Protoplanetary disks around HAeBe stars at sub-AU scales

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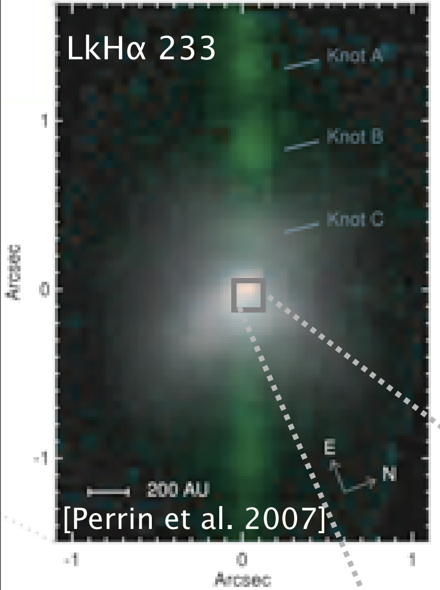
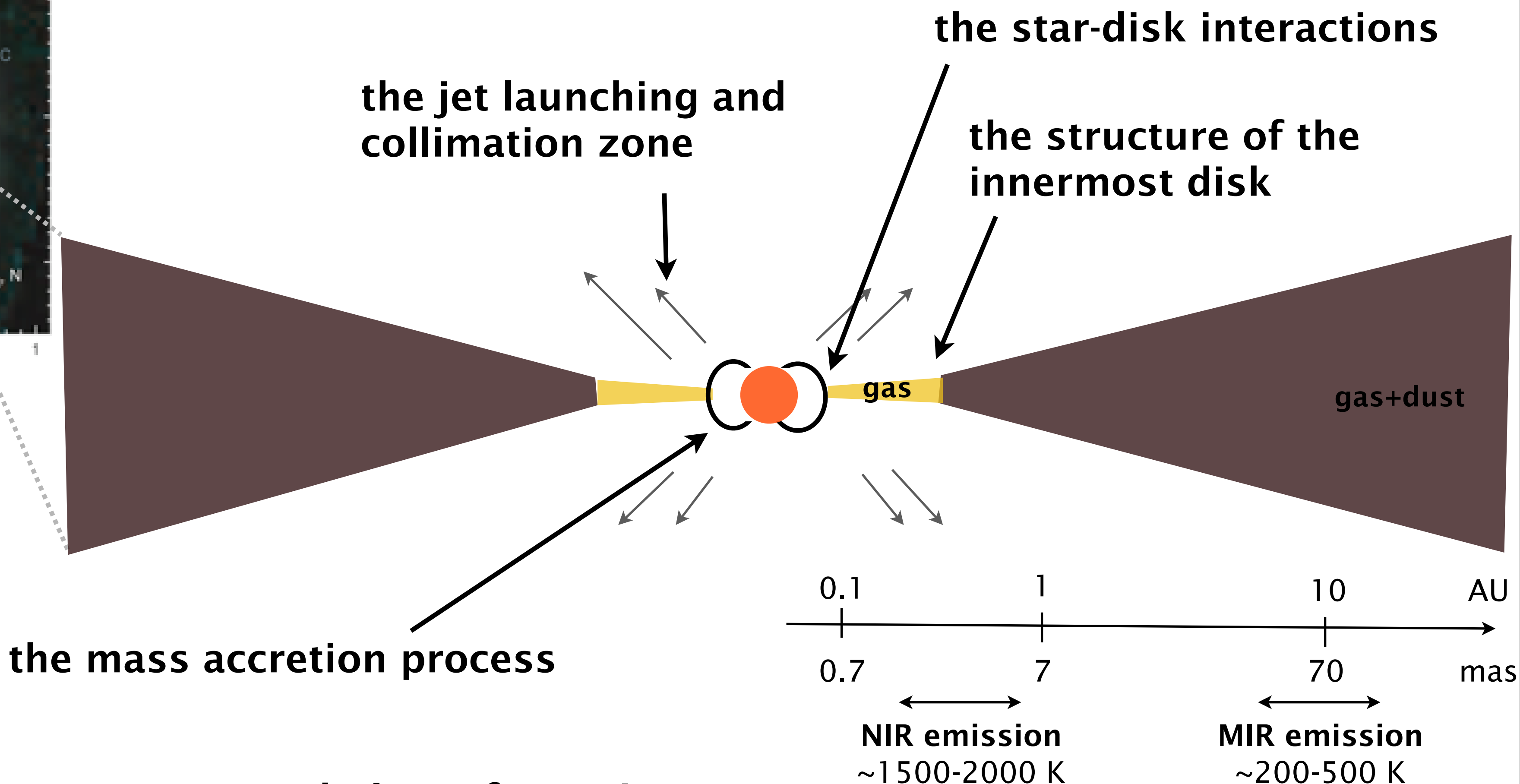
The close environment



In search for *spatially resolved* constraints on:



... and planet formation!

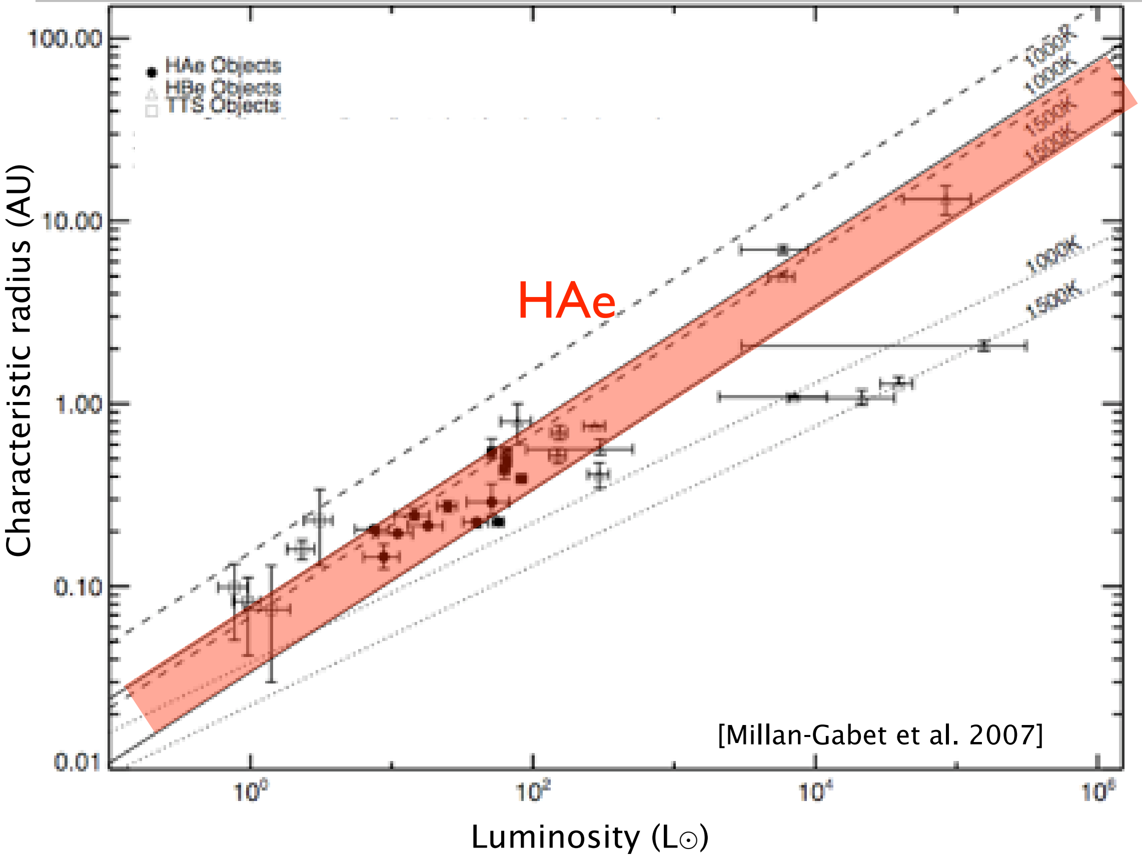
Sub-AU scale studies (mas resolution) require **near-infrared interferometry**

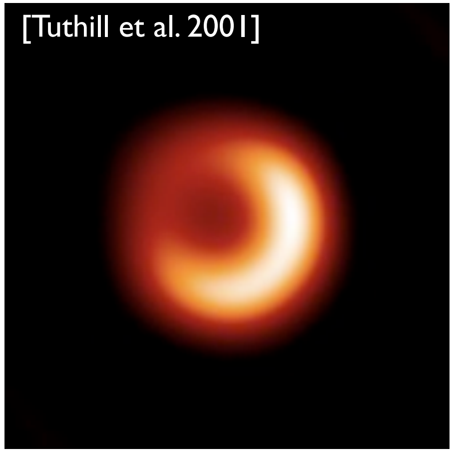
$V^2 \Leftrightarrow$ characteristic size

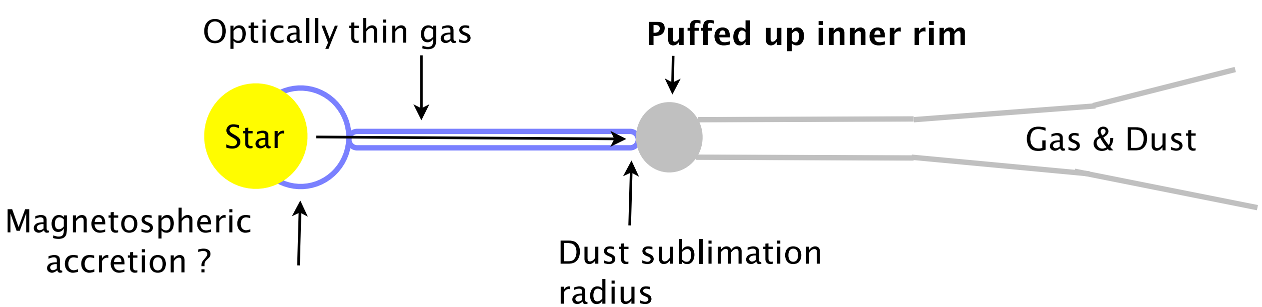
CP$\Leftrightarrow$ asymmetry

NIR size-luminosity relation

$R_{NIR} \propto L_*^{1/2} \propto R_{sub}$







[Natta et al. 2001, Dullemond et al. 2001, Isella & Natta 2005, Tannirkulam et al. 2005]

The NIR flux is due to direct thermal emission from hot dust located at the edge of the disk.

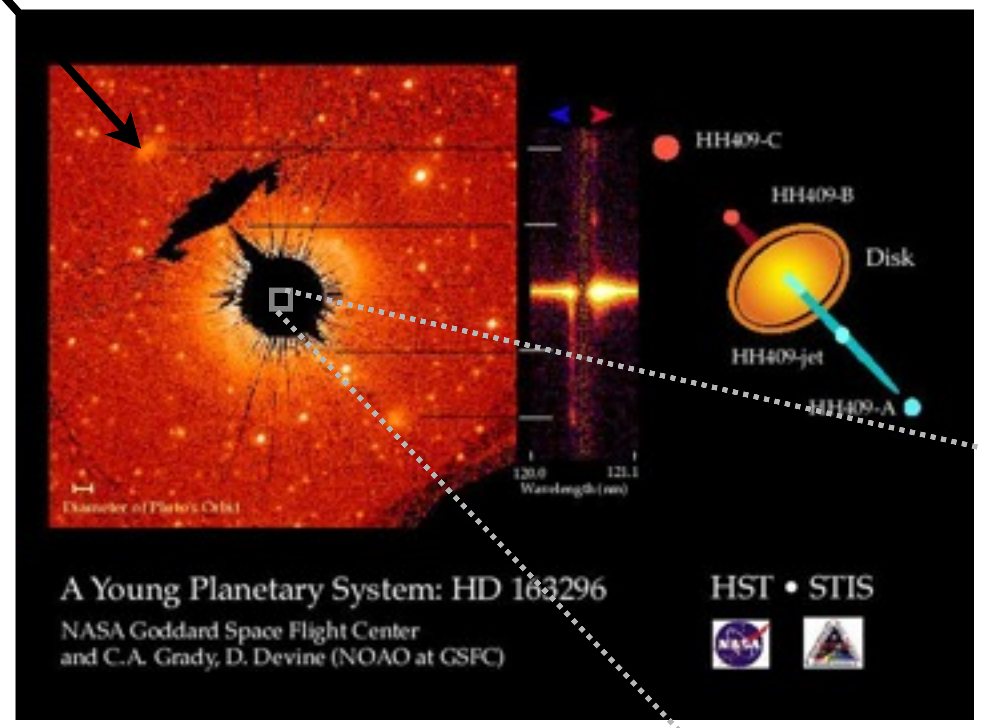
Physical conditions?

↓

Spectro-interferometry
HD163296 & HD100546

What is the origin of the NIR excess in HD163296 ?

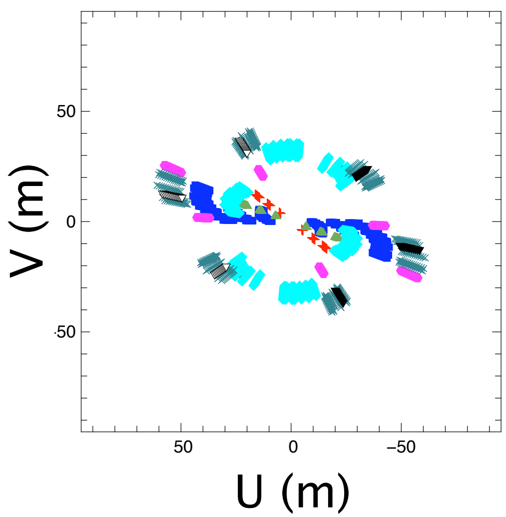
jet



[Grady et al. 2005]

Herbig Ae star A1V, 2-4 M_{yrs}
T_{eff}~9250K, 2.3$M_{\odot}$
with a large scale keplerian disk and a jet
Accretion rate (Brγ): 8.10^{-8} $M_{\odot}$/yr
[Grady et al. 2000,2005; Devine et al. 2000; Isella et al. 2007]

Spectro-interferometry with AMBER/VLTI



5 VLTI configurations
H & K bands R~35
~1500 V^2 and 450 CP

The *entire* circumstellar matter emitting in the NIR is resolved at resolutions of 3 to 12 mas.

Characteristic sizes increase with wavelength and change with baseline orientation.

Smooth V^2 -variation with spatial frequency.

Drop of V^2 and CP=0 at small spatial frequencies.

↓

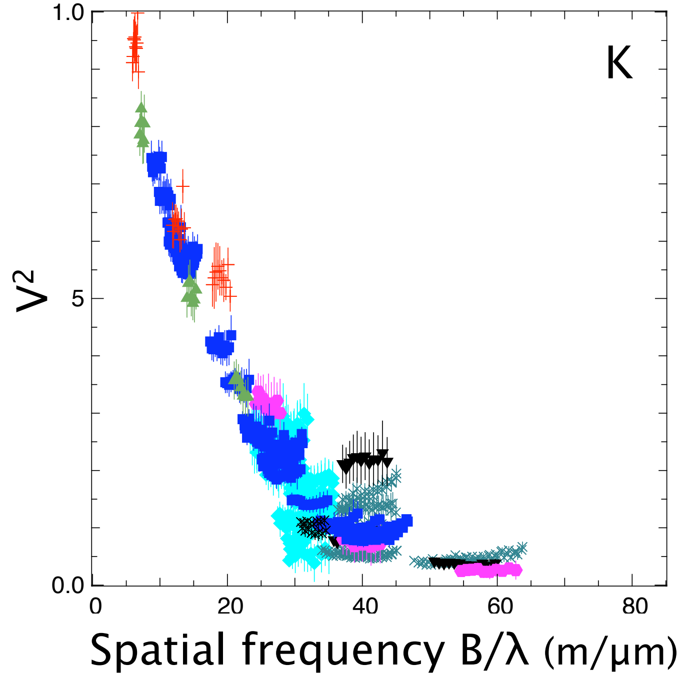
i~48° & PA~135° consistent with outer disk observations.

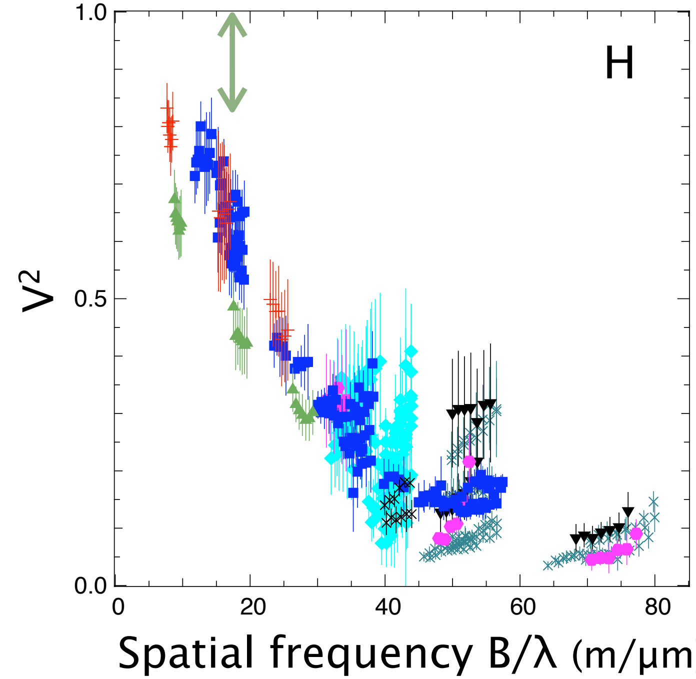
Is there an extended halo?

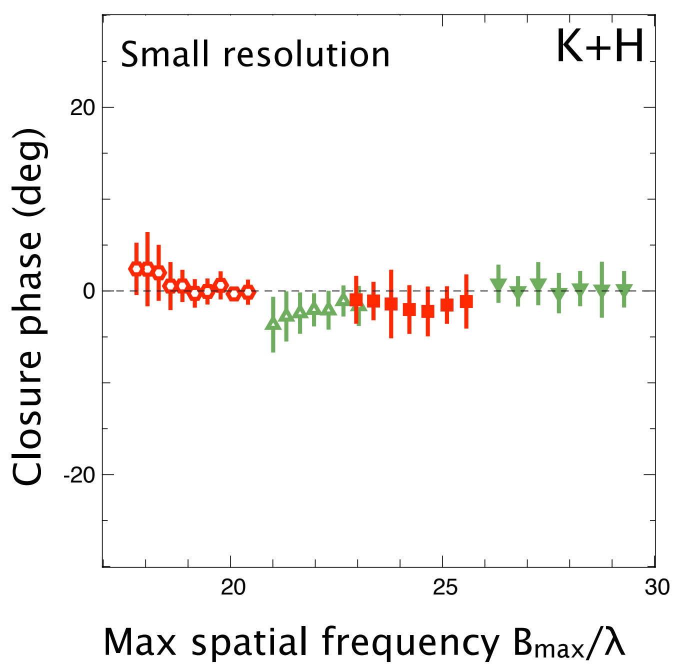
No strong discontinuity in the brightness distribution.

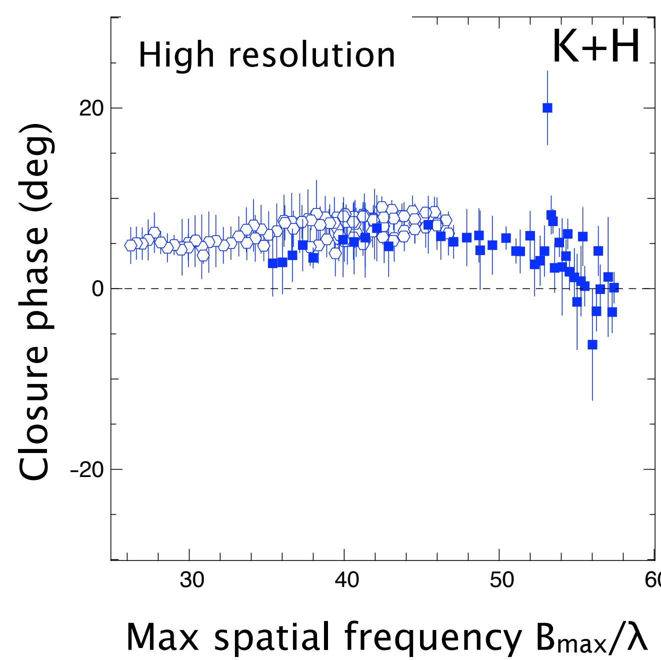
↓

Rim alone



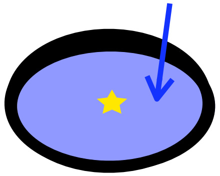






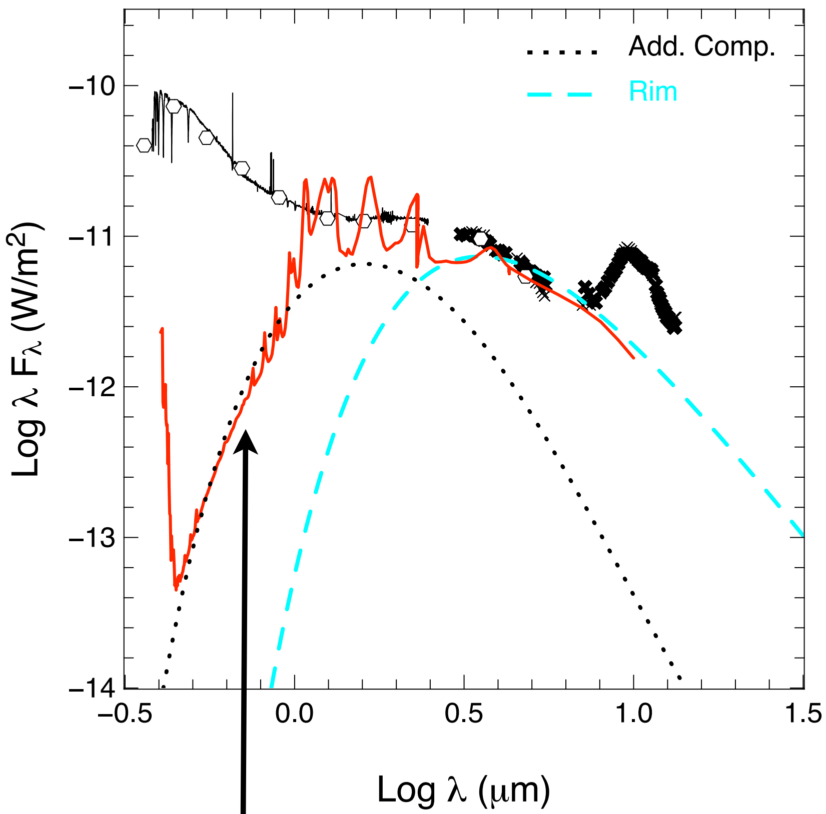
A gaseous inner disk?

Model: the star + a rim at the silicate sublimation radius [Isella & Natta 2005] + **an additional component**



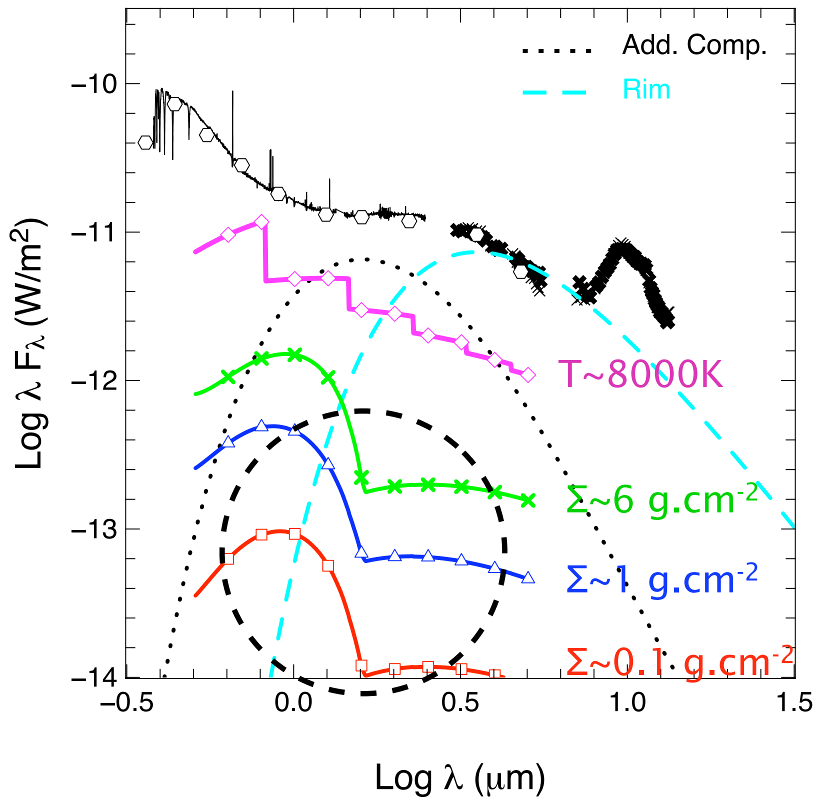
Gas ?

[Tannirkulam et al. 2008;
Eisner et al. 2007; Isella et al. 2007]



LTE gas in accretion disk: no molecular lines!

[Sitko et al. 2008; Muzerolle et al. 2004]



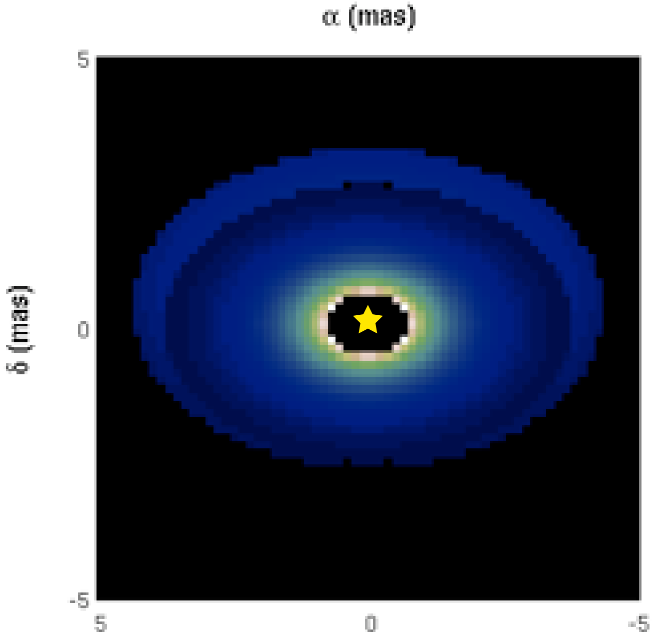
Thin atomic or ionized non-LTE gas
(disk upper layers)

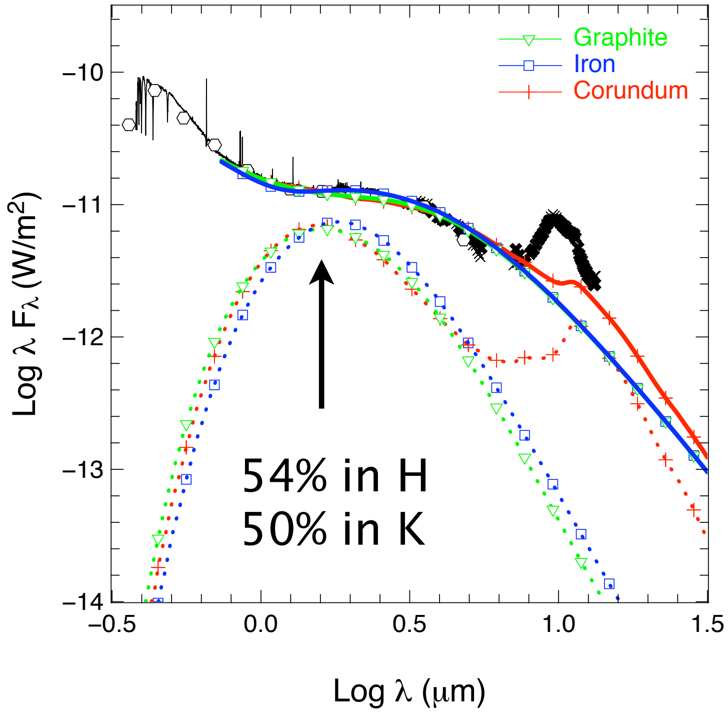
[Ferland et al. 1998; CLOUDY]

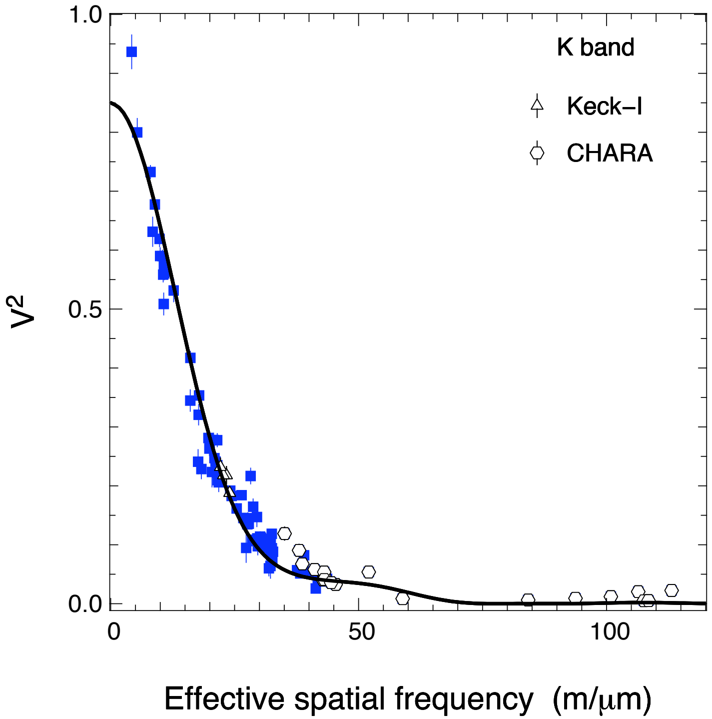
unlikely to produce a strong NIR continuum...

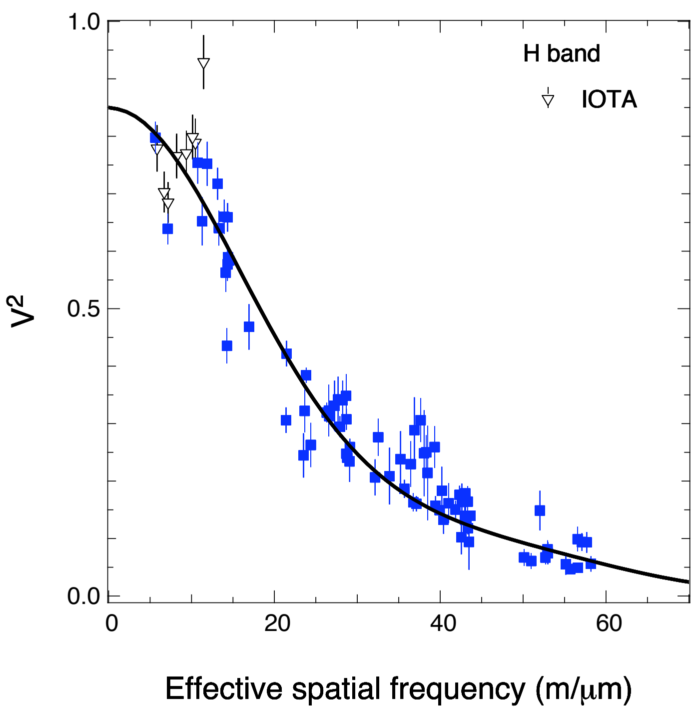
Refractory grains in a low density region inside the rim?

Iron, corundum, graphite dust grains in an **optically thin** inner disk ($\tau_{K,0.1AU}$~0.2) from **0.1 to ~0.45 AU** - where a partially shielded silicate rim forms.





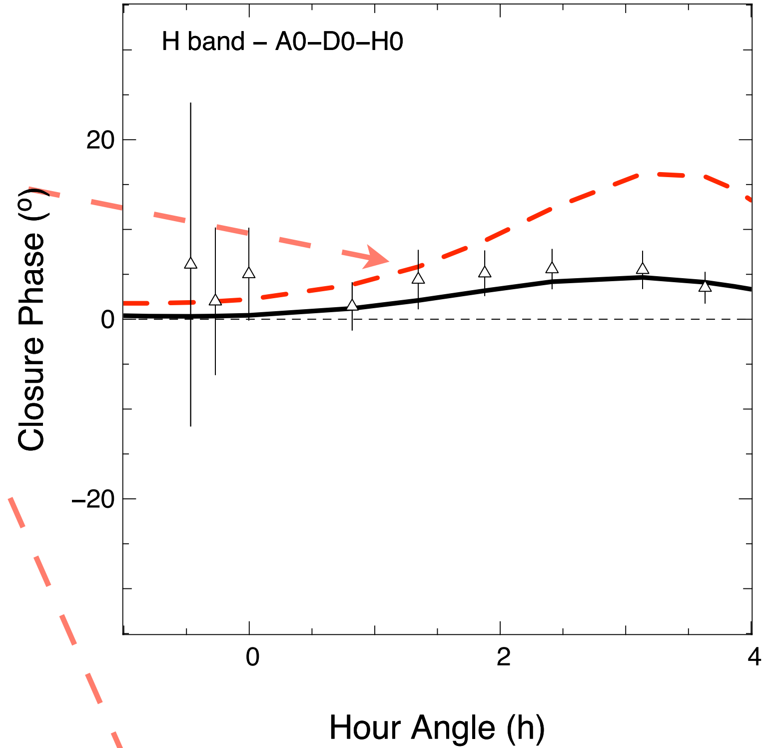




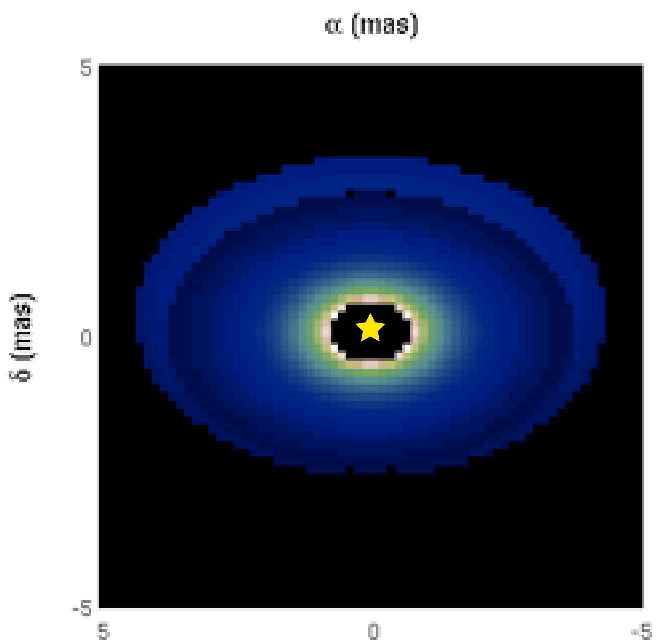
[Pollack et al. 1994; Koike et al. 1995; Begemann et al. 1997; Laor&Draine 1993]

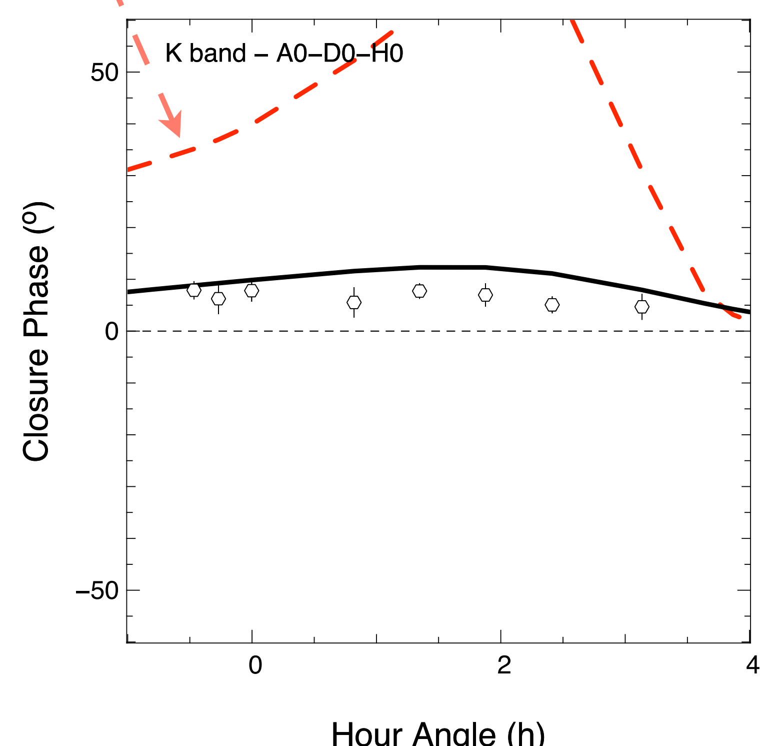
Refractory grains in a low density region inside the rim?

rim alone



The star+rim+refractory grains model successfully reproduces the level of asymmetry





Summary

- The puffed up inner rim alone does **not** dominate the NIR emission

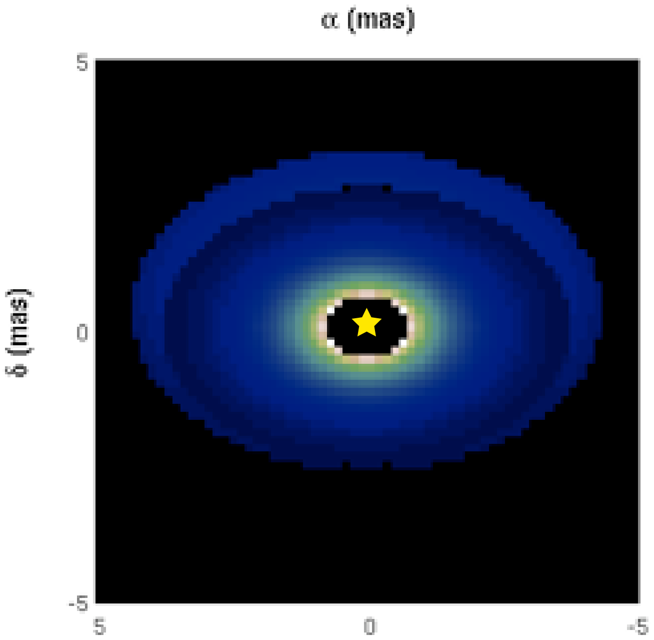
- The inner zone is tenuous ($M_{iron} \sim 10^{-5}\ M_{\oplus}$):
Partially cleared inner region in a massive disk: common in HAe? [S.Kraus talk].
Evidence for disk evolution?

Refractory dust grains?

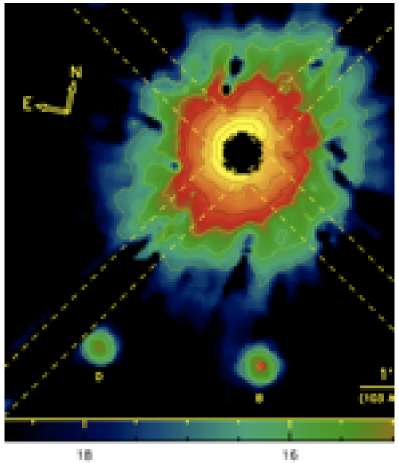
- A low density region allows a rim to be formed.

- The grains must survive to very high temperatures (2100 K @ 0.1 AU): nature and origin of these?

- Strong need for self-consistent models of gaseous and dusty inner disks!



Benisty, Natta, Isella, Berger et al. 2009, A&A, in press



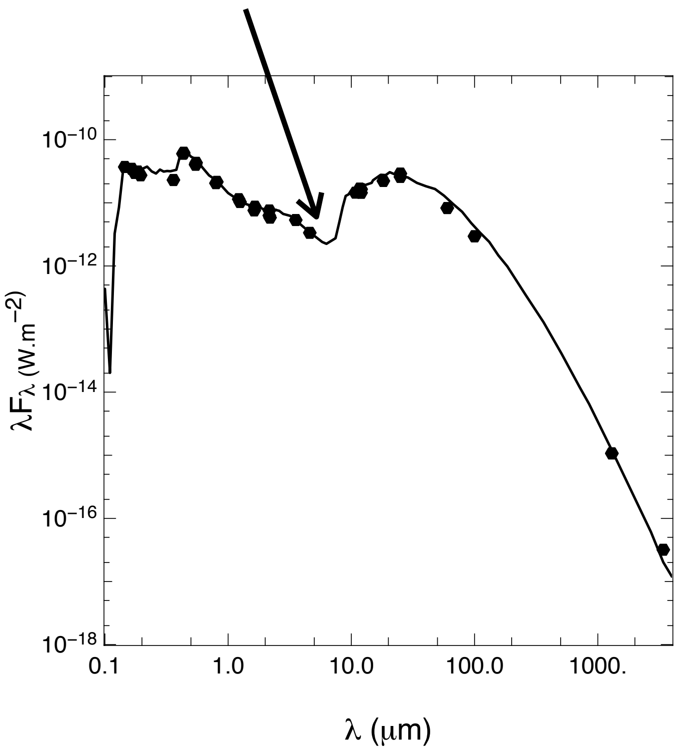
[Augereau et al. 2001]

What is the origin of the NIR excess in HD100546 ?

Herbig Be star B9.5Ve, >10 Myrs, T_{eff}~10500K, 2.0$M_\odot$

Large scale **disk** with **a gap** inferred by SED fitting and spectroscopic observations. The innermost disk is *not* empty.

Lack of emission at 2-8 μm: gap



[Bouwman et al. 2003; Grady et al. 2005; Acke & van den Ancker 2006; Brittain et al. 2009]

AMBER+MIDI observations resolve the hot (~1500K) and cold (~200K) dust

3-zone disk model

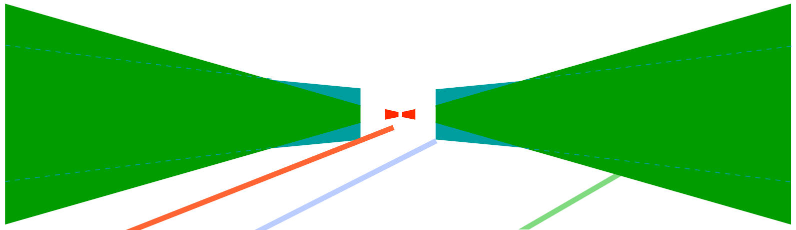
3D radiative transfer calculations including scattering
[Pinte et al. 2006]

Silicate disk model:

Inner disk: R_{in}=0.25 AU - R_{out}=4 AU, optically thin

Gap: 4-13 AU

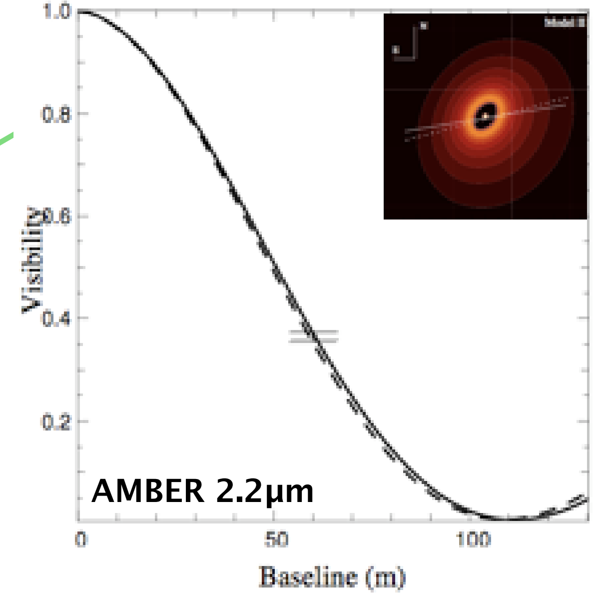
Outer disk: 13-350 AU, optically thick with small grains at the surface

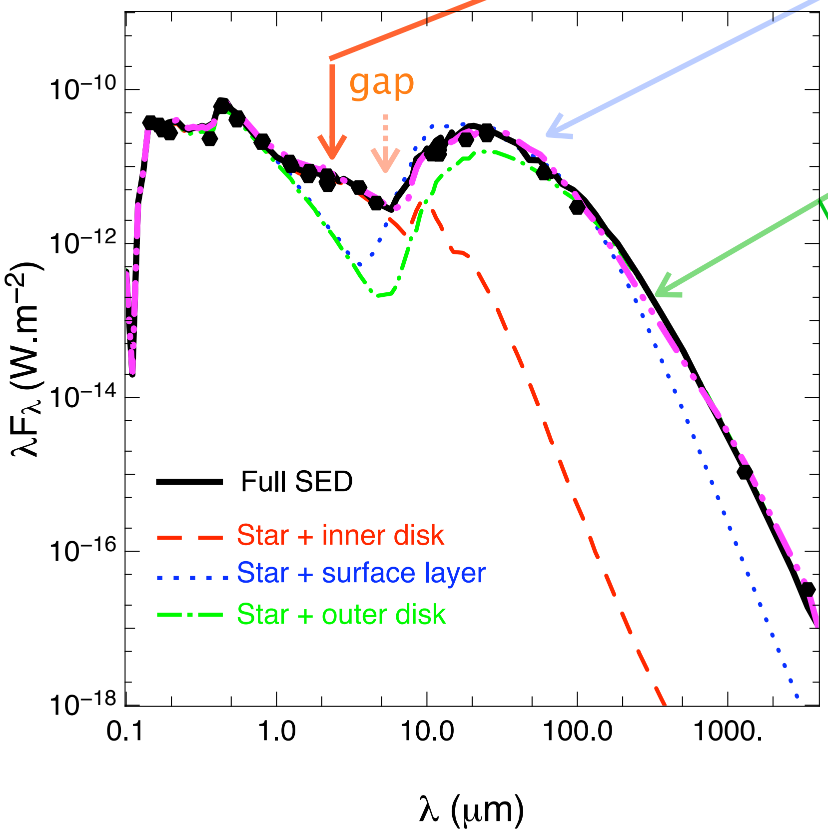


inner disk (0.1-5µm)

small grains at the surface (0.05-1µm)

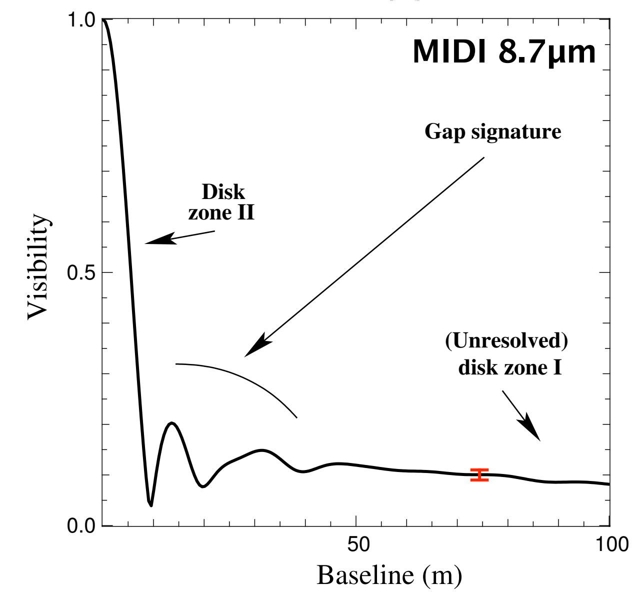
large grains in the mid-plane (1µm-1cm)





AMBER observations locate the bulk of the K-band emission.

MIDI observations are consistent with a gap ending at 13 AU.



The strong contribution from scattered light

AMBER observations constrains R_{in}~0.25 AU i.e. the silicate grain sizes (~µm): scattered thermal light is **~38%** of the K-band flux

The NIR emission is **not** entirely due to direct thermal emission from hot dust located at the sublimation radius.

Already known for TTauri stars [Pinte et al. 2008; Akeson et al. 2005] .... is it the case for all HAeBes?

Modelling of spectro-interferometric observations is consistent with:

- an inner disk with µm-size silicate grains
- optically thin and tenuous (~10^{24}g of dust; consistent with CO observations) [Brittain et al. 2009]
- a **gap** located from ~4 to 13 AU (consistent with CO and spectroscopy)
- small grains at the disk surface
- large grains in the mid-plane

(small grains at the disk surface + large grains in the mid-plane) ← **evidence for sedimentation** ?

Detailed analysis required with additional data (VLTI-3T/4T; Herschel; ALMA...)

Benisty, Tatulli, Ménard, Swain, A&A, subm.

Spectro-interferometry is a powerful tool that provides unique constraints on the disk morphology and physical conditions at play.

HD163296: SED, NIR visibilities and closure phases are well reproduced using a model of a star, a silicate rim, and a low density region dominated by **refractory grains inside the rim.** The nature of these grains is uncertain.

HD100546: SED, NIR and MIR visibilities well reproduced using a model of a star and a 3-zone disk. In this case, the **scattering** can not be neglected.

A puffed-up inner rim **alone** is not sufficient to reproduce the observations... and models should be refined.

Is it common in Herbig AeBe stars?
Needs spectro-interferometry **and** very long baselines...

[Tannirkulam et al. 2008;
Isella et al. 2008;
Kraus et al. 2008, 2009;
Eisner et al. 2009]