Disk Properties, Accretion and Lifetimes: An Observer's View

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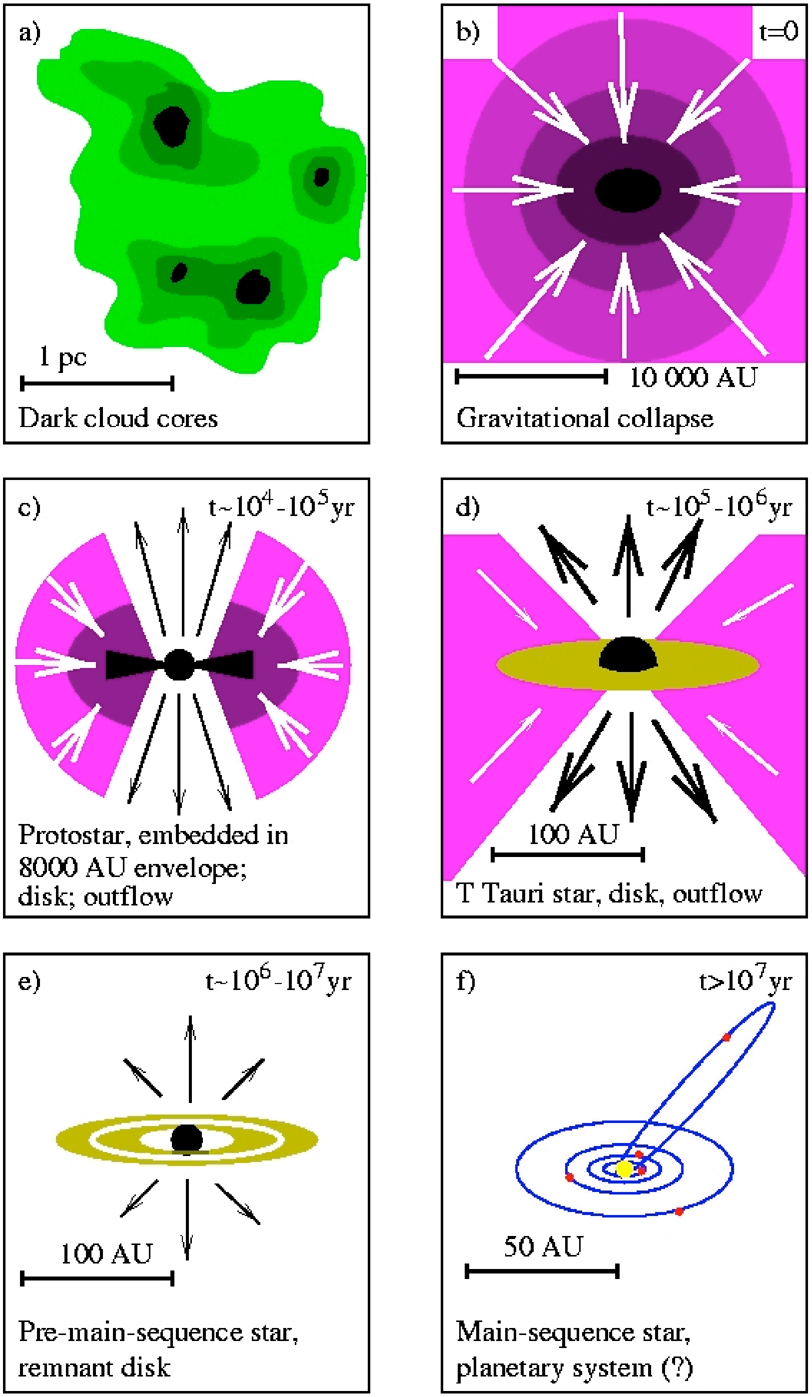
From Clouds to Planets

(schematic with spatial and temporal scales)



a) Dark cloud cores

b) Gravitational collapse

c) Protostar, embedded in 8000 AU envelope; disk; outflow

d) T Tauri star, disk, outflow

e) Pre-main-sequence star, remnant disk

f) Main-sequence star, planetary system (?)

Hogerheijde 1998, after Shu et al. 1987

Classifying Young Stellar Objects from their SEDs

Class I (& flat sp.): $\alpha \geq -0.3$

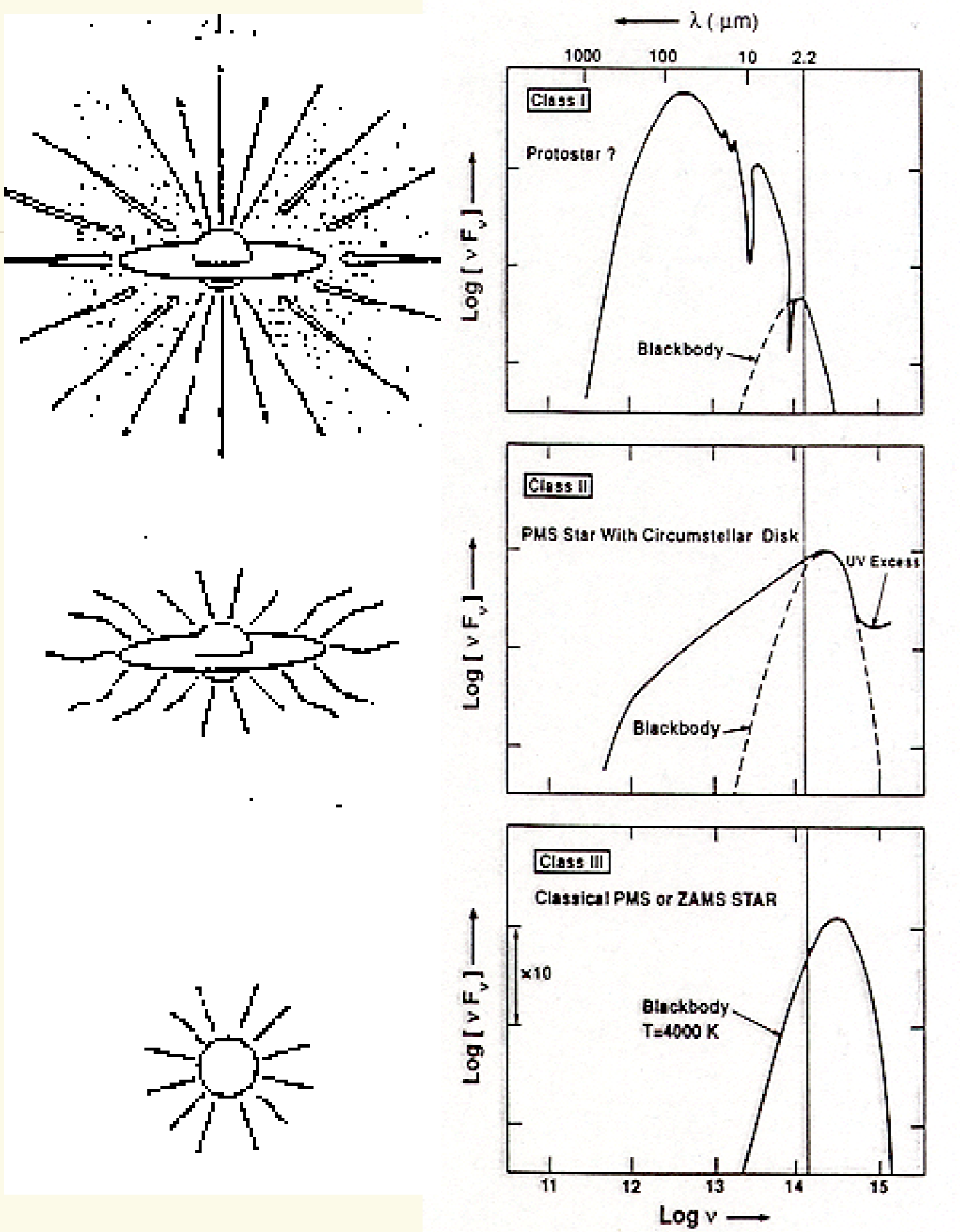
Class II: $-0.3 > \alpha \geq -1.6$

Class III: $\alpha < -1.6$

Spectral index

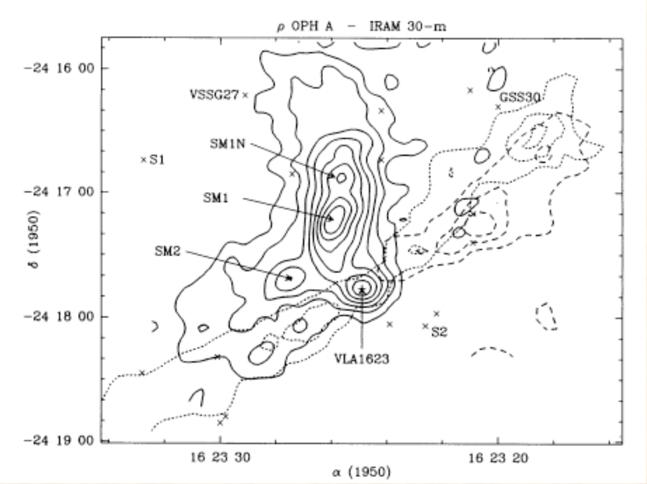
$$\alpha = d\log(\lambda F_\lambda)/d\log(\lambda).$$

cf. Lada (1987)



Class 0 YSOs: true protostars?

(André, Ward-Thompson, & Barsony 1993)

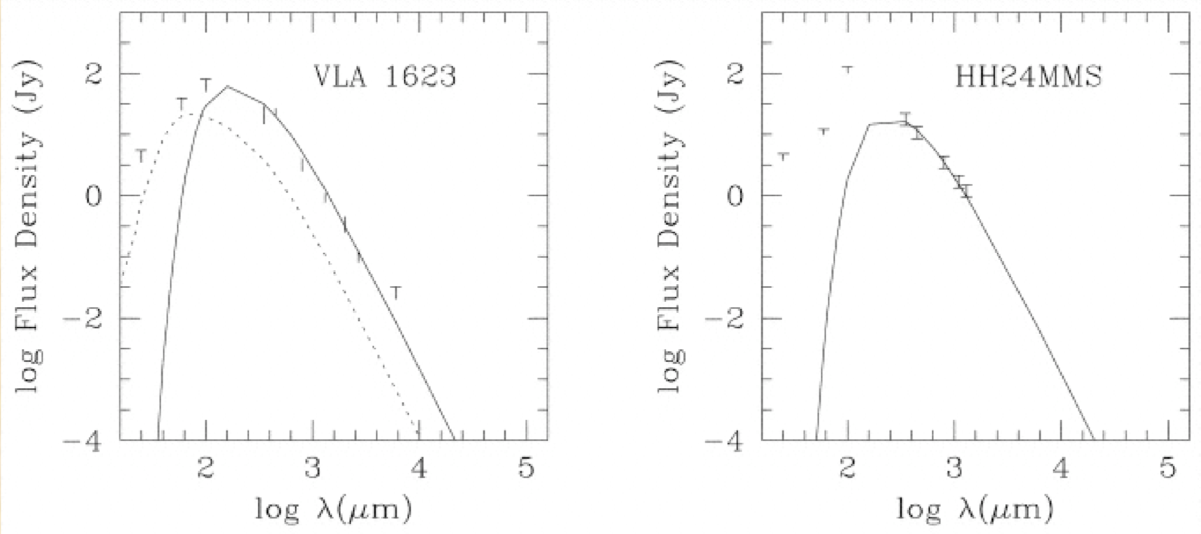


SEDs that peak at sub-mm λ

invisible at λ < 10 μm

$M_{env} > M_*$

strong outflows (e.g., in CO)

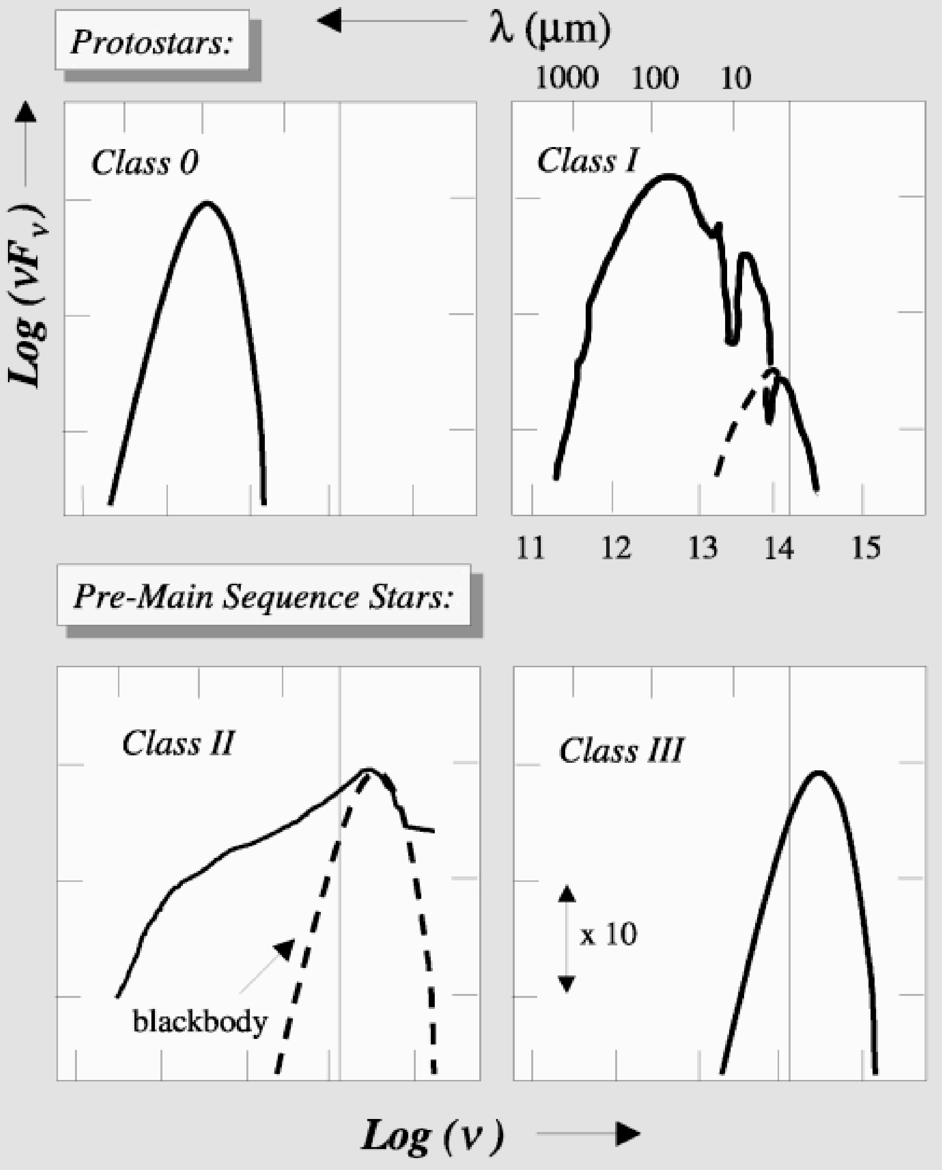


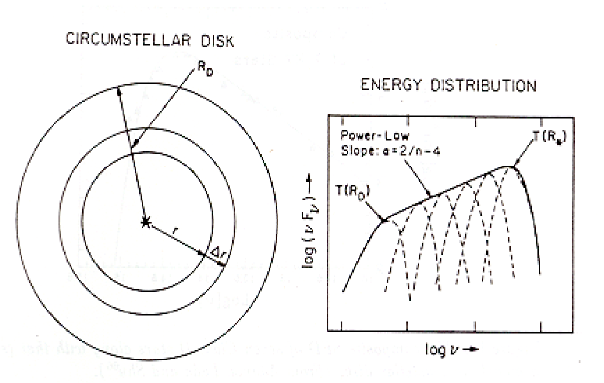
infall rates

$\geq 10^{-4}\ M_{Sun}/yr$

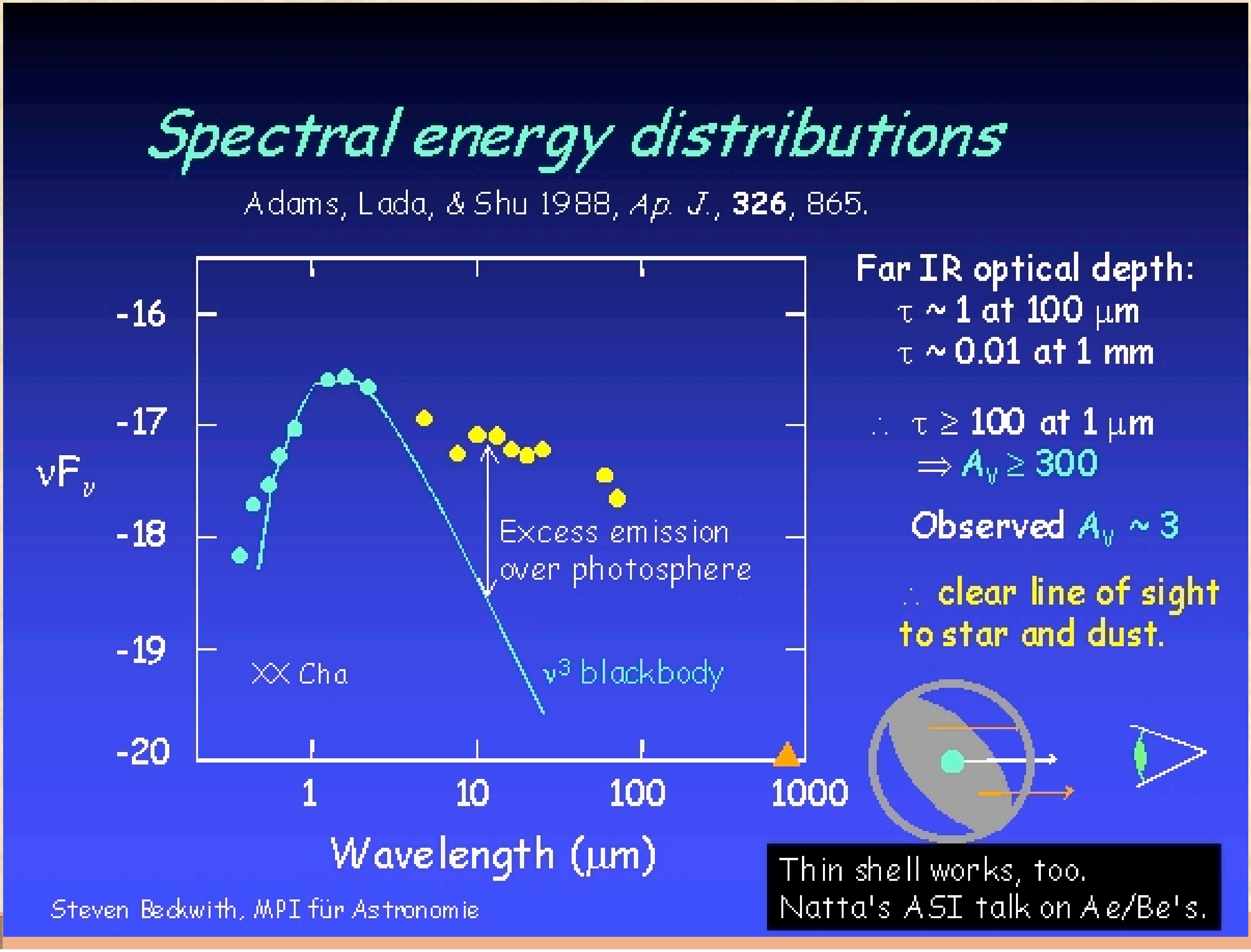
(Jayawardhana, Hartmann & Calvet 2001)

YSO ENERGY DISTRIBUTIONS





How do we know disks exist?



Spectral energy distributions

Adams, Lada, & Shu 1988, *Ap. J.*, **326**, 865.

Far IR optical depth:
$\tau \sim 1$ at 100 μm
$\tau \sim 0.01$ at 1 mm

$\therefore\ \tau \geq 100$ at 1 μm
$\Rightarrow A_V \geq 300$

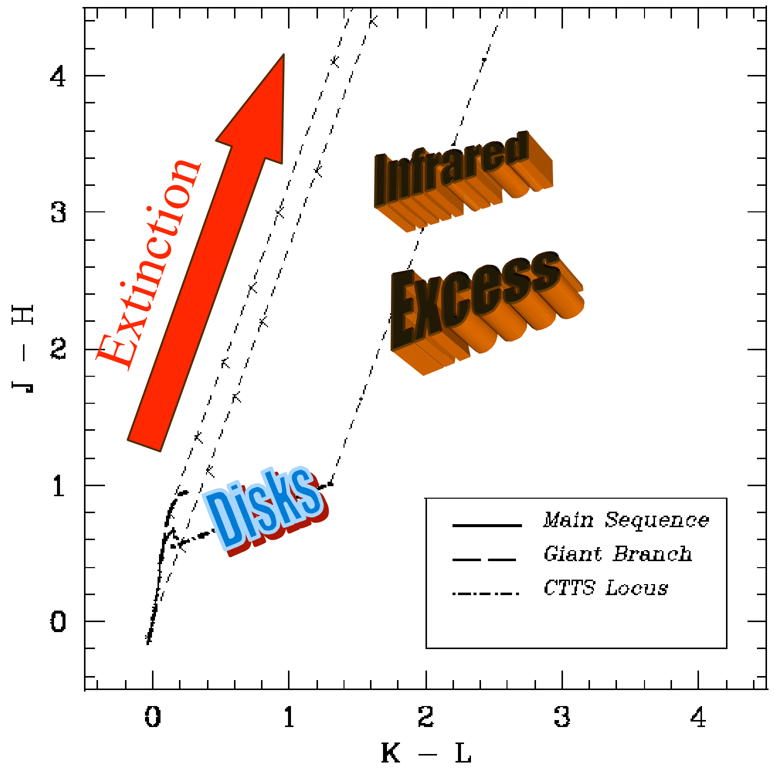
Observed $A_V \sim 3$

$\therefore$ clear line of sight to star and dust.

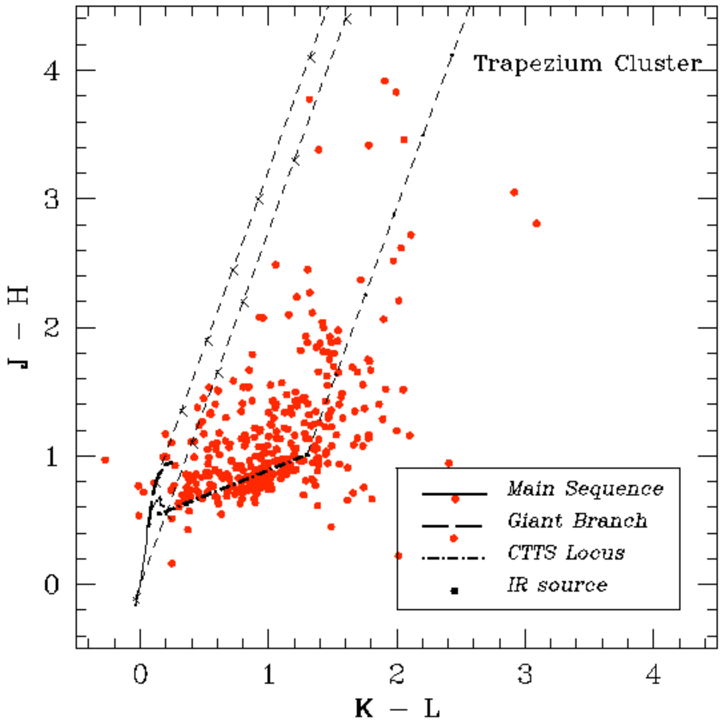
Thin shell works, too.
Natta's ASI talk on Ae/Be's.

Steven Beckwith, MPI für Astronomie

Infrared Color-Color Diagram

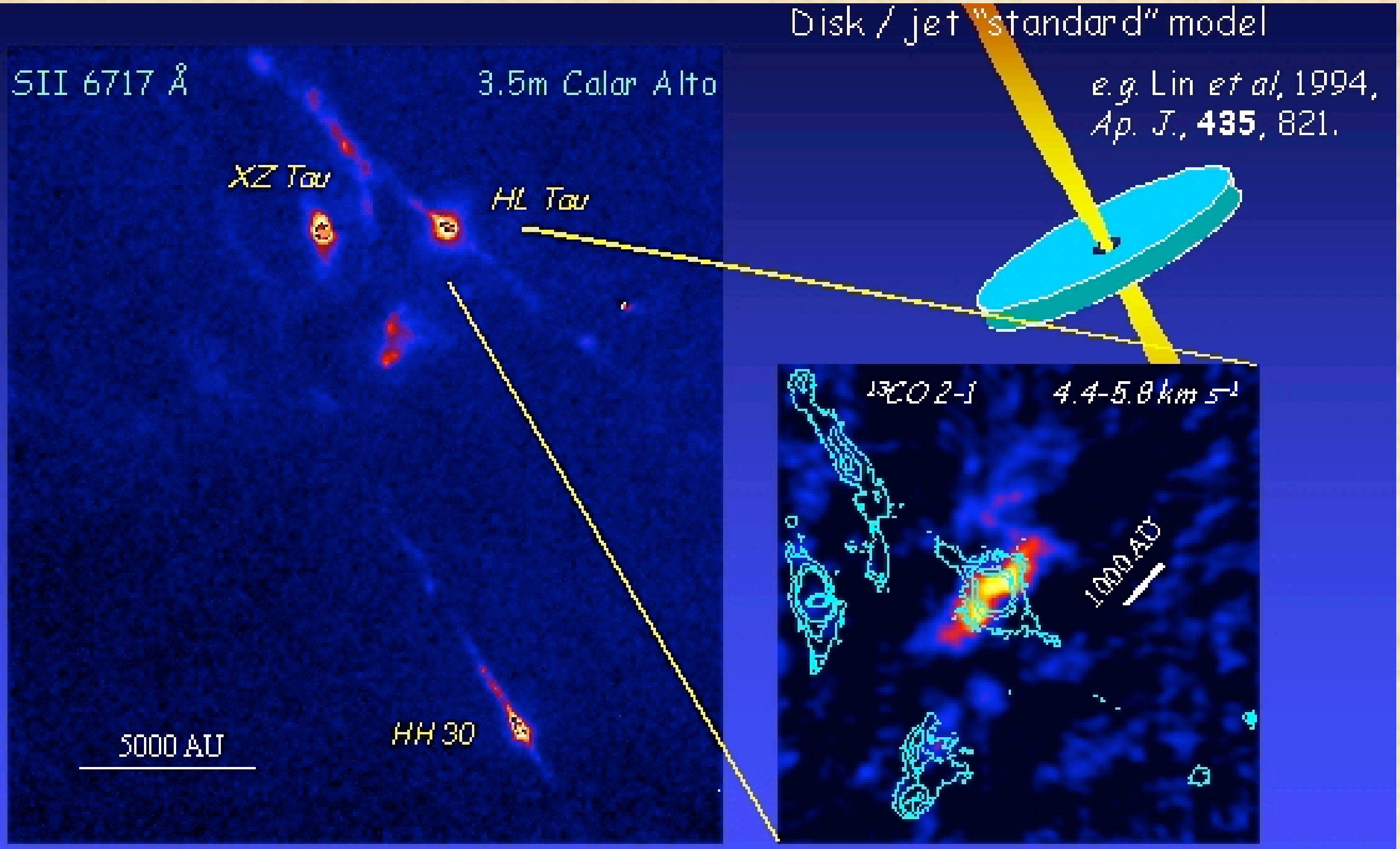


Excess infrared emission, consistent with disks, seen in 50-90% of 1-Myr-old stars



J-H/K-L for Trapezium
(Lada et al. 2000)

Images of disks provided “proof”



Disk / jet “standard” model

e.g. Lin *et al*, 1994, *Ap. J.*, **435**, 821.

Mundt *et al.* 1990, *A&A*, **232**, 37.

Sargent & Beckwith 1987, *Ap. J.*, **323**, 294.

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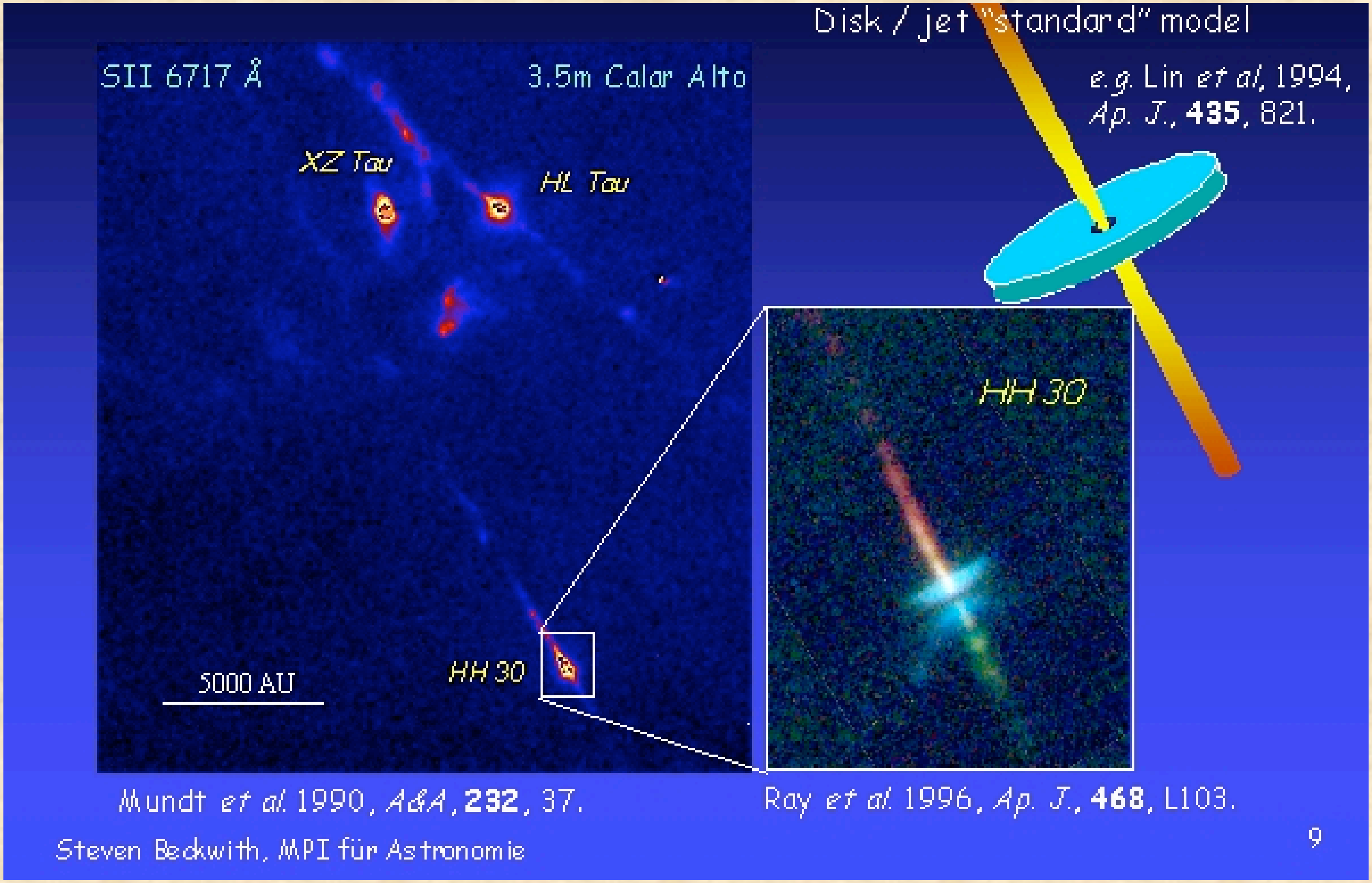

Disk / jet "standard" model

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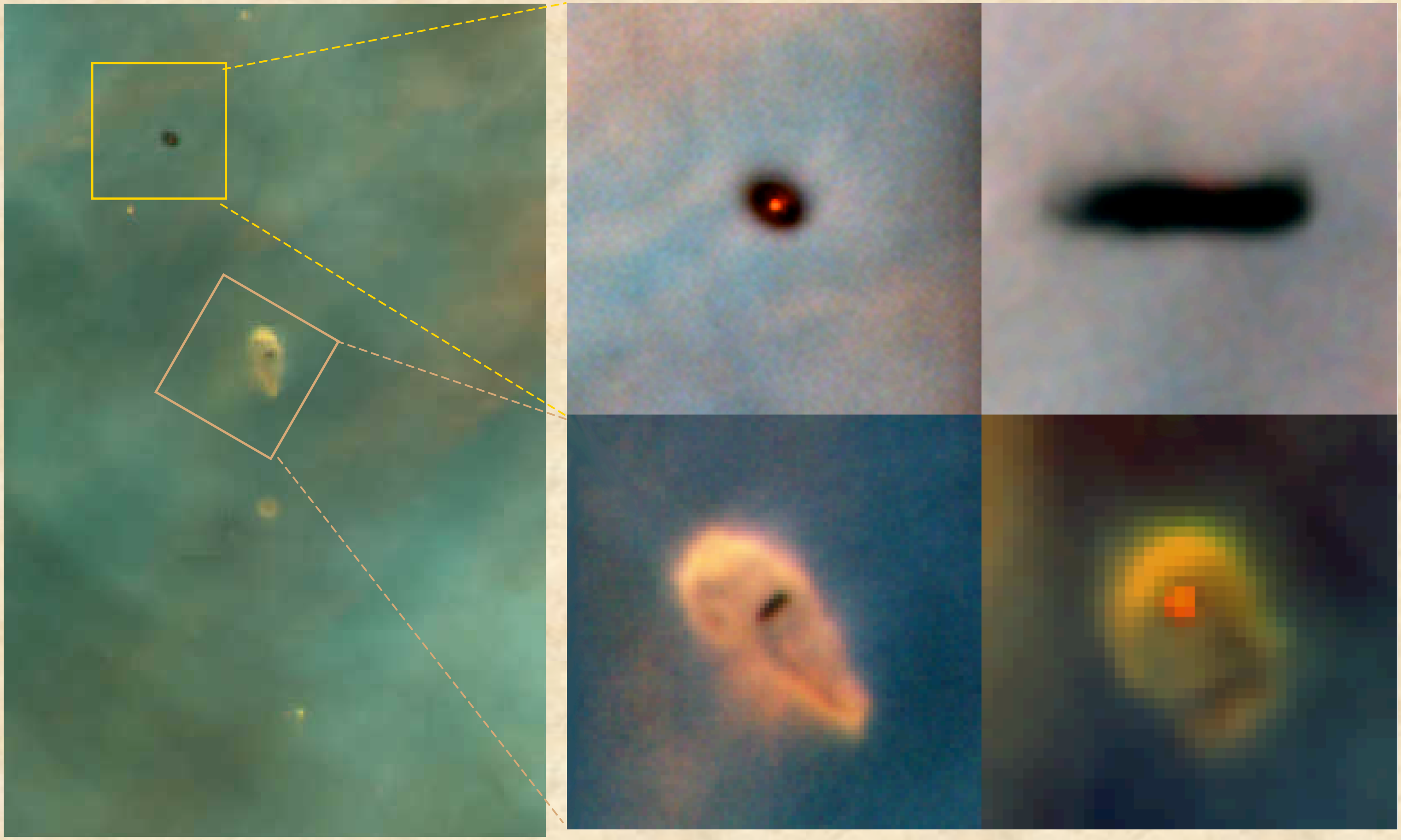
Mundt *et al.* 1990, *A&A*, **232**, 37.

Ray *et al.* 1996, *Ap. J.*, **468**, L103.

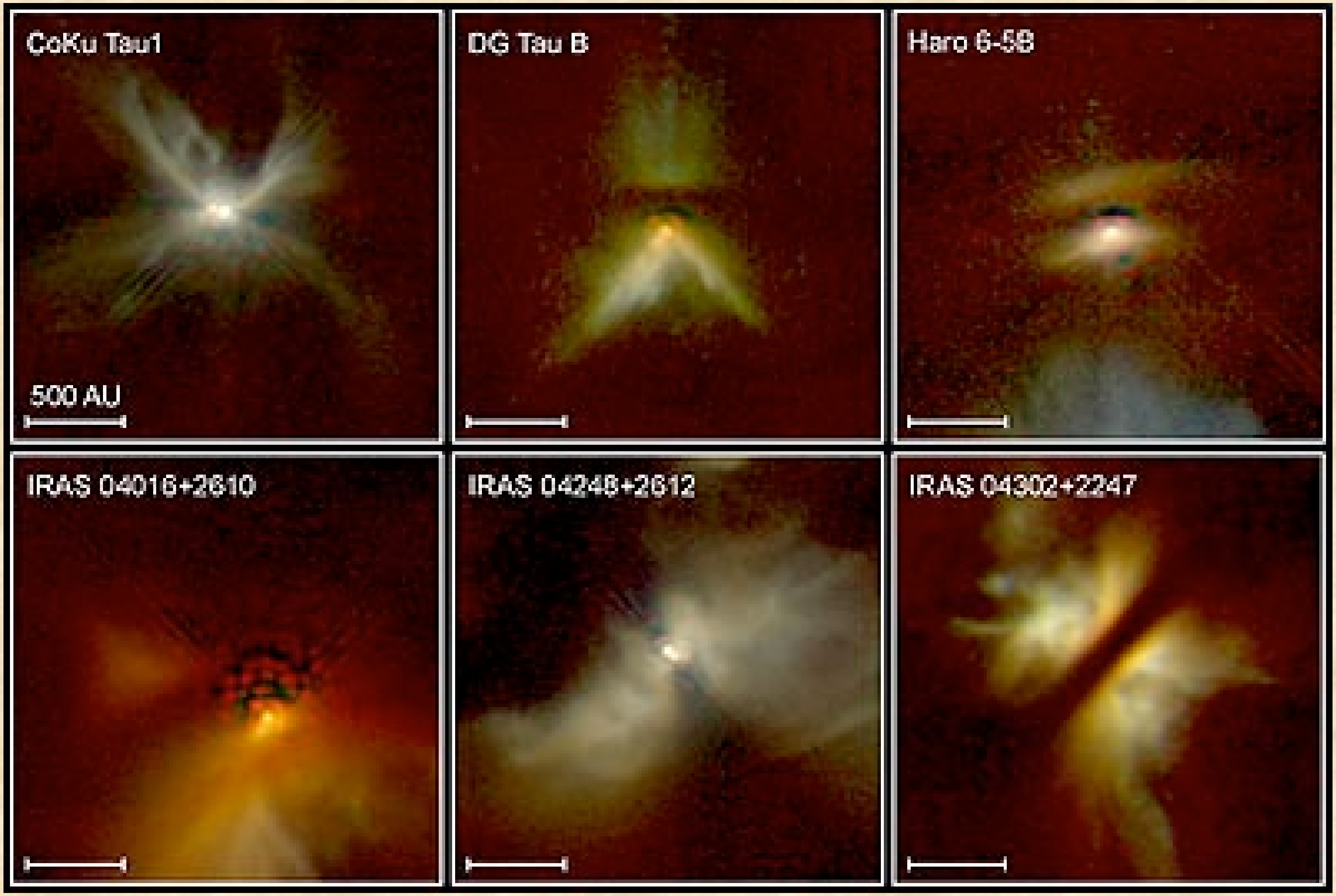
Steven Beckwith, MPI für Astronomie

Many resolved disks in Orion



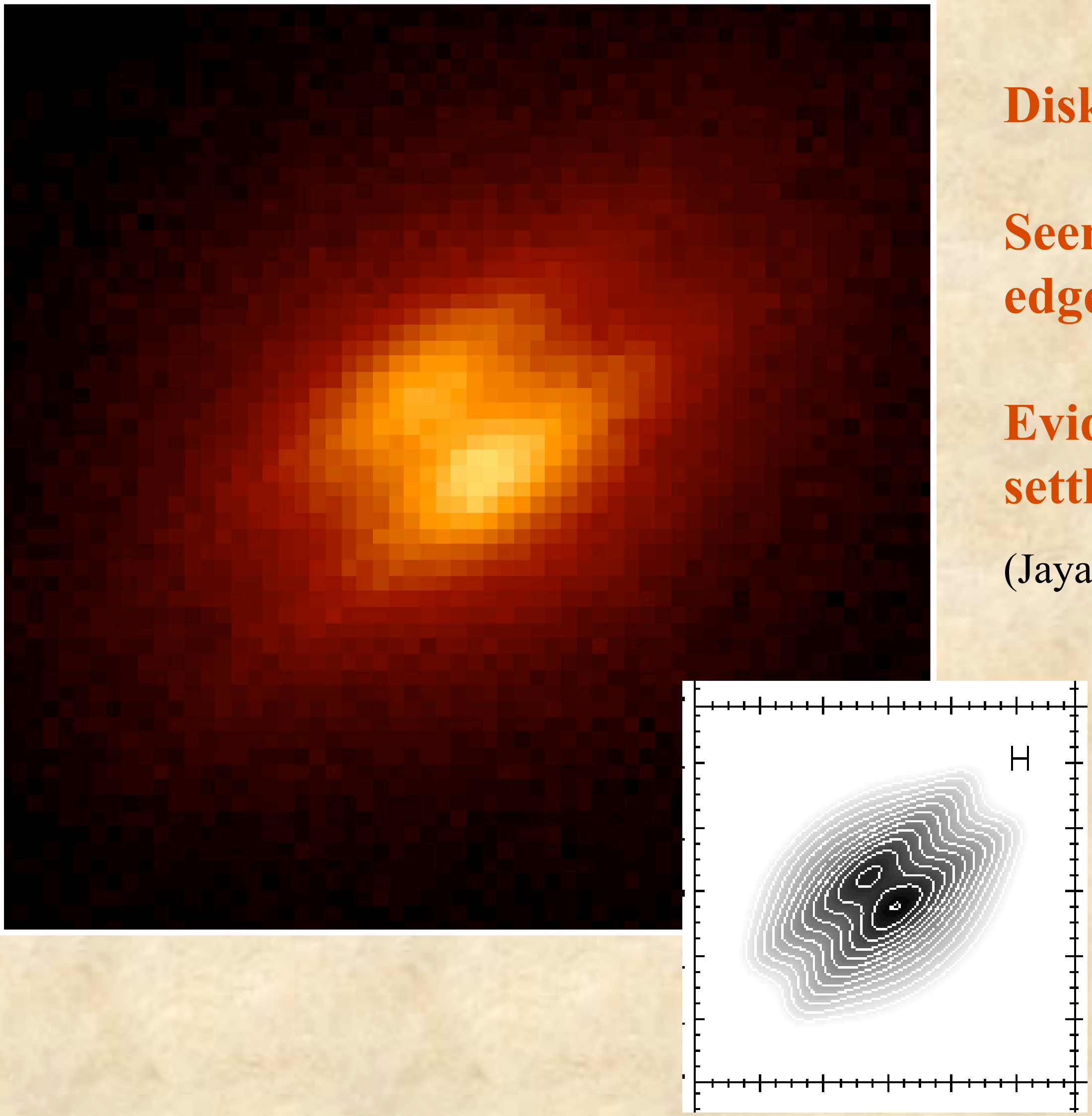
(O'Dell & Wen 1992; McCaughrean & O'Dell 1996)

NICMOS Images of Protoplanetary Disks in Taurus



Padgett et al. (1999)

Detection of an Edge-On Disk in MBM12 with Gemini AO



Disk is 150 AU in radius

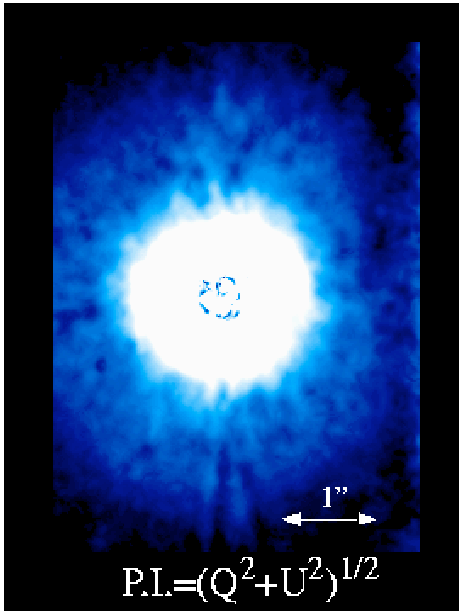
Seen just 3 degrees from edge-on

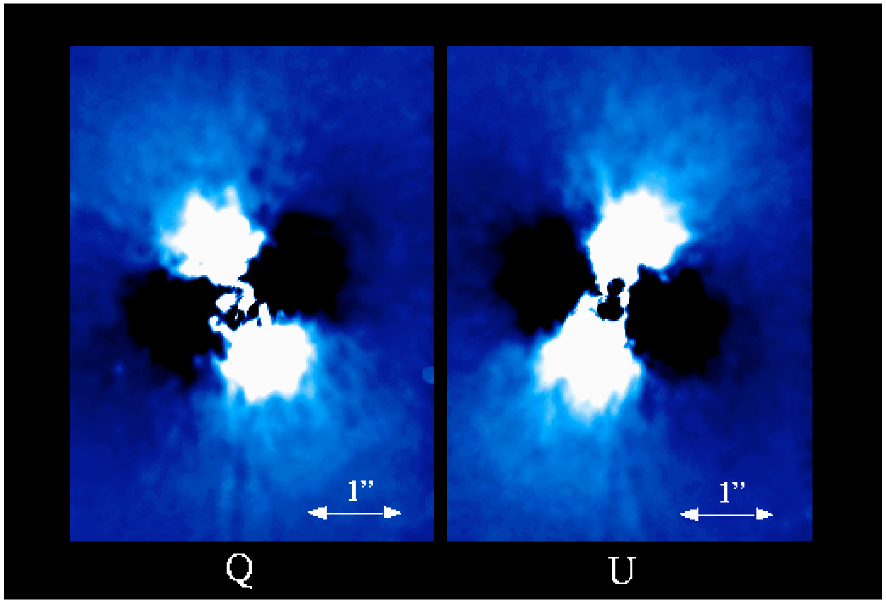
Evidence for dust settling to the midplane?

(Jayawardhana et al. 2002)

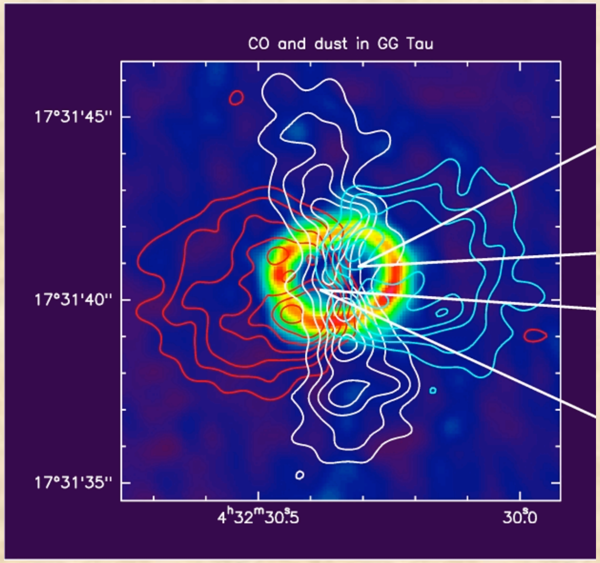
TW Hydra H-Band Dual Imaging Polarimetry

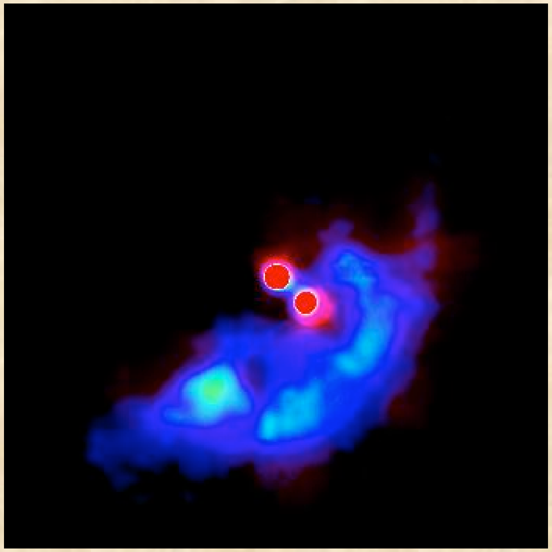
Observations taken by Dan Potter (UH) with the 36 element curvature AO system "Hokupa'a" mounted on the Gemini North Telescope.



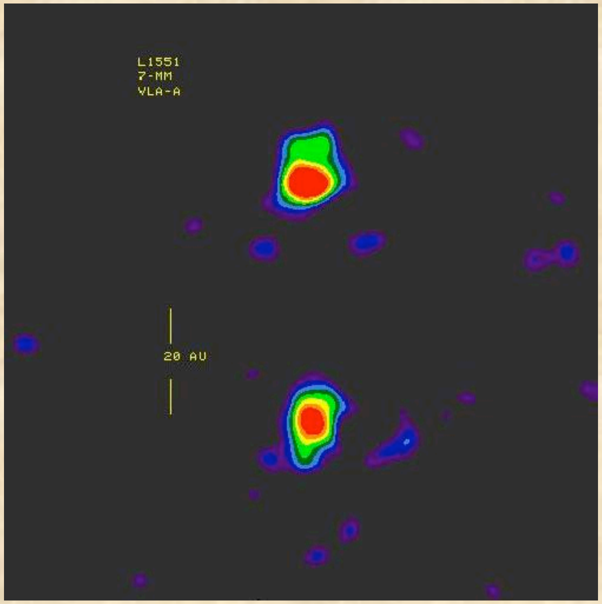


Disks in Binary Systems





GG Tau in scattered light with AO



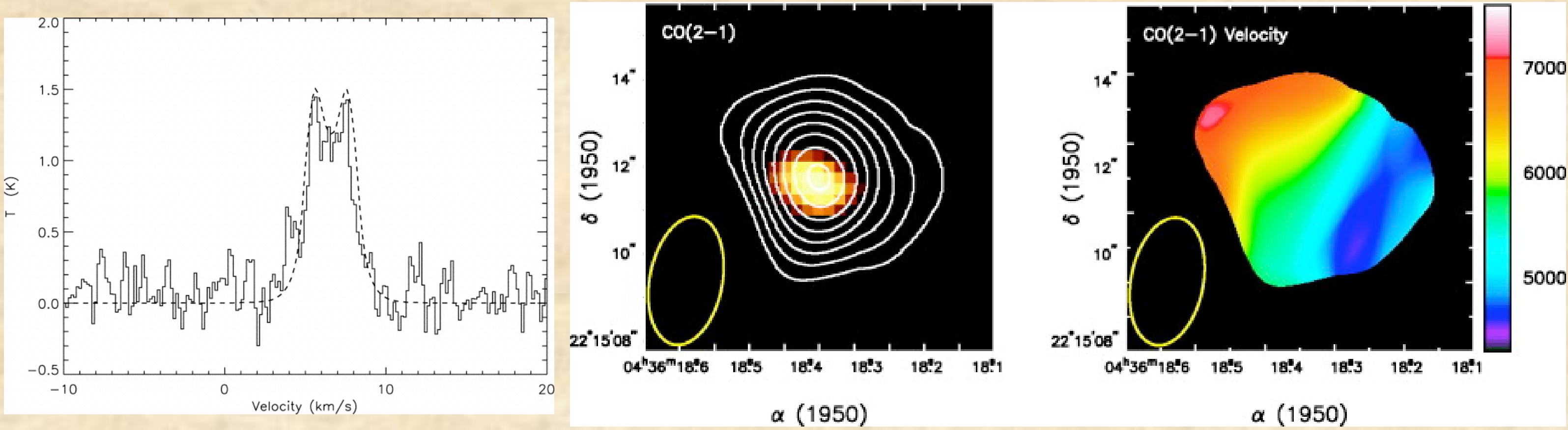
Detecting Gas in Disks

Difficult to detect H_2

Depend on CO, which is a tracer species

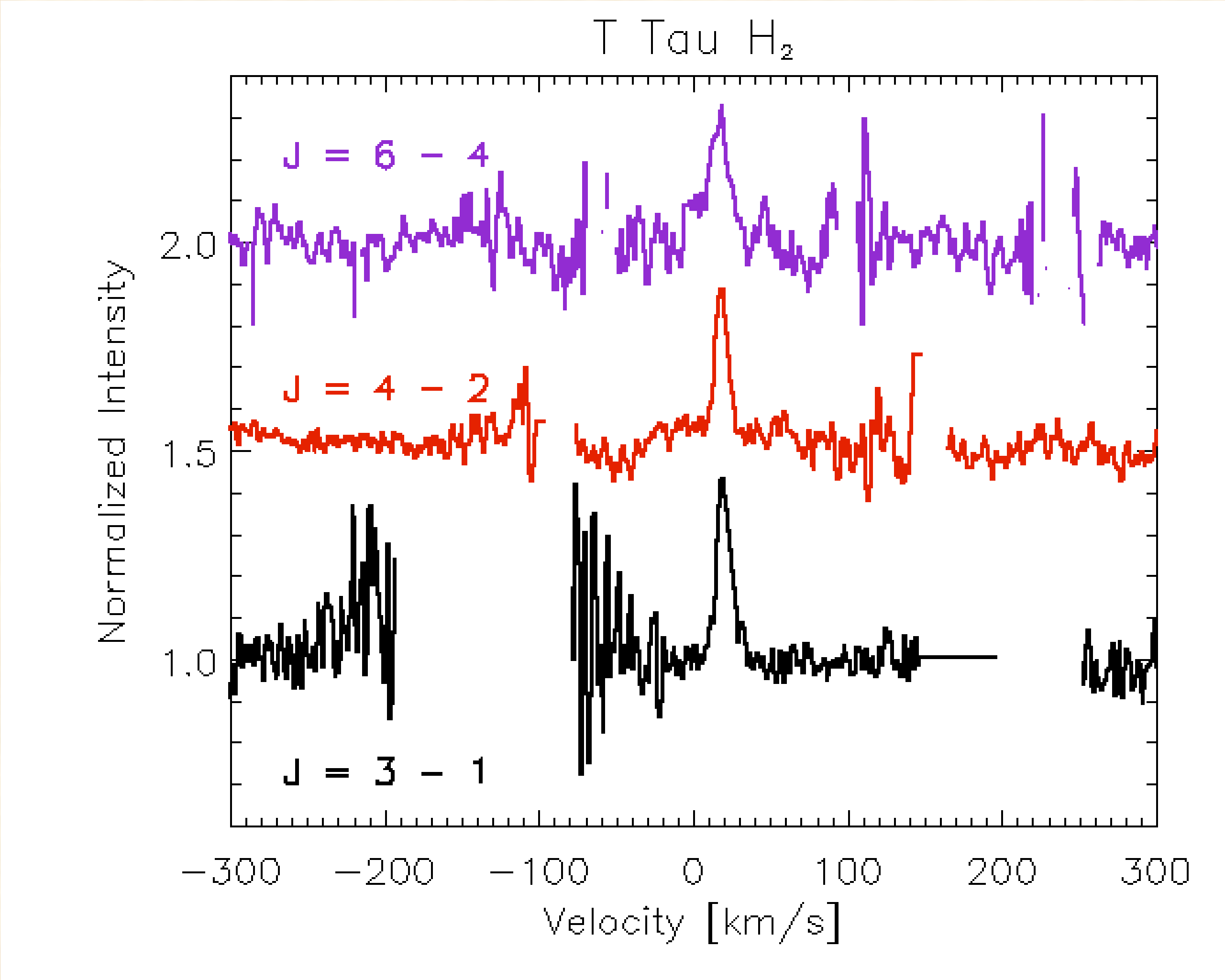
Possible to trace Keplerian rotation

But CO could “freeze out” on to grains and deplete

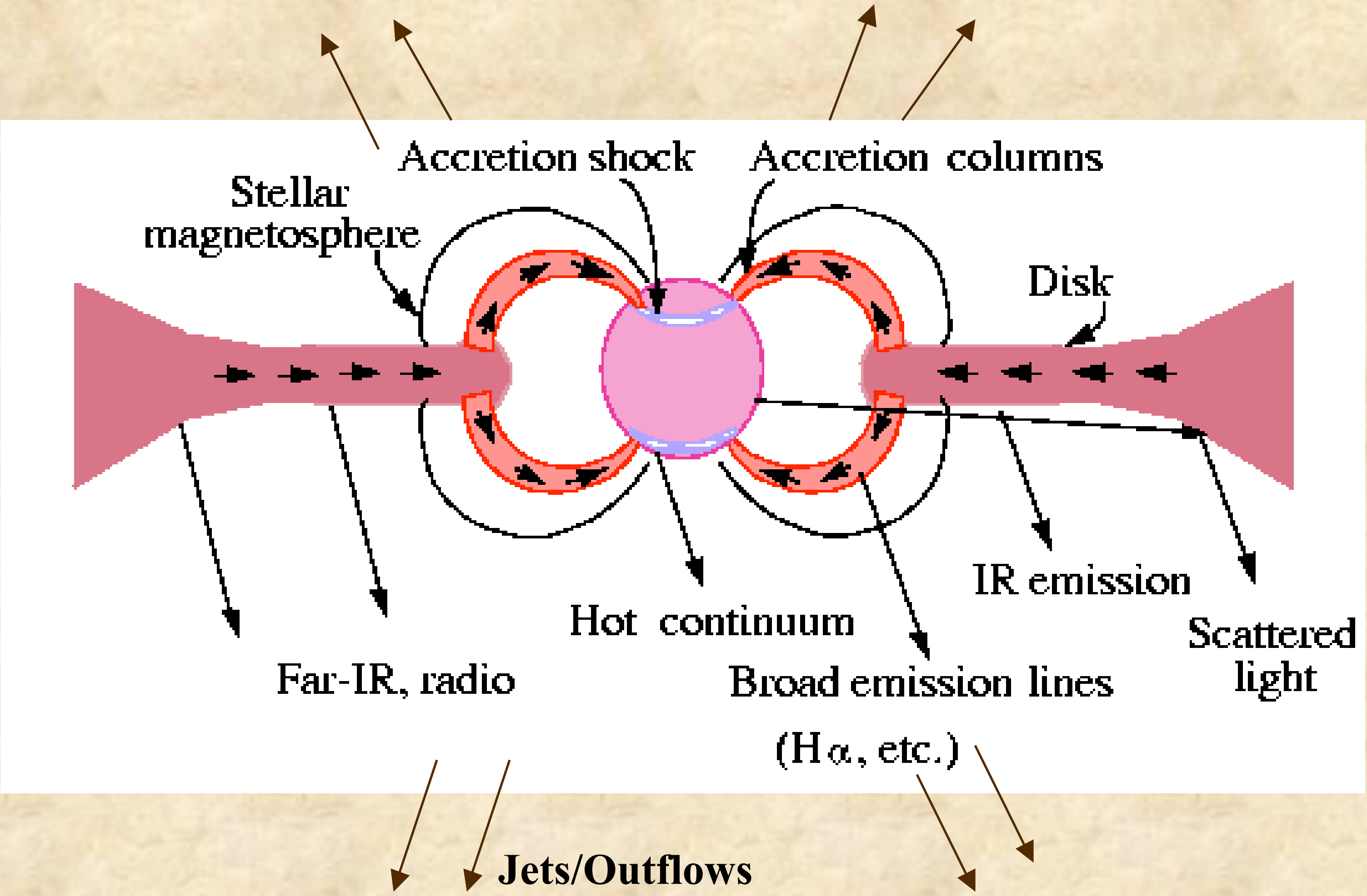


LkCa 15 (Qi et al. 2003)

Detecting (Warm) Gas: pure rotational line of H_2



T Tauri Star


Accretion shock
Accretion columns
Stellar magnetosphere
Disk
IR emission
Scattered light
Hot continuum
Far-IR, radio
Broad emission lines
(Hα, etc.)
Jets/Outflows

How are T Tauri disks heated?

"Standard" flat disks (with or without accretion)

Lynden-Bell & Pringle (1974)

Adams, Lada & Shu (1987, 1988)

How does T_{disk} vary with r? What's the resulting SED?

HOMEWORK PROBLEM!

Geometrical changes: Flaring

Kenyon & Hartmann 1987, *Ap. J.*, **323**, 714.

- gravity $\approx (z/r)(GM/r^2) \sim r^{-3}$
- absorbed radiation $\sim \sin\theta' \gg \sin\theta$
- $T_{flare}(r) > T_{flat}(r)$, especially at large r

$$\frac{h}{r} \sim r^{2/7}$$

$$T_i(r) \sim r^{-6/15}$$

BUT

→ cannot account for *flat* SEDs

→ needs radiative transfer, too.

Radiative transfer

Chiang & Goldreich 1997, *Ap. J.*, 490, 368.

- optical light absorbed $\tau_V \sim 1$, $\tau_{IR} \ll 1$
- small grains "bare" => $T_{grain} > T_{blackbody}$
- disk emission $\tau_{IR} < 1$ (5 - 100 μm)

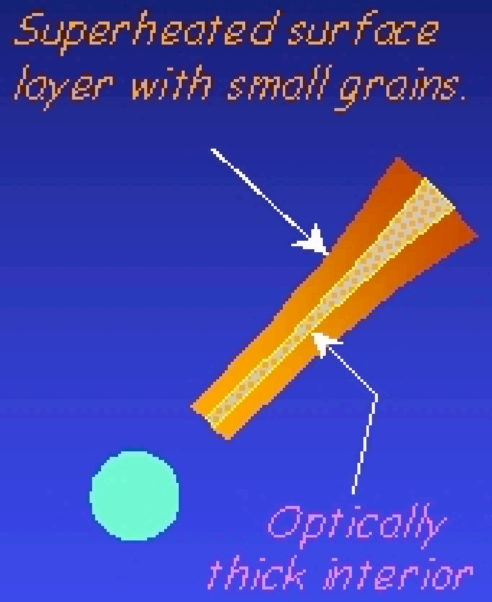
$$\frac{h}{r} \approx 0.9 \left(\frac{r}{209\ AU}\right)^{\frac{13}{45}}$$

still cannot account for *very flat* SEDs but does fit majority.

$$T_i(r) \approx 21\,K \left(\frac{r}{209\ AU}\right)^{\frac{19}{45}}$$

Prediction: infrared emission is optically *thin*.

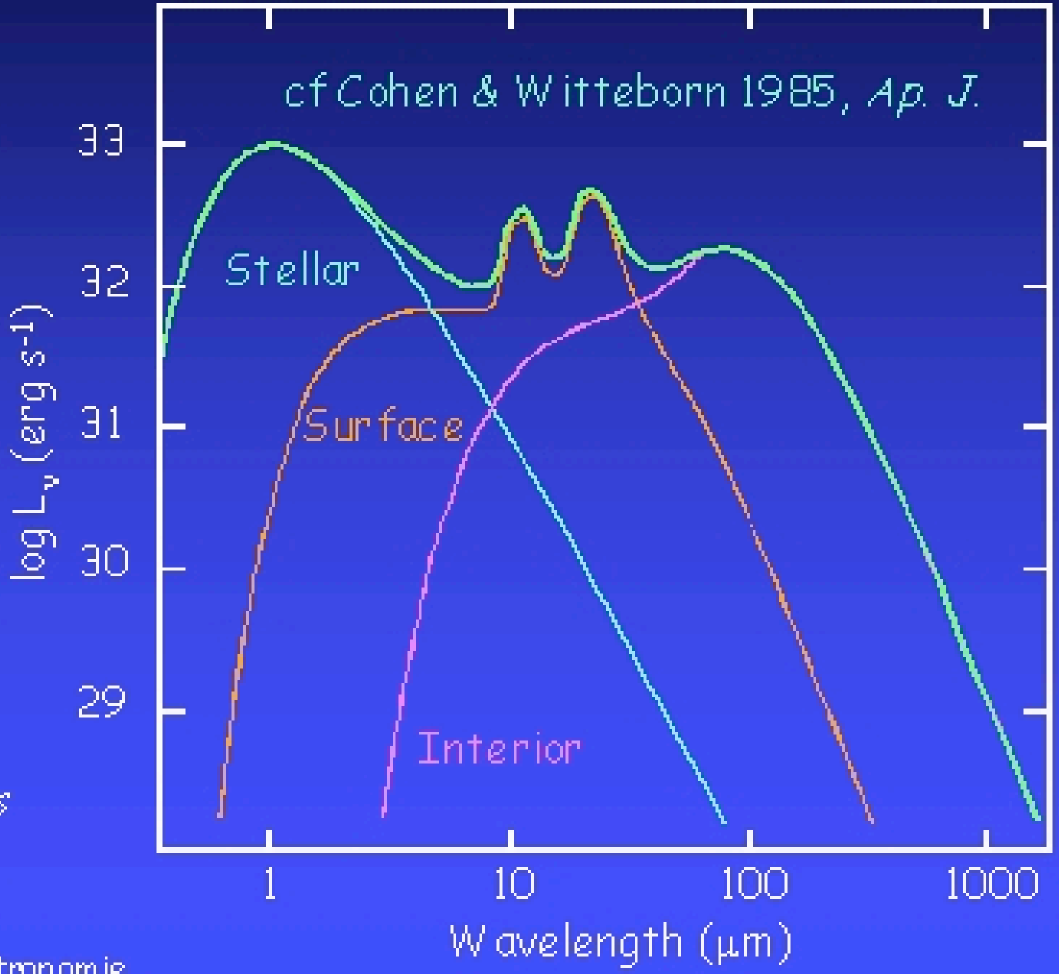
Optically thin ⇒ emission features



Superheated surface layer with small grains.

Optically thick interior

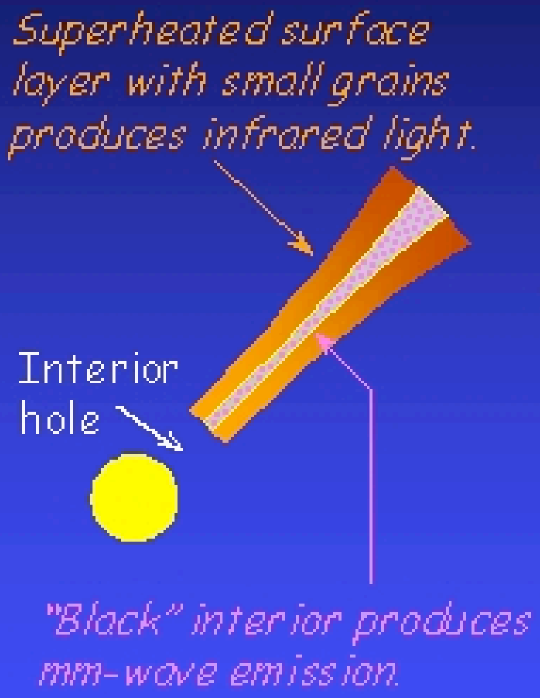
Chiang & Goldreich 1997, *Ap. J.*, **490**, 368.



cf Cohen & Witteborn 1985, *Ap. J.*

Surface layer τ_1:
dust emission features
(face-on orientation).

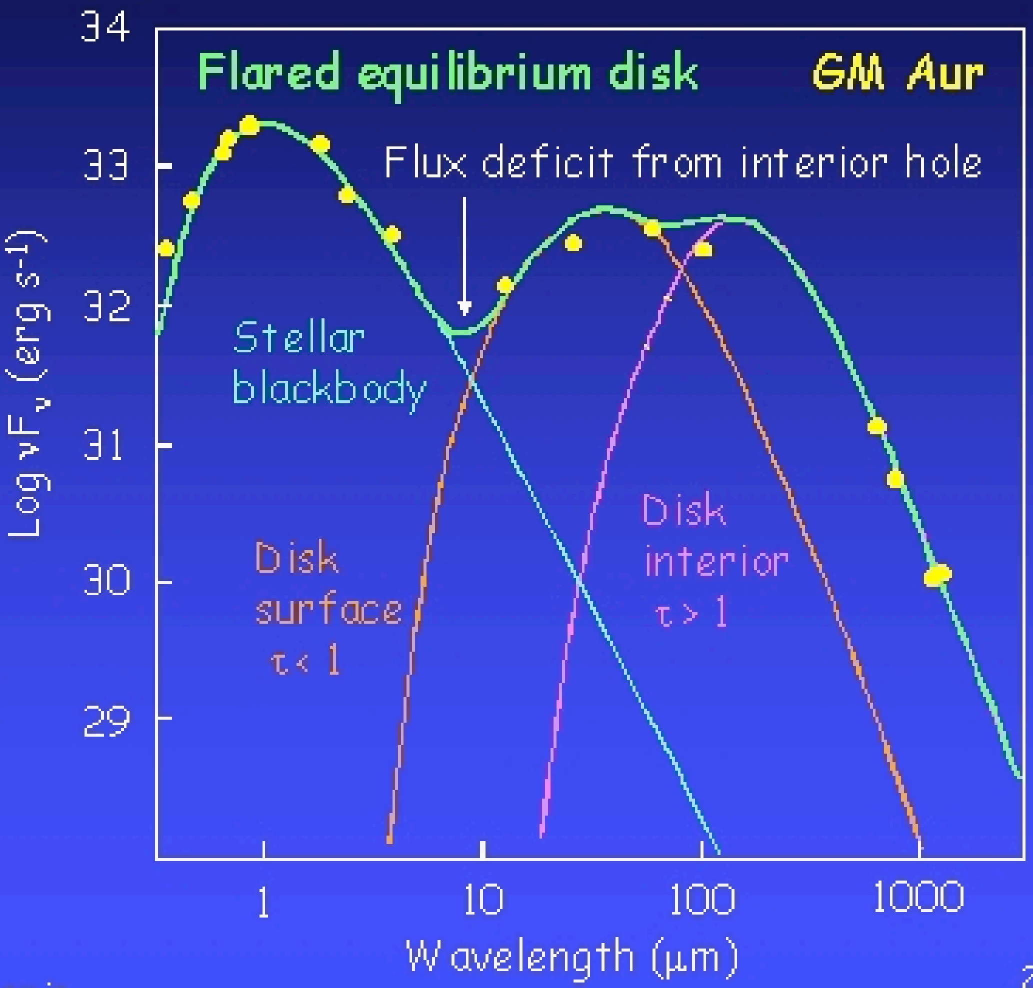
Inner holes produce flux deficits



Superheated surface layer with small grains produces infrared light.

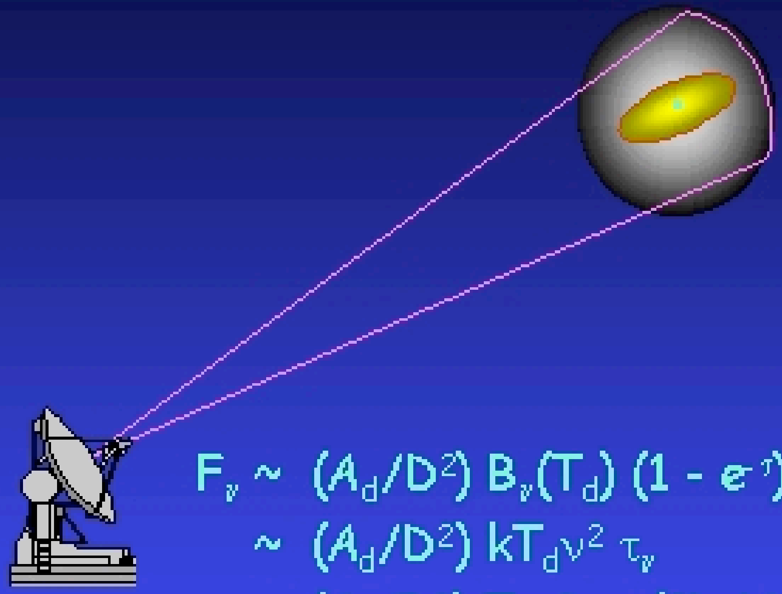
Interior hole

"Black" interior produces mm-wave emission.



How do we observe mass?

BSCG 1990,
AJ, **99**, 924.



We want to observe where the disk is transparent
(to see *all* the material)

For long enough wavelengths ($\lambda > 200\ \mu m$), the dust $\tau < 1$.

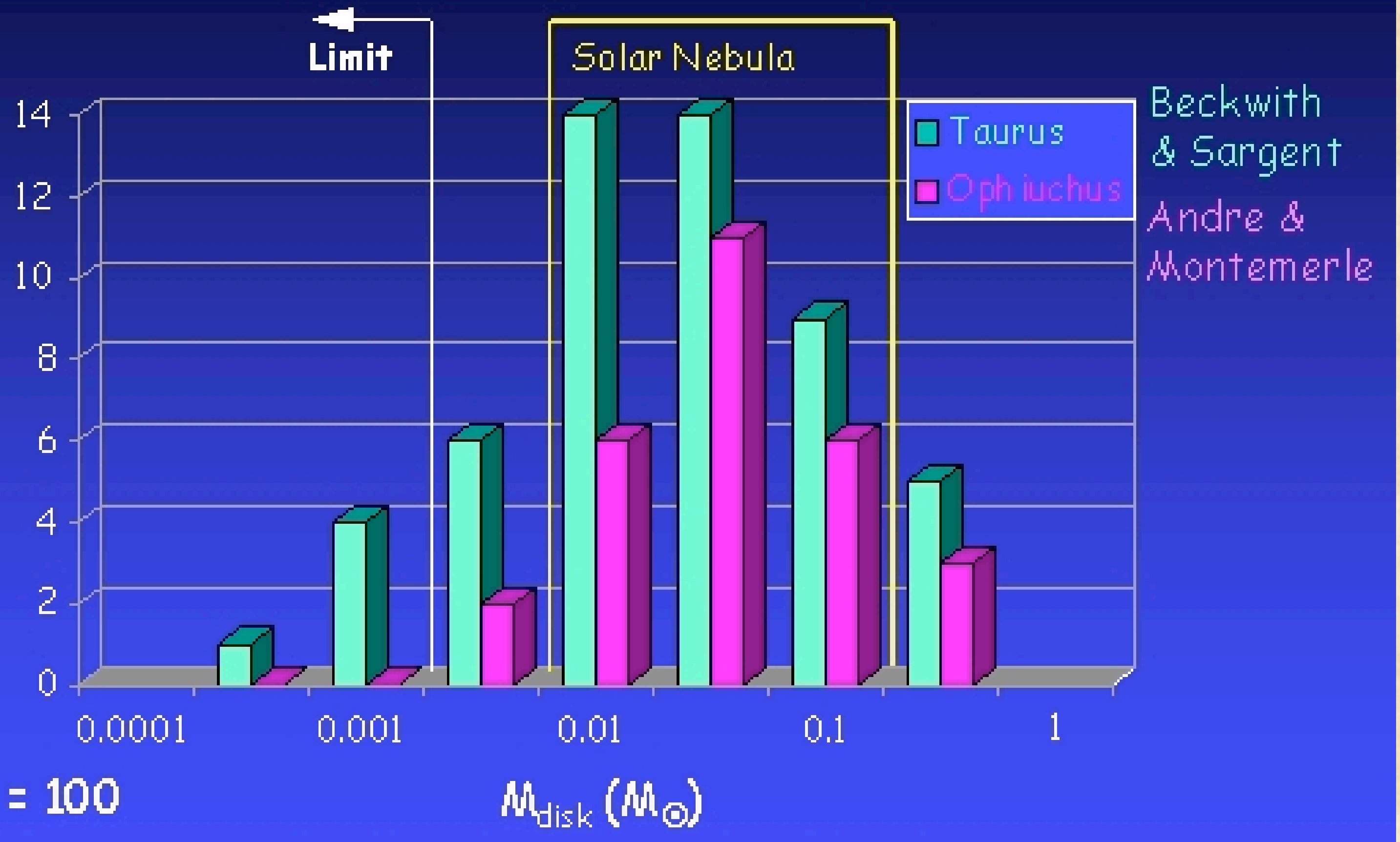
$$
\begin{aligned}
F_\nu &\sim (A_d/D^2)\, B_\nu(T_d)\, (1 - e^{-\tau}) \\
&\sim (A_d/D^2)\, kT_d \nu^2\, \tau_\nu \\
&\sim (A_d/D^2)\, T_d \nu^2\, \kappa_\nu\, (M_d/A_d) \\
&\sim D^{-2}\, T_d\, \nu^2\, \kappa_\nu\, M_d
\end{aligned}
$$

A_d ≡ disk projected area
D ≡ distance to source
T_d ≡ disk particle temperature
τ_ν ≡ optical depth at ν
M_d ≡ mass of disk
κ_ν ≡ mass opacity ($cm^2\ g^{-1}$)

$$\kappa_\nu \sim \kappa_0\, (\nu/\nu_0)^\beta$$

$$\boxed{F_\nu \sim \kappa_0 \nu^{2+\beta}\, T_d\, M_d}$$

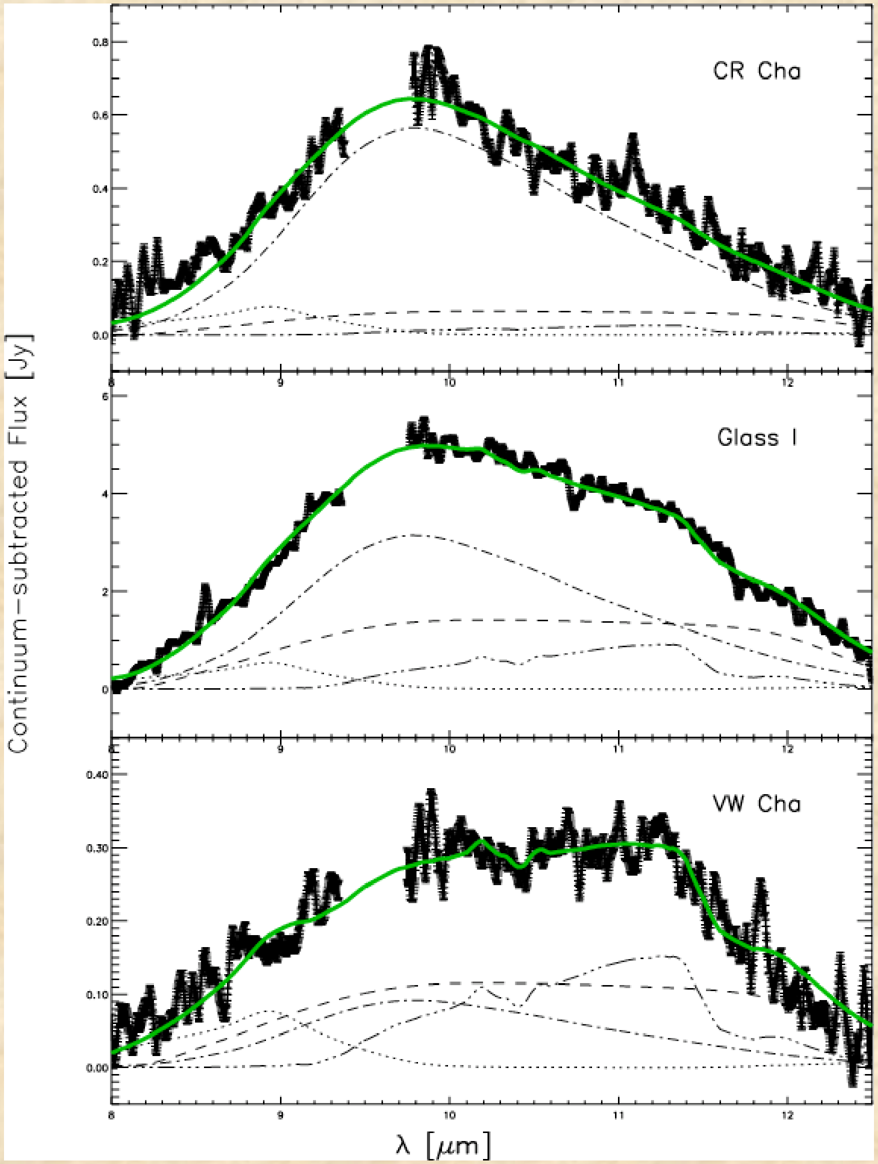
Disks can build planets



assumes gas/dust = 100

similar mass distribution for NGC 2071 by E. Lada 1998
but *not* Orion HST disks (E. Lada *et al.*, Bally *et al.*, unpublished)

Mineralogy of T Tauri disks



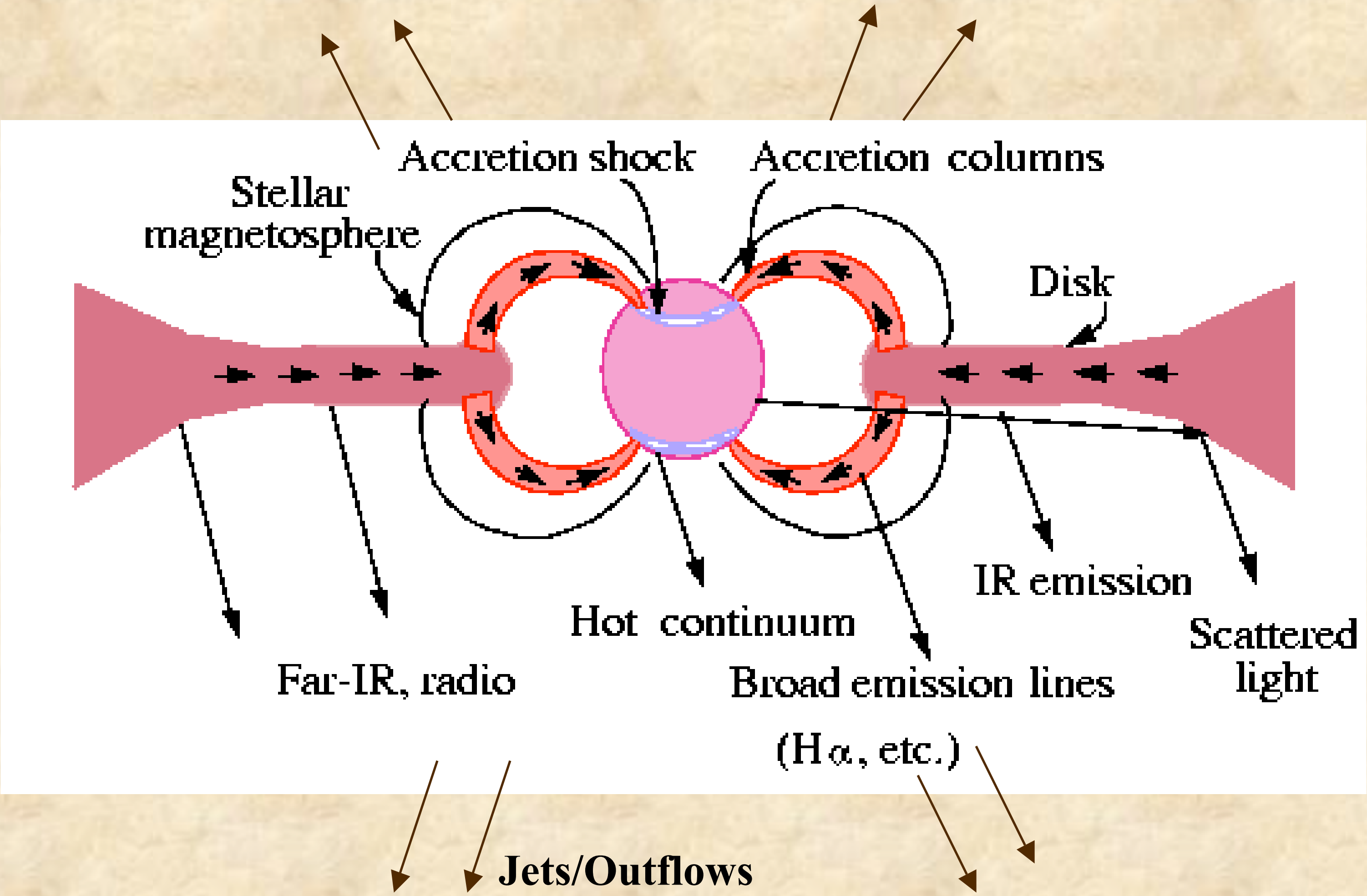
silicate emission from

T Tauri disks in Cha I

--> constaints on grain composition and size

Meeus et al. (2003)

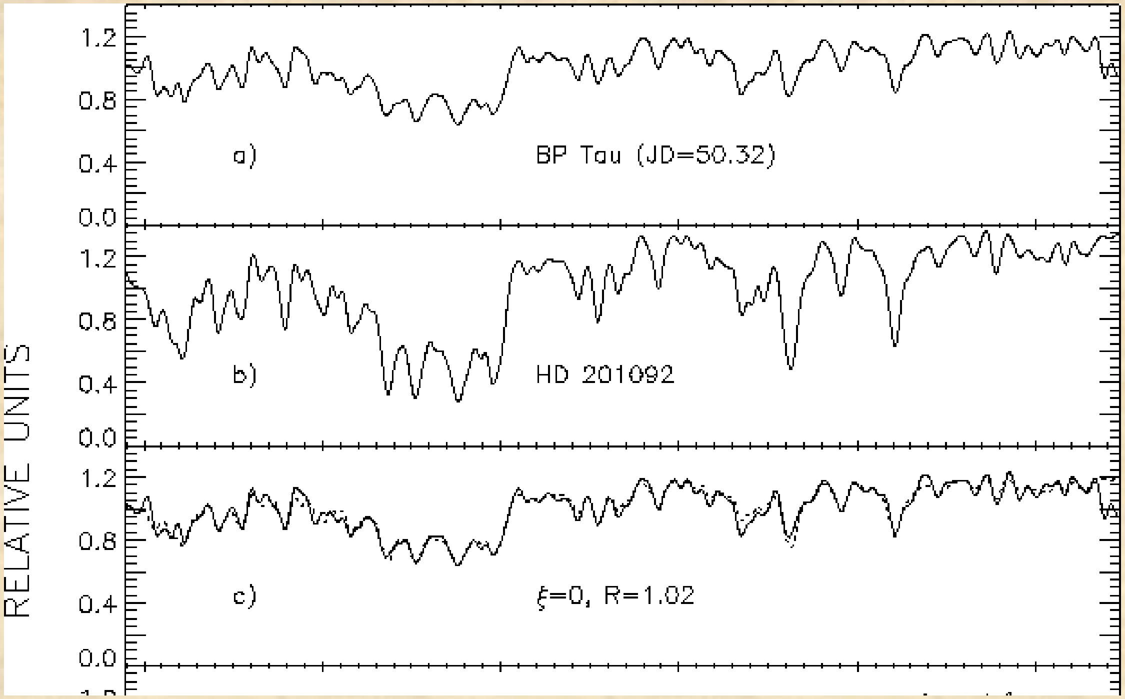
T Tauri Star



Jets/Outflows

Signatures of Accretion

Continuum excess (or “veiling”) in optical spectra

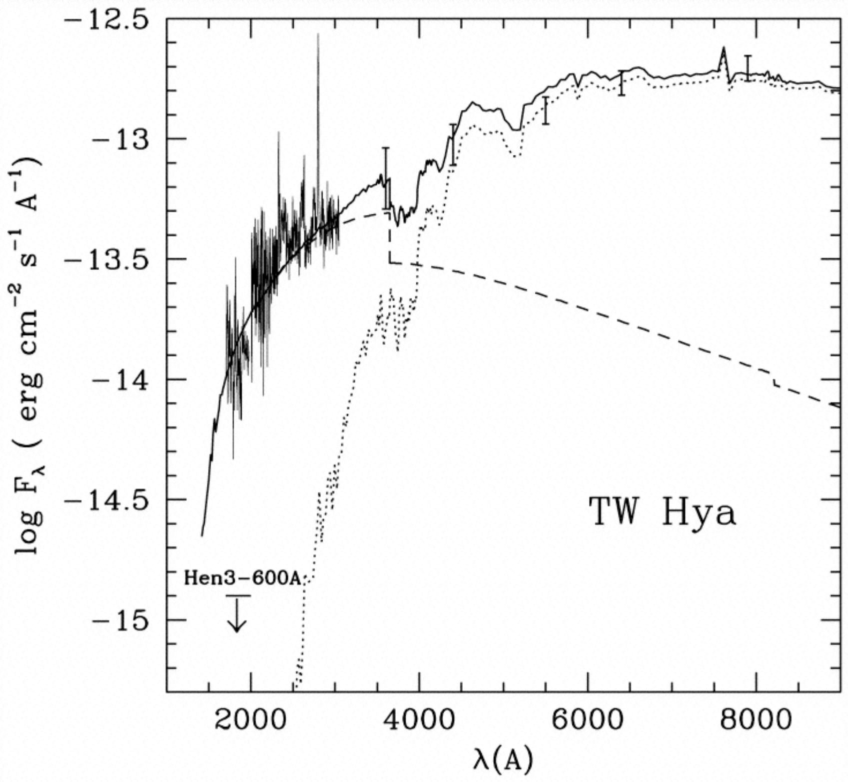


(Chelli et al. 1999)

measure veiling --> accretion luminosity --> accretion rate

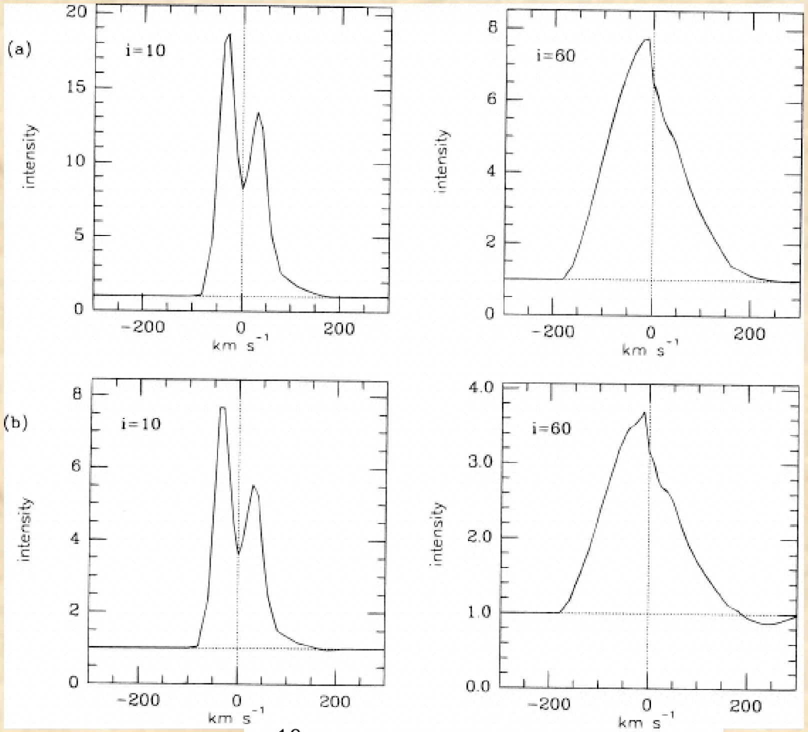
Signatures of Accretion

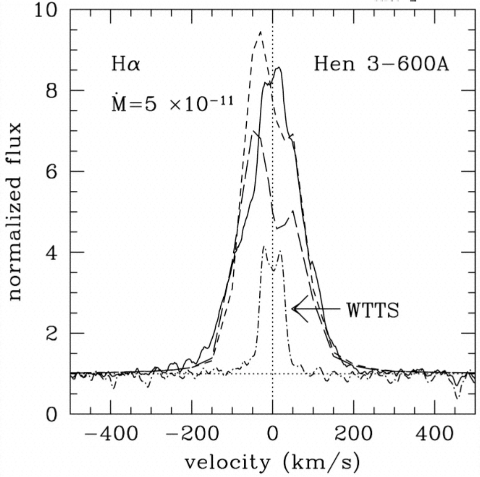
UV excess (from accretion shock)



(Muzerolle et al. 2000)

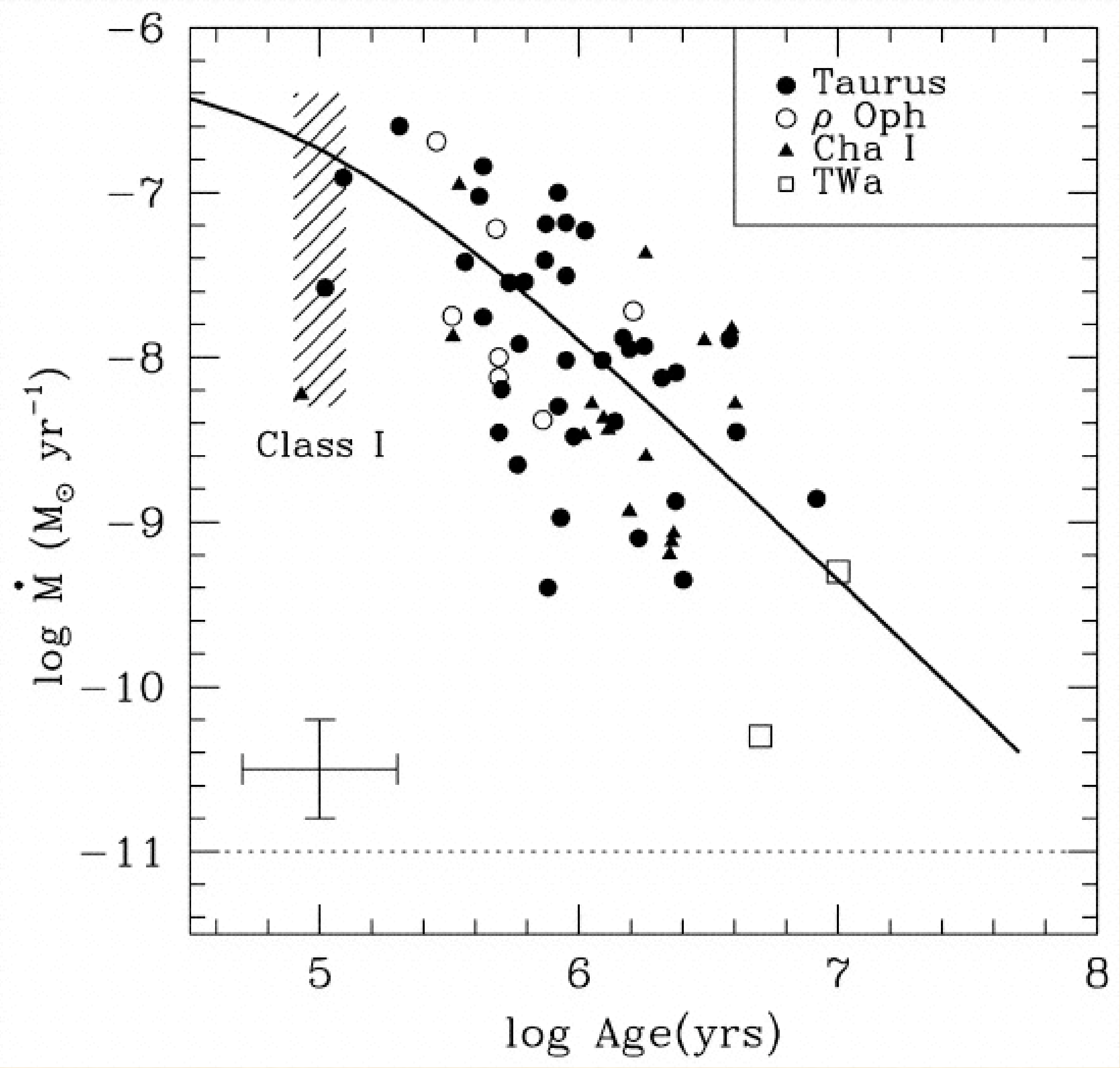
Broad, asymmetric Hα





Evidence for Disk Evolution

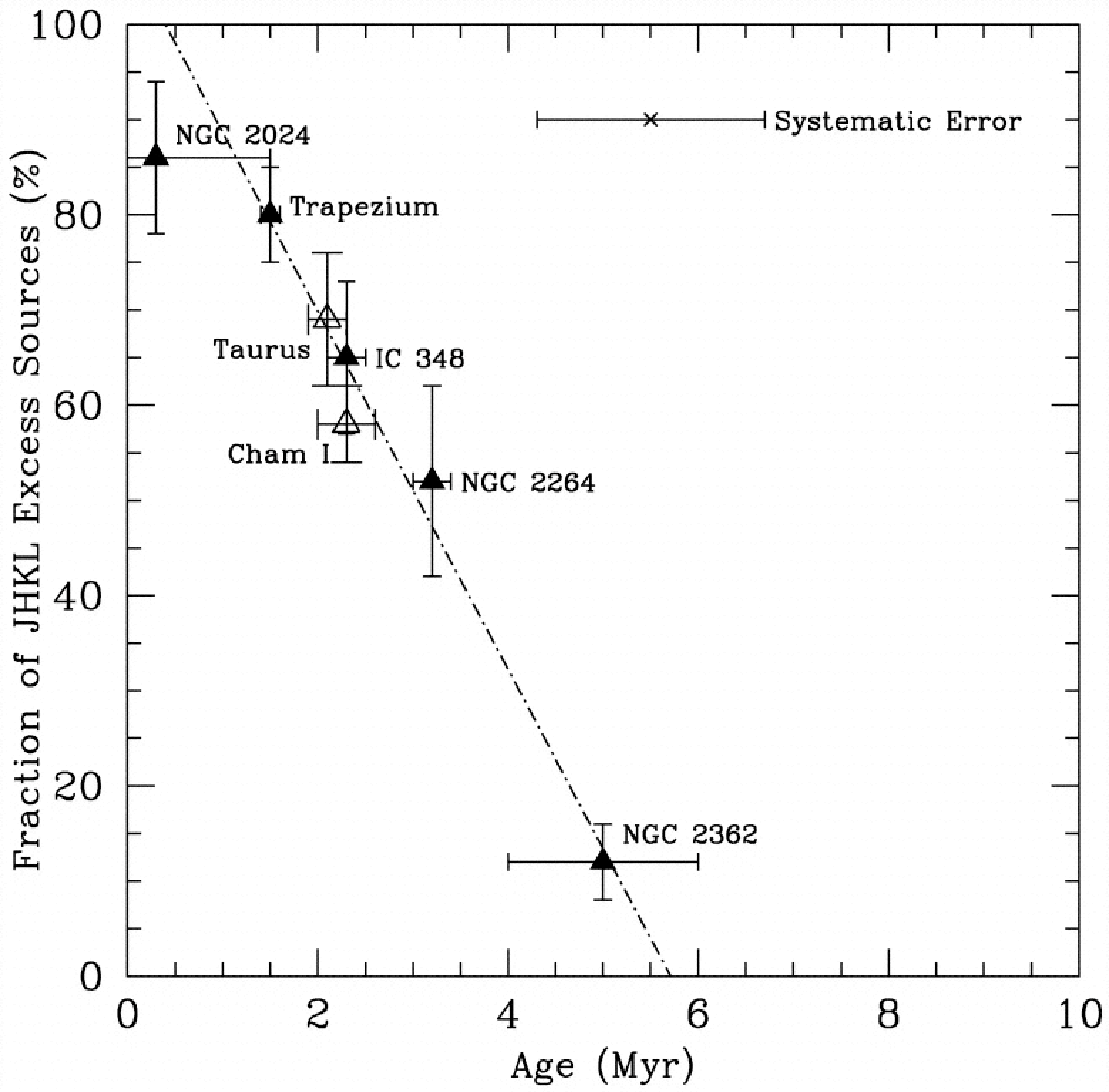
Evolution of accretion rates?



(Muzerolle et al. 2000)

Time Constraint: Disk Lifetimes

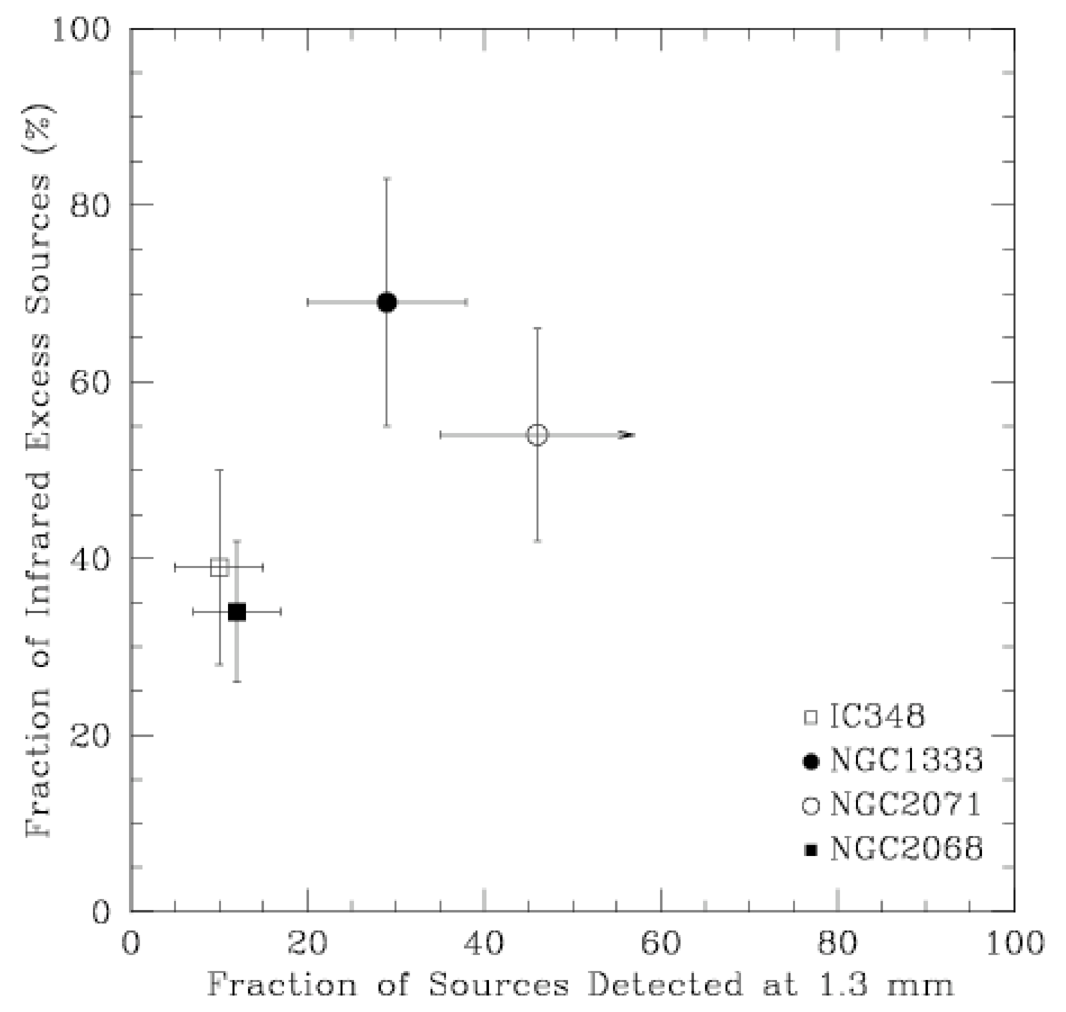
Fraction of stars with inner dust disks



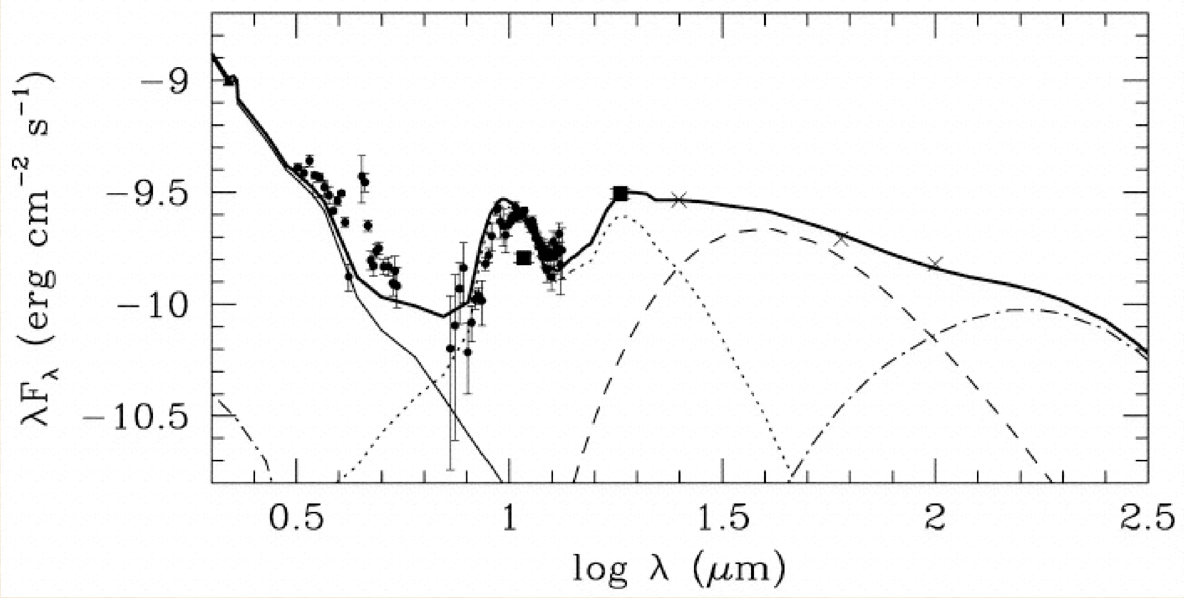
(Haisch et al. 2001)

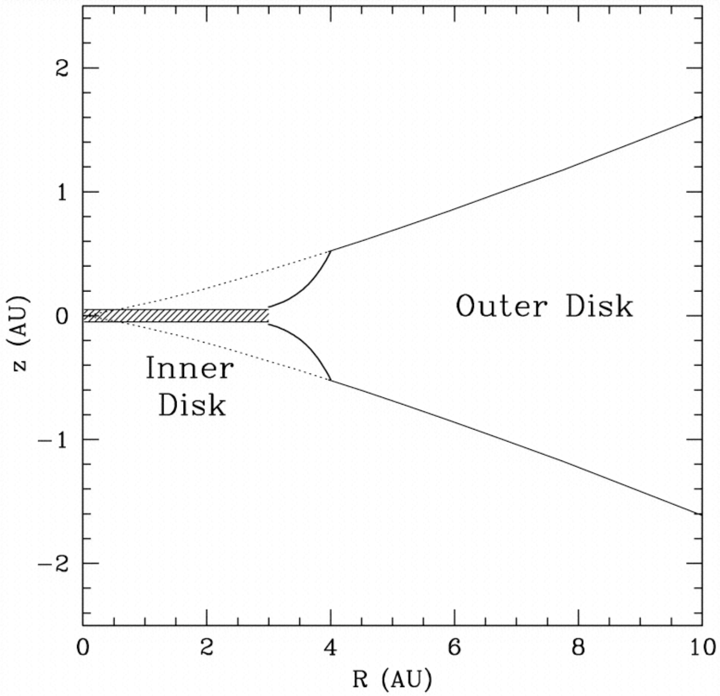
What about gas?

mm vs IR disk fraction



(Haisch & Lada 2005)



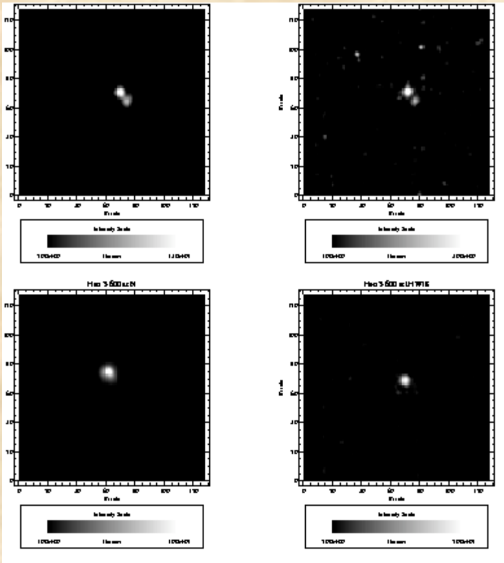


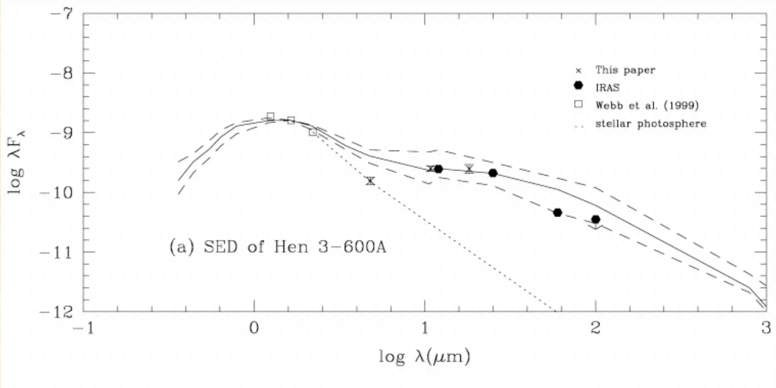
Case of TW Hydrae

(Calvet et al. 2002)

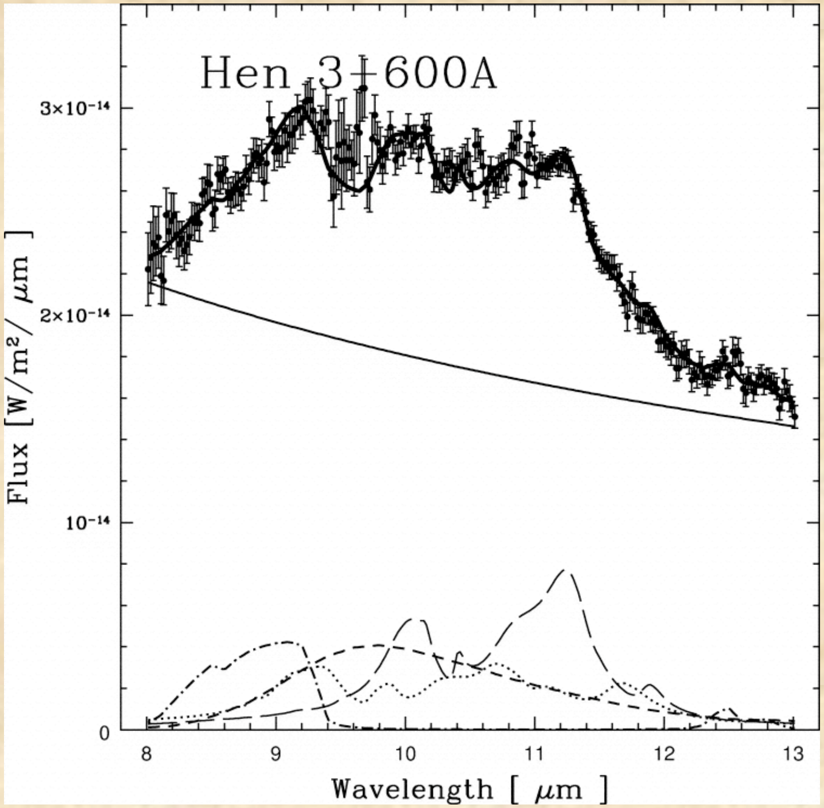
Mineralogy of disks in the TW Hydrae group

Hen 3-600 @ 10 Myrs



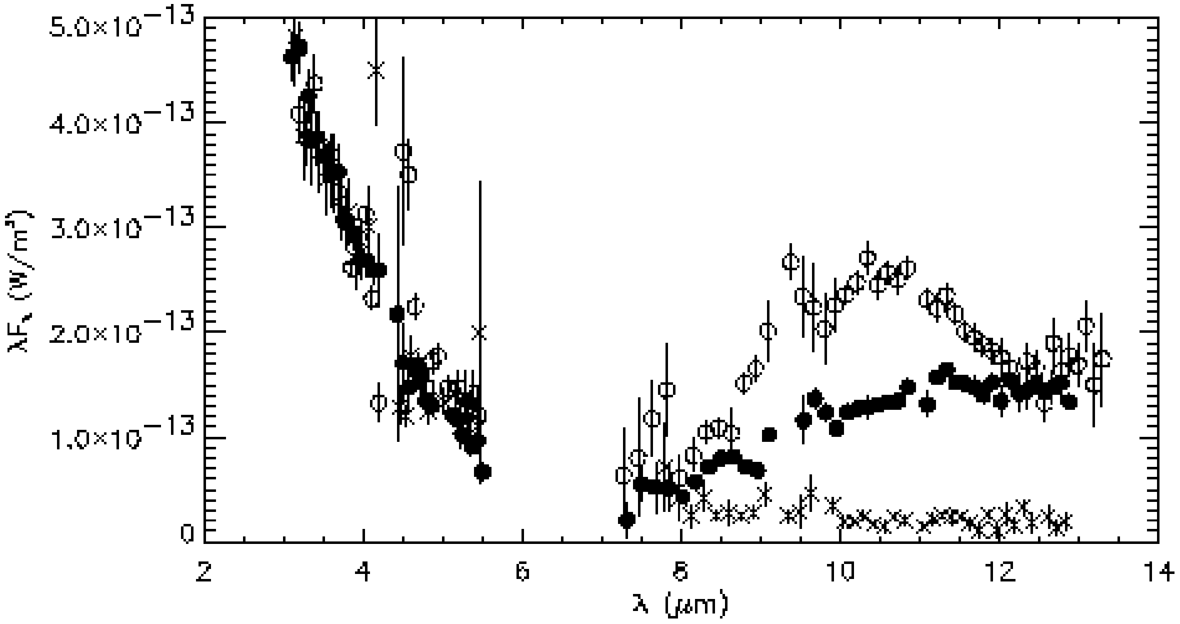


Jayawardhana et al. (1999a)



Honda et al. (2003)

Mineralogy of planet-forming disks



Sitko et al. (2000)

A dusty tale

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