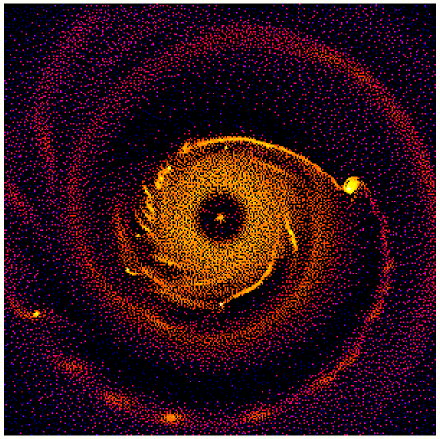
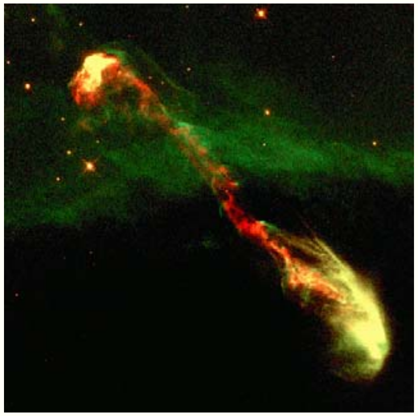
Disk evolution and lifetimes





Lee Hartmann
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Topics

- Diversity of systems $\Rightarrow$ timescales
- accretion rates
- evolution of disk structure

Diversity of disks (timescales)

The "centrifugal radius" r_c at which material initially rotating at angular velocity Ω at radial distance R lands on a "disk" around mass M is

$$r_c = \frac{\Omega^2 R^4}{GM} \,. \tag{1}$$

In terms of the limiting angular velocity for the initial protostellar cloud,

$$\Omega_b = (GM/R^3)^{1/2} \,, \tag{2}$$

$$\frac{r_c}{R} = \left(\frac{\Omega}{\Omega_b}\right)^2 \,. \tag{3}$$

A factor of 3 change in Ω/Ω_b is a factor of 10 change in r_c;

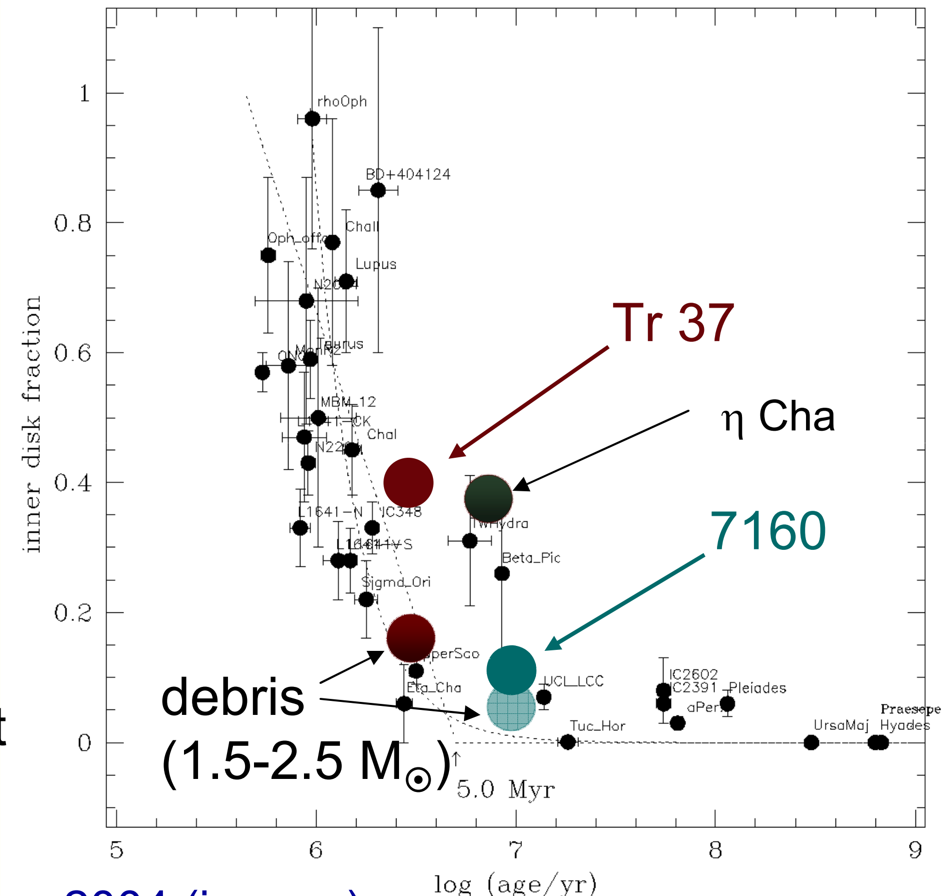
$\rightarrow$ orbital period changes by a factor of 30; for the same disk mass, the surface density changes by a factor of 100.

Dust evolution in inner disk

- Large range at given age

- By ~10 Myr, dust emission from inner disk is gone (Strom, Skrutskie, et al; a long time ago)

note: ~3% accreting among 1.5-2.5$M_\odot$ stars in Tr 37
$\Rightarrow$ lifetimes mass-dependent



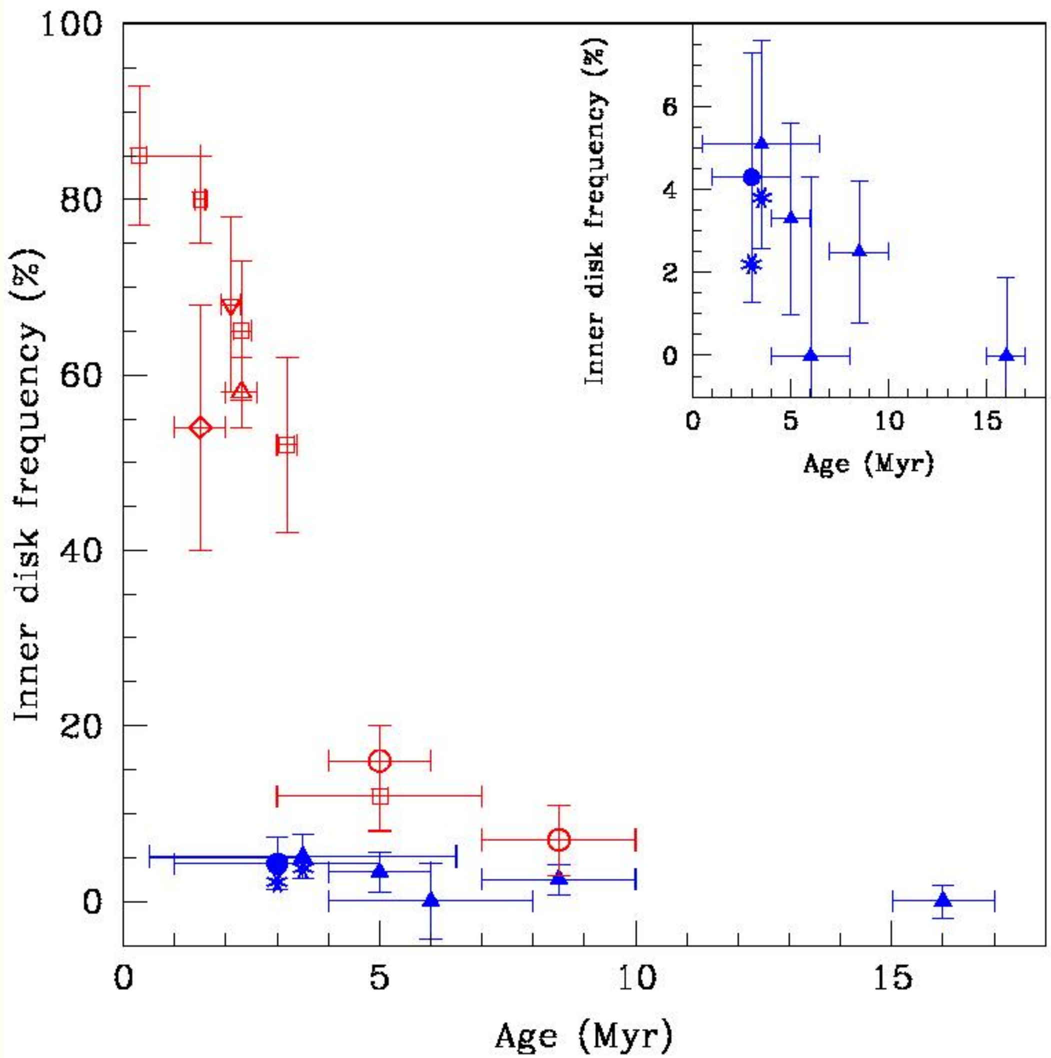
Hillenbrand, Carpenter, & Meyer 2004 (in prep)

Sicilia-Aguilar et al. 2004

also Haisch, Lada^2 2001

Megeath et al. 2005

Mass dependence of disk "fraction"

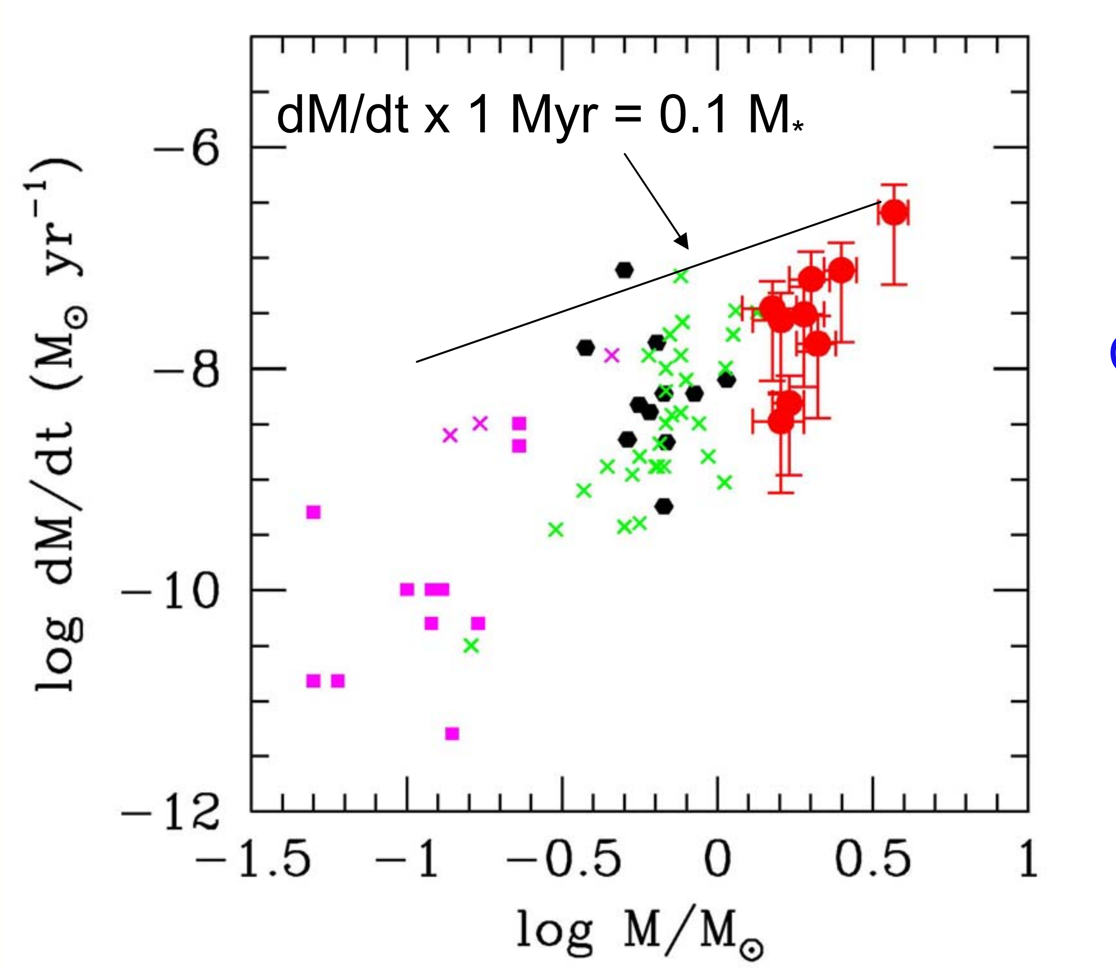


Low-mass stars:
Haisch et al. 2001
Kenyon & Hartmann 1995
Gomez & Kenyon 2001
Briceño et al 2005 (Ori OB1)
Gutermuth et al. 2004

Herbig Ae/Be stars
(really accretion):
LOWER fraction
(FASTER EVOLUTION)

Hernandez et al. 2005

Disk accretion rates depend on M_*



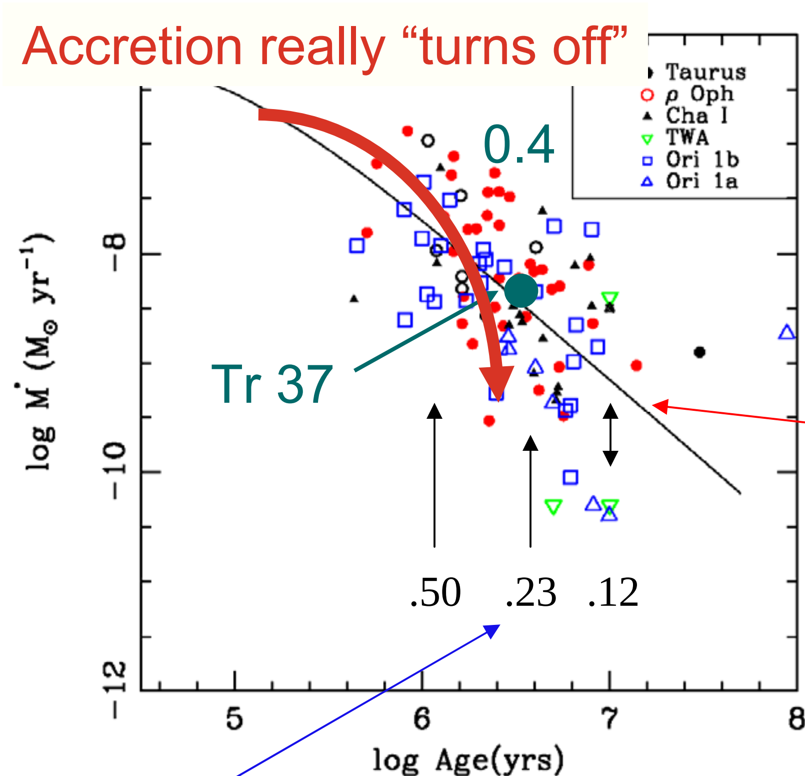
Calvet et al. 2004

dM/dt $\propto$ M^2 approximately; why??

some weak evidence that M(disk) $\propto$ M_*; what is the other factor??

Evolution of mass accretion rates

Importance - measure of gas, not just dust



$\langle dM/dt \rangle \times \langle t \rangle \approx 0.02\ M_\odot$

simple viscous disk model

Hartmann et al. (1998),
Muzerolle et al. (2001),
Calvet et al. (2004)

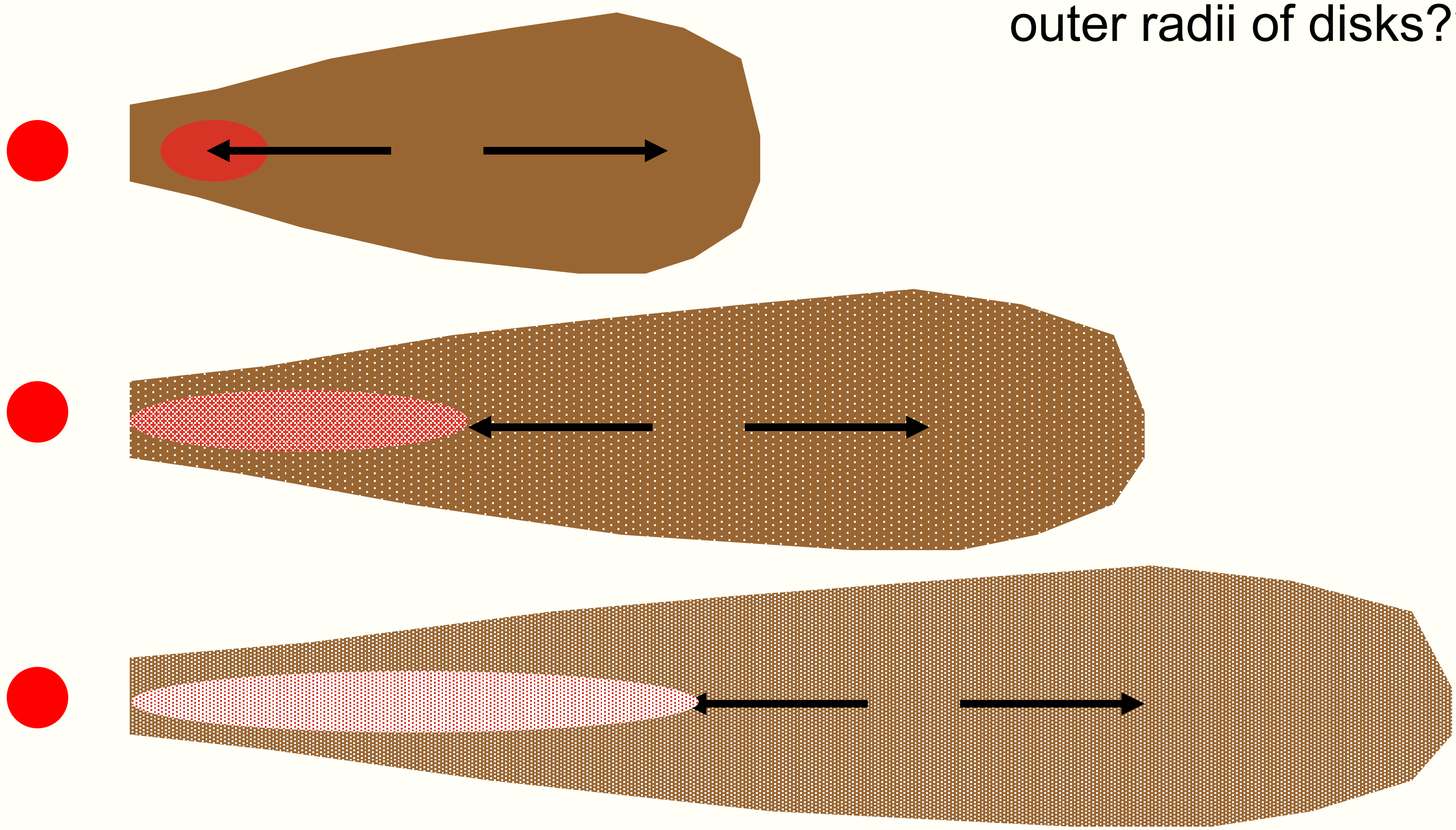
Sicilia-Aguilar et al. 2004

Fraction of accreting objects decreases with time

Key challenge: transport/diffusion/motion

viscous accretion disk: expands to conserve angular momentum

outer radii of disks??

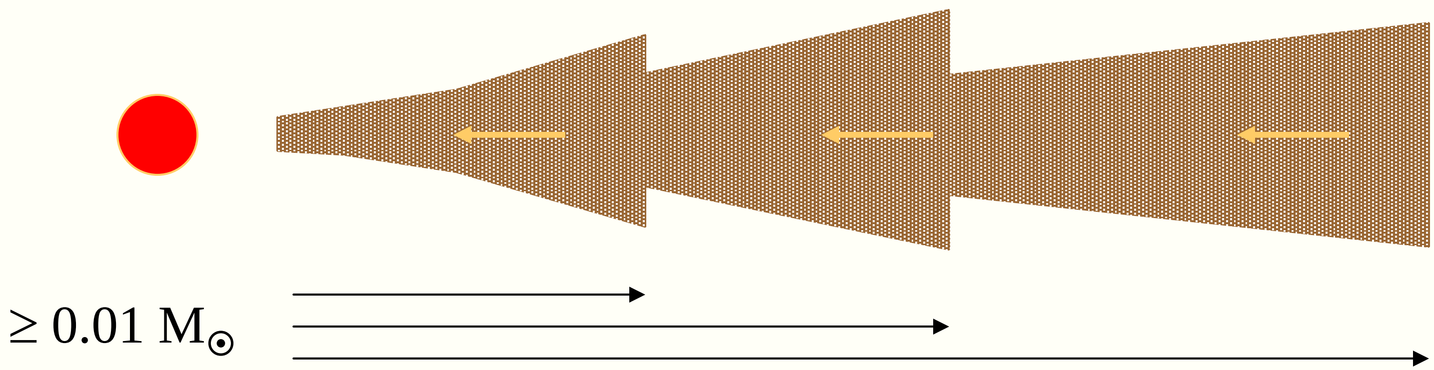


Disk accretion and migration

T Tauri stars accrete ~ 0.01 $M_\odot$ in 1 Myr

Accrete in 1 Myr from:

1 AU	10 AU	100 AU
α = 0.0001	= 0.001	= 0.01

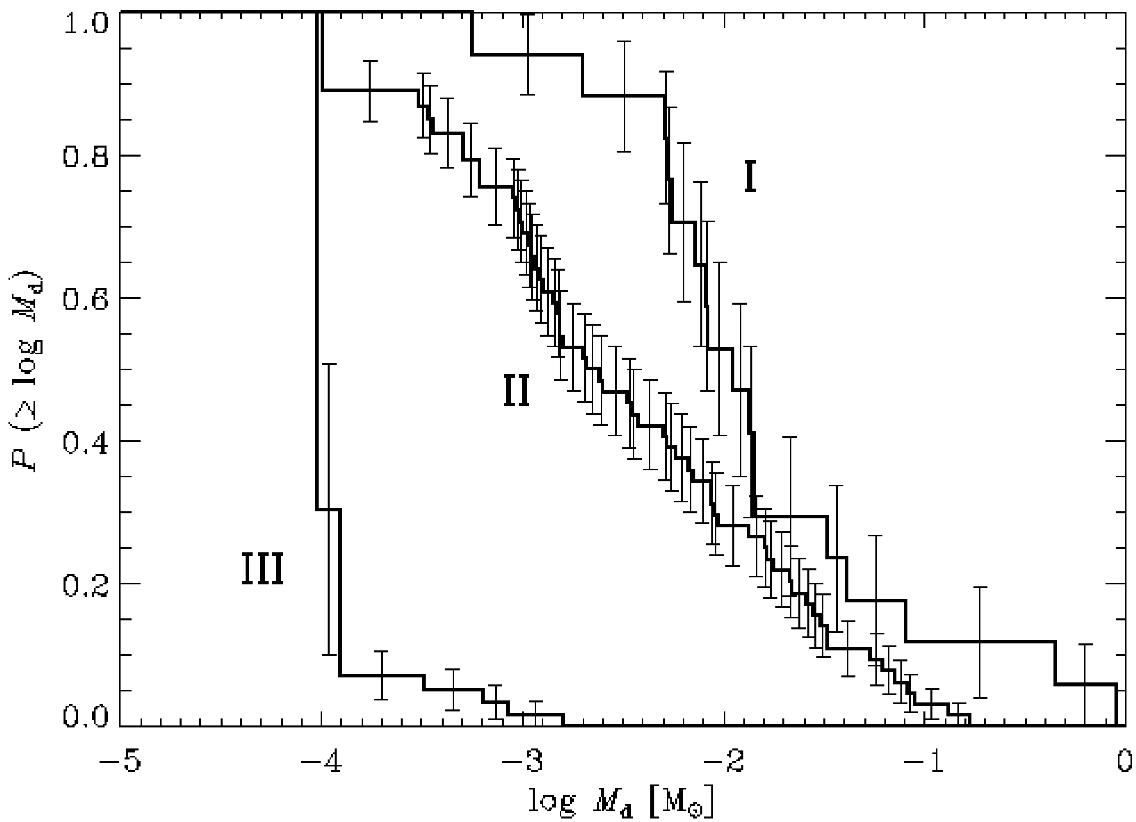


So where does the disk mass reside??

Disk masses and accretion

Taurus (870 micron)

Andrews & Williams poster



Are we underestimating TTS disk masses?

<M(disk)> / age (lifetime)

≈ 0.005 $M_\odot$ / 2 Myr

≈ 2.5 x 10^{-9} $M_\odot$ / yr (!)

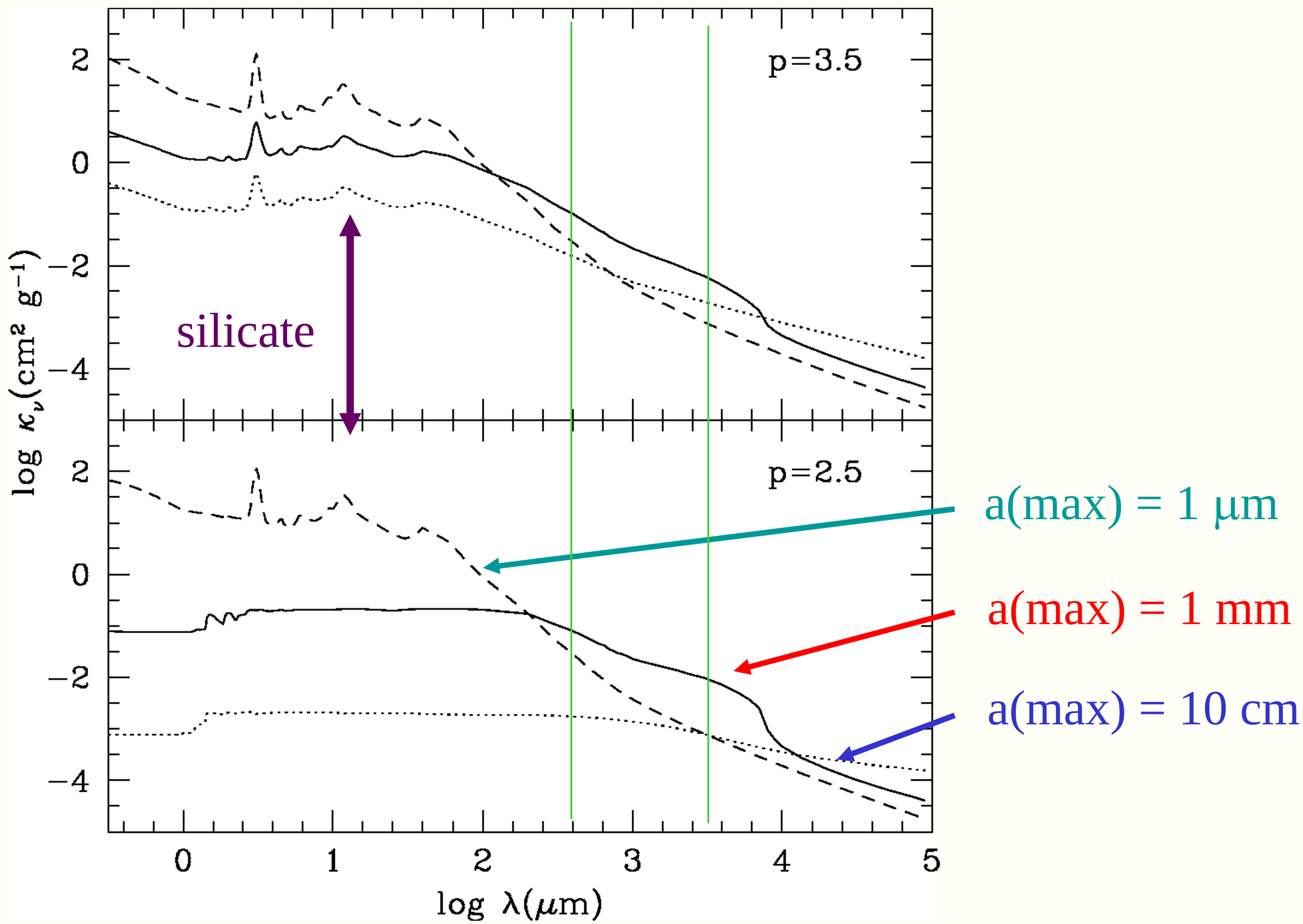
AND: need more mass in disk to leave something behind

AND dM/dt may be underestimated by a factor of two or so (White & Hillenbrand)

Dust growth (implied mass dependence)

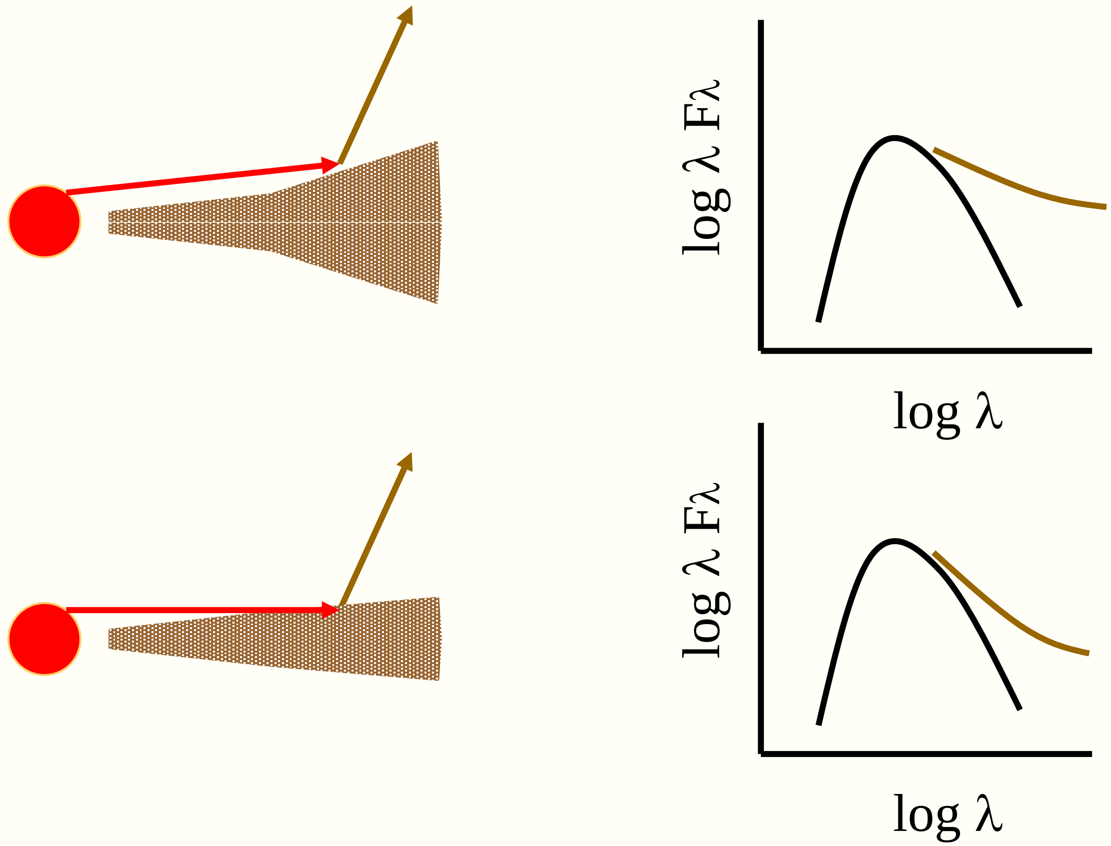
$n(a) \propto a^{-p}$

D'Alessio, Calvet, & Hartmann 2000



As maximum dust size increases for these power-law distributions, the mm-wave opacity grows, and the 10 μm silicate feature disappears

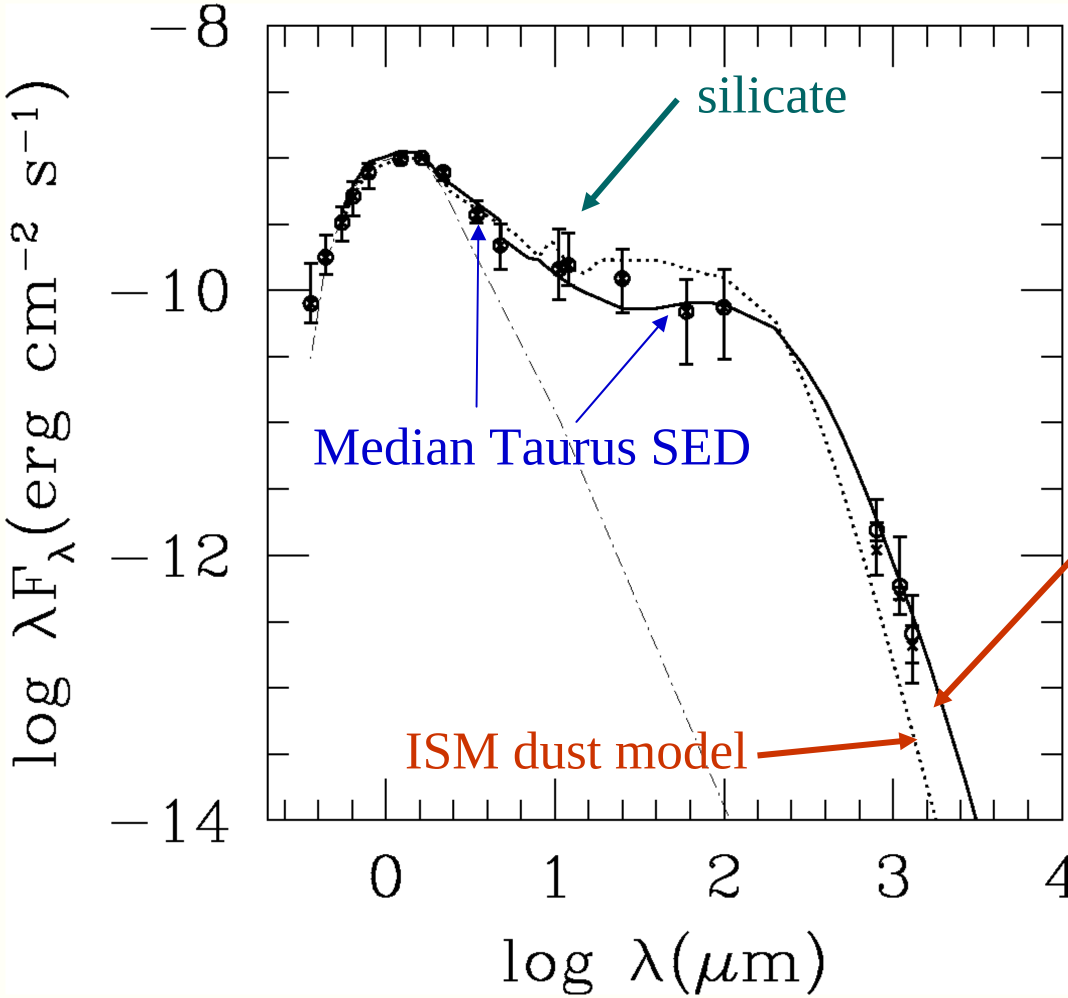
Disk/dust/SED evolution



As disk dust settles vertically, disk photosphere is lower
⇒ less IR excess;
evidence for this in Taurus SEDs (Miyake & Nakagawa 1995)

Disk/dust/SED evolution: dust growth

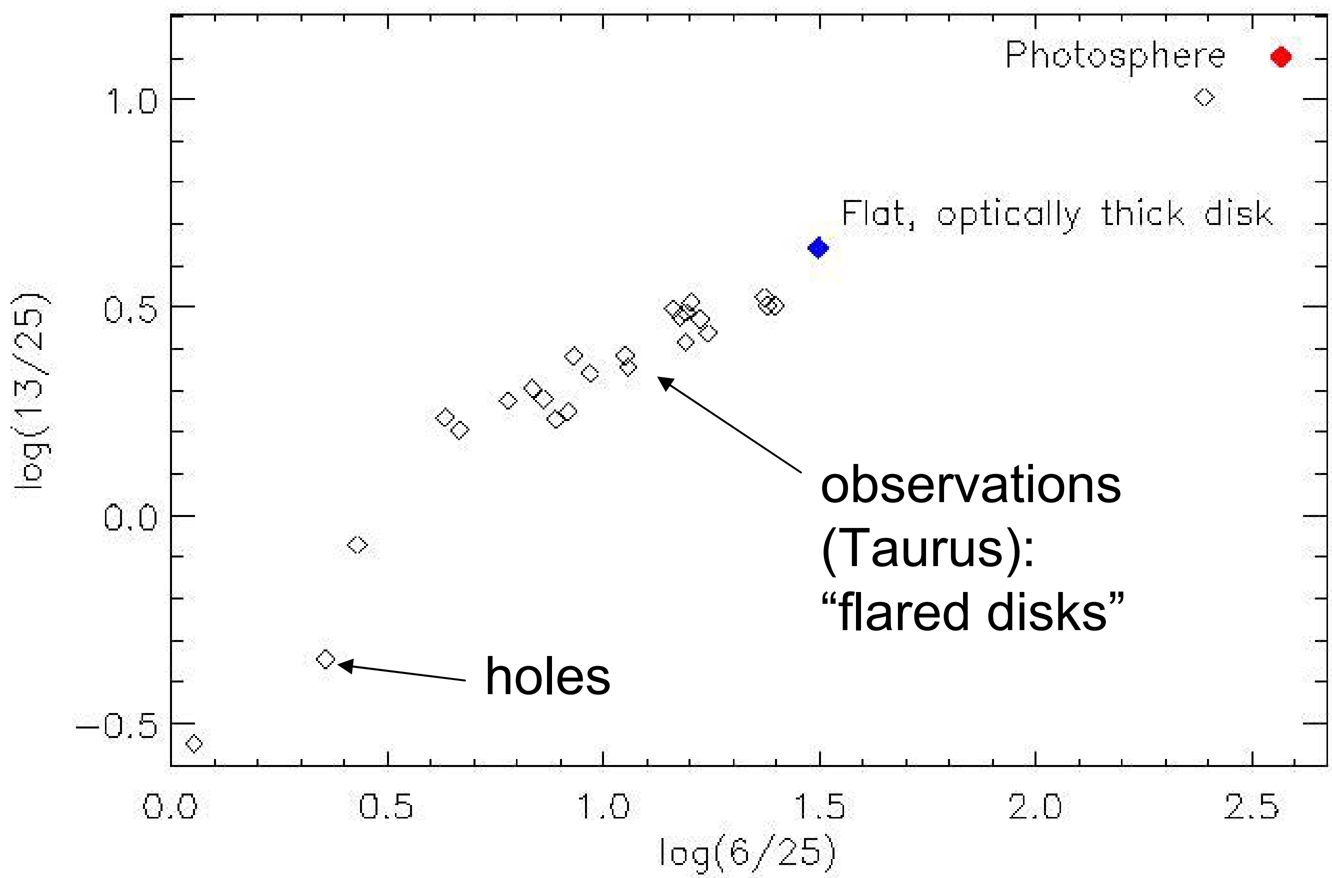
D'Alessio, Calvet, & Hartmann 2000



$n(a) \propto a^{-3.5}$,
$a(max) = 1$ mm

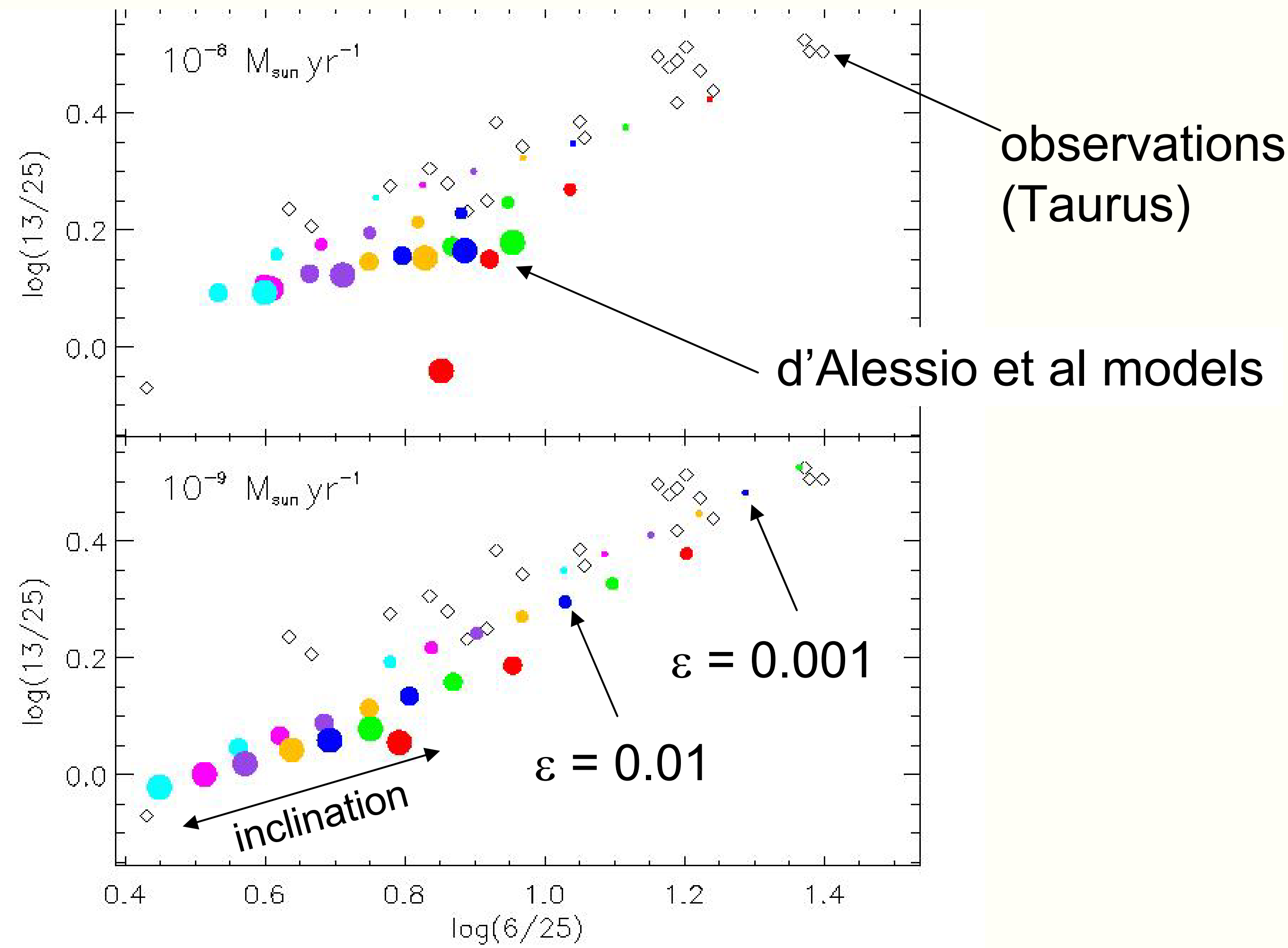
maximum dust size ~ 1 mm to explain mm-wave fluxes; but small grains needed to explain observed silicate emission ⇒ *differential settling*

Dust settling/growth in disks



Furlan et al. 2005

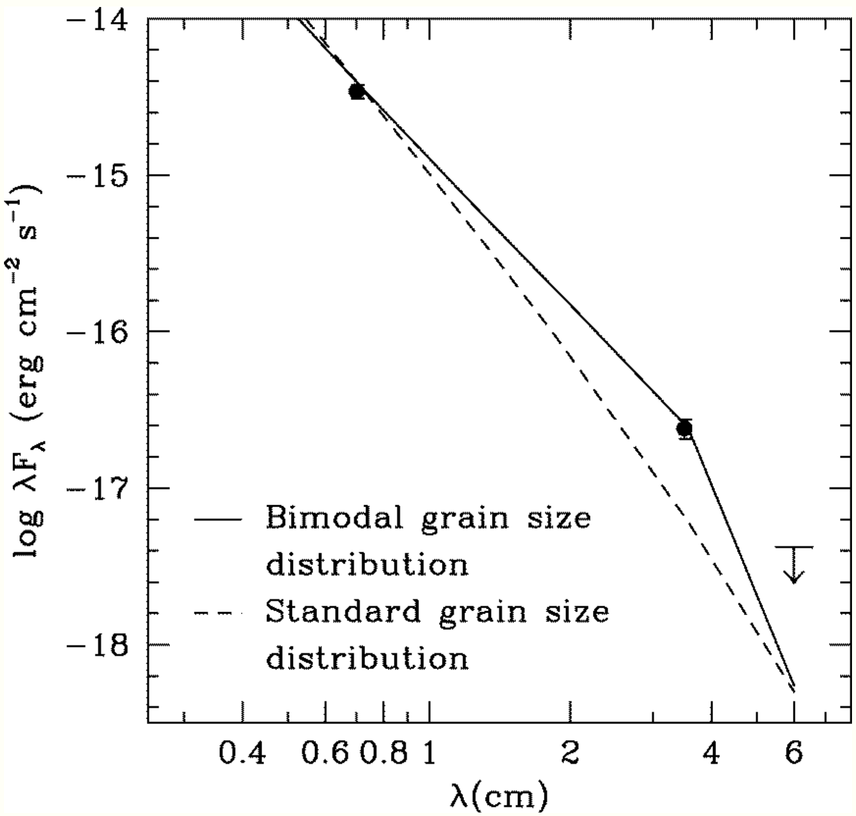
Dust settling/growth in disks

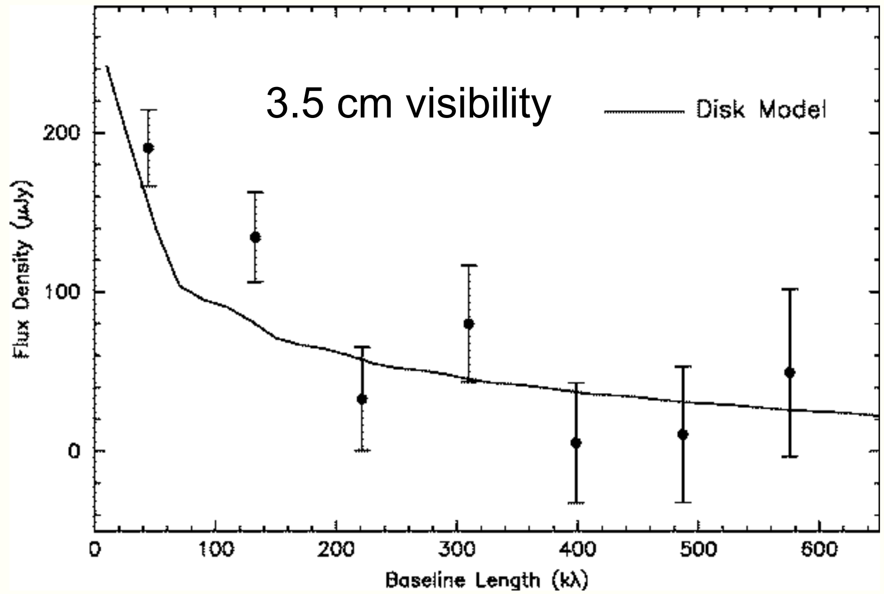


Furlan et al. 2005

Grain growth @ 10 Myr: TW Hya

Wilner et al. 2005



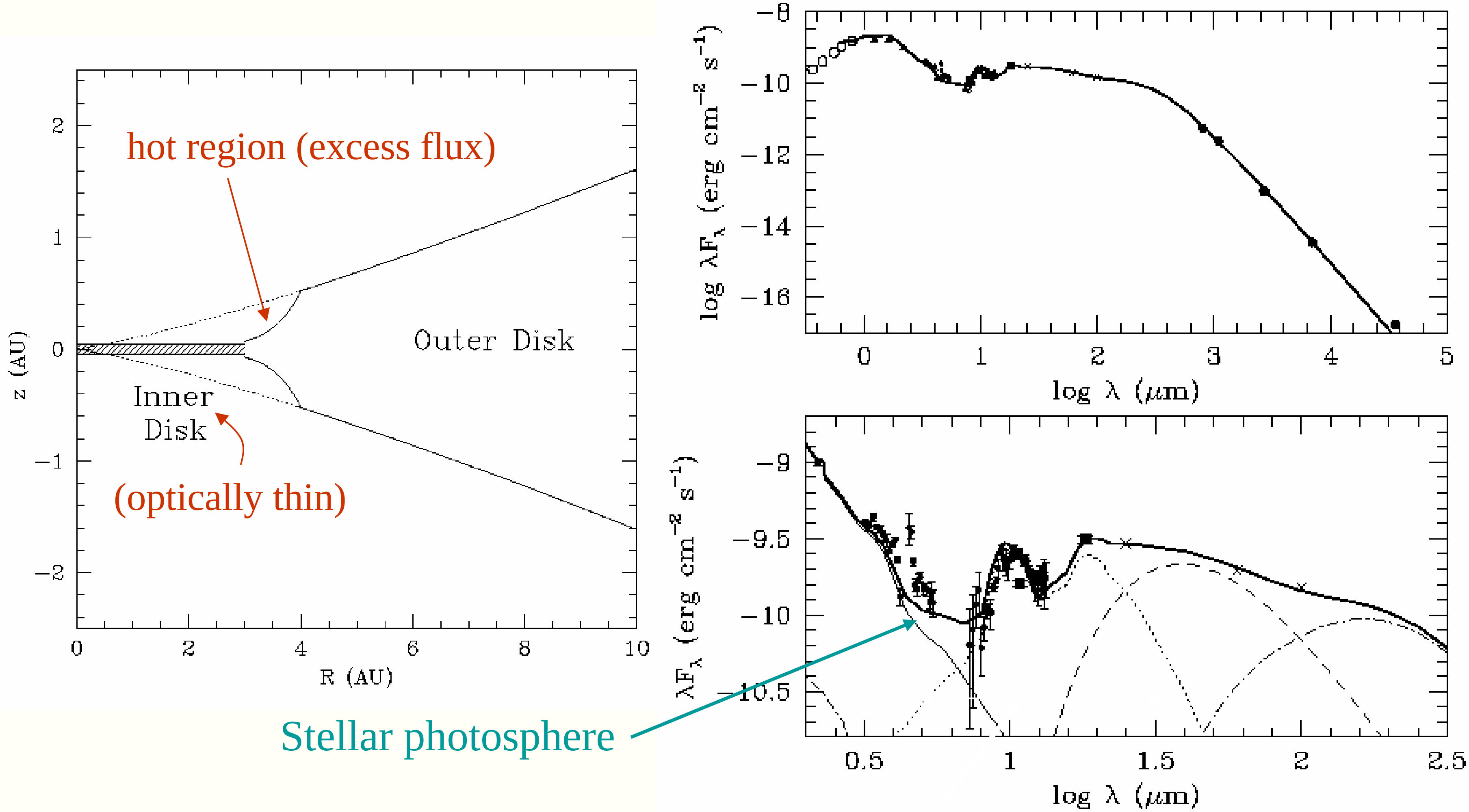


Models suggest most disk mass is in 0.5 - 0.7cm particles

(≈ 0.1 $M_\odot$ with 0.01 dust/gas ratio)

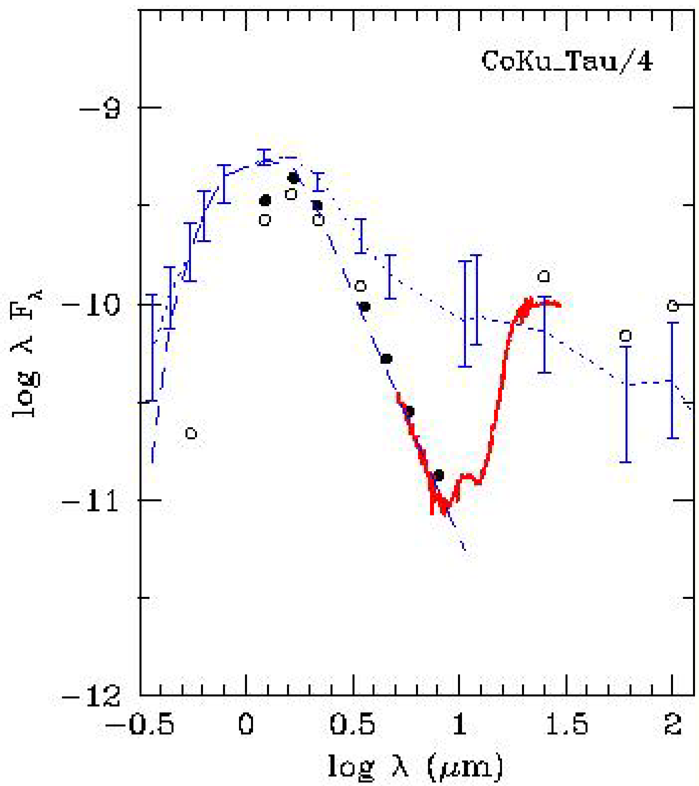
TW Hya and disk models (~ 4 AU hole)

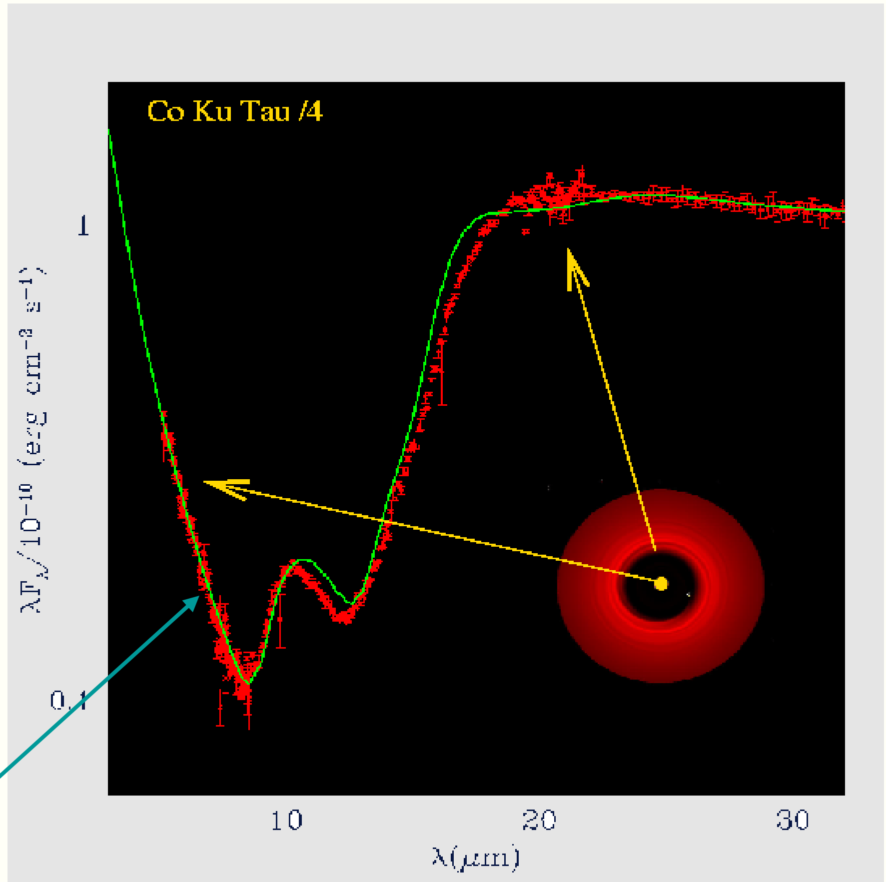
Calvet et al. 2001



CoKu Tau 4 (~ 10 AU hole)

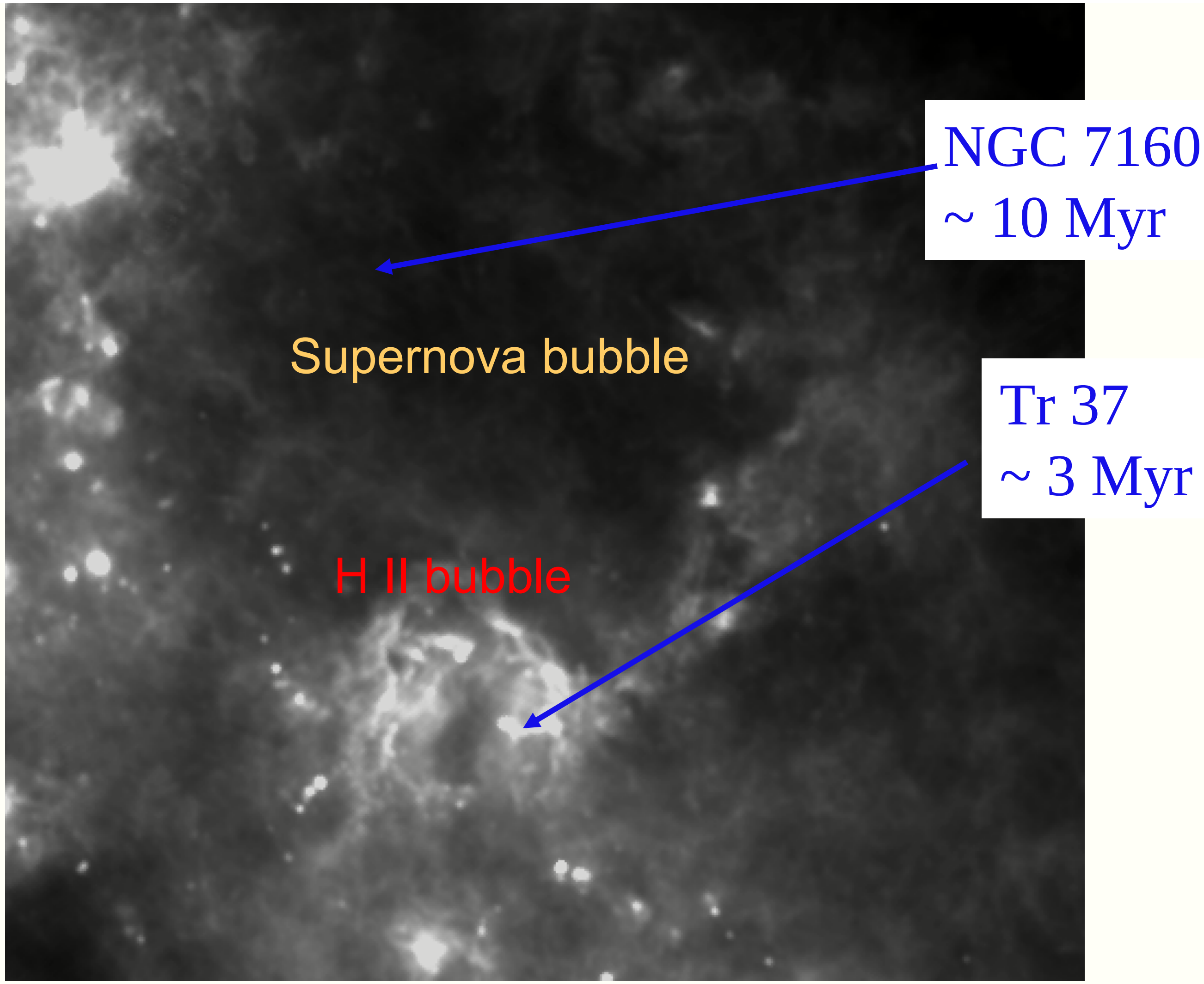
Forrest et al. 2004, D'Alessio et al. 2005





Stellar photosphere

Two clusters to study disk evolution

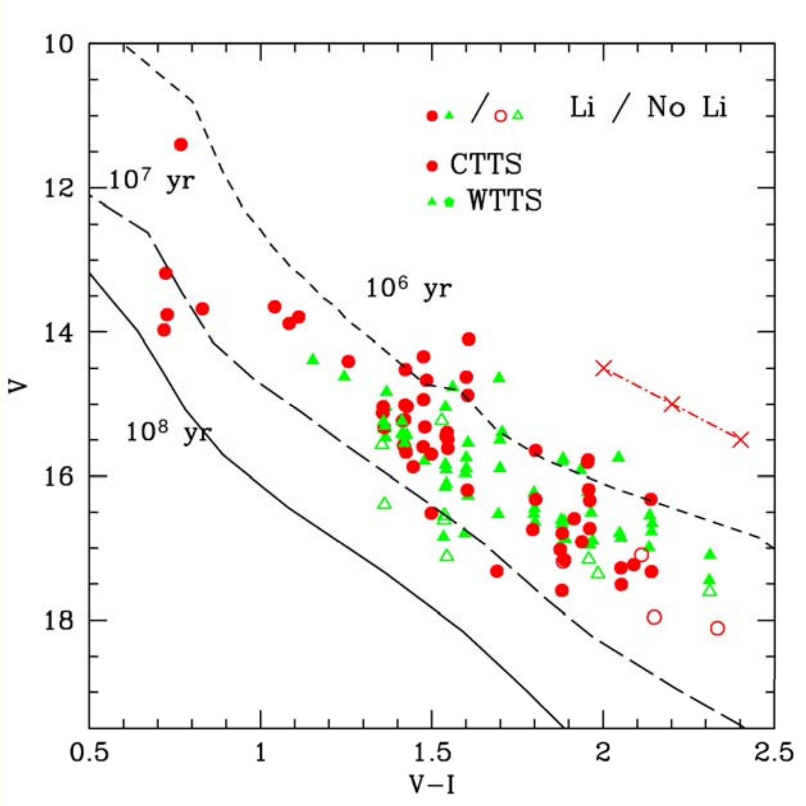


50 pc

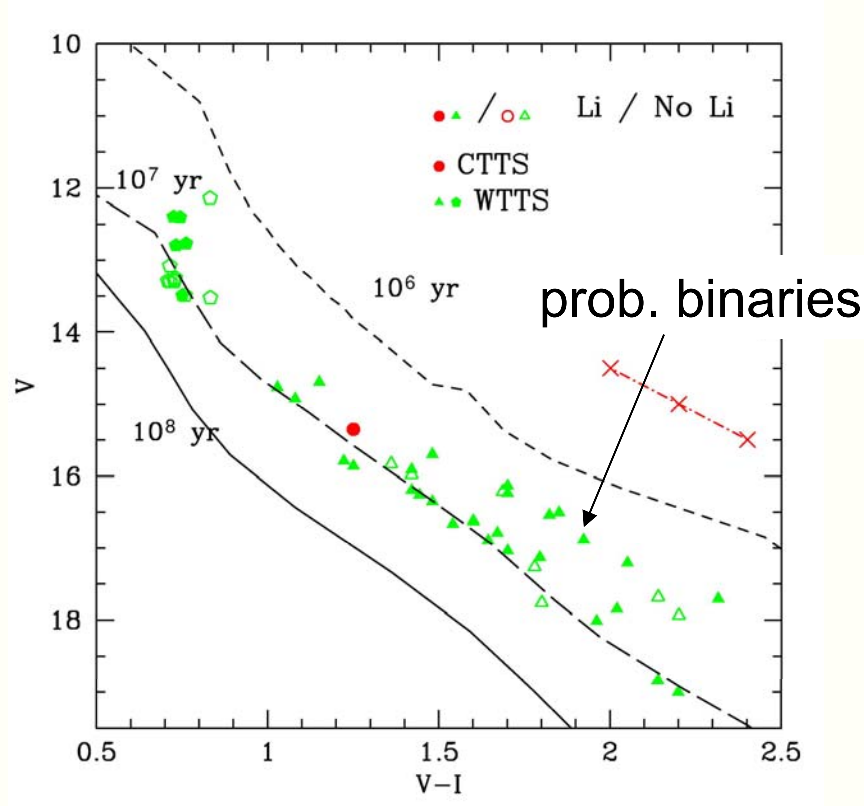
100 μm IRAS
dust emission

Two clusters

Tr 37, t ~ 4 Myr



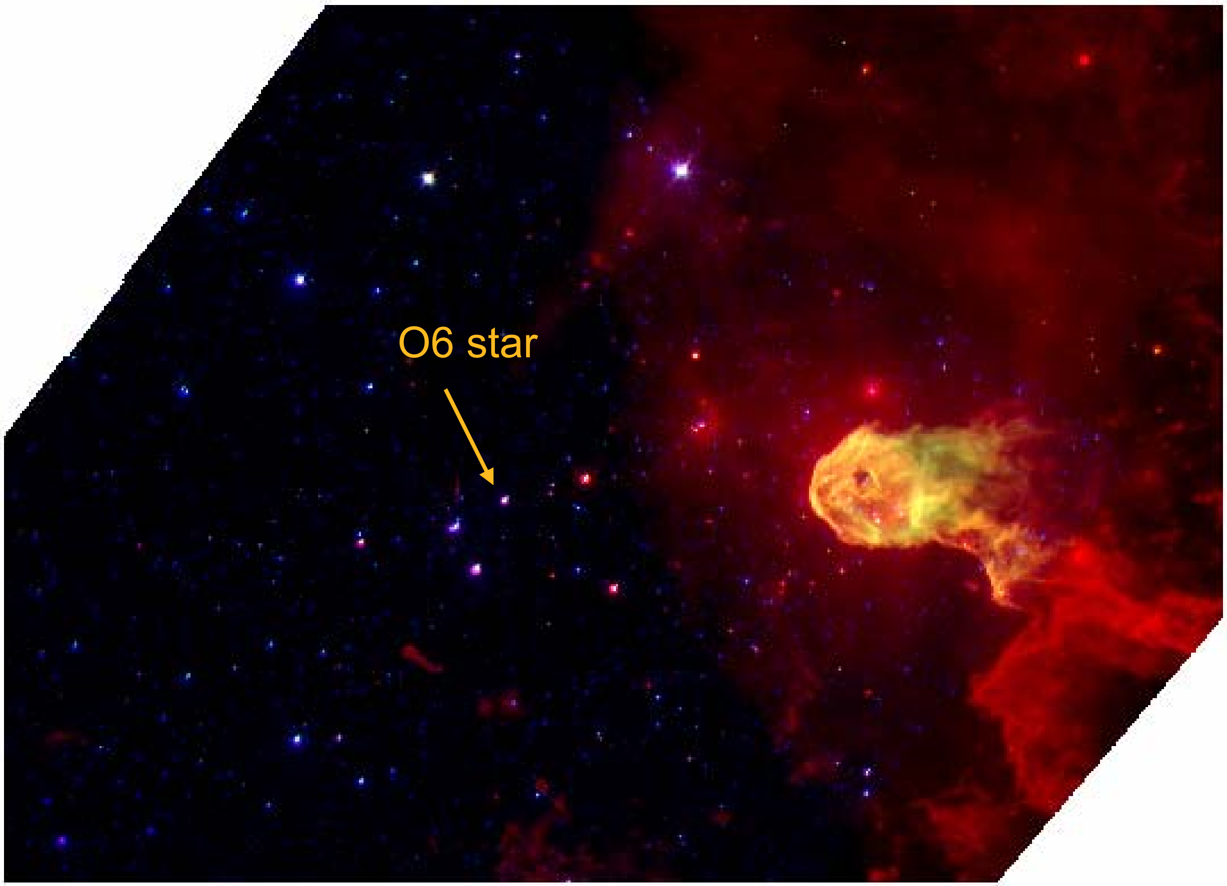
NGC 7160, t = 10 Myr



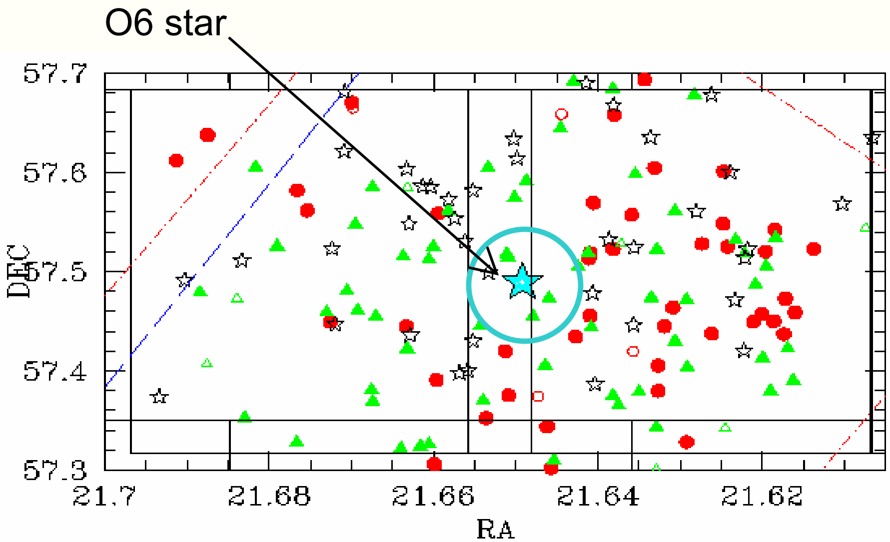
Sicilia-Aguilar et al. 2004

Note: 1-2 $M_\odot$ stars are same “age” in both clusters - “birthline problem” (haven’t contracted much in radius)

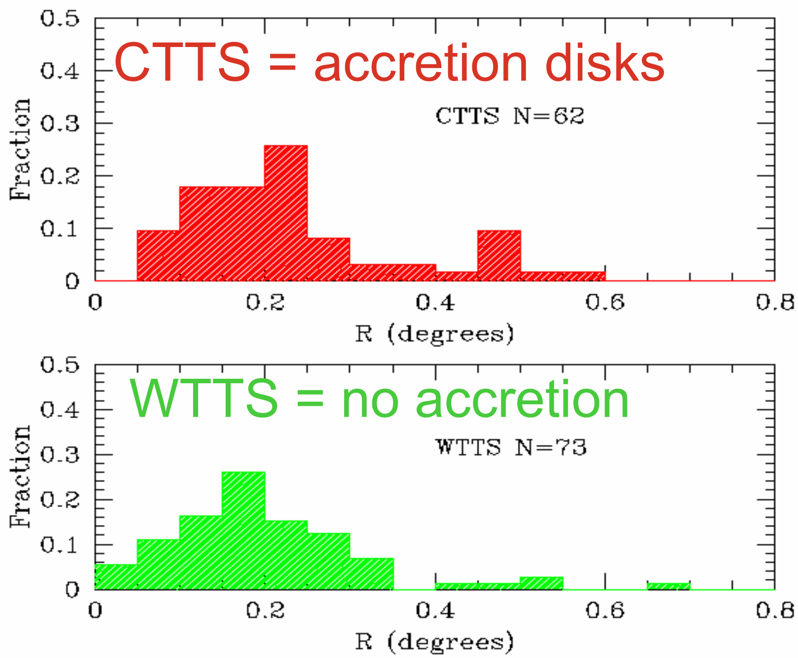
Tr 37/IC 1396

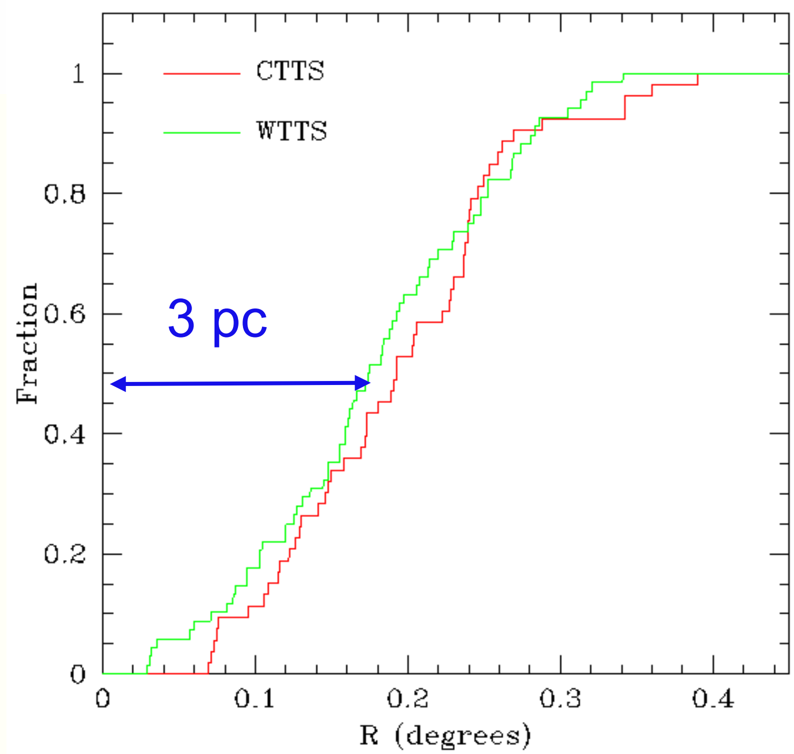


Tr 37; stars with and without disks



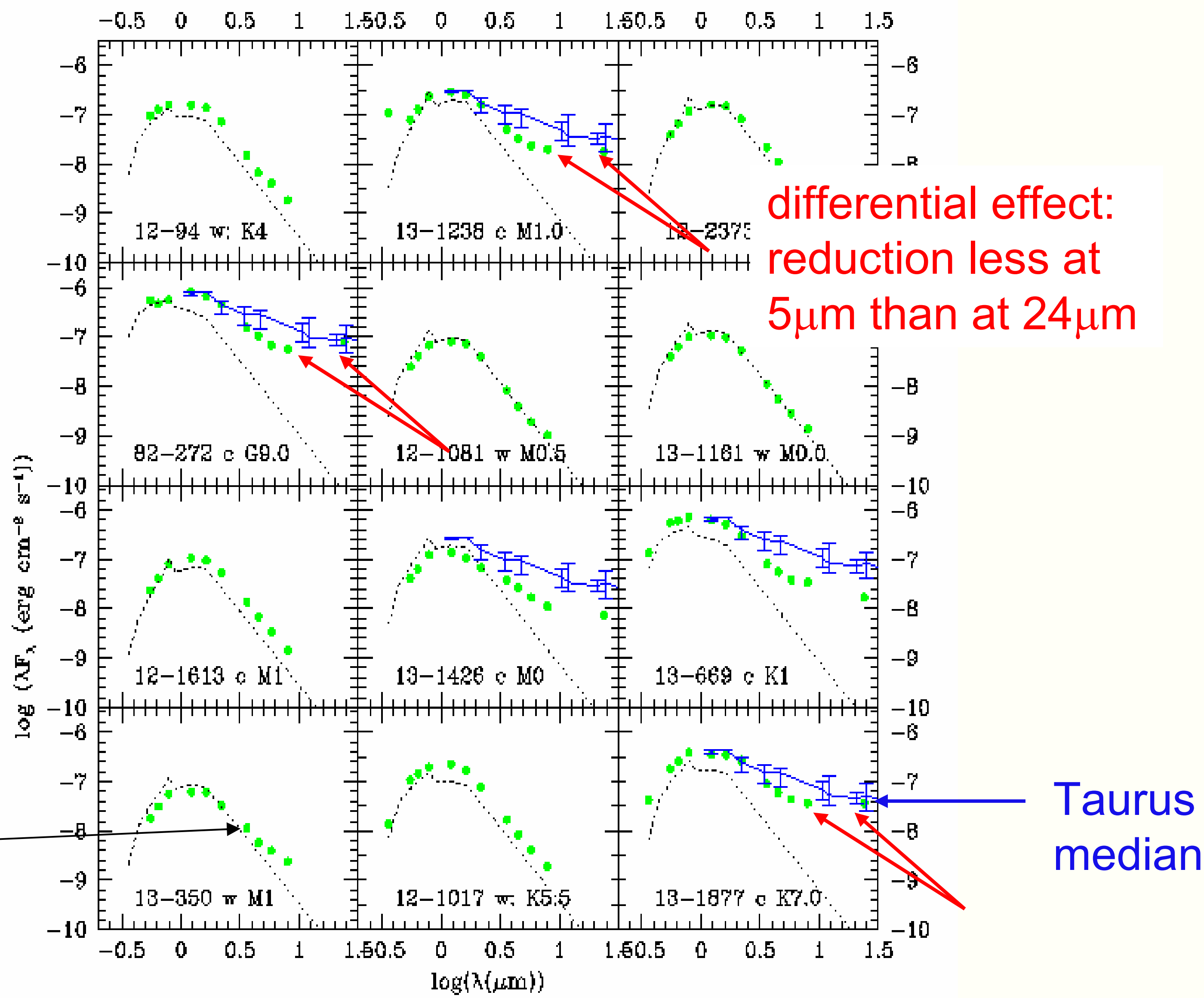
- No CTTS inside ~0.07 degrees radius (<0.7pc) from the O6 star.
- lack of CTTS (inner disks) due to photoevaporation? (+ accretion) (not statistically significant)



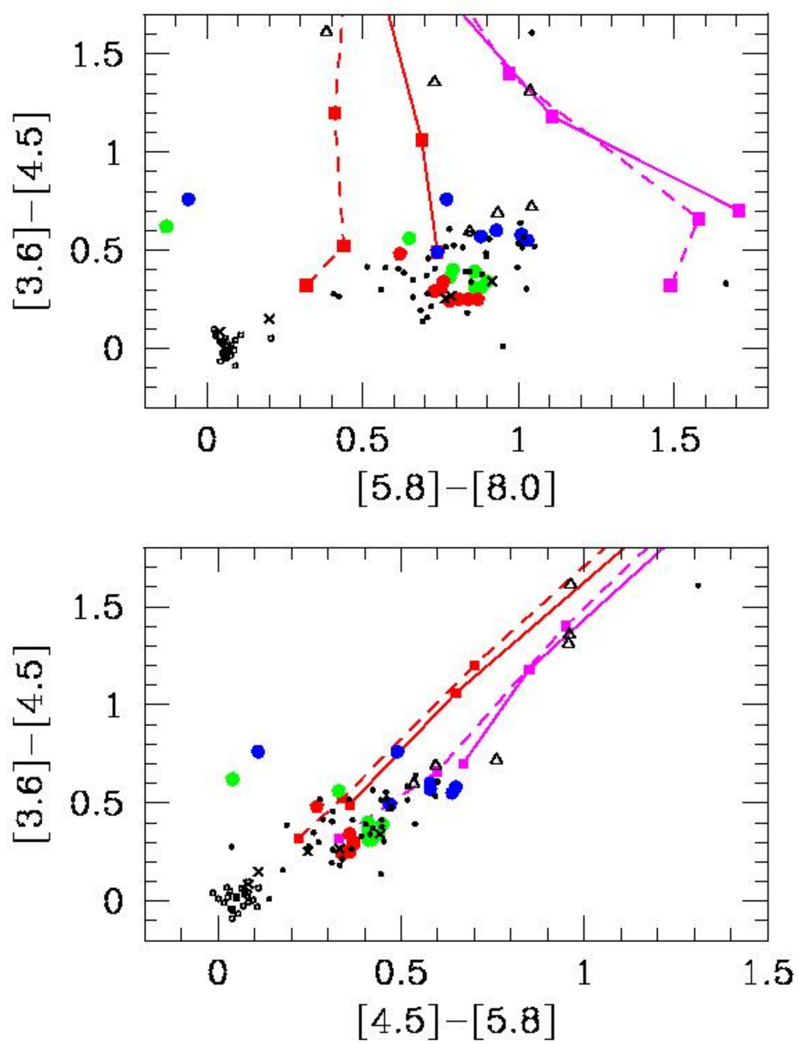


Tr 37: less IR disk emission = dust settling, or coagulation, or disk clearing (r < 1-2 AU), t ~ 3 Myr

Sicilia-Aguilar et al. 2004

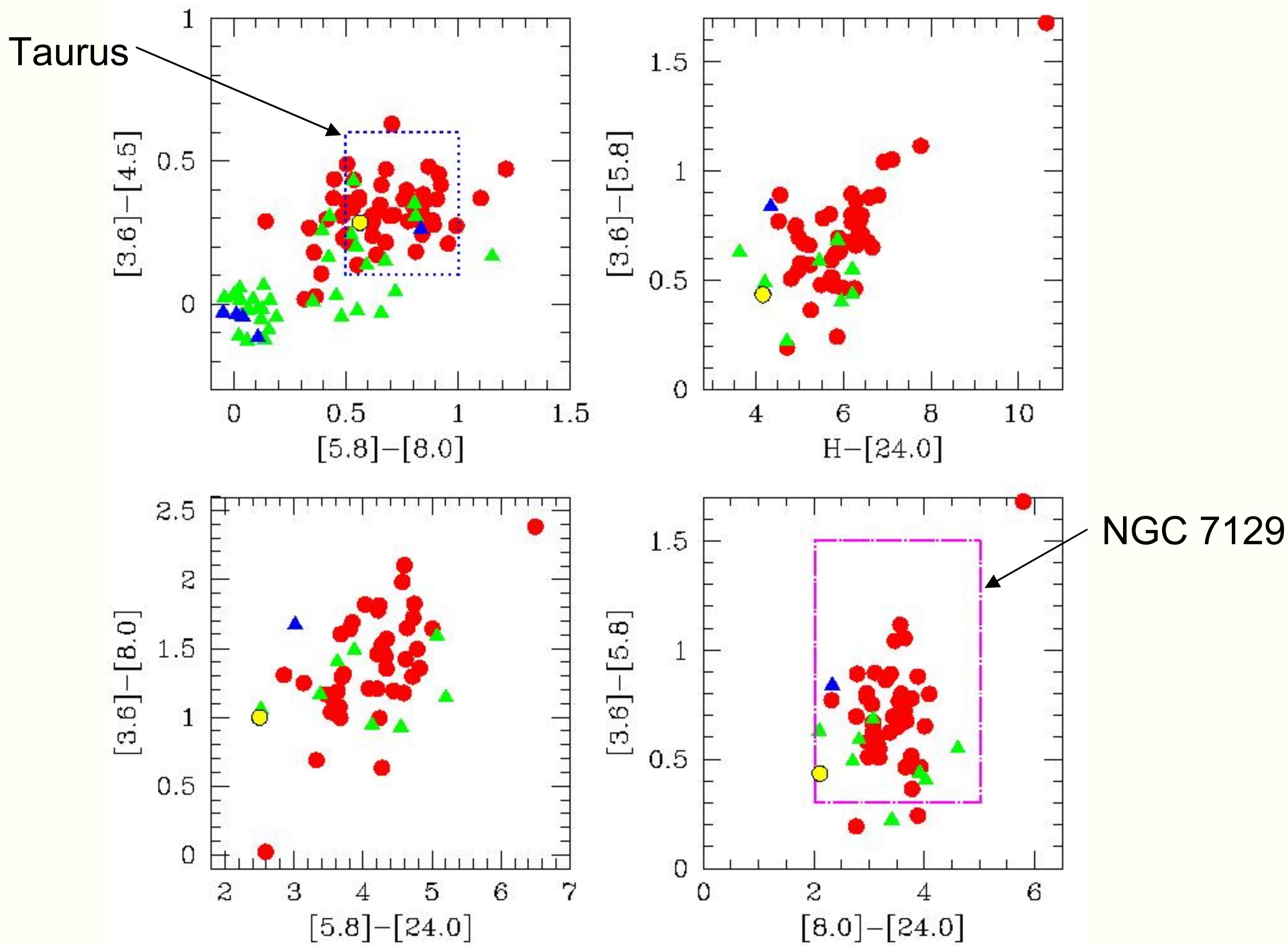


Taurus: IRAC vs. models

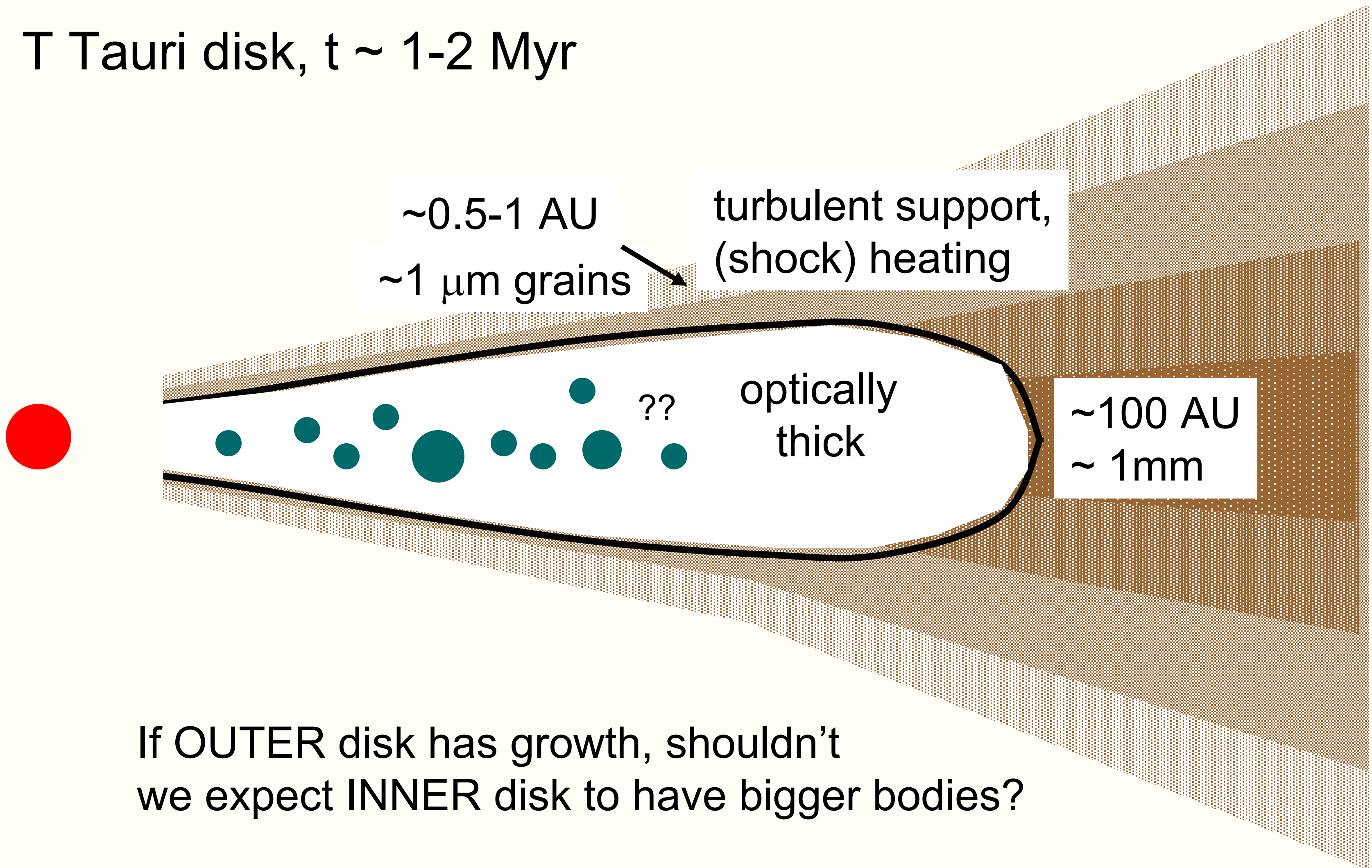


Hartmann et al. 2005

disk evolution in Tr 37 (~ 4 Myr)



T Tauri disk, t ~ 1-2 Myr



If OUTER disk has growth, shouldn't
we expect INNER disk to have bigger bodies?

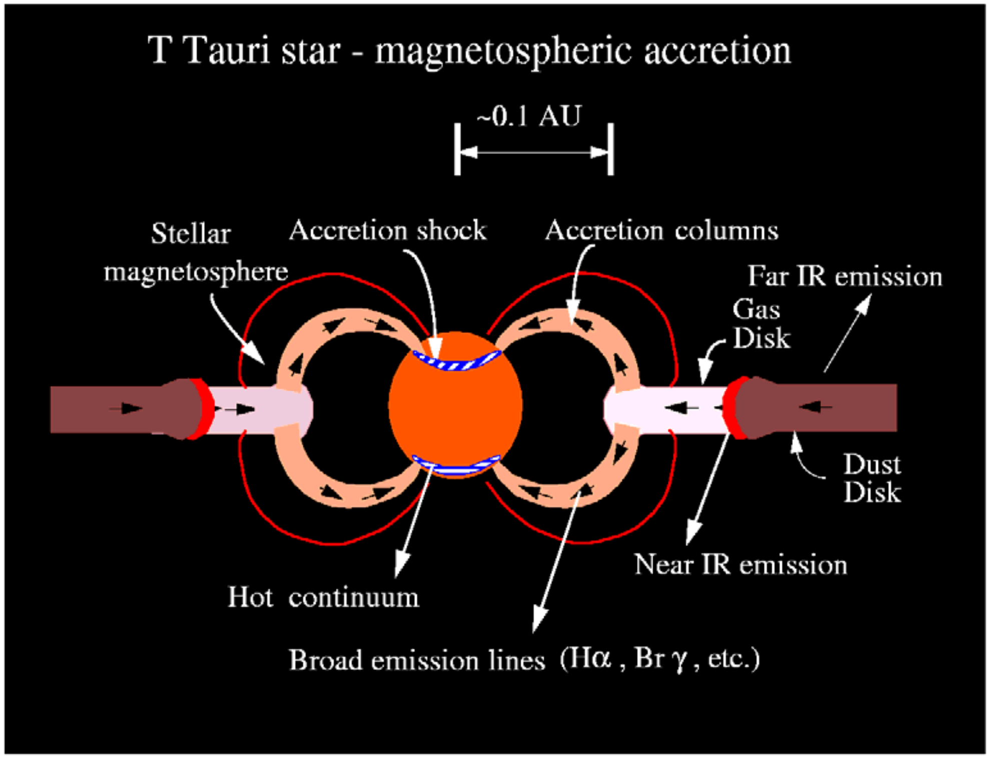
(turbulence suspends some small dust to
several scale heights, obscuring our view)

Summary and speculations

- Initial conditions (angular momenta) ⇒ wide range of disk timescales, ~ 1-10 Myr. How, exactly?
- Disk masses, accretion rates may be somewhat underestimated ⇒ closer to gravitational instability?
- Increasing evidence from Spitzer for settling, inside-out disk evolution ⇒ plus lag time of 1-10 Myr ⇒ core accretion, not (direct) gravitational instability
- Disk evaporation by nearby O star in a cluster may be less dramatic than some suggestions. Disks can survive for several Myr at a few pc.
- Transport processes poorly understood...

Near-IR emission mostly from wall at dust destruction radius (at least dust destruction TEMPERATURE) small silicates; others?

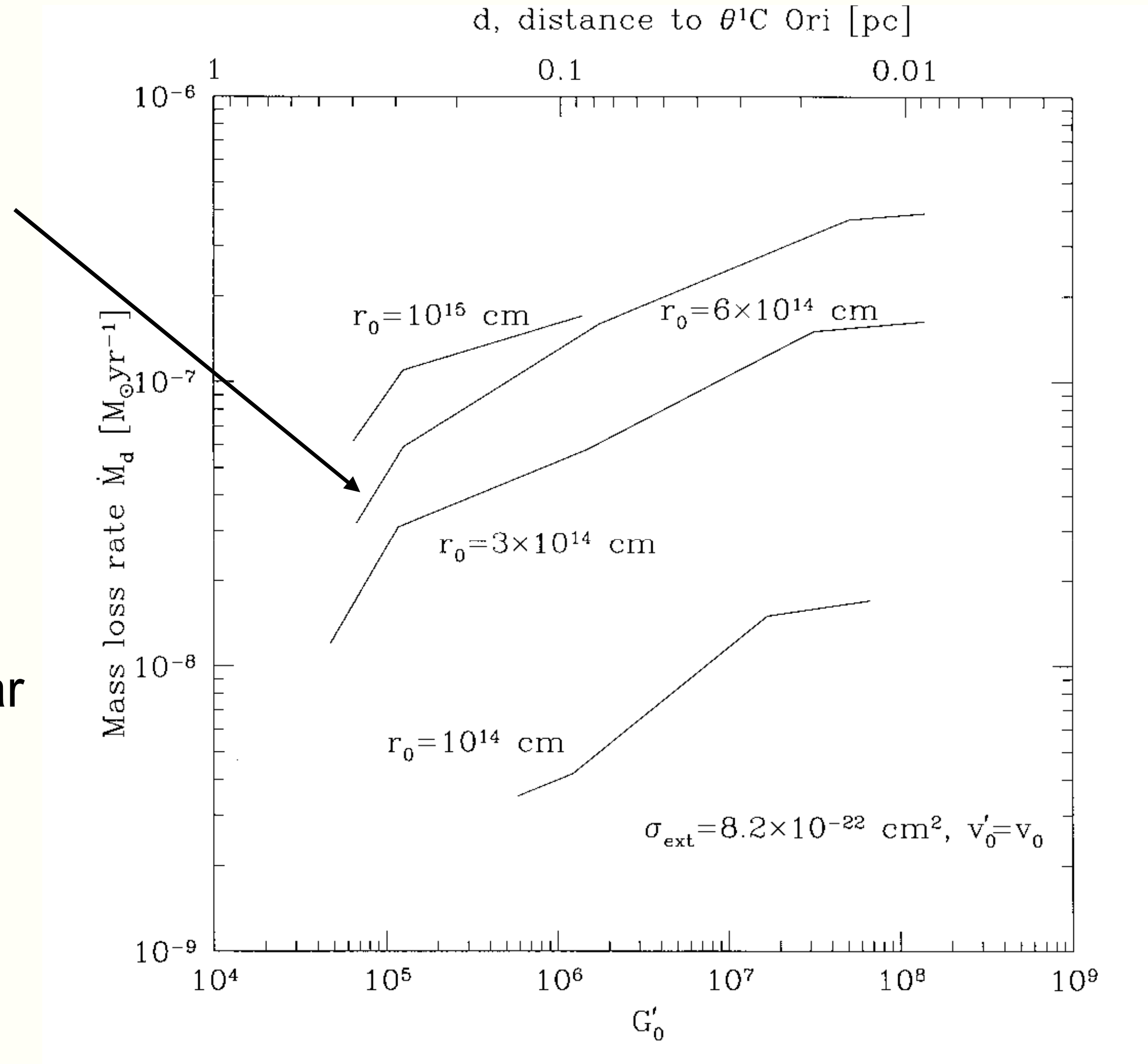
INNER DISK STRUCTURE EXTREMELY COMPLEX



Evaporation: Orion & Tr 37

mass loss rate from disk drops at ~ 0.5 pc

MOST cluster stars reside at larger distances from O star



Störzer & Hollenbach 1999