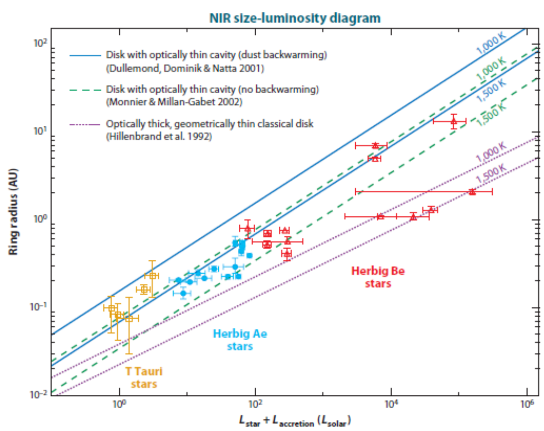
Practical session on Star Formation – VLTI School 2013

R.D. Oudmaijer, September 2013

As discussed during the lecture, interpreting the data of stars with dust shells or envelopes, involves modeling both the Spectral Energy Distribution (SED) and the interferometric visibilities simultaneously. Analyzing each independently has limitations as the SEDs alone are degenerate, while visibility data essentially only provide geometric information. Combining both is the way forward, but extremely time consuming. We will not try to do this in this workshop.

This session is meant to provide you insight into the processes and considerations involved, and we will not use computers. Instead, you will be using a pen, paper and perhaps your pocket calculator. We will first derive some quantities based on astrophysical principles.

- Infrared emission is due to dust heated by the star's radiation. The further dust is away from the star, the cooler it is. *Relate the distance d of a dust grain to a star as a function of the star's radius R_*, temperature T_* and the dust grain's temperature T_d.* For this derivation, you can assume that the star radiates like a black body, and that a spherical dust particle absorbs 100% of the energy that falls on it, which it then re-radiates as a black body.



For dust at its sublimation temperature, this relationship also predicts the observed size-luminosity relationship that was determined with the first interferometric continuum survey data as shown in the lecture ($R \alpha L^{1/2}$, this also holds for Active Galactic Nuclei!).

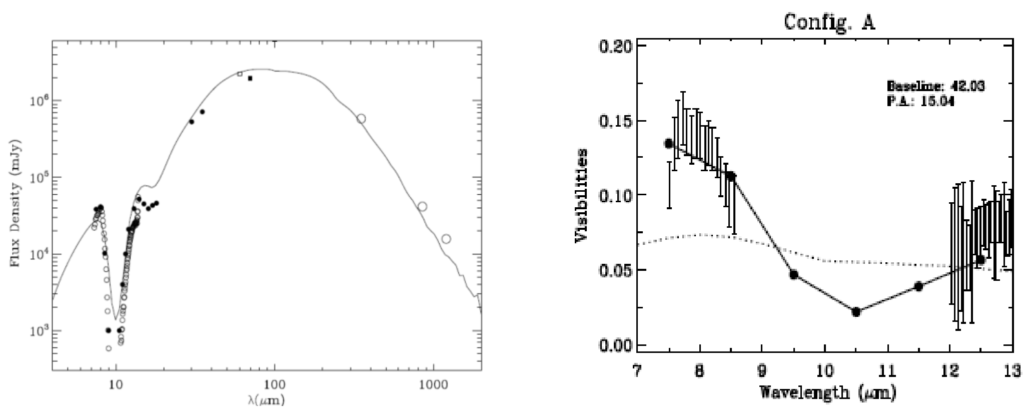
Figure: Millan-Gabet et al 2007

Take a few minutes to discuss with your colleagues how Spectral Energy Distribution fitting uses the information such as the grain temperature as a function of distance to derive the properties of the circumstellar dust shell and confirm that this technique is degenerate and can not provide unambiguous information on the geometric distribution of the dust.

- A typical Massive Young Stellar object has T_* = 35000K and R_* = 8.4 solar radii, and is at a distance of 3.8 kpc. *Now, take the dust grain at its sublimation temperature, say 1000K, and work out the angular distance of this dust grain to the star.*
- How does this compare to the resolution of AMBER and MIDI?
- Most such objects are too faint for AMBER. With the help of Wien's displacement law *estimate which size scales and temperatures we can probe with MIDI.*

Let us now consider information MIDI data can provide us with. The plots below show the SED and one visibility spectrum of a Massive Young Stellar Object. The deep silicate absorption prevents visibilities to be measured in the centre of the line. The solid line is a model prediction, ignore the dotted line. Try to explain the following features:

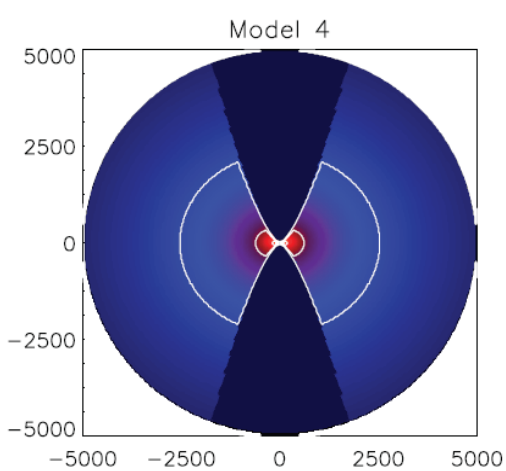
- Why does the visibility decrease in the line wing (e.g. between 8.5-9 micron)?
- Why is the visibility of the continuum smaller at the longest wavelengths than at the shortest wavelengths? Do not forget that the resolution of the instrument decreases with wavelength.



(Figure: de Wit et al. 2010)

There are many parameters affecting the shape and appearance of SED and visibilities. Let us restrict ourselves to considering the *inclination* of the system.

- Remember that the 10 micron emission comes mostly from the walls of the cavity. Make a rough sketch of the SED as a function of inclination of the system.
- Do the same for the interferometric visibilities at 10micron, how do they change with inclination?



A typical geometry used as input for the dust modelling. A dense, dusty disk is seen in the center (viewed edge-on), while a cavity is carved out by the bipolar outflow. Scales are in au.

In this figure the disk is edge-on, the inclination is 90degrees.

Figure: Whitney et al. 2003

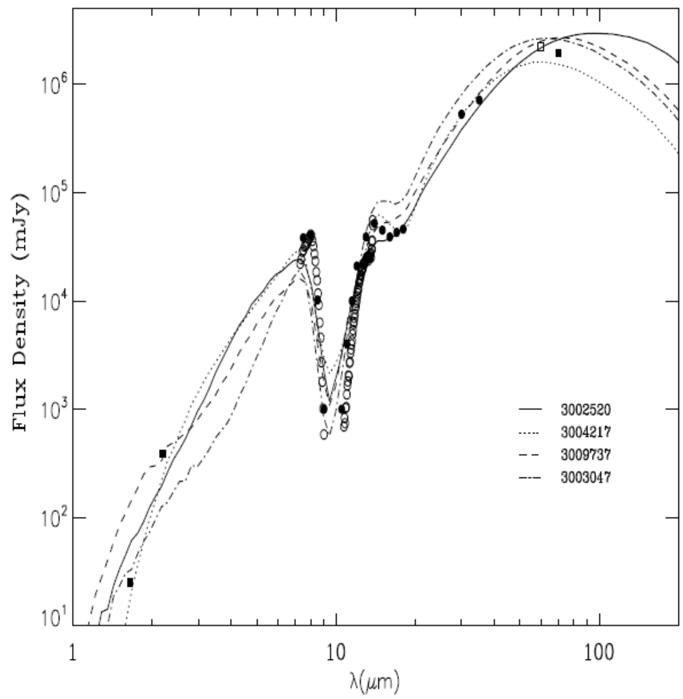


Fig. 12. Predicted SEDs of the discussed models obtained from the SED web fit procedure listed in Table 3.

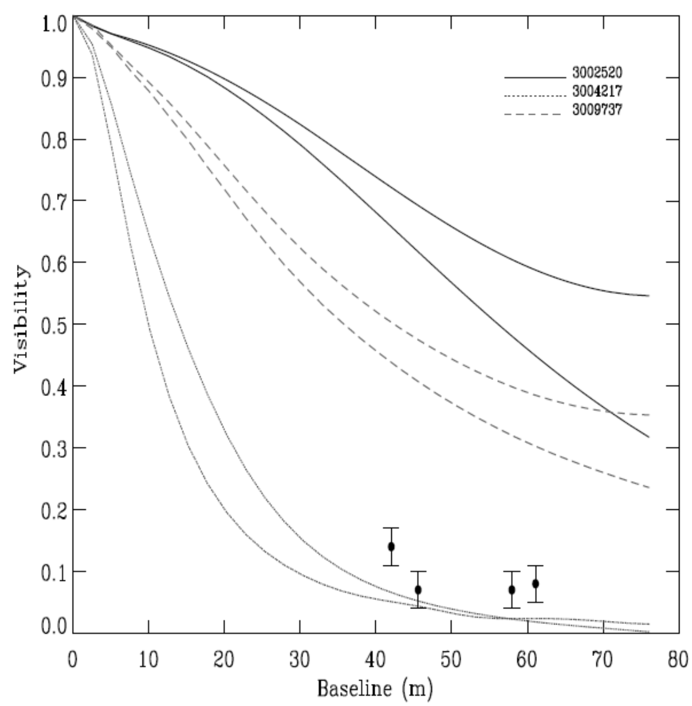


Fig. 13. Predicted visibilities along the major (lower curve for each model) and minor axis (top curve for each model) at 8 μm as a function of baseline for the discussed models obtained from the SED web fit procedure (Table 3). MIDI visibilities for the four baselines are also shown.

Now that we have a good feel for the effect of parameters on the observables, let's revisit the best fitting SEDs (taken from the dedicated website) to the object W33A which generally did not match the MIDI data.

Concentrate on model 3004217 (dashed line), which reproduces both SED and visibilities. However, the inclination of this model is less than 20 degrees, much smaller than observed for this object (50 degrees).

Have a brief chat how this model could differ from "reality" in order to produce a good fit. Consider the various free parameters

Finally, if you have time left, the following challenge:

Computing the SED for a given set of model parameters is very quick on a typical computer. Computing one single image for one set of parameters is very time consuming (hours on a high end PC).

What is the most efficient methodology to obtain the best model for a dataset (SED + interferometry)? Topics that you can discuss are formal fitting procedures, weighting of different datasets etc. Consider the pros and cons.

Figures: de Wit et al. 2010