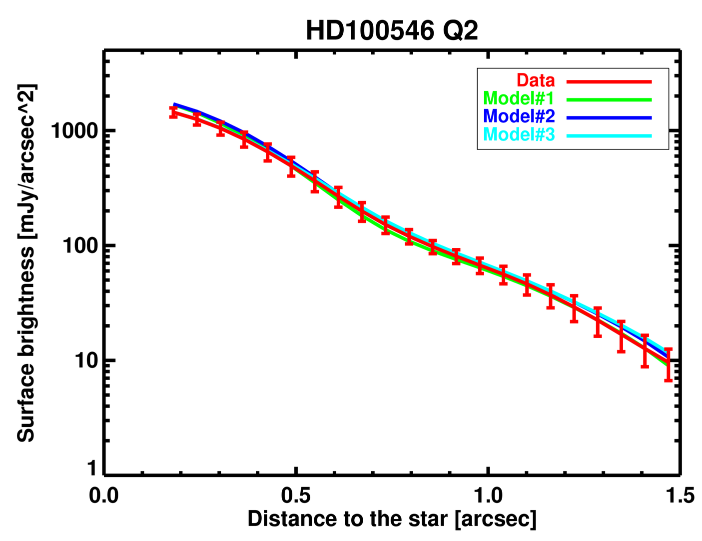


Disk Geometry

The low near infrared excess indicates that the inner disk is depleted in dust, creating an illuminated wall at 13 AU that is responsible for the large mid infrared excess (e.g. Bouwman et al. 2003, Grady et al. 2005, Benisty et al. 2010)

To constrain the outer disk geometry, we fit the radial intensity profiles from VISIR Q2 (18.7 µm) and Hubble scattered light images (Debes et al, in prep) with the radiative transfer code MCMax. We find that a disk in hydrostatic equilibrium with a surface density proportional to r^{-1} can fit the images. Reducing the surface density in the inner disk self-consistently produces the illuminated disk wall required to fit the SED (top left).



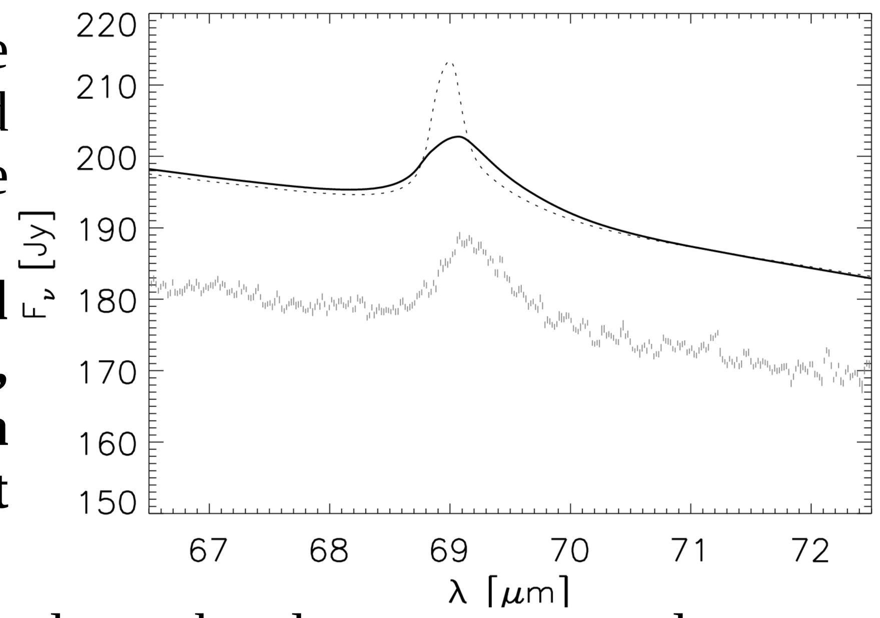


Can we constrain the location of crystalline forsterite?

Forsterite location

Using the derived disk geometry, we study the radial distribution of forsterite in the disk of HD100546. We focus on the feature strengths at 11.4, 23.8, 33.7 and 69 µm and the shape of the latter.

Our best fit includes 40% iron-free forsterite between 13 and 20 AU, and fits the shape of the 69 µm feature reasonably well (solid line). **This indicates that, when optical depth effects are taken into account, iron-free forsterite can provide a reasonable fit at 69 µm without contradictions at short wavelengths.**



We can achieve a similar fit with an abundance that decreases outwards: 40% *(R/13 AU)$^{-2}$. The cold forsterite in the outer disk then dominates the 69 µm feature (dotted line) and some iron may be necessary to shift the peak towards longer wavelengths.

Origin: shocks or thermal?

The 2D radiative transfer modelling shows that the forsterite is concentrated close to the disk wall at 13 AU, and can be iron-free.
The temperature in these regions is too low to form forsterite by thermal annealing or condensation from the gas phase.

Radial mixing

In the inner disk, temperatures are high enough to form forsterite. It must then be transported outwards by radial mixing in the disk. Additionally, radiation pressure can transport crystalline dust across a gap from the inner disk to the outer disk.

Production in shocks

Crystalline material can also be produced locally in shocks, for example by a population of colliding planetesimals in or near the disk wall. A proto-Jupiter within the gap could be responsible for stirring the population, providing a link between the disk's crystallinity and gapped geometry (Bouwman et al 2003).

References:
Sturm et al. (A&A accepted, Herschel special issue)
Mulders et al. (in preparation)

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