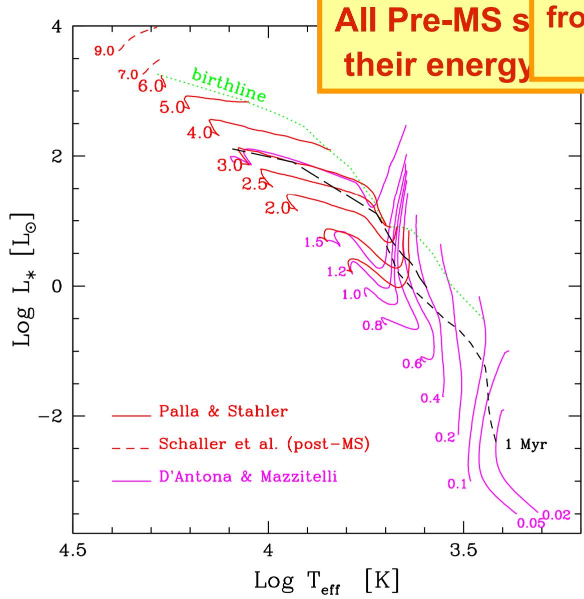
A review of disk obervations - III & IV

Antonella Natta

Are there disks around stars of all masses?

All Pre-MS s
their energy

Mass and ages mostly from HR diagram
tracks!



Questions:

- Same formation process for all masses?
- Can planets form around stars of all masses?
- Can we better constrain disk physics?

Disks across the stellar mass spectrum

- Brown dwarfs
- Solar type stars
  - (T Tauri stars: 0.1-1 Msun)
- Intermediate-mass stars
  - (Herbig Ae:1.5-3 Msun)
- Massive stars

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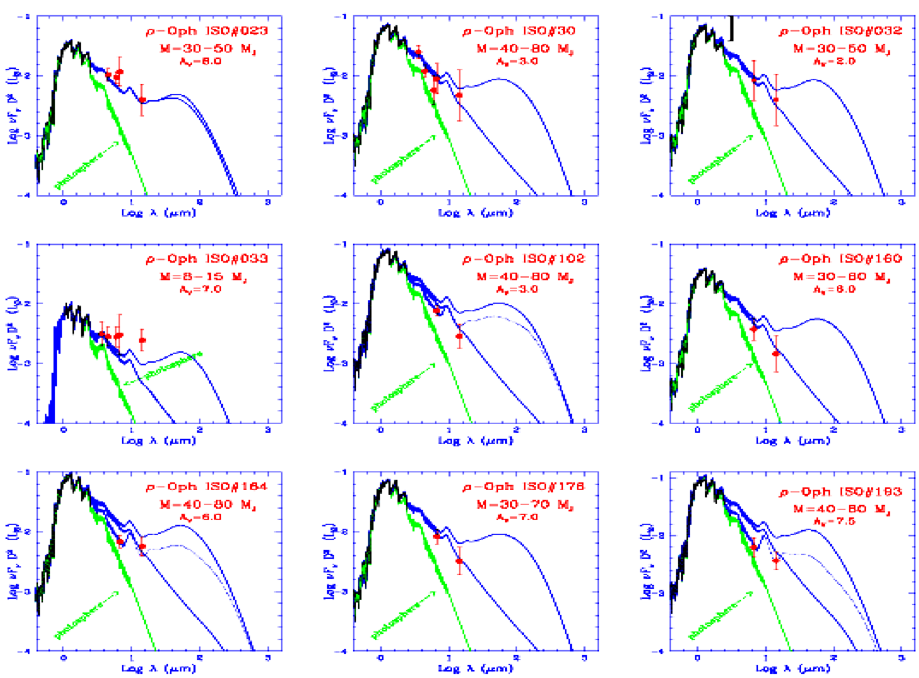
BDs: the rho-Oph sample

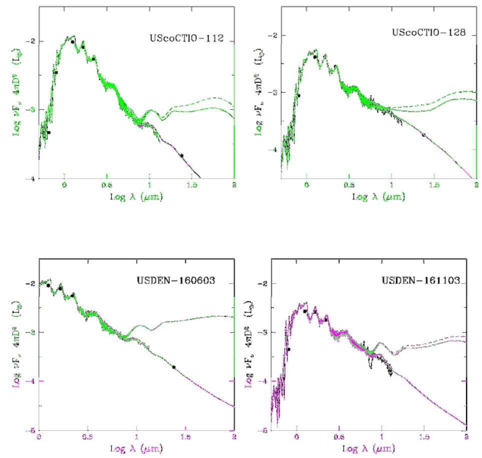
[Natta et al. 2002]



Spitzer is producing a wealth of SEDs of BDs

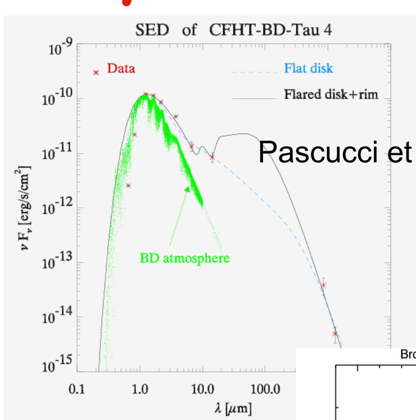
Some older BDs

- ★ Spectral types from M5.5 to M9
- ★ Luminosities L=0.003-0.01
- ★ No flared disks
- ★ >1mic silicates
- ★ Rin ~ several Rstar
- ★ Inclination is always large (??)
- ★ Optically thin disks (?)

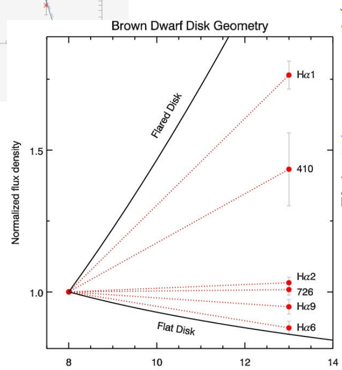


Mohanty et al., in prep.

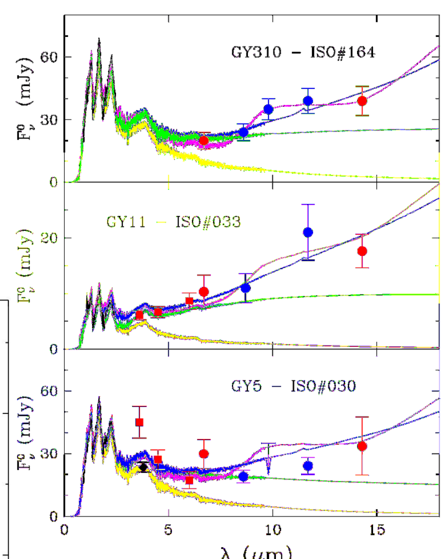
Very few BDs with flared disks



Pascucci et al. 2003

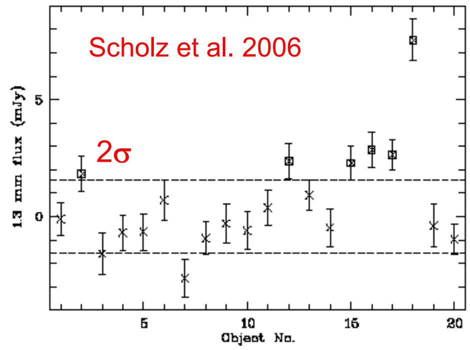


Apai et al 2005
(Chamaeleon)



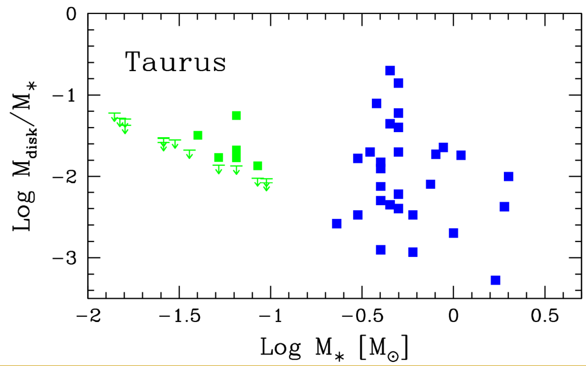
Mohanty et al. 2004
(Ophiucus)

BD disk masses?



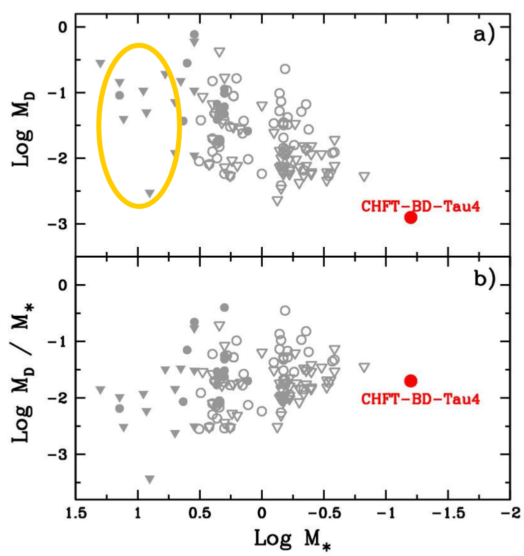
Taurus BDs

- Few mm detections (6/20) at 2-3σ using MAMBO on the IRAM 30m
- Mdisk~few MJupiter (Mgas/Mdust=100, k~1cm²/g)
- Sizes are not constrained (Rd>10-20AU)



Massive stars (>8 Msun)

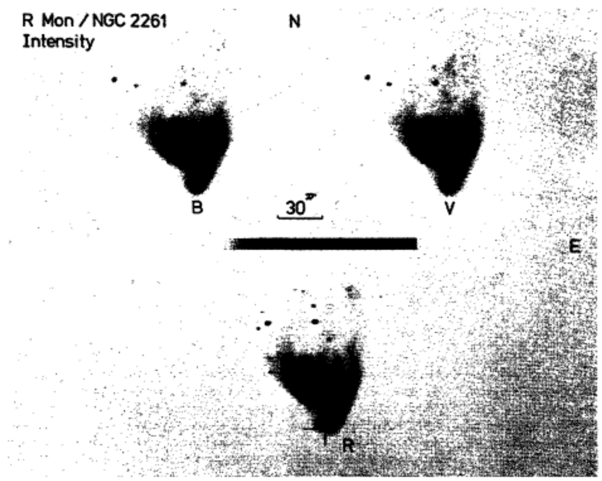
- Young embedded early B stars have disks
- Most Herbig Be are not detected at mm wavelengths with interferometers
- The single-dish emission comes from rings/shells
  - (Fuente et al.)



Disks around early B stars are detected only when very young

R Mon

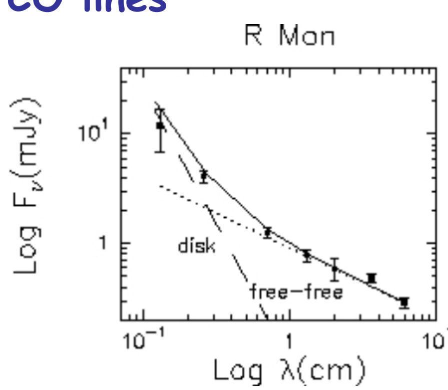
B0, young,
Mstar~8 Msun
(from CO)
D=800pc

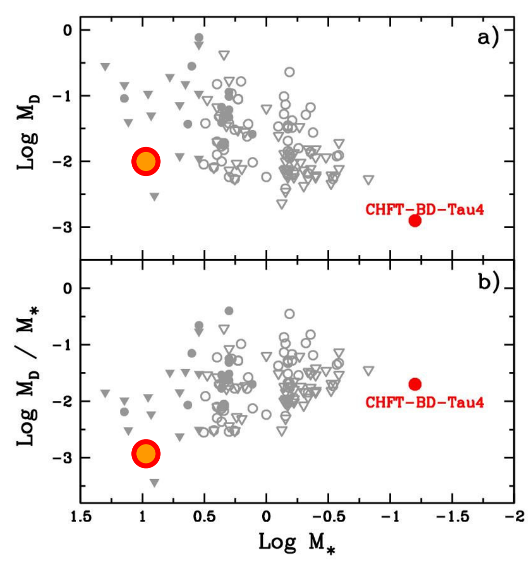


Aspin et al. 1985

R Mon: detected at 1.3mm with PdB

- Mdisk~0.01 Msun
- Beta~0.5-0.8
- Keplerian rotation in CO lines





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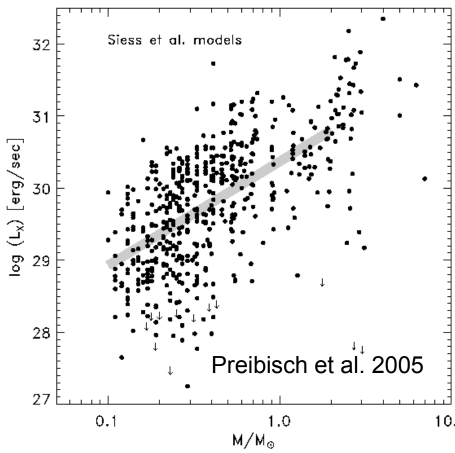
- ★ Objects of all masses have disks
  - Same formation process

A great laboratory to study disk physics

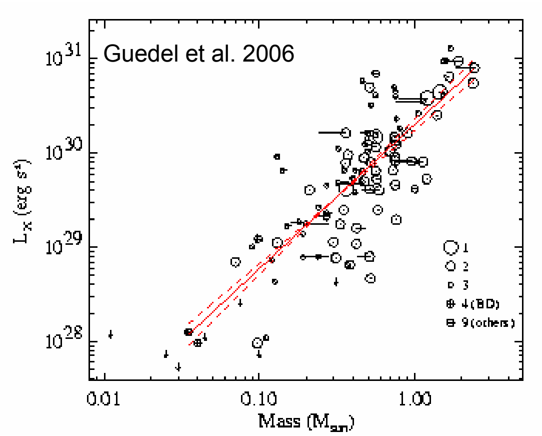
- ★ Large range of stellar properties
  - Mass
  - Intensity and hardness of the radiation field
  - X-rays
- ★ Large range of disk properties
  - Temperatures
  - Ionization fraction

X-rays

Orion -COUP



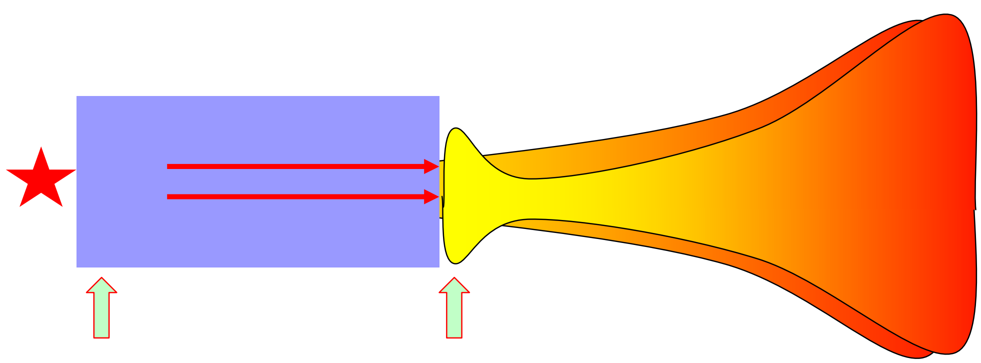
Taurus - XMM



L_x/L_{bol} ... read

Is this relevant for disk ionization and MRI?

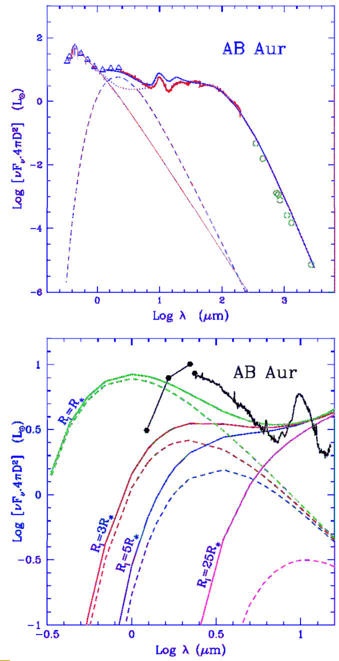
Inner disk: rims



- The edge of the disk is always at the dust evaporation temperature
- It is further away from the star
- The rim is hotter than the disk behind it: it puffs-up

Natta et. al (2001)
Dullemond et al. (2001)
Isella & Natta (2006)

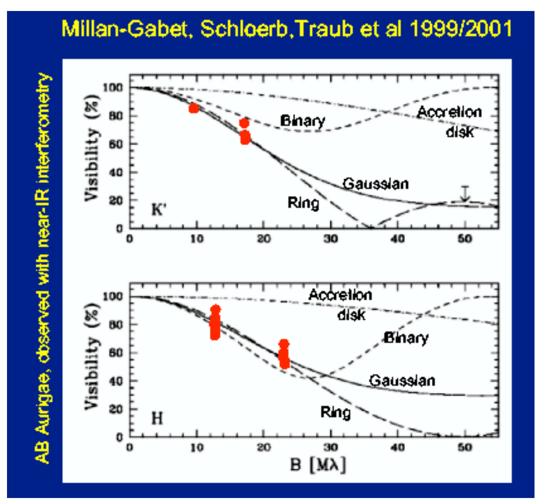
Why think of it? The SED of HAe stars



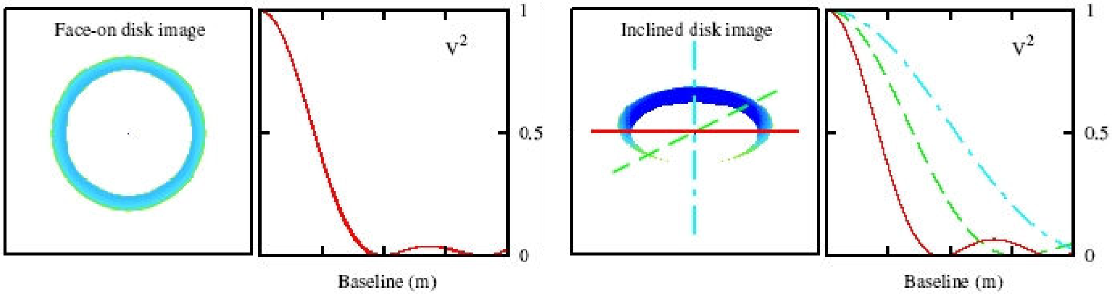
- ★ HAe stars have a large excess in the near-IR (10-25%), which peaks at about 3μm
- ★ It is not possible to reproduce the shape and intensity of this excess with flared or flat disk models
- ★ A puffed-up rim works, it has the right temperature and intercepts the right fraction of L_*

Near-IR interferometry

- ★ HAe disks have large inner holes, roughly consistent with rim models



How to use rim models to understand near-IR interferometry results: from images to visibilities



The visibility depends on the baseline orientation

You need to "observe" your preferred disk model with the same instrumental configuration used in the observations (baseline, HA)

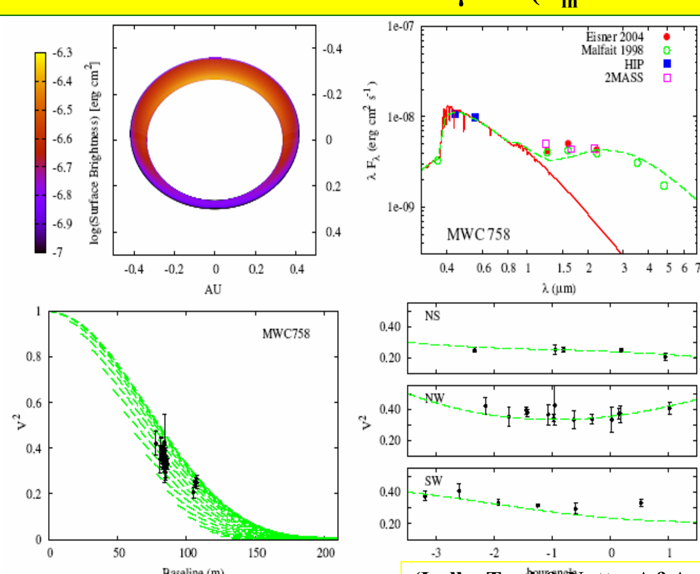
Analisys of the observations :

rim models have 3 parameters (inclination & PA, dust properties)

Incl = 40° -- PA = 145° -- a = 1.2 μm (R_{in} = 0.32AU)

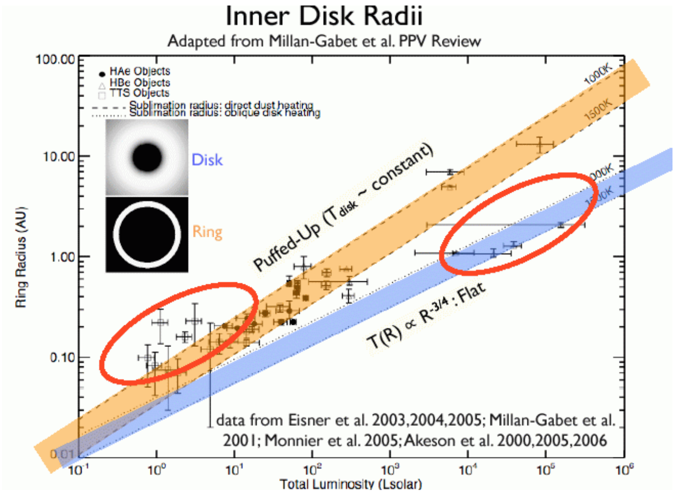
MWC 758

χ^2 test on the 3-dimesional space of the parameters



(Isella, Testi & Natta, A&A, 451, 951)

Rim models do well to first order



But the observations are still sparse, and the constraints weak

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- Disk masses are very poorly known
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- Evidence of keplerian rotation in the inner and outer disk
  - Some evidence of deviations (AB Aur)
- Stars of all masses have disks
- Many disks of HAe and TTS have rims
  - Inner regions (0.5AU for HAe stars) with gas only

Accretion: from the disk onto the star

★ Measurements of the mass accretion rate Macc (dM/dt) provide crucial information on the disk physical properties

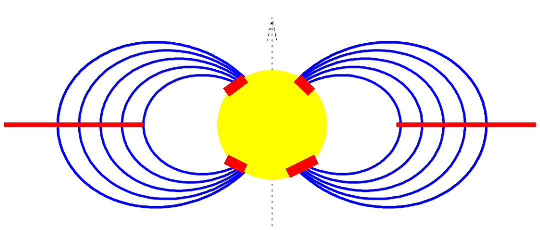
$$M_{acc} = \Sigma(R)\ 2\pi\ R\ v_R(R)$$

Disk mass

Mass and angular momentum transfer: viscosity

Magnetospheric accretion models

★ If the star has a magnetic field, the disk is truncated where the rate at which the magnetic field removes angular momentum from the disk exceeds the viscous stress



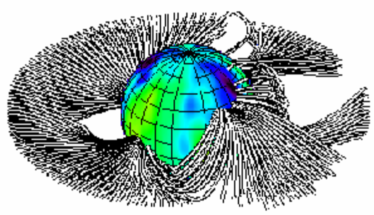
Hot spots: shock-heated photosphere
Very optically thick
$T \sim 10^4$ k
f ~1-10%
Continuum emission (veiling) forms here

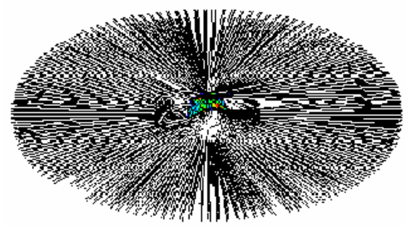
Accreting columns:
V(poloidal)~V(kepler)
High density
$T \sim 10^4$ K (?)
Optical emission lines form here

Magnetospheric accretion models for dipole field:
Calvet, Hartmann & Co., Lamzin et al.

Magnetospheric accretion:the role of stellar magnetic field

- ★ More complex field configurations are likely: do we have to revise Macc values??

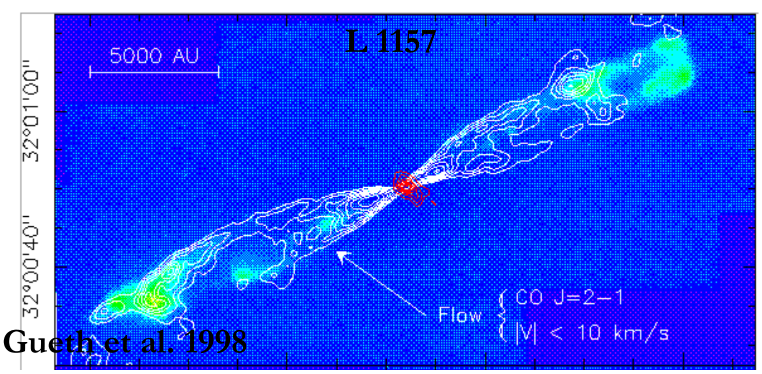




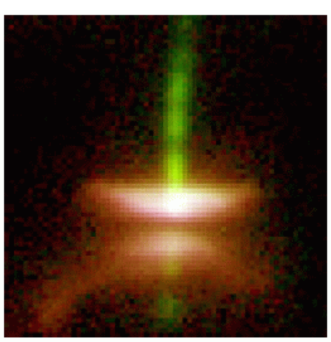
[Gregory et al. 2006]
[Romanova et al. 2002, 2004]
[Bouvier et al., PPV]

One needs to predict observable quantities

Outflows e Jets accompany accretion



Gueth et al. 1998



Mloss = dm/dt (outflow) ~ 10% Macc

very uncertain!!

How does one measure Macc?

- 1- From UV veiling, comparing observations to models

  TTS

- 2- By fitting Ha profiles, idem

  BDs+TTS

- 3- Using secondary indicators, calibrated on 1&2
  - U-band excess
  - Hydrogen IR line luminosity
  - CaII IR triplet luminosity

One starts with a sample of TTS in Taurus where Macc has been derived by comparing the observed veiling properties to model predictions; for some, it has been checked that the models reproduce also the hydrogen line profiles

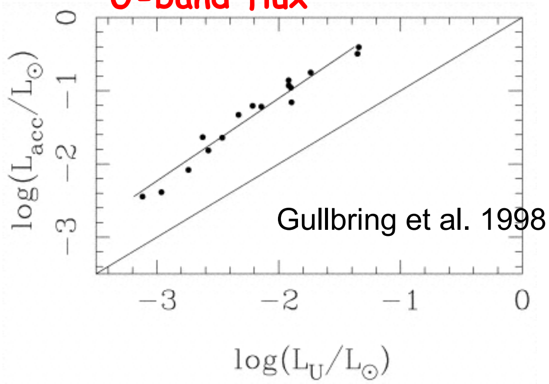
↓

For a few BDs, Macc has been derived by fitting Halpha profiles to models

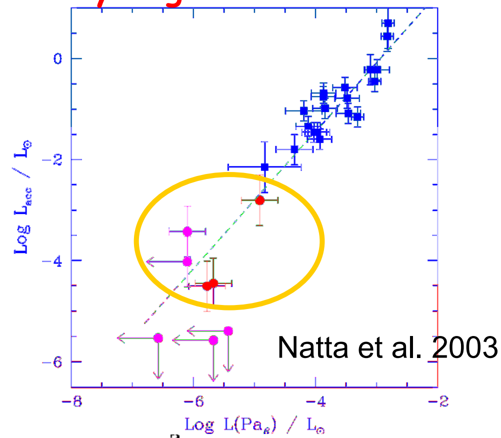
↓

The Macc of this sample are used to calibrate all secondary indicators

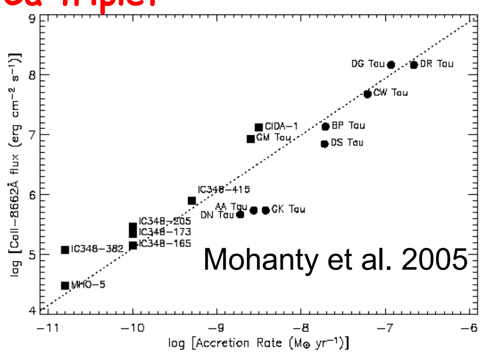
U-band flux

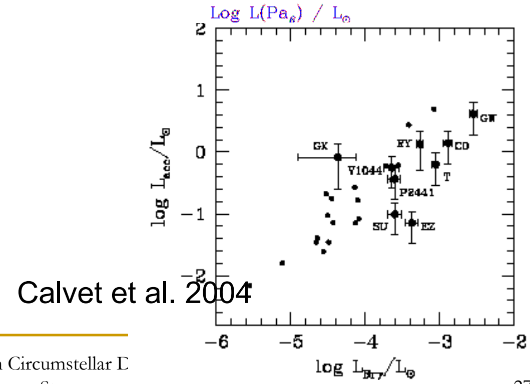


Hydrogen IR lines



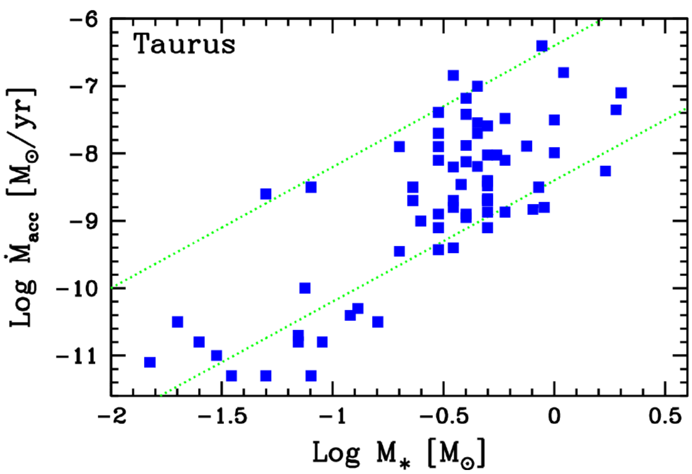
Ca triplet





Taurus

- ★ Class II + BDs with disks
- ★ Method: veiling + Ha fitting +CaII IR

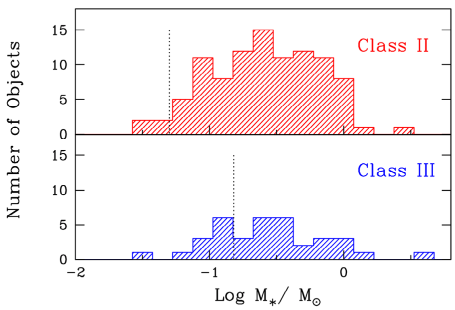


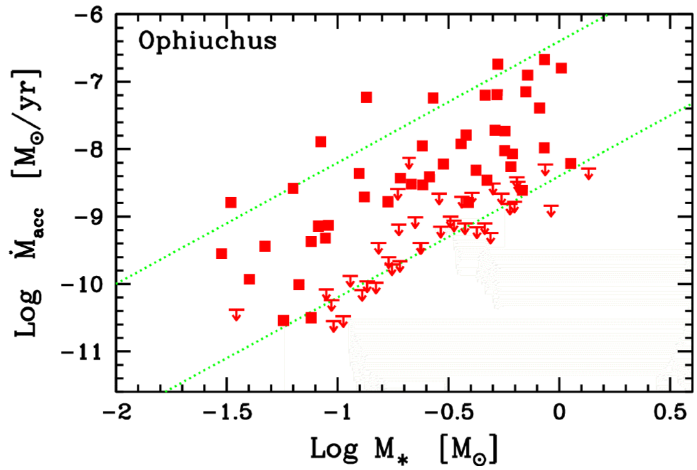
Gullbring et al. 1998
Muzerolle et al. 2003, 2005
Mohanty et al. 2005

Ophiuchus Class II

- ★ISOCAM Class II (complete to ~50 M_J)
- ★Method: from Pab luminosity

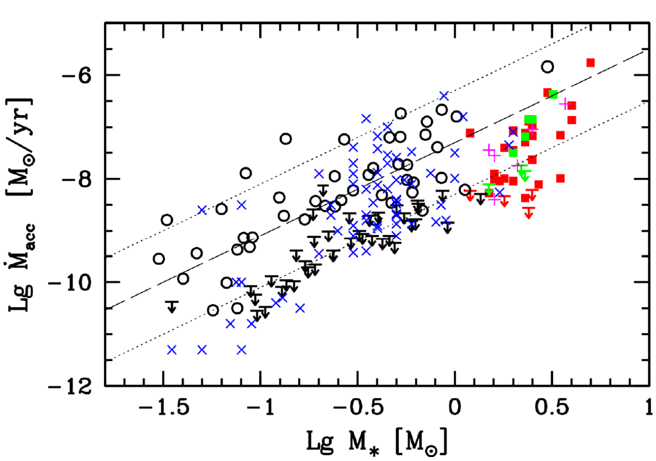
Natta et al. 2006

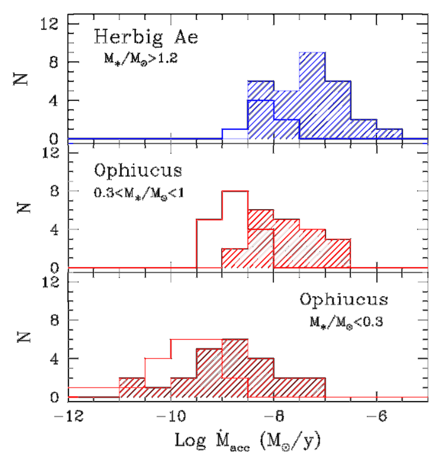




Herbig Ae

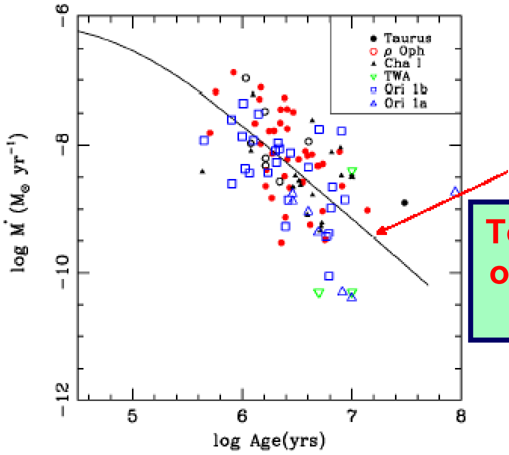
- ★30 Class II
- ★Method: from Brg luminosity





Garcia Lopez et al. 2006

Macc decreases with time



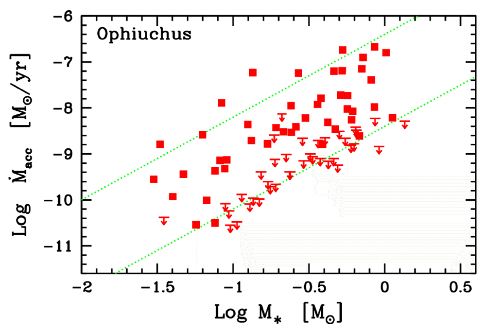
Macc ∝ $t^{-1.5}$

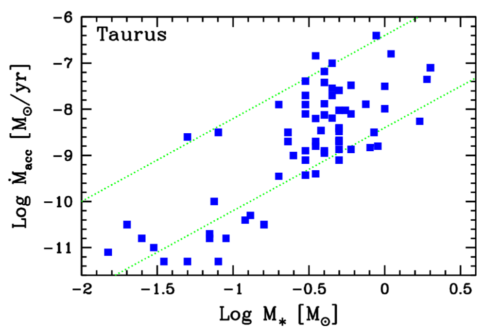
To account for a variation of a factor 100, one needs a spread in age of a factor 20: Too large!!

Sicilia-Aguilar et al. 2006

Current status of the observations

- Accretion in the inner disk is detected in objects of all mass, from BDs to intermediate-mass stars, in a number of star forming regions
- In each star forming region, there is a large spread (>a factor 100) of Macc for same Mstar, covered ~ uniformly.
- This is too large to be accounted for by the age spread.
- There is a steep correlation between Macc and Mstar (Macc ∝ Mstar$^{1.8}$)
- If true, this is steeper than standard viscous disk models can explain





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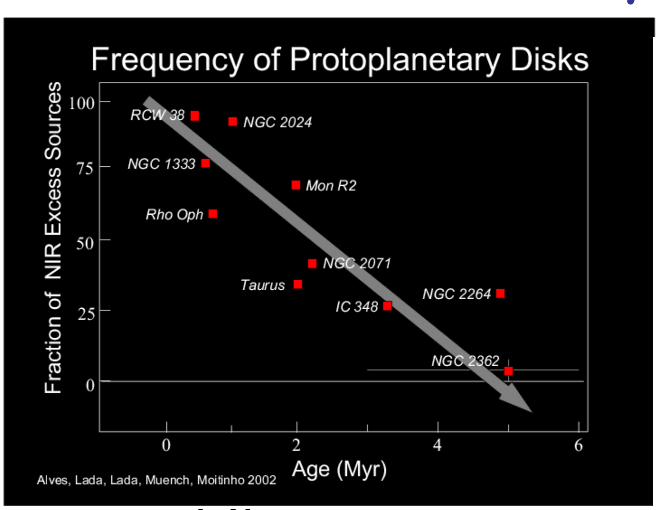
- ★ Objects of all masses have disks
  - – Same formation process
- ★ **Matter is accreted from the disks onto the star**

If the mass accretion rate traces disk physics, then we need to understand which factors control it, in addition to mass and time

is very

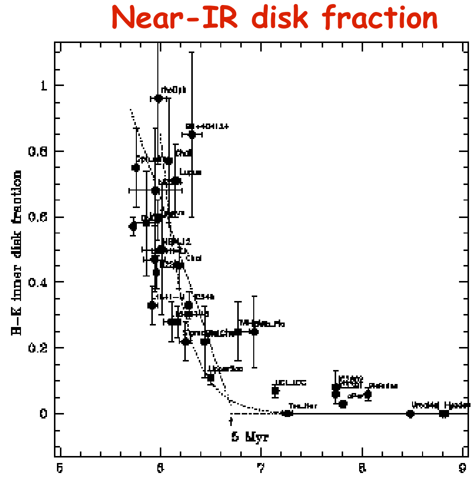
Evolution of disks with time

- ★ **Disks live few million years**



J. Alves

Near-IR disk fraction

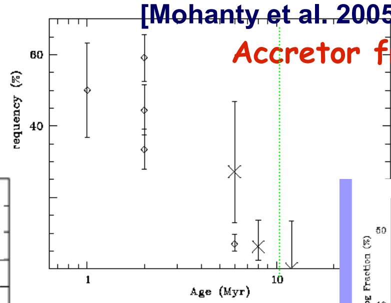


L. Hillenbrand

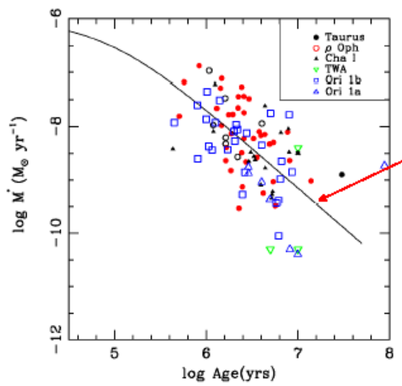
Time evolution: Macc decreases with time

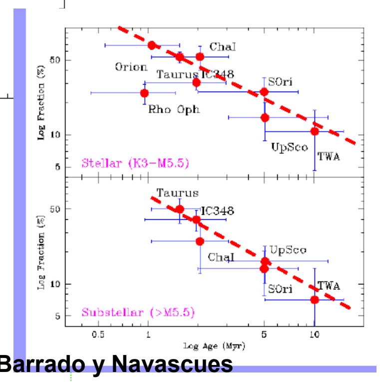
[Mohanty et al. 2005, Jayawardhana et al. 2006]

Accretor fraction



Sicilia-Aguilar et al. 2006





Barrado y Navascues

Macc ∝ $t^{-1.5}$, consistent with viscous

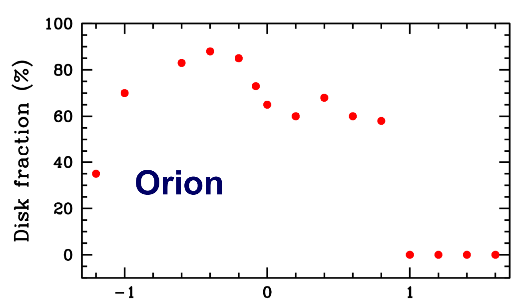
After 10 Myr, there are no disks left

Disk lifetime seems to be shorter in more massive objects

- Very few HBe stars have mm-detected disks
- Hillenbrand et al. 1998:

  "there is a clear trend of decreasing disk frequency with increasing stellar mass"

But plenty of HAe stars (isolated/older?) have disks



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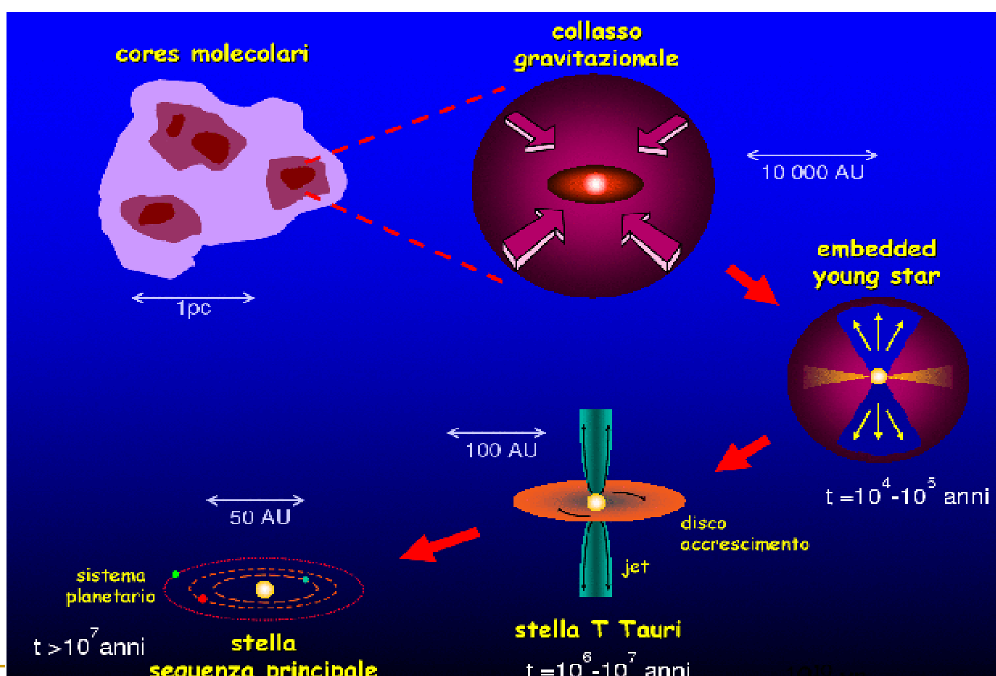
- Many disks of HAe and TTS have rims
  - Inner regions (0.5AU for HAe) with gas only stars
- Objects of all masses have disks
  - Same formation process
- Matter is accreted from the disks onto the star in objects of all masses
  - Macc increases sharply with Mstar, but the spread is very large
- All disks disappear in ~10 Myr, but many live much less- Why?

Pre-MS disks have a past



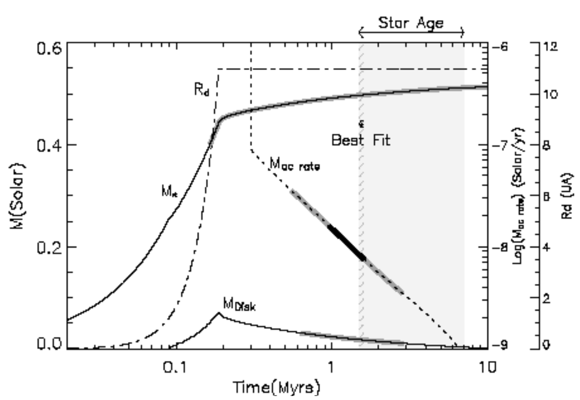
Cores and disks: a toy model

- The collapse of an isothermal sphere + disk viscous evolution: a core with solid body rotation Ω collapses, forming a disk and a central star; the disk evolves viscously while accreting from the core, and continues its evolution after the infall phase is over [Hueso and Guillot 2005]
- Model parameters: core mass Mcore (→ Mstar), infall rate Minfall (≡ sound speed), core rotation velocity Ω, viscosity (α)
- For fixed values of the parameters, one follows the evolution of Macc with time

Same Mcore, same Mstar, same t_0, different Ω

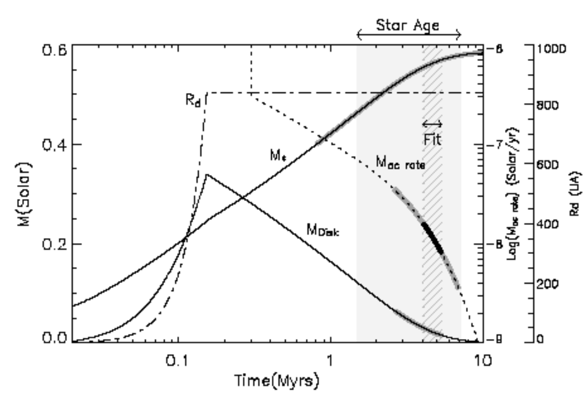
Small Ω, $Rc(t_0)$=11AU

Low Mdisk and Macc



Large Ω, $Rc(t_0)$=800 AU

Large Mdisk and Macc



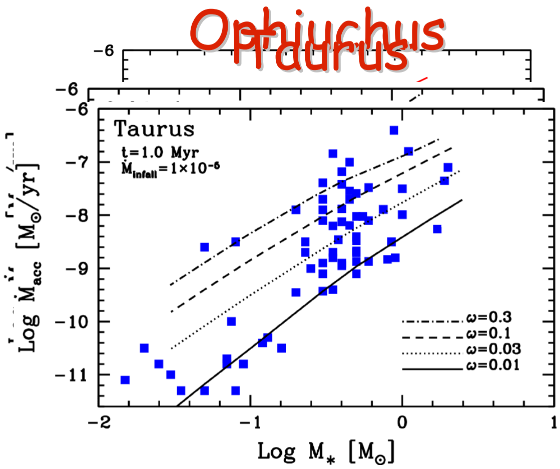
Hueso & Guillot 2005

The initial conditions may be the missing parameter(s) that determine disk properties and evolution

- Choose the core rotation so that for each M_{core} it is a fixed fraction of the core break-up speed:

Ω/Ω_{break} = ω = const.

Macc ☸ $Mstar^{1.8}$



Dullemond, Natta & Testi 2006

Beware of toy models!

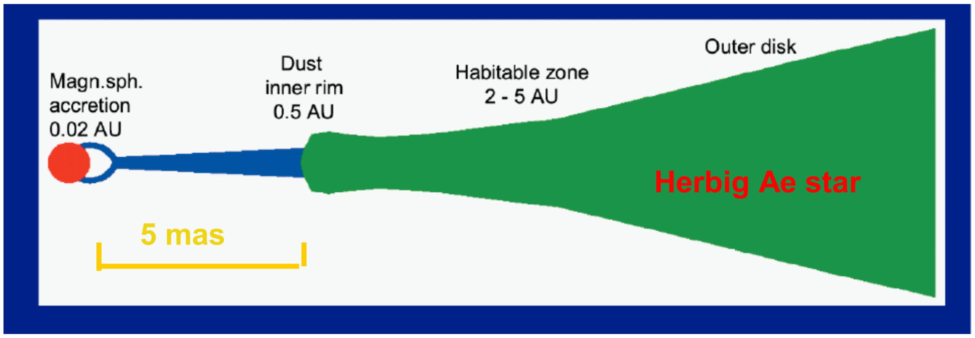
Summary

- Pre-MS disks are flared, to varying degree (SEDs)
  - Grain growth and settling
- Disks are large, R ~ a few hundreds AU
- The surface density decreases roughly as 1/R
- We are beginning to see structures in disks
- Disk masses are very poorly known
  - Estimates in the literature are likely underestimated
- Evidence of keplerian rotation in the inner and outer disk
  - Some evidence of deviations (AB Aur)
- Many disks of HAe and TTS have rims
  - Inner regions (0.5AU for HAe) with gas only stars
- Objects of all masses have disks
  - Same formation process
- Matter is accreted from the disks onto the star
  - Objects of all masses accrete
  - Macc increases sharply with Mstar, but the spread is very large
- All disks disappear in ~10 Myr, but many live much less- Why?
- To understand disks, we may have to understand cores!

Grand summary

- Pre-MS disks properties vary very much from object to object – what is a typical disk?
- We know disks around stars over a mass range >100, we should make use of it.
- We should be aware of the limitations of the observations (but we should not ignore them either!)

The inner disk is very small!



It is a job for near-IR interferometers: VLTI/AMBER

In HAe stars, there is a significant portion of the inner disk with no dust.