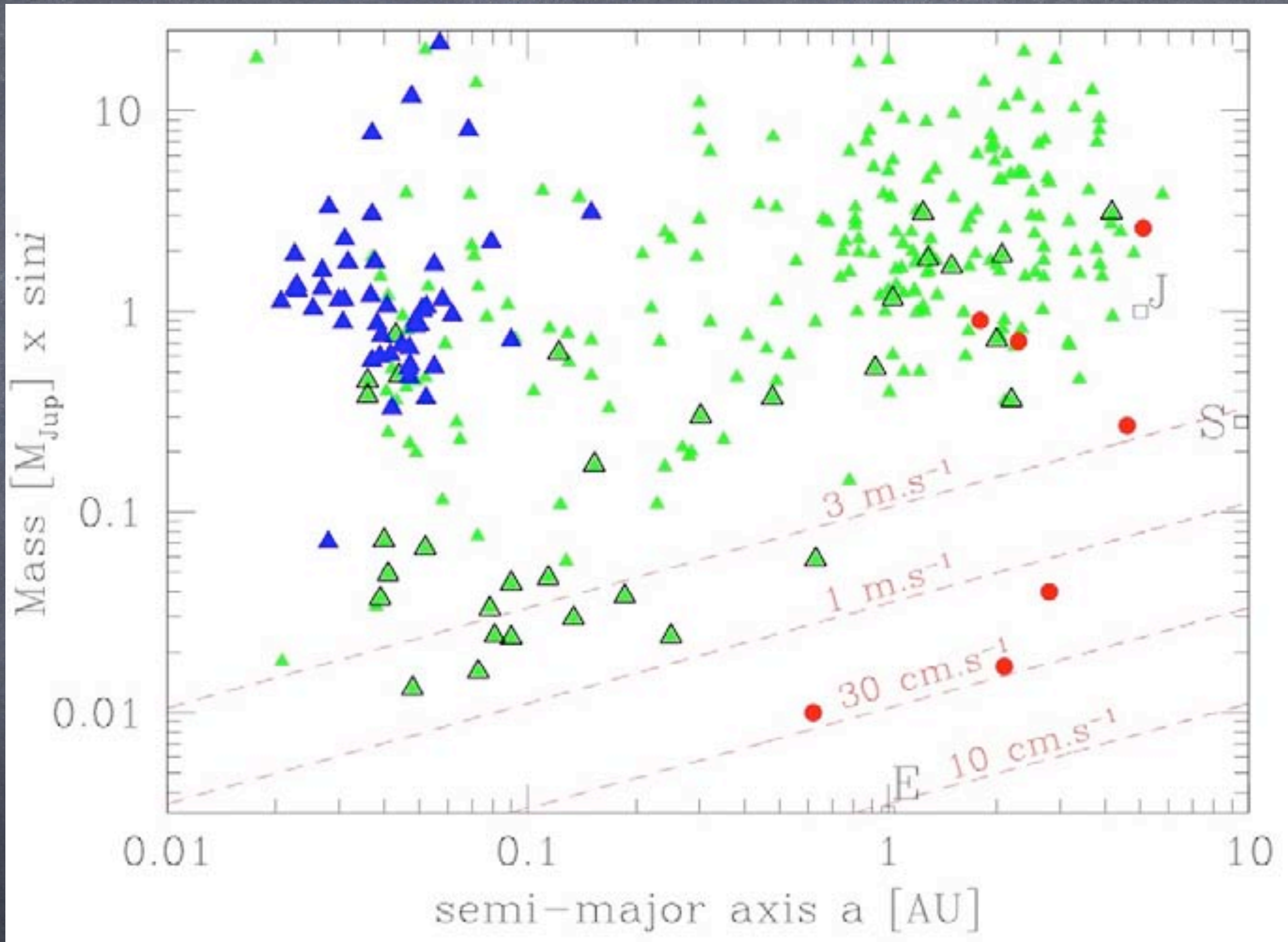
The Inner Astronomical units of Herbig AeBe stars as seen by PIONIER/VLTI.

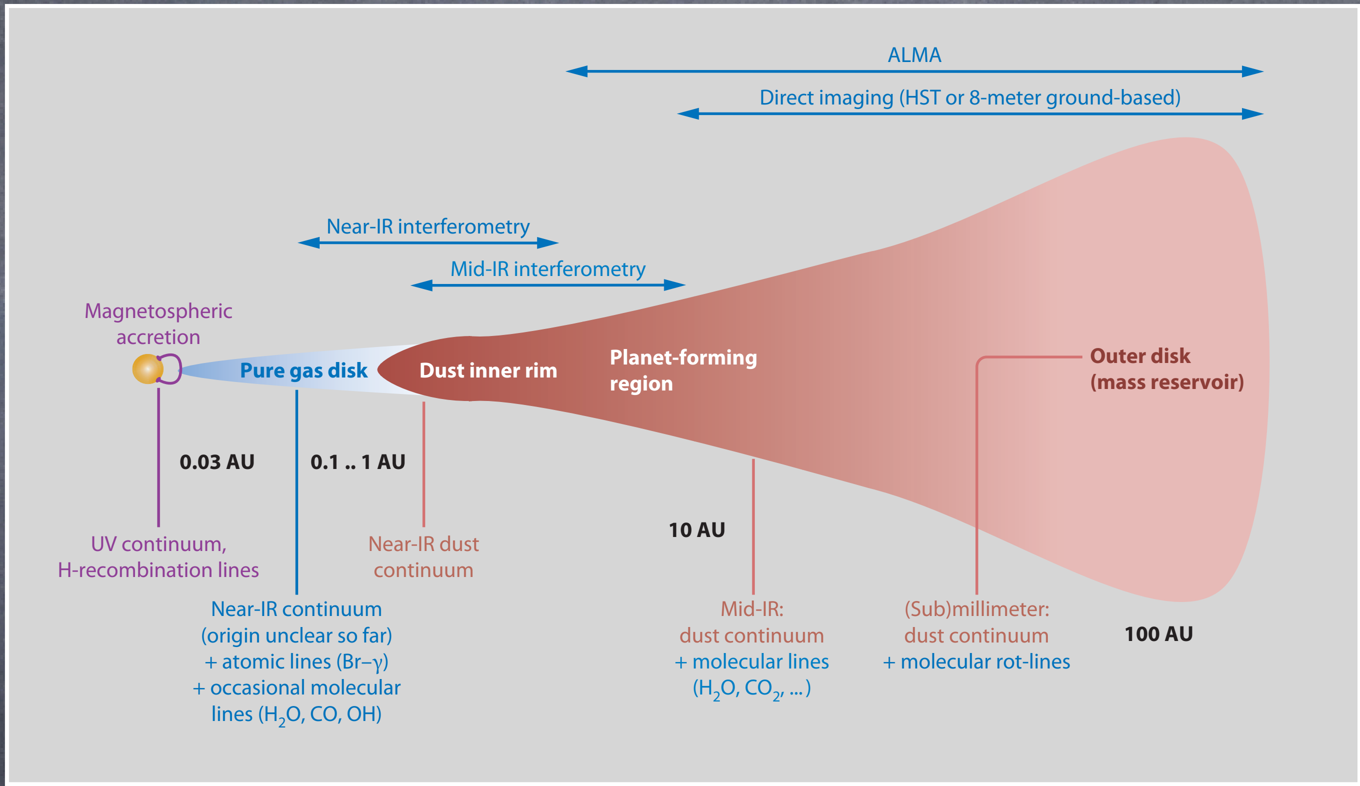
JP Berger, B. Lazareff, J. Kluska, J.-B Lebouquin, F. Malbet, M. Benisty. W.-F Thi, O. Absil, C. Dominik, , G. Duvert, A. Juhasz, A. Isella, S. Kraus, F. Ménard, J. Monnier, C. Pinte

Disks as planet cradles

A variety of exoplanetary systems

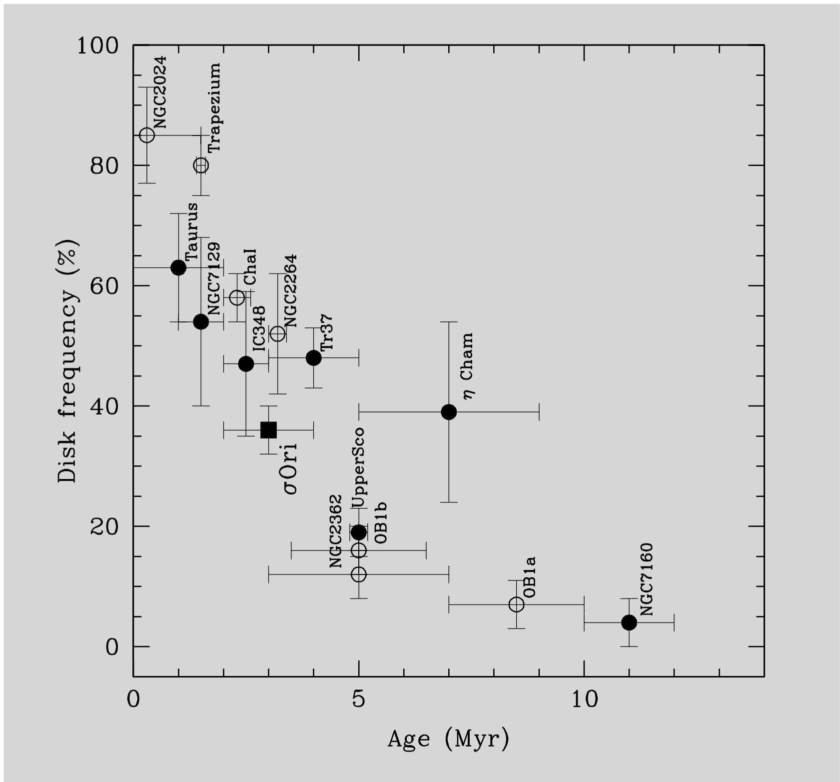


Disk structure



Dullemond & Monnier 2010

Planets form (rapidly) in disks

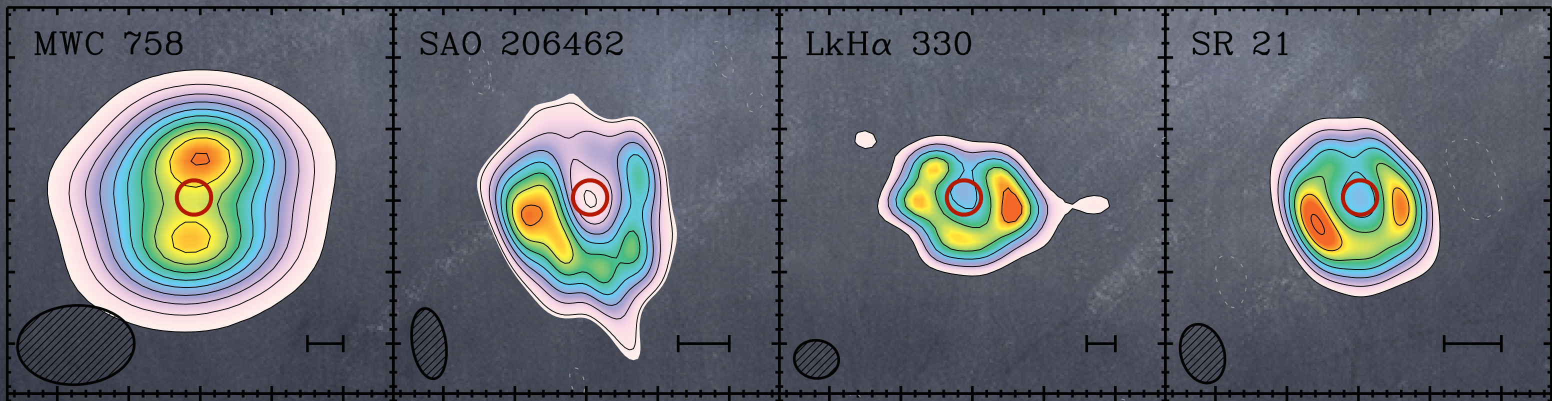


Hernandez et al. 2007

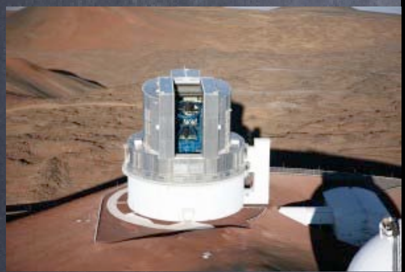
Competing mechanisms shape the disk structure

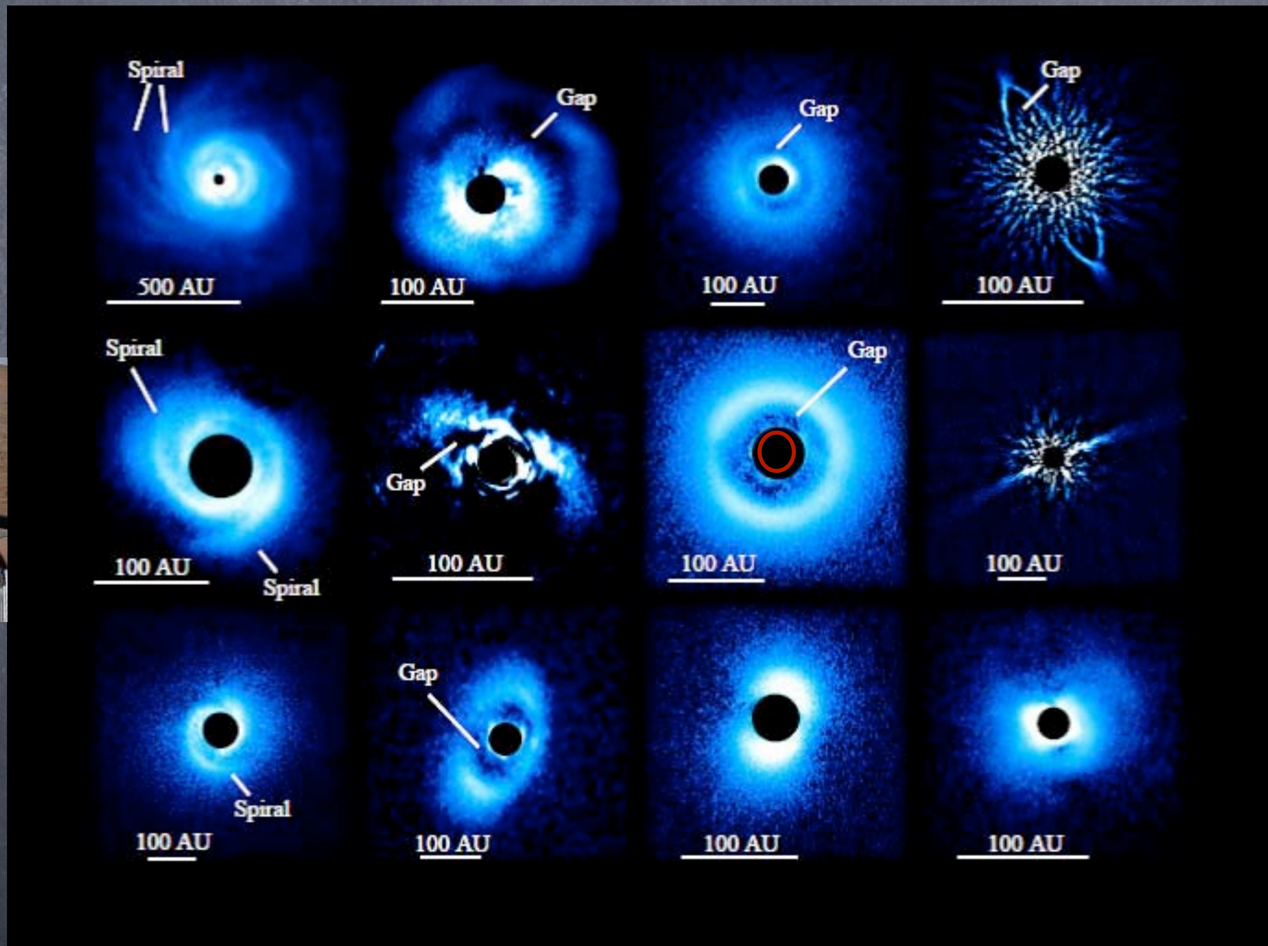
- Accretion/Mass loss
- Dust evolution (growth, crystallinisation, settling)
- Photoévaporation
- Presence of planets forming within the disk.
- Presence of (sub) stellar companions

Spatially resolved signposts of planet formation (1)

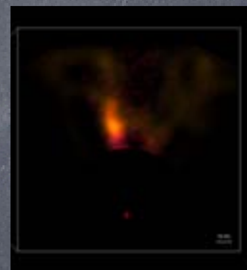


Spatially resolved signposts of planet formation (2)



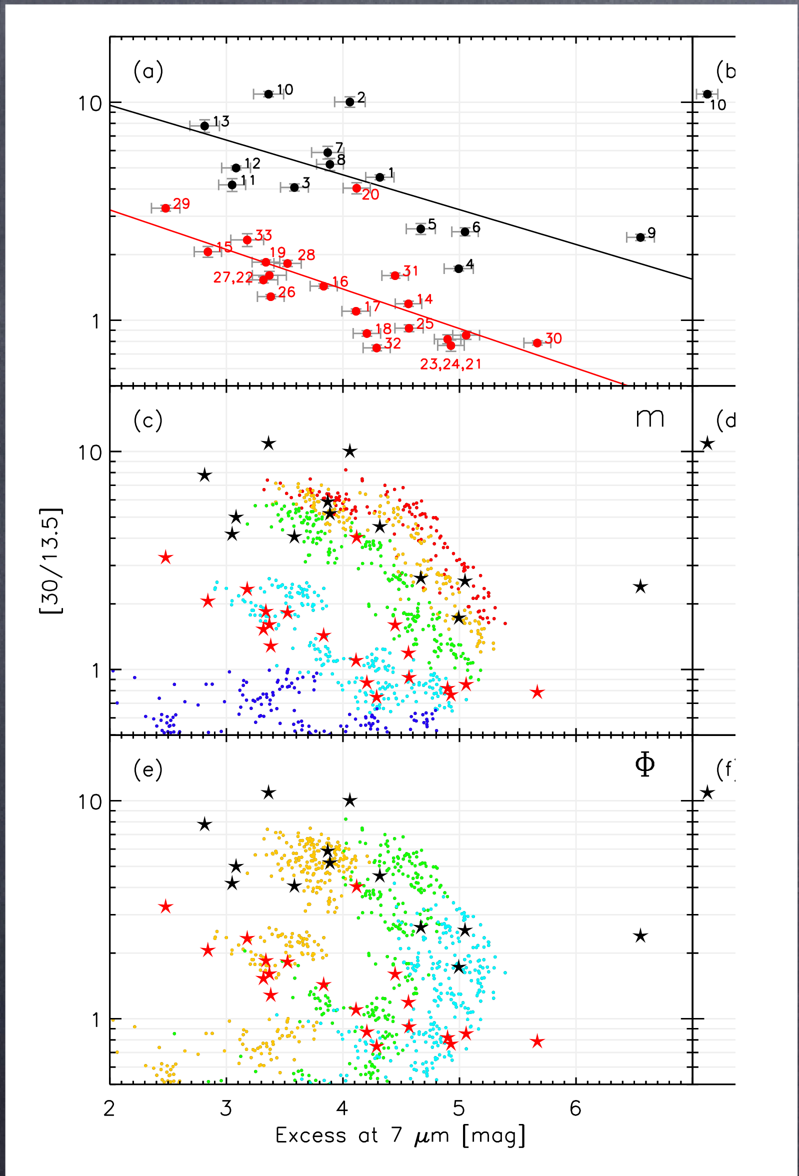


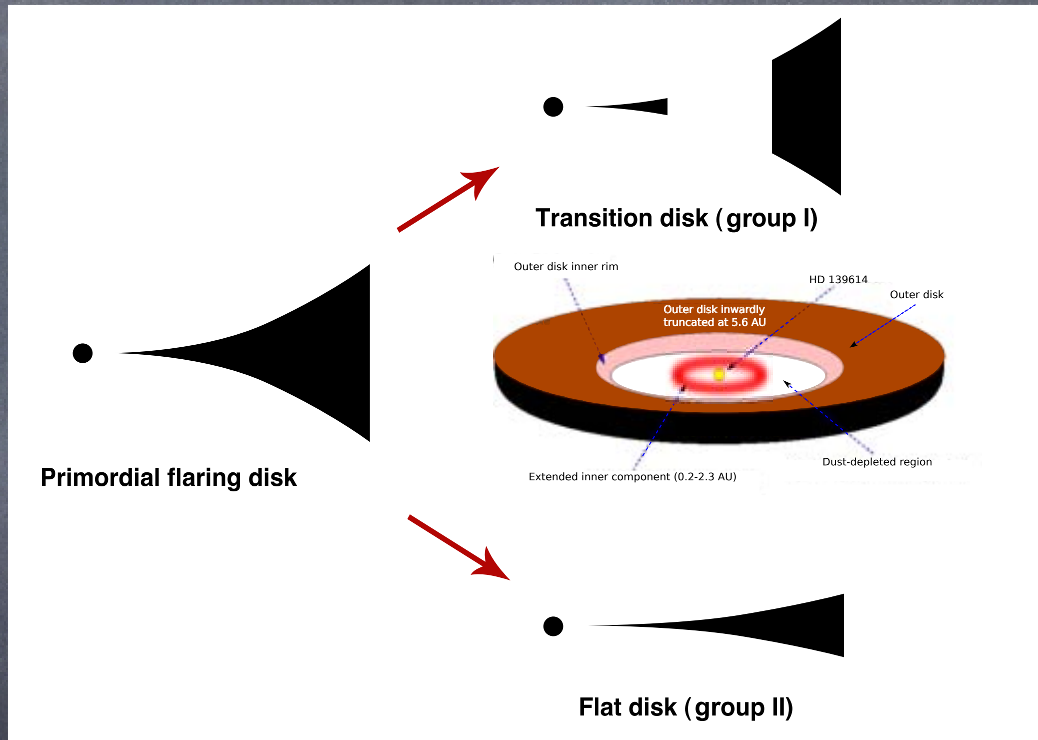
SEEDS collaboration



Quanz et al. 2013

Signposts of planet formation – VLTI
Thermal infrared(3)

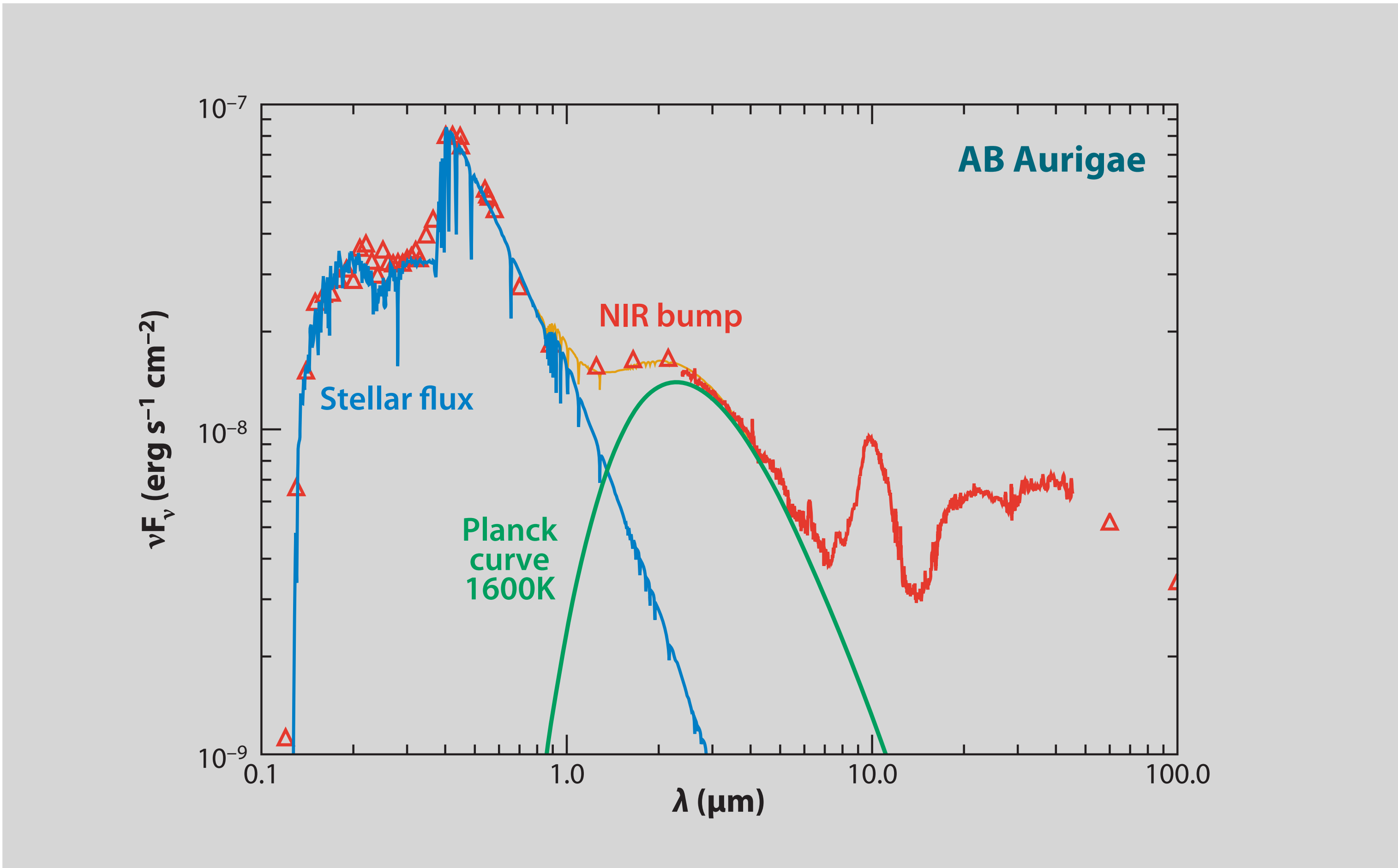




Maaskant et al. 2013

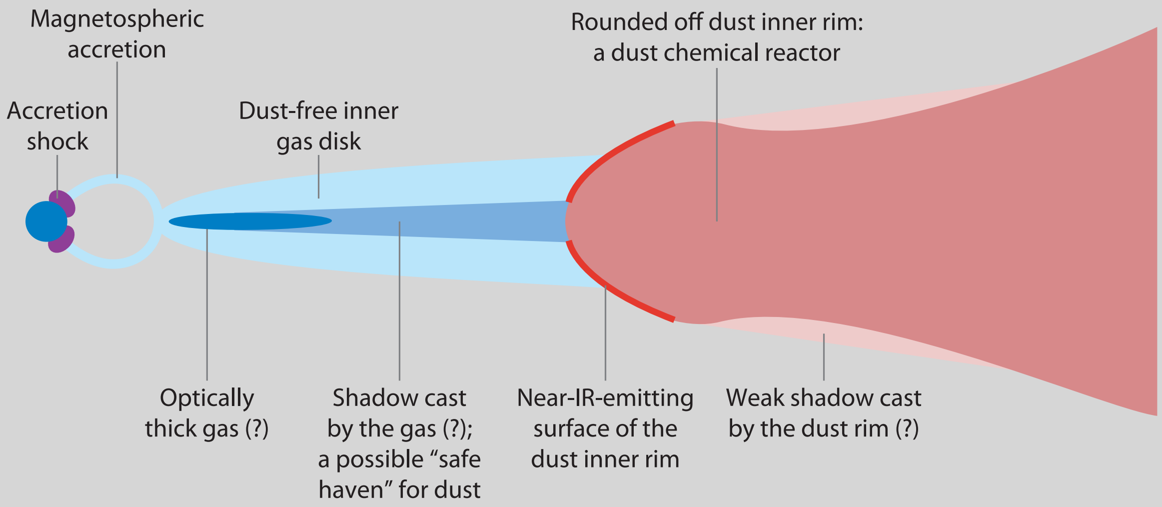
Meeus et al. 2001,Acke et al. 2009, Juhasz et al. 2010

The inner astronomical units



Natta et al. 2001

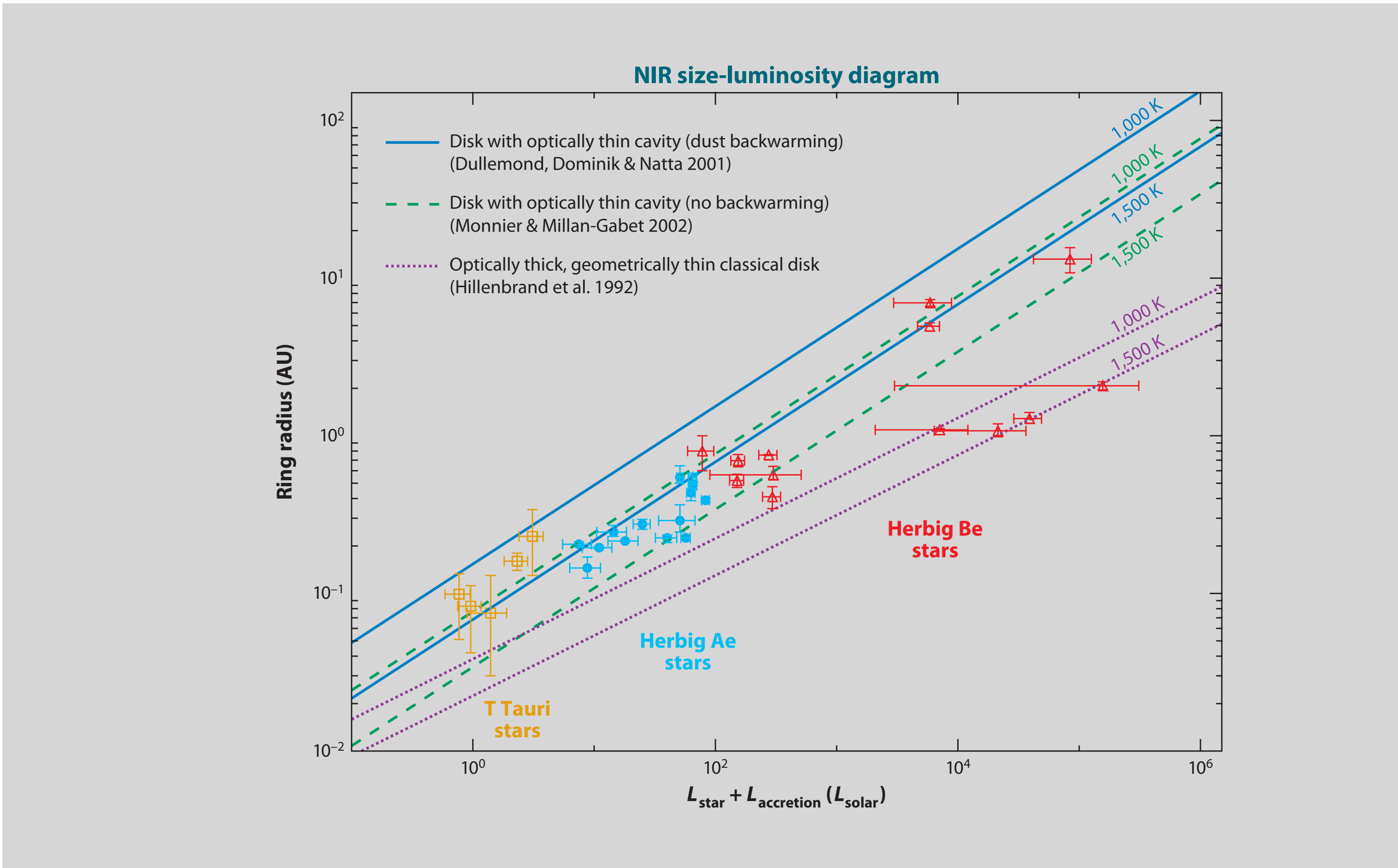
The inner astronomical units



This talk: focusing on the near infrared

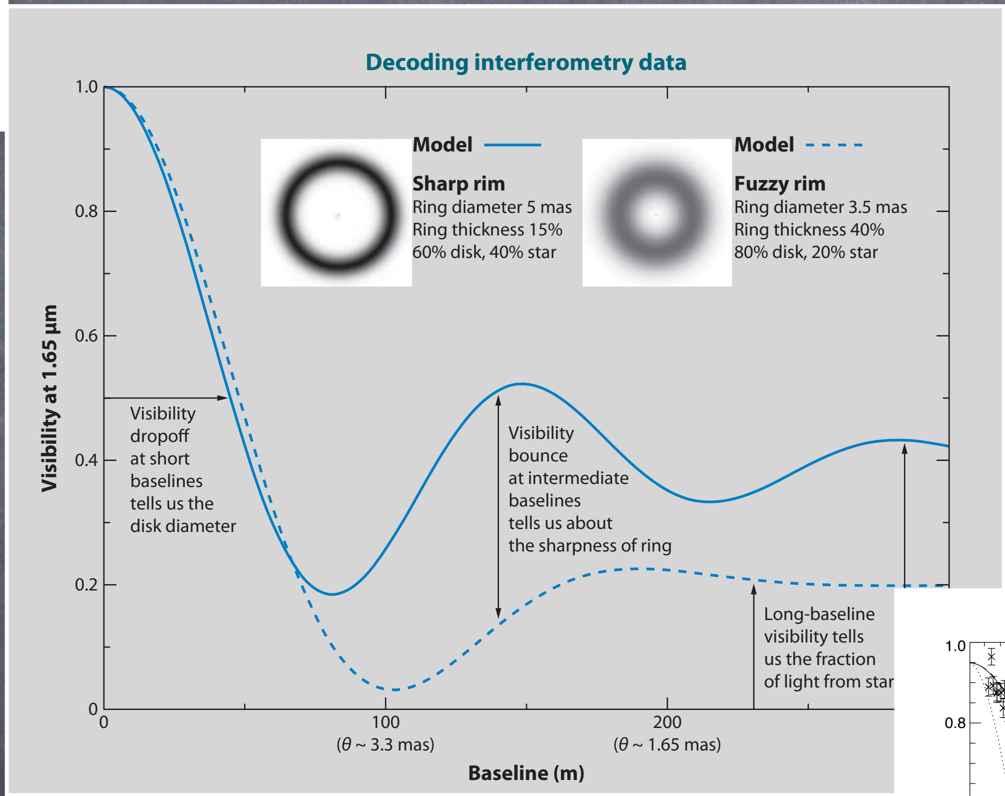
The importance of of the inner disk

- Disk “rim” height determines outer disk irradiation (global energy balance);
- Dust processing factory;
- Sets the inner boundary to planetary formation (?);

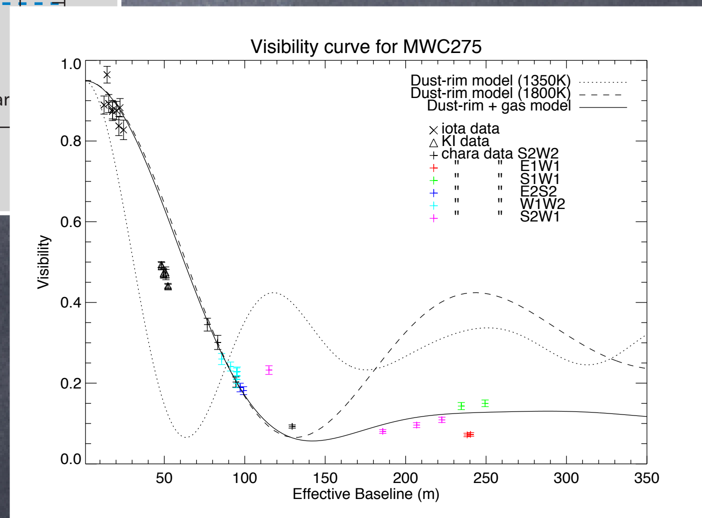


Monnier & Millan-Gabet 2002, Monnier et al. 2005, Akeson et al. 2005 ...

A not so simple inner structure



Malbet, et al. 1998

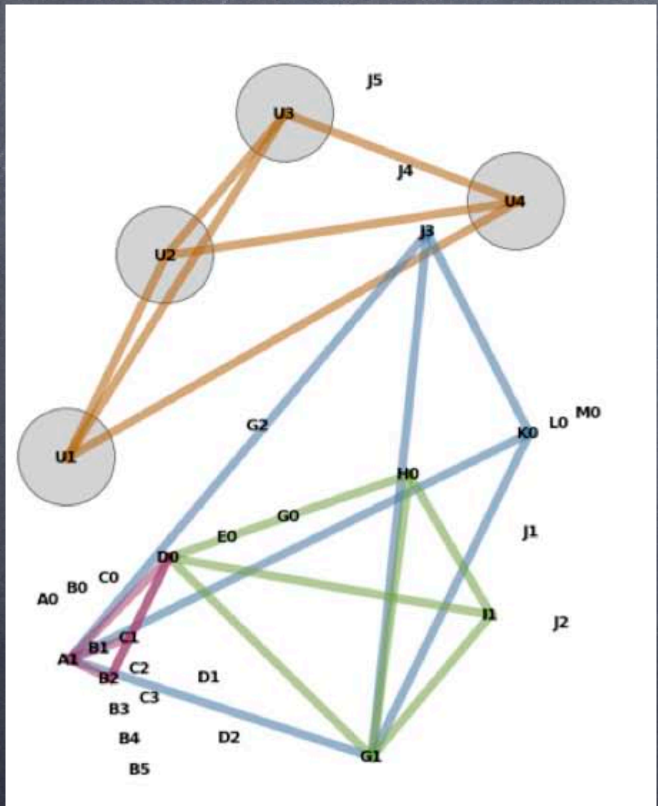


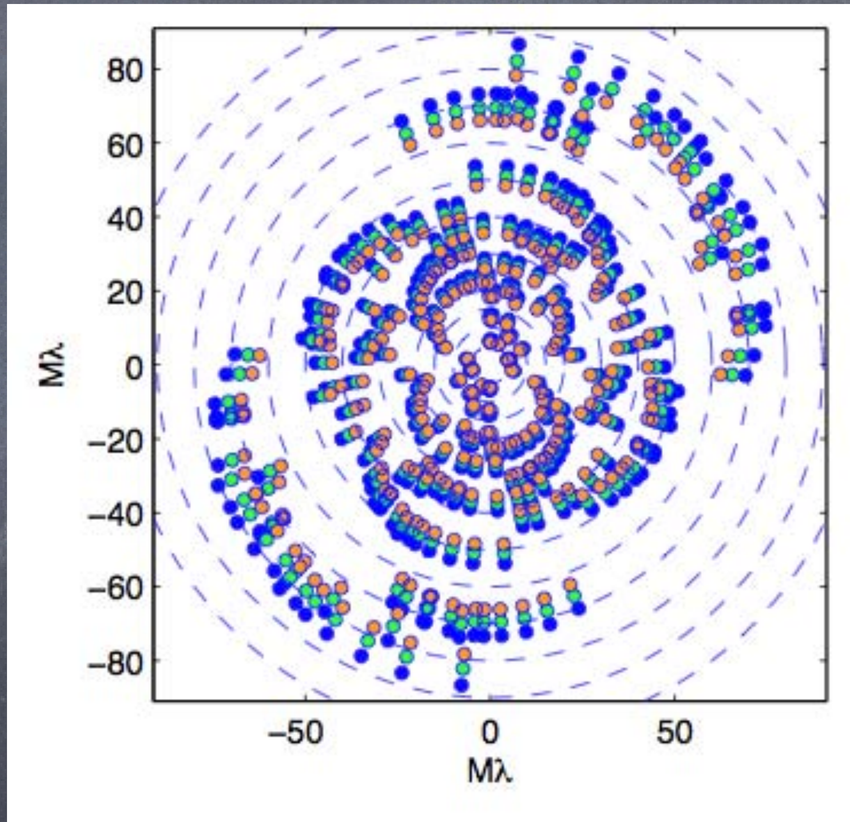
A survey of Herbig AeBe stars

ESO Large Program 090C-0963(PI: Berger)

Aperture synthesis at VLTI is now operational

VLTI

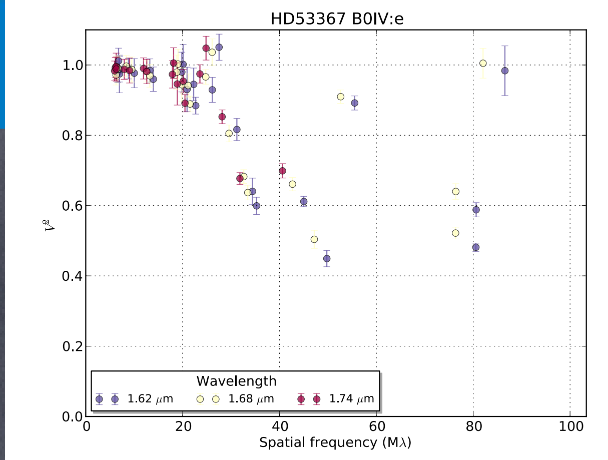


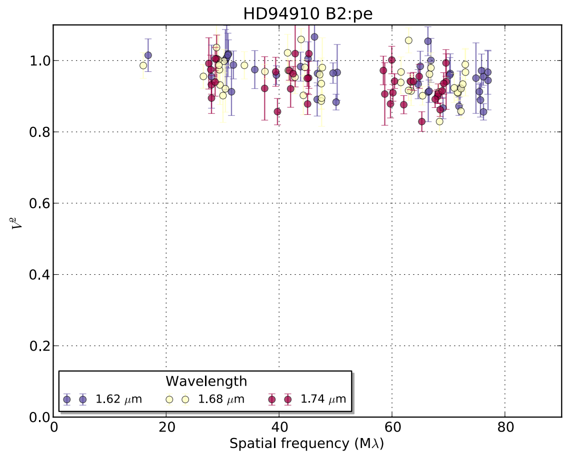


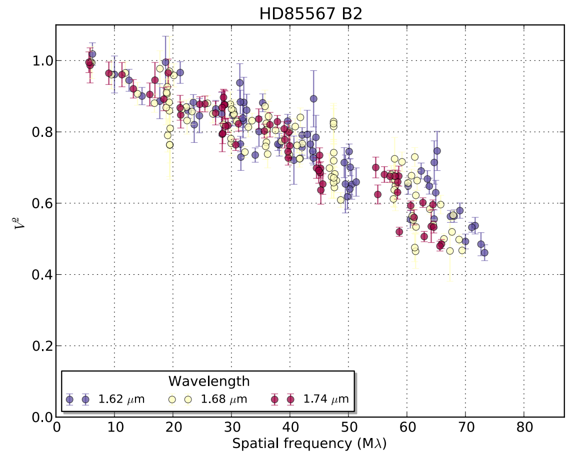
The SAMPLE

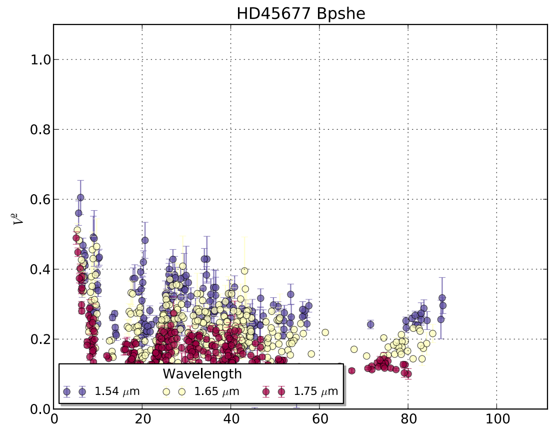
- PIONIER: 4 telescopes H band combiner small spectral resolution (3), no spectral R in faintest case
- Sample: Hillenbrand et al. (1992), Thé et al. (1994), Malfait et al. (1998) from B0 to G
- VLTI: 3 configurations small-medium-large
- 30 nights awarded and used
  - dec (small) - jan (large) - feb (medium)
  - jun-jul
  - 55 targets surveyed (with additional OI)

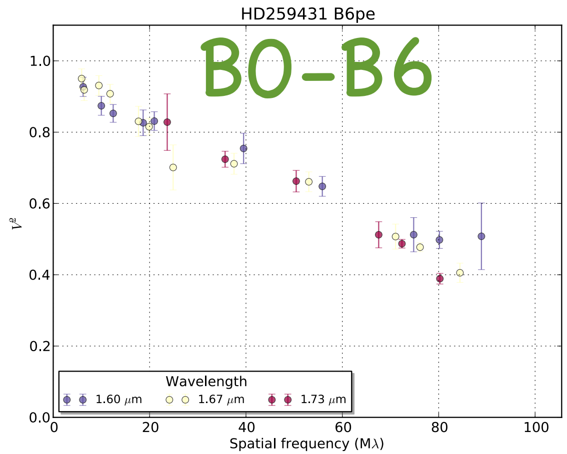
B0-B6

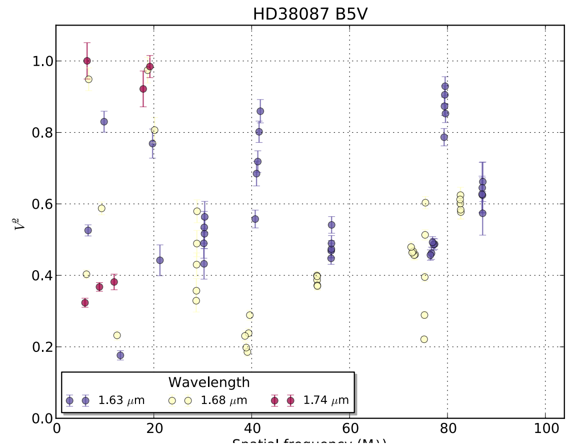

HD53367 B0IV:e
V²
Spatial frequency (Mλ)
Wavelength
1.62 μm
1.68 μm
1.74 μm

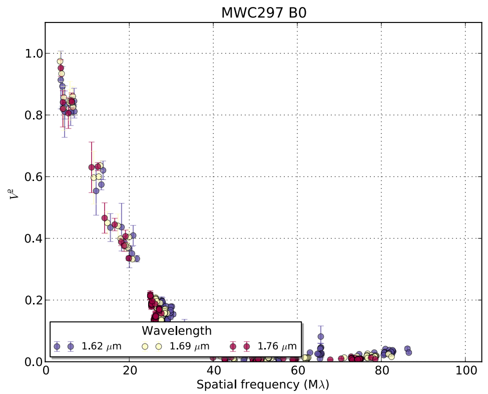

HD94910 B2:pe
V²
Spatial frequency (Mλ)
Wavelength
1.62 μm
1.68 μm
1.74 μm

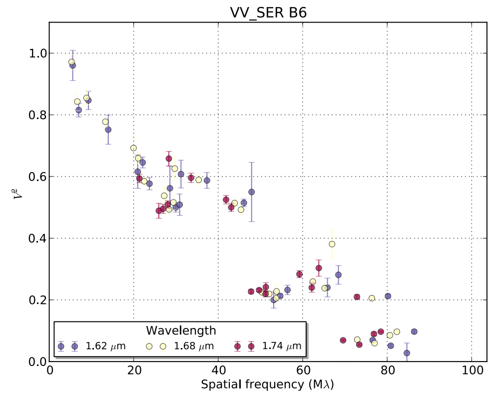

HD85567 B2
V²
Spatial frequency (Mλ)
Wavelength
1.62 μm
1.68 μm
1.74 μm


HD45677 Bpshe
V²
Wavelength
1.54 μm
1.65 μm
1.75 μm

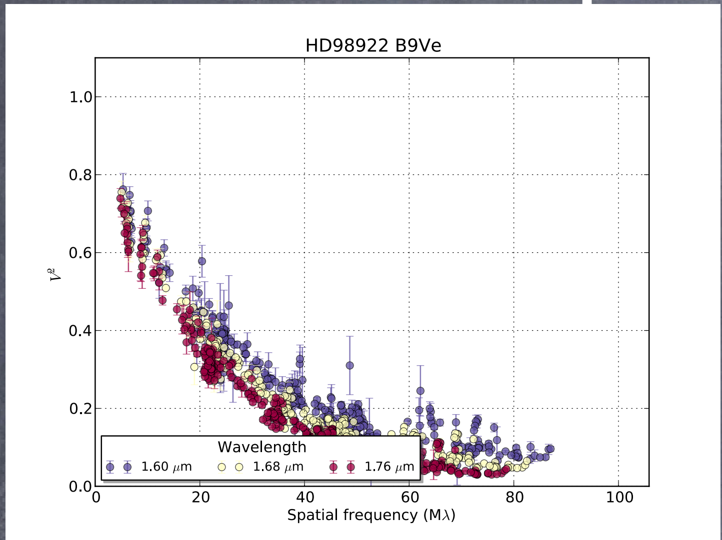

HD259431 B6pe
V²
Spatial frequency (Mλ)
Wavelength
1.60 μm
1.67 μm
1.73 μm

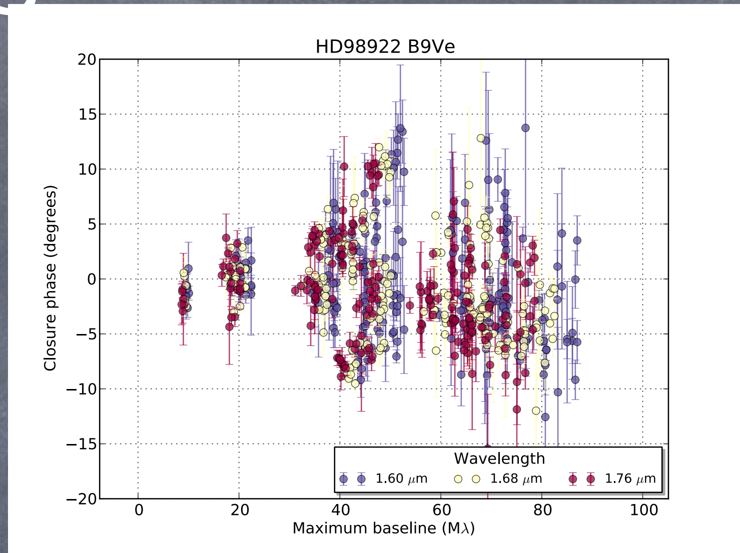

HD38087 B5V
V²
Wavelength
1.63 μm
1.68 μm
1.74 μm

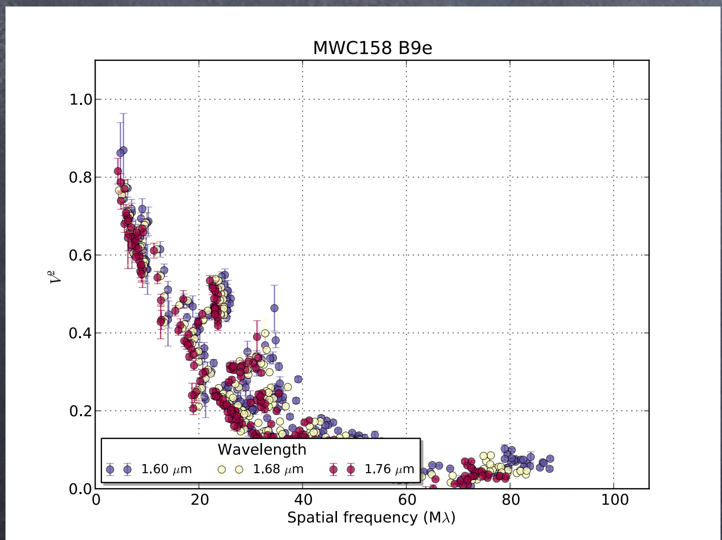

MWC297 B0
V²
Spatial frequency (Mλ)
Wavelength
1.62 μm
1.69 μm
1.76 μm

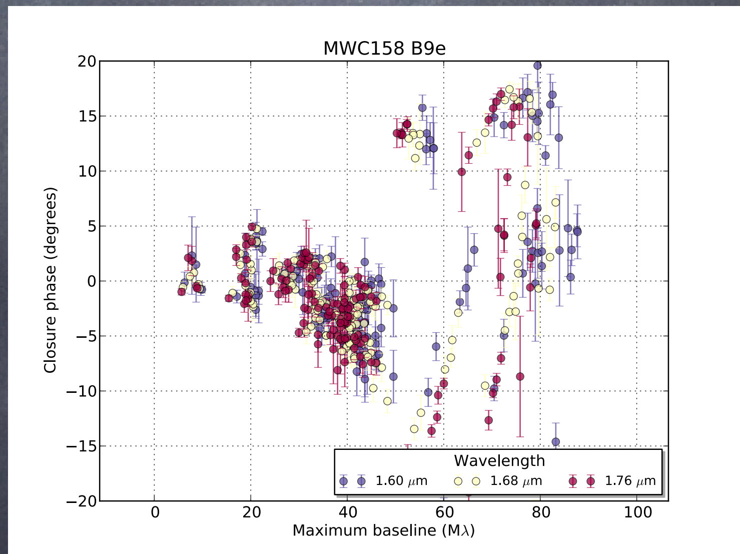

VV_SER B6
V²
Spatial frequency (Mλ)
Wavelength
1.62 μm
1.68 μm
1.74 μm

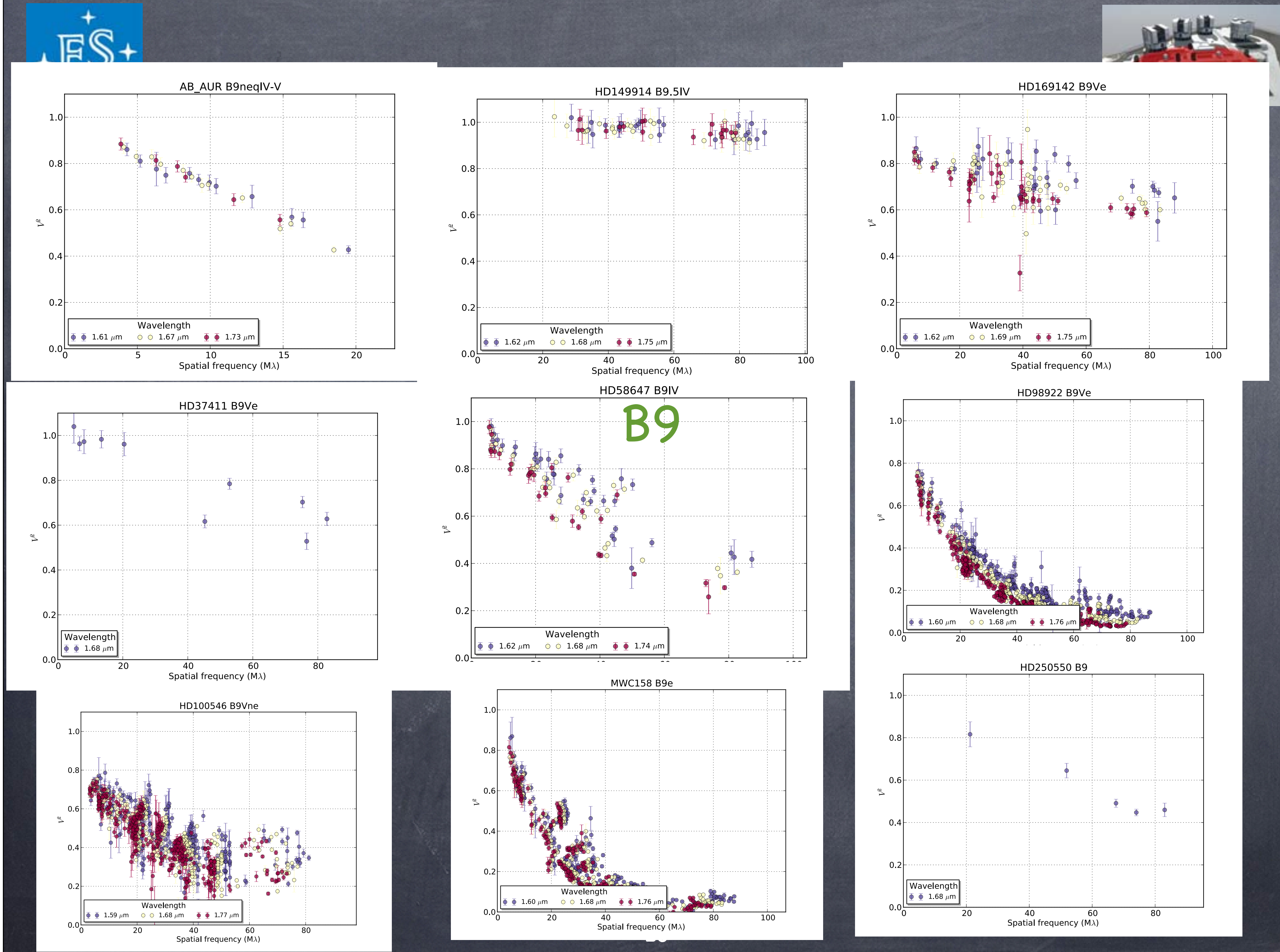
“Structured” non zero closure phase signal











AB_AUR B9neqIV-V
HD149914 B9.5IV
HD169142 B9Ve
HD37411 B9Ve
HD58647 B9IV
B9
HD98922 B9Ve
HD100546 B9Vne
MWC158 B9e
HD250550 B9
Wavelength
1.61 μm 1.67 μm 1.73 μm
1.62 μm 1.68 μm 1.75 μm
1.62 μm 1.69 μm 1.75 μm
1.68 μm
1.62 μm 1.68 μm 1.74 μm
1.60 μm 1.68 μm 1.76 μm
1.59 μm 1.68 μm 1.77 μm
Spatial frequency (Mλ)
V^2

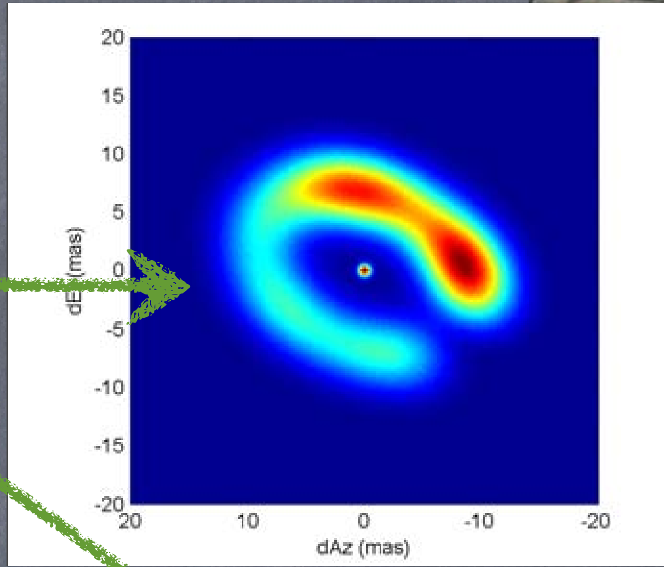
Data analysis strategy

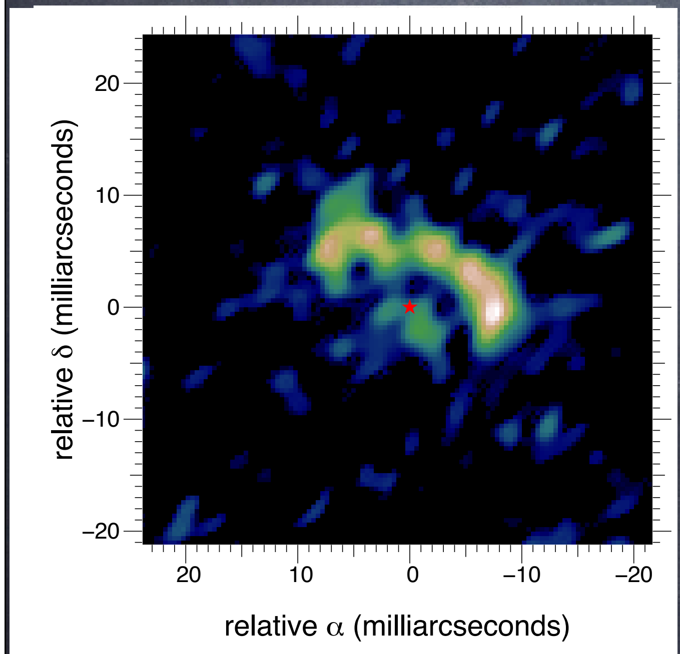
- Model fitting of all visibility and closure phase curves.
    - Underlying model: a smooth sublimation transition with azimutal modulation
- Image reconstruction of the best uv coverage data.
- Detailed radiative transfer modelling of best observed targets

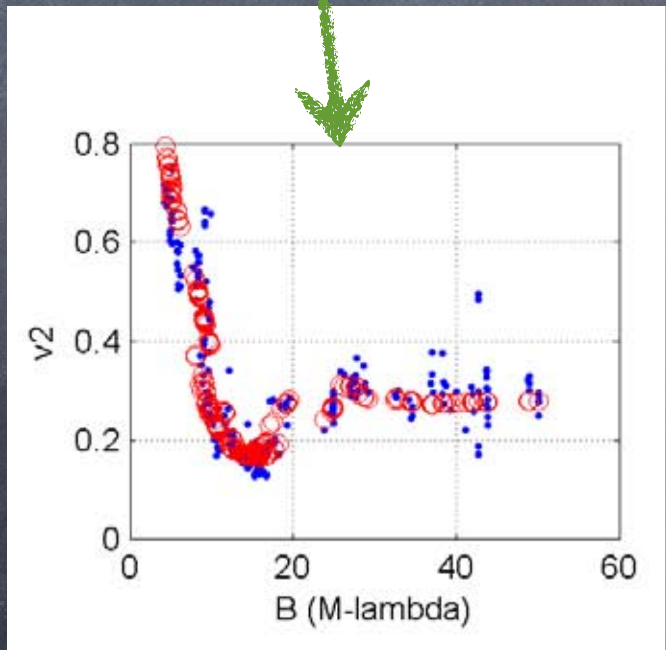
$$B(\vec{r}) = \delta(r-a)\cdot\begin{bmatrix} c_1\cos\alpha + s_1\sin\alpha + \\ c_2\cos 2\alpha + s_2\sin 2\alpha \end{bmatrix}$$

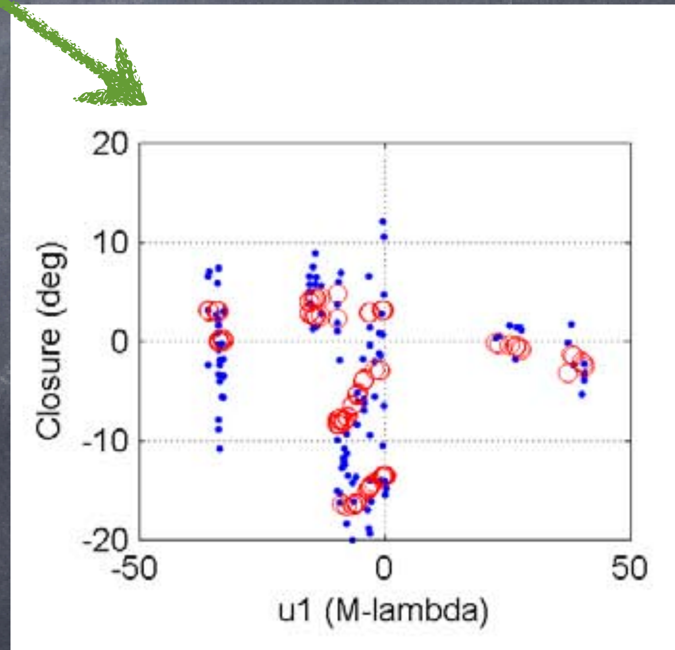
$$s = \sqrt{u_c^2 + v_c^2}$$

$$\begin{aligned} V_{neb}(u,v) = {} & J_0(2\pi a s) \\ & -i\left(c_1\cos\alpha + s_1\sin\alpha\right)J_1(2\pi a s) \\ & -\left(c_2\cos 2\alpha + s_2\sin 2\alpha\right)J_2(2\pi a s) \end{aligned}$$



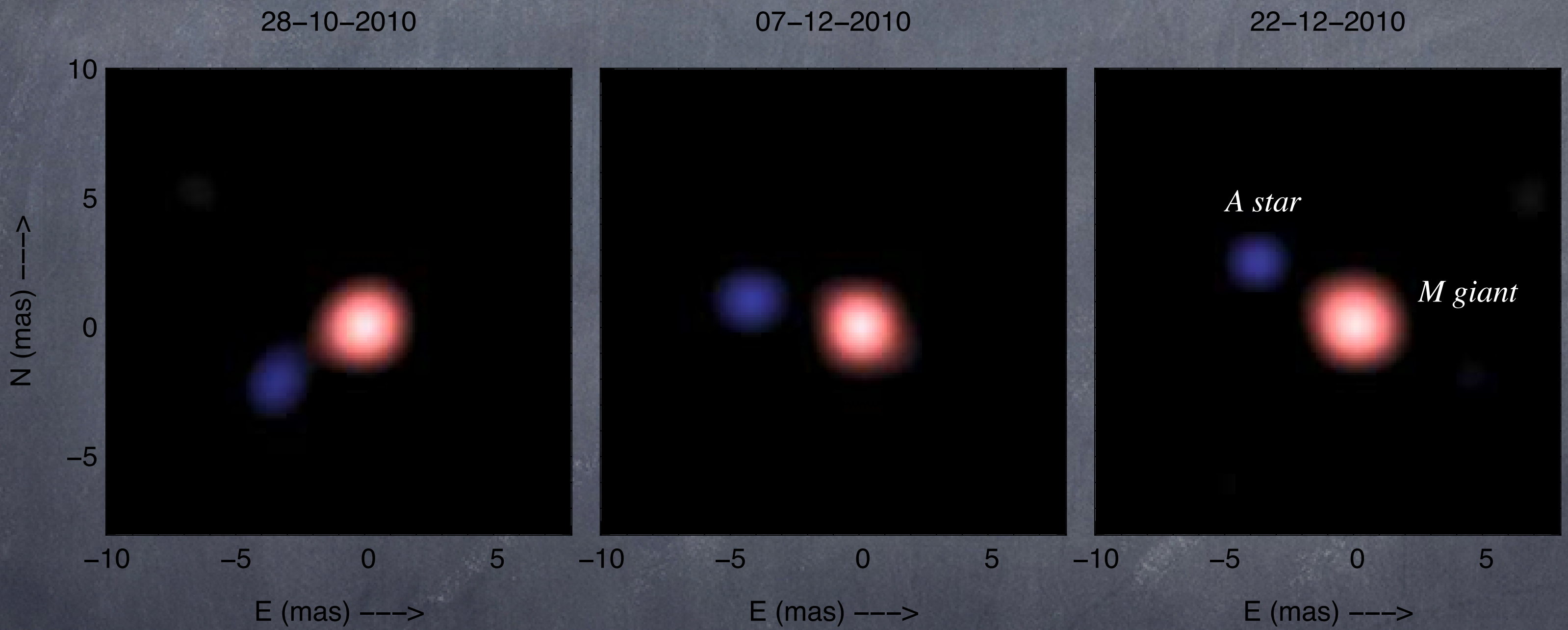






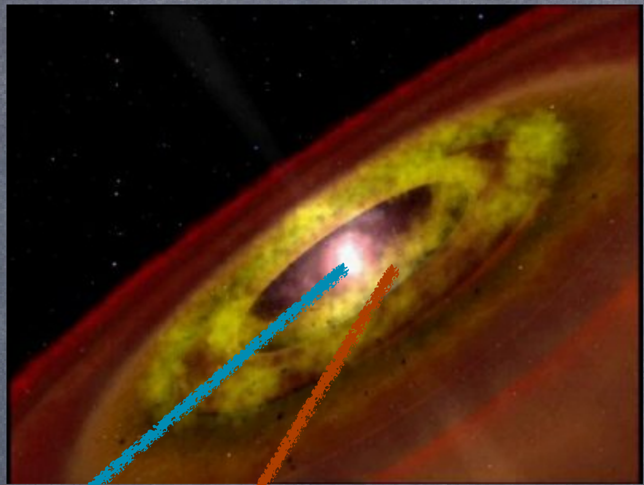
Preliminary analysis

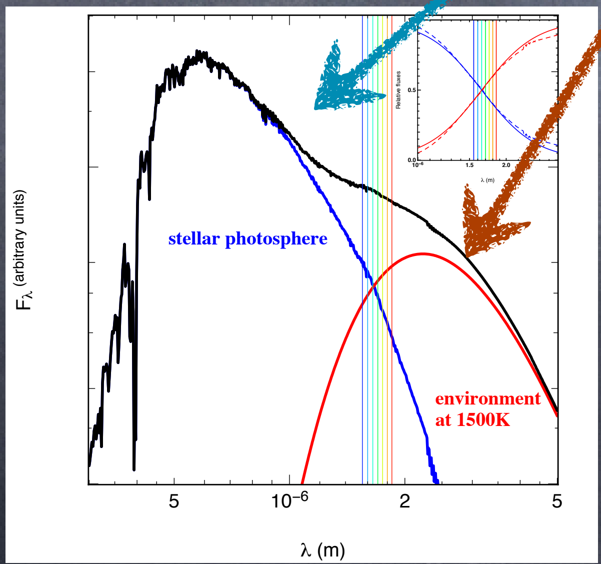
Outliers ...

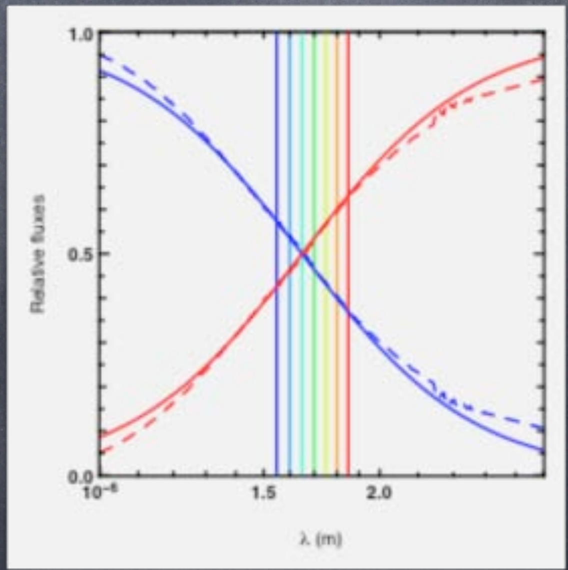


Blind et al. 2011

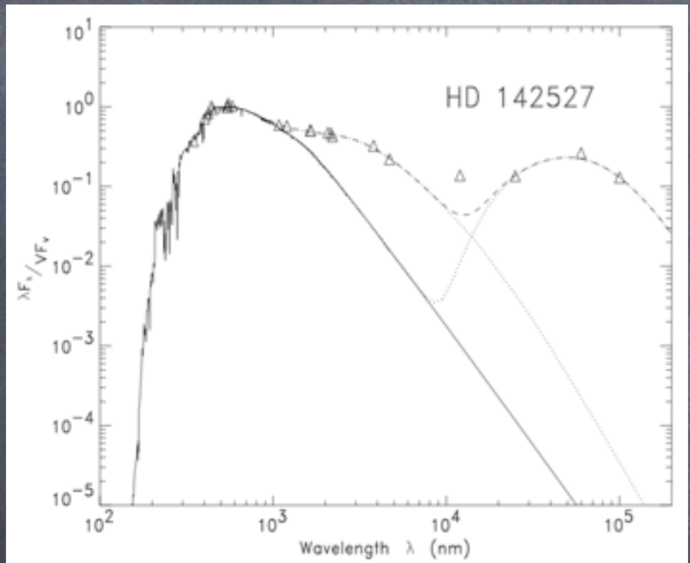
Dust/Star differential spectral index

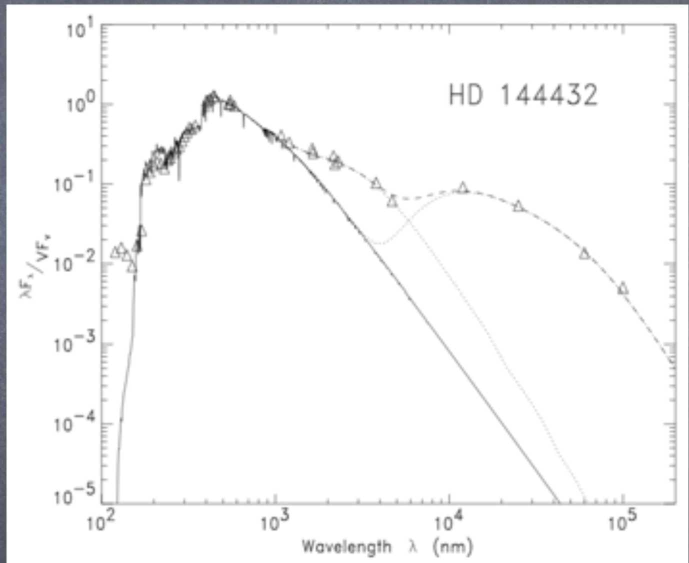






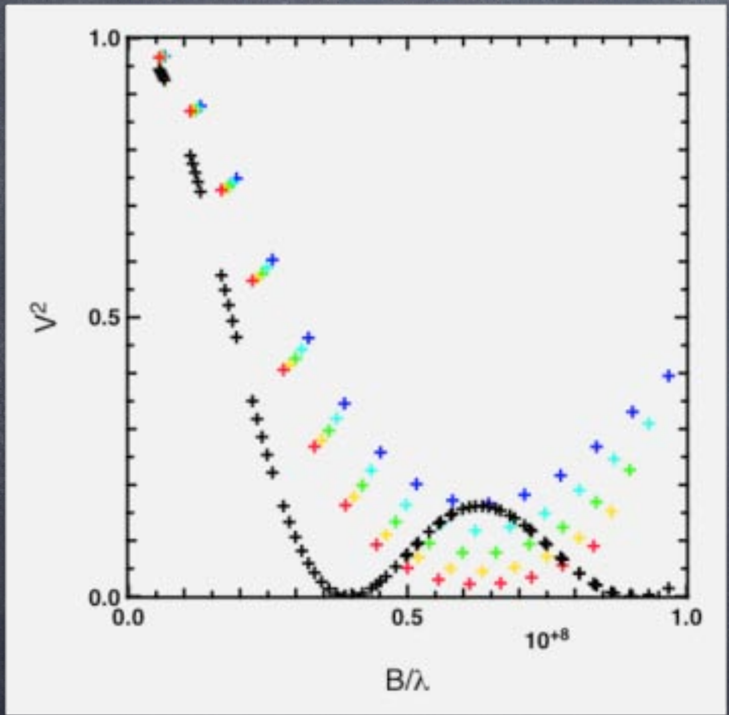
At least two near infrared emitters

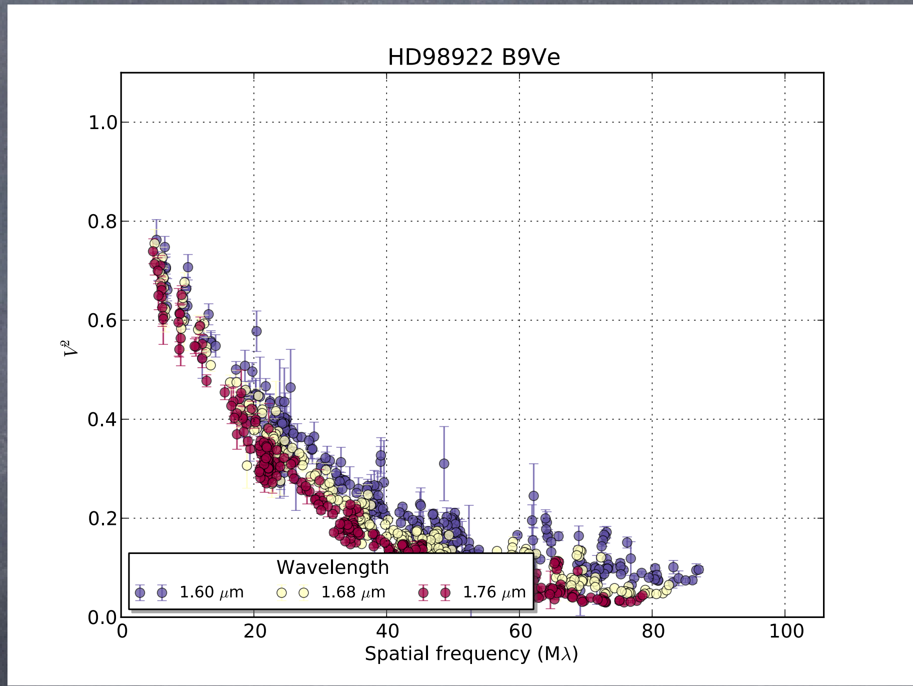




Malfait et al. 1998

Chromatic response explained (?)





The inner disk of HD 100546

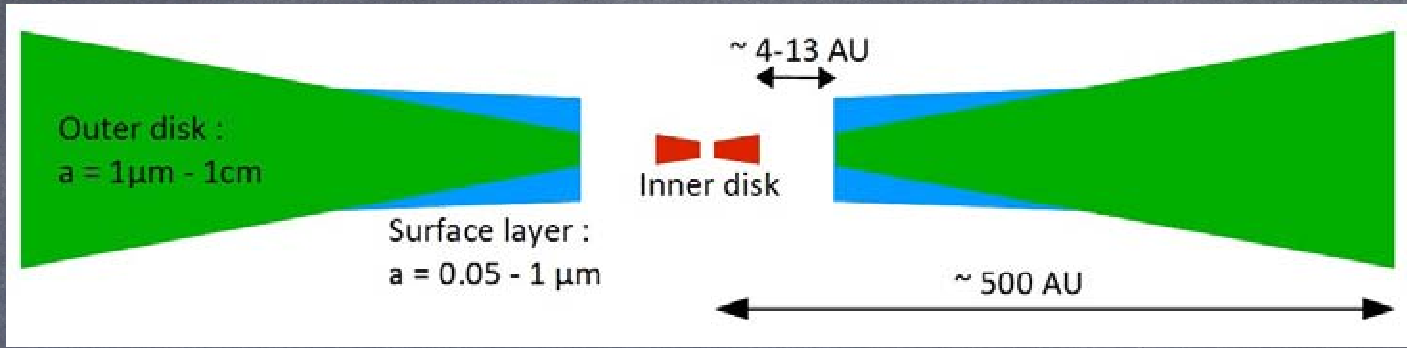
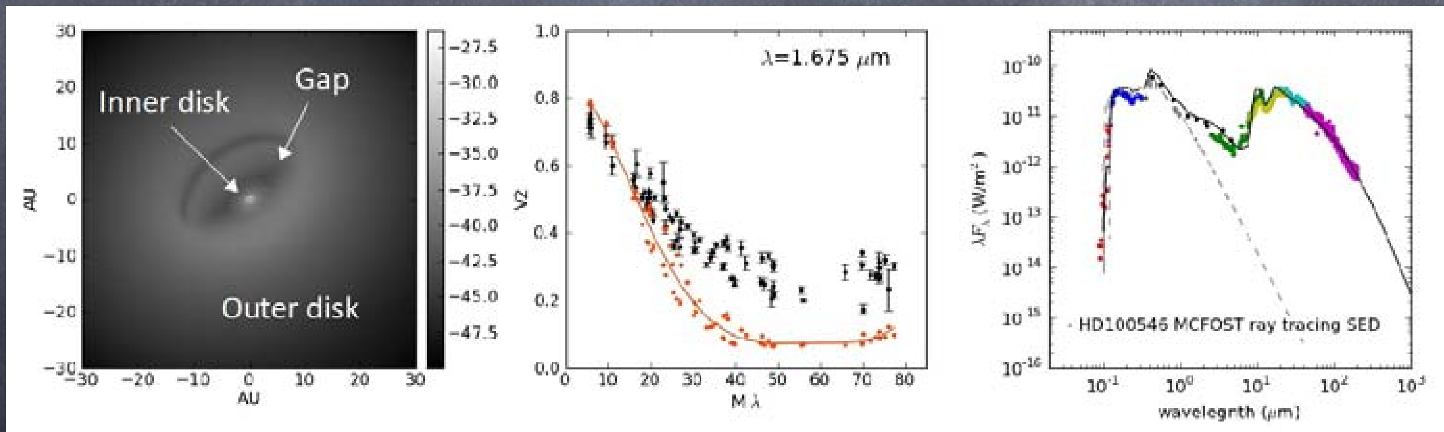
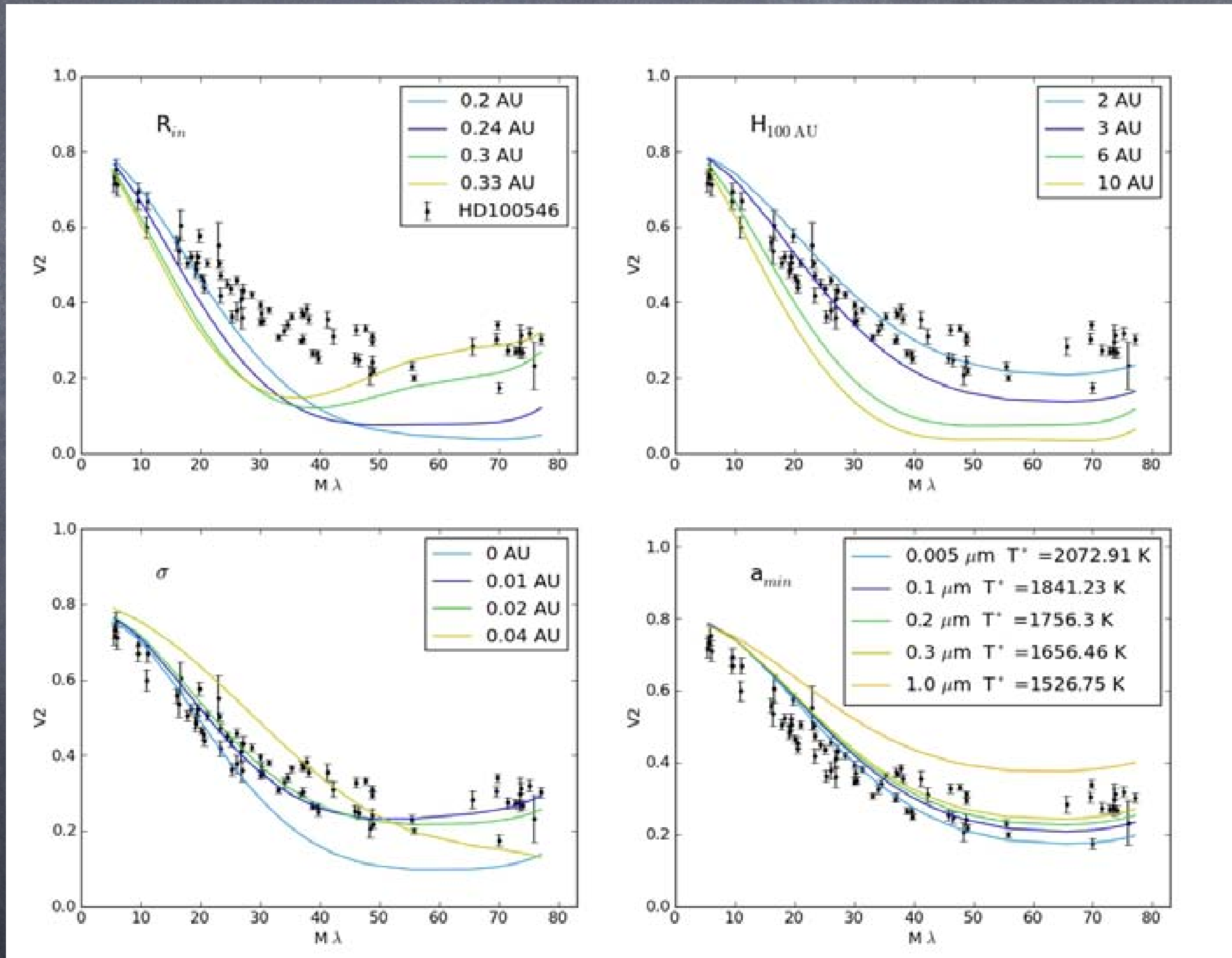
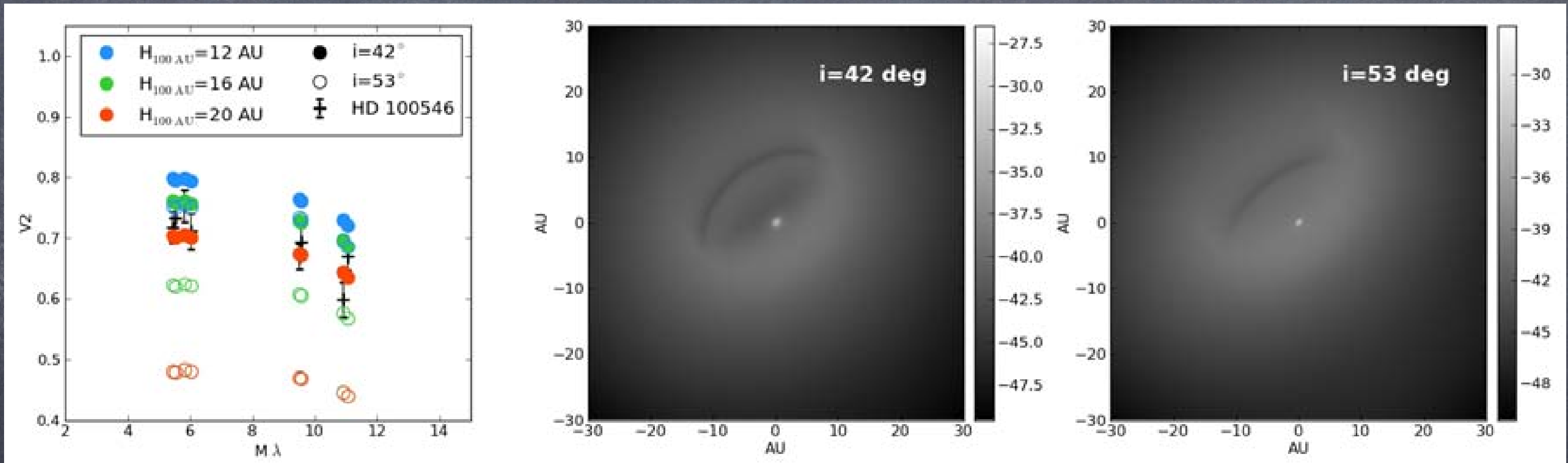
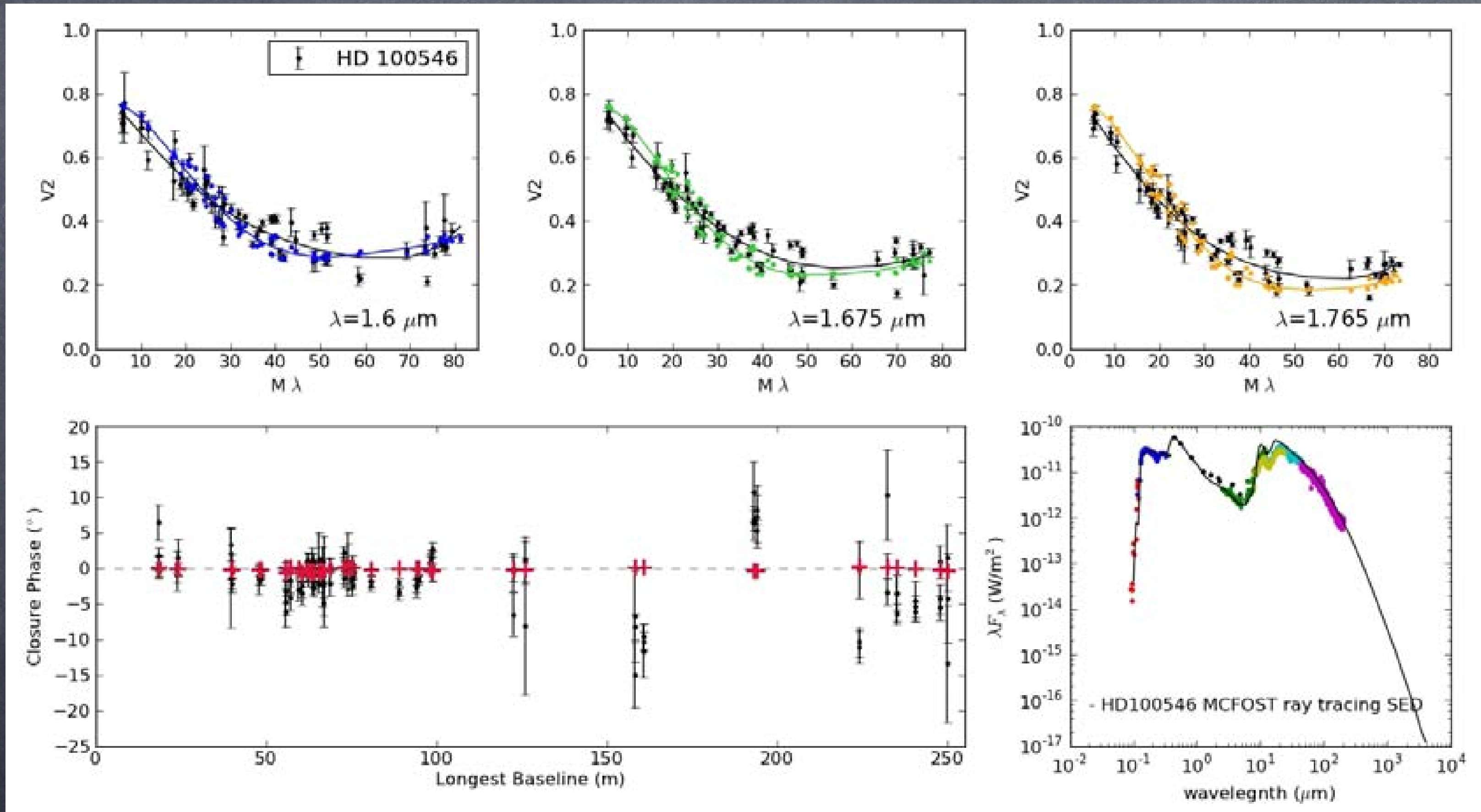


Fig. 7: Schematic view of the disk model with the three different regions : an inner tenuous disk, a gap, a massive outer disk wit
small grains in an upper layer. Adapted from Benisty et al. (2010b).

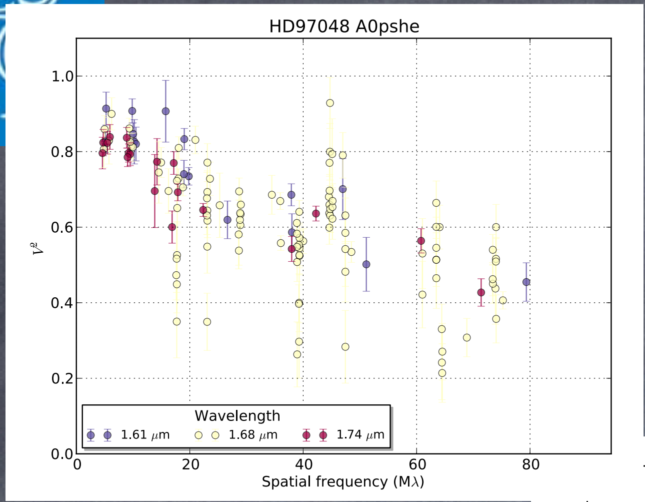


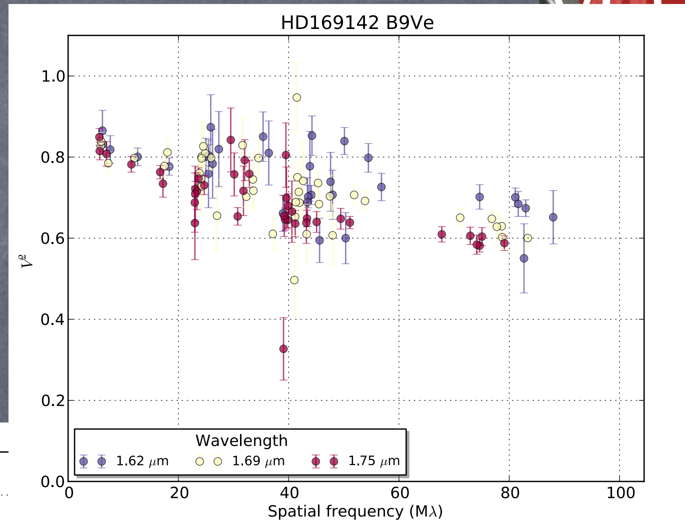

R_in
0.2 AU
0.24 AU
0.3 AU
0.33 AU
HD100546
H_100 AU
2 AU
3 AU
6 AU
10 AU
σ
0 AU
0.01 AU
0.02 AU
0.04 AU
a_min
0.005 μm T* =2072.91 K
0.1 μm T* =1841.23 K
0.2 μm T* =1756.3 K
0.3 μm T* =1656.46 K
1.0 μm T* =1526.75 K
V2
M λ

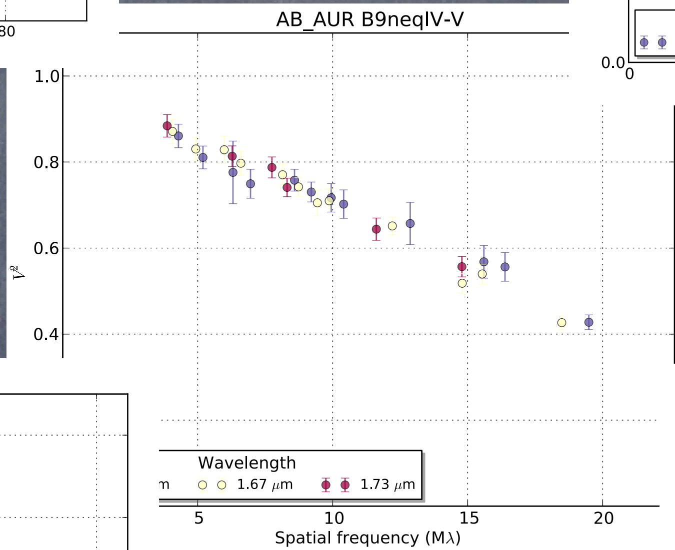

H100 AU=12 AU
H100 AU=16 AU
H100 AU=20 AU
i=42°
i=53°
HD 100546
V2
M λ
i=42 deg
i=53 deg
AU
AU
AU
AU

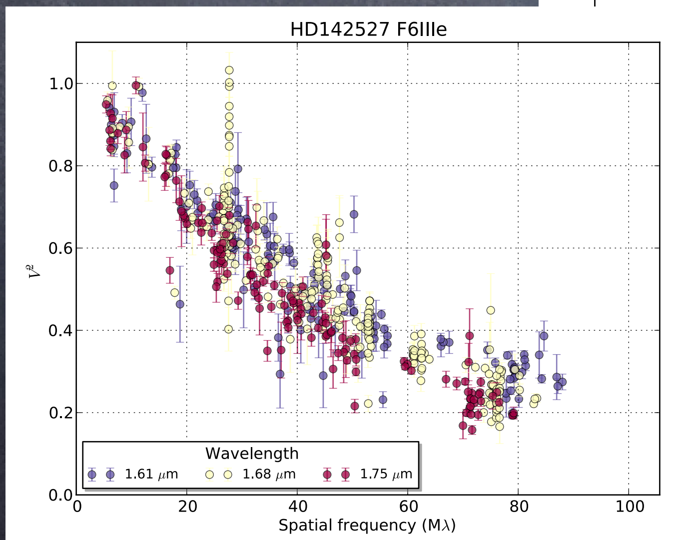

HD 100546
V2
M λ
λ=1.6 μm
λ=1.675 μm
λ=1.765 μm
Closure Phase (°)
Longest Baseline (m)
λF_λ (W/m^2)
wavelegnth (μm)
HD100546 MCFOST ray tracing SED

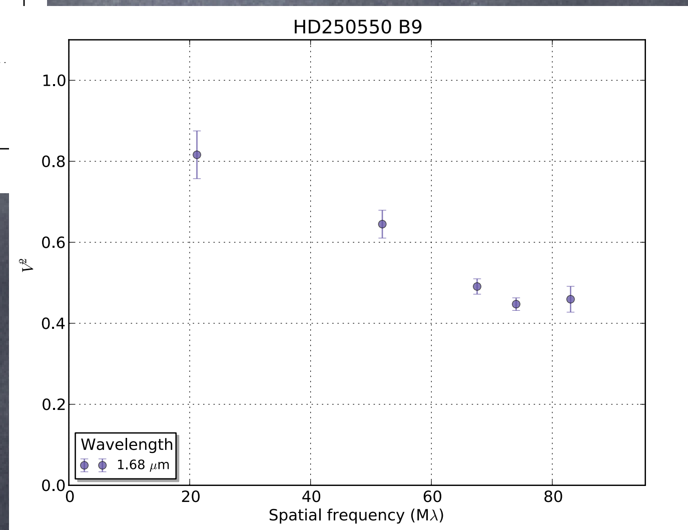
Group I sources



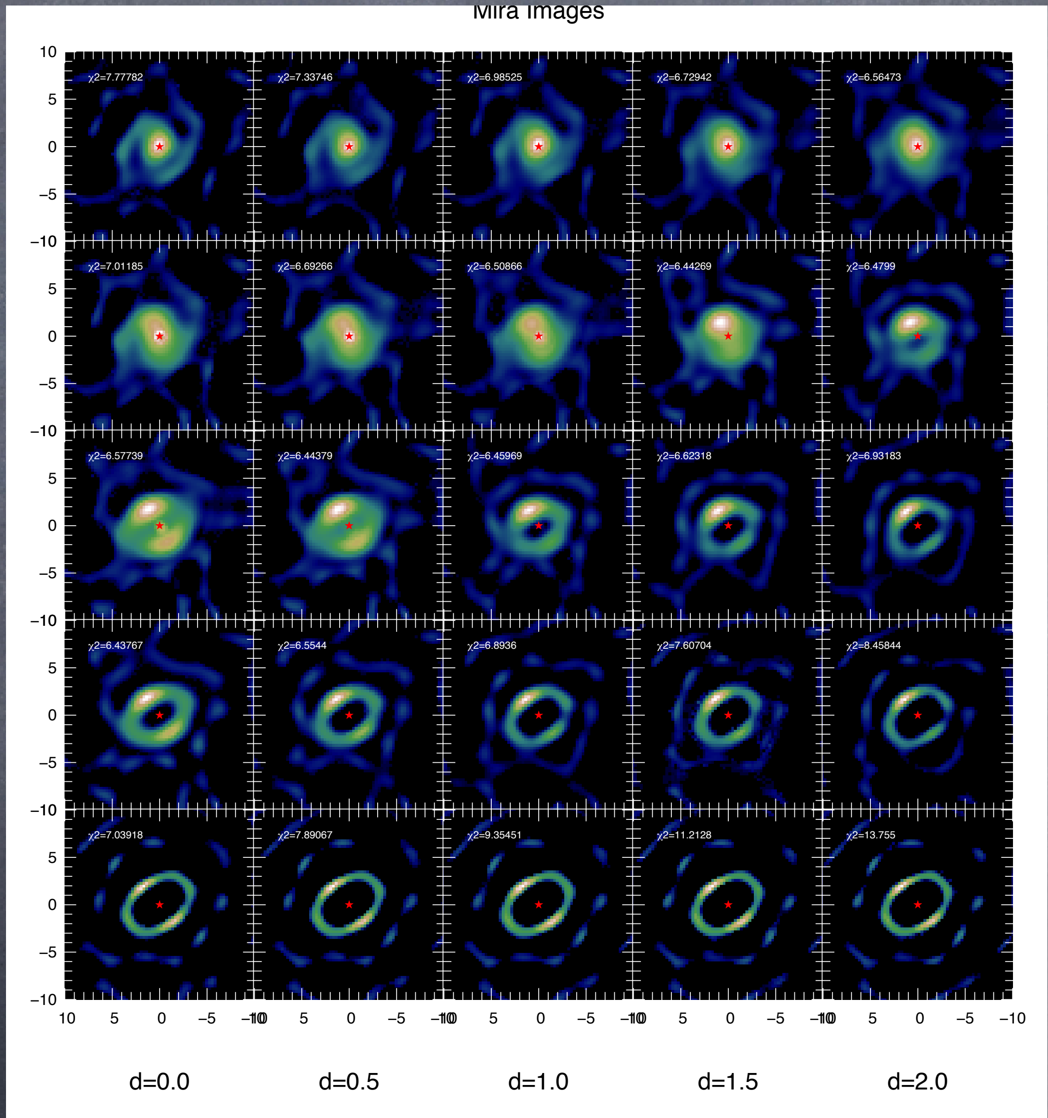






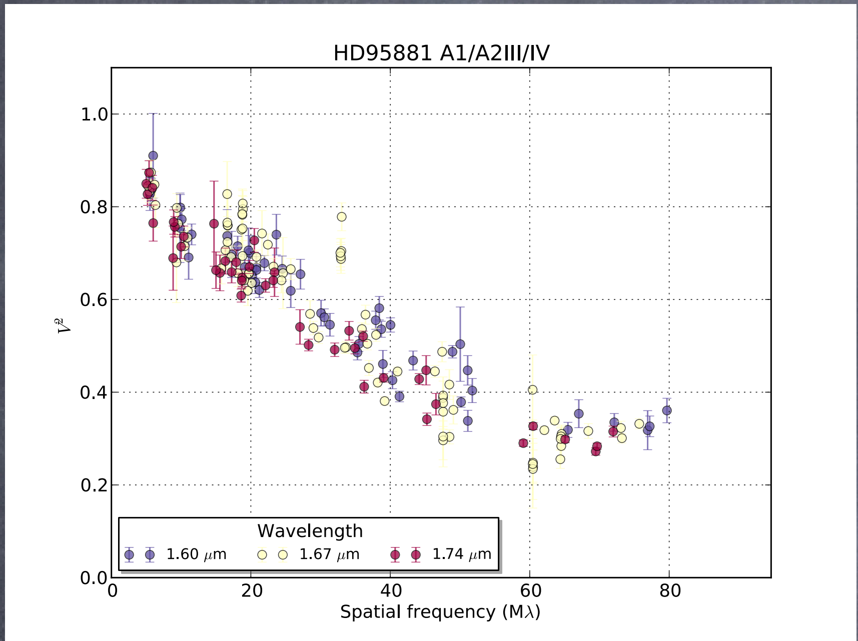


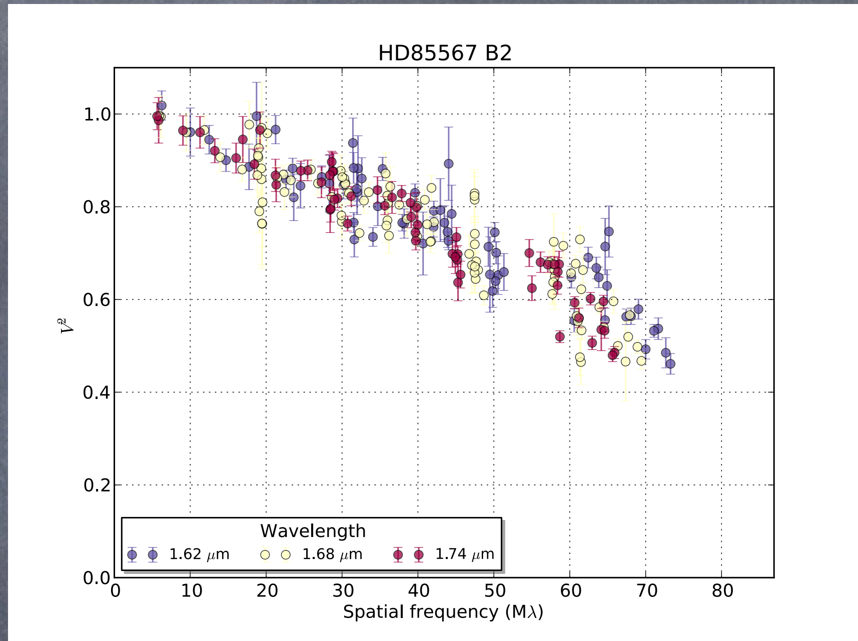
The crucial problem of photometry



Kluska et al. in submitted

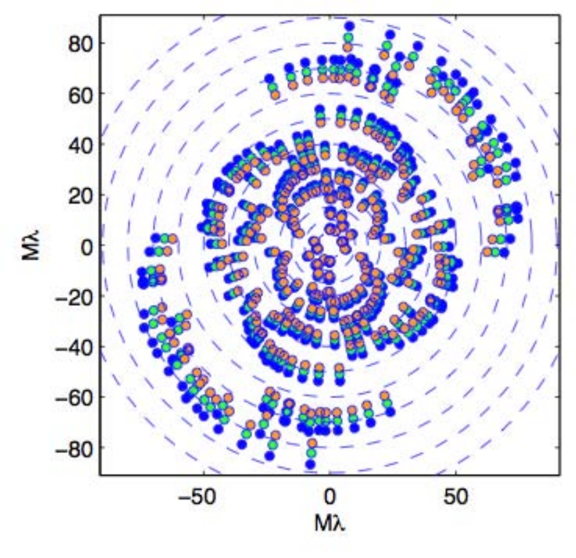
The crucial problem of photometry

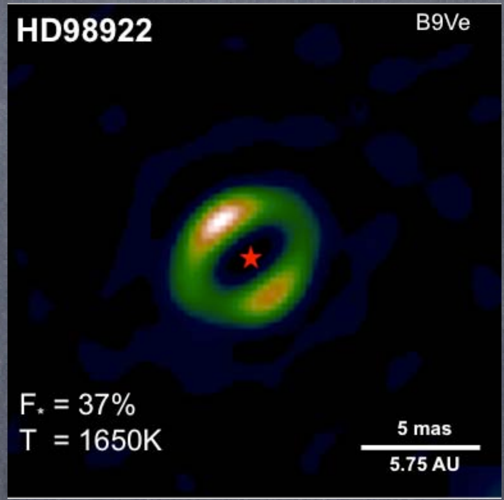




Using archival photometry but variability forces photometry program (REM and SAAO)

Image reconstructions





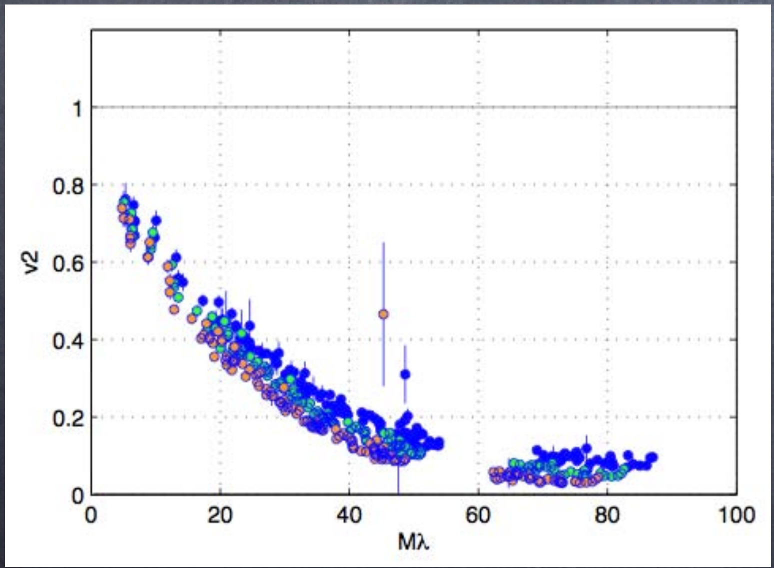
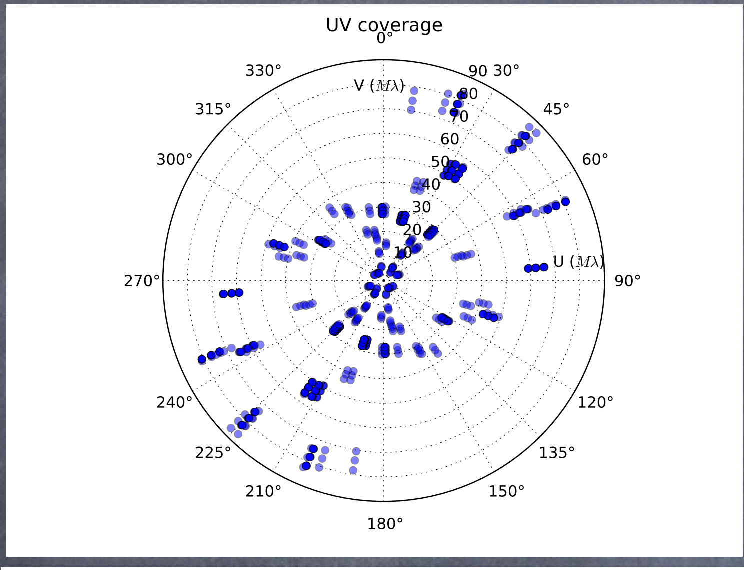
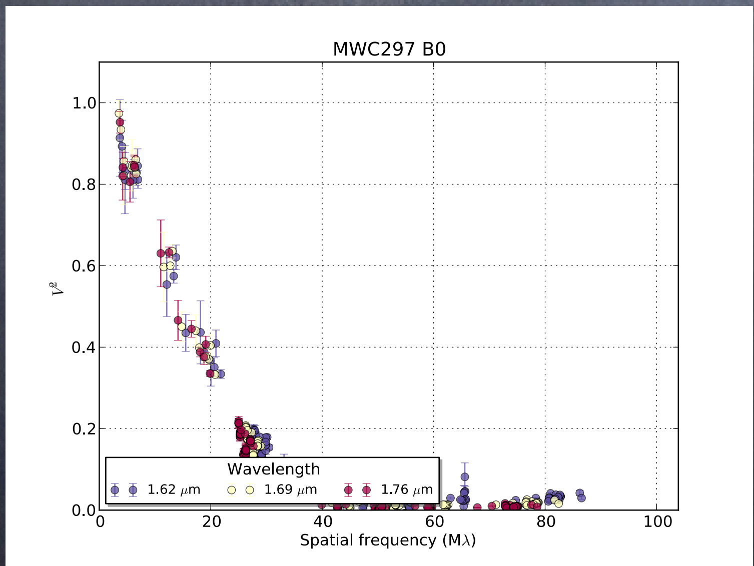
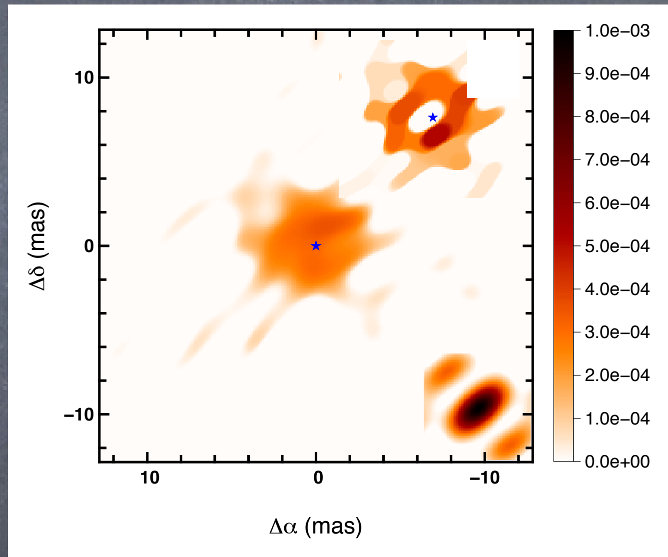


Image reconstructions





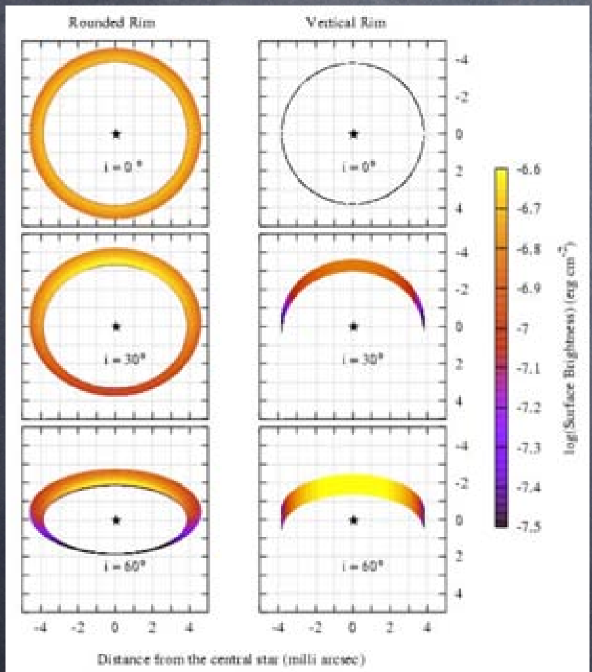


Where to go now ?

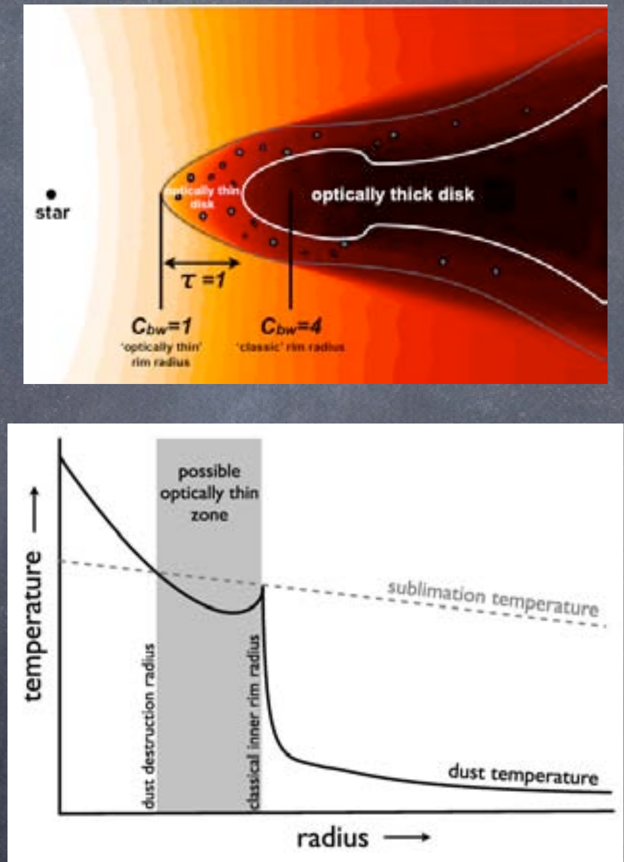
Survey first results

- A large fraction of the sample is spatially resolved
- 7 candidate binaries out of 52
- Inner rim smooth except for some high massive stars (wind?)
- Image reconstruction is possible but requires good photometric knowledge. Same for visibility fitting.
- Reconstruction reveals inner rim but also the absence of it ?
- Evidence for unresolved non-stellar component
- Evidence for extended flux. Relation with inner rim of outer disk component (group I vs group II)
- Are we seeing symmetric component (i.e inclination independent)

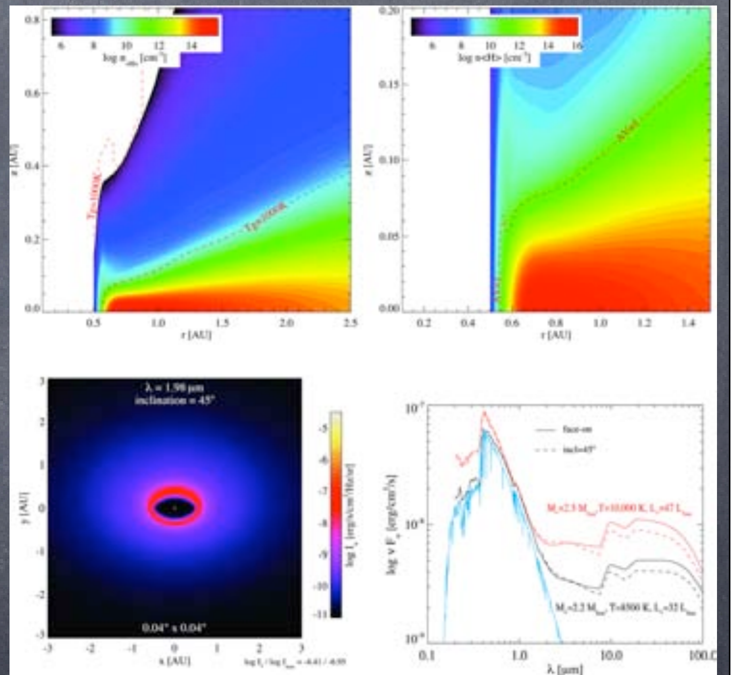
The physics of the inner rim



Isella 2005



Kama 2009



Thi 2011

The physics of the inner rim

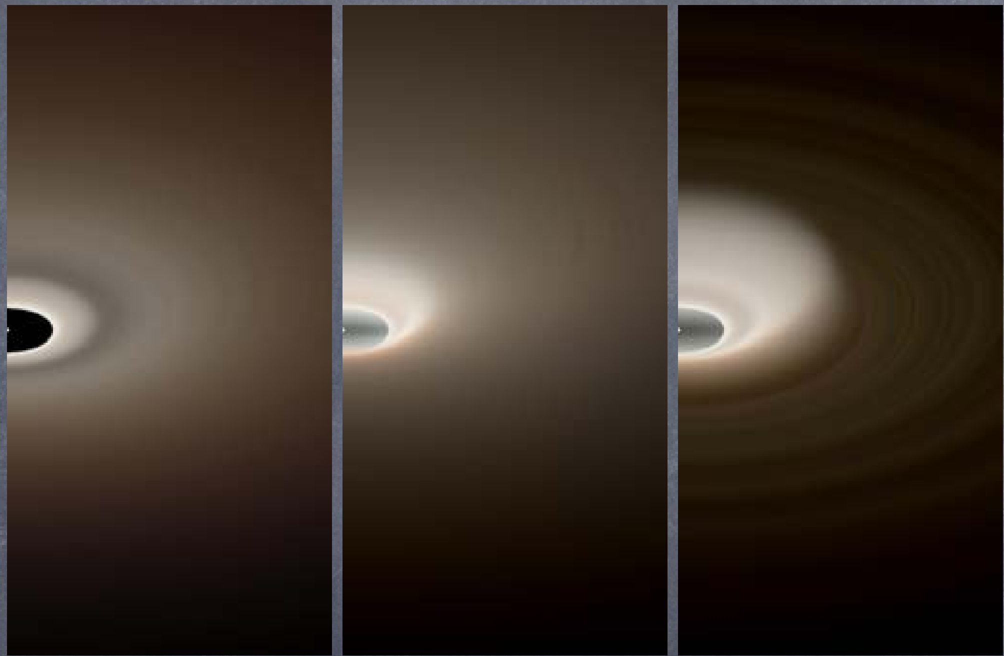


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Fig. 5.— Synthetic images of the central region of the dusty Herbig disk with (left to right) no magnetic support, magnetic support throughout, and a magnetically-supported bump. The field of view is 2.5 AU wide and the system is inclined 60° from face-on. The star is shown to scale at the center of each panel's left edge. The blue, green and red channels in each image correspond to wavelengths 1.25, 1.6 and 2.2 μm or J, H and K bands, respectively. A shared logarithmic intensity scale is used in all three panels.

Directions

- Do we see a dependance of parameters with spectral type ?
- Can we constraint physical mechanisms controlling disk evolution;
- Can we link inner rim emission with accretion/ wind activity ?
- What is the origin of inner disk emission ?
- Can we relate inner properties with outer (e.g the group category and flaring)
- Tight integration with ALMA disk studies