Disks around young Brown Dwarfs as critical testbeds for models of dust evolution: an investigation with ALMA

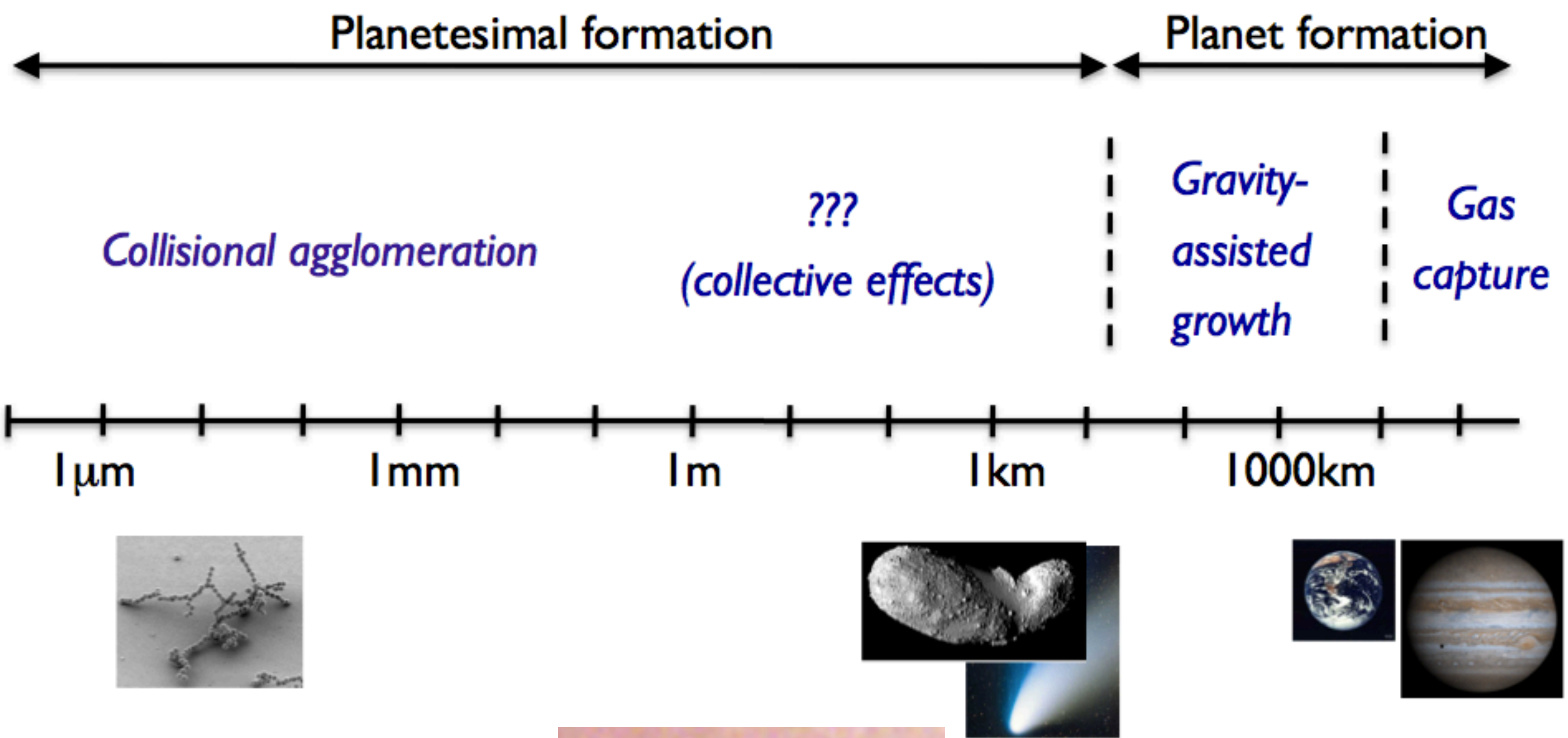
ALMA (ESO/NAOJ/NRAO)/Kornmesser, Calcada (ESO)

Luca Ricci (CARMA Fellow, Caltech)

Testi (ESO/Germany), Natta, Scholz (DIAS), de Gregorio-Monsalvo (ESO/Chile)

Isella, Carpenter (Caltech), Pinilla (ITA), Birnstiel (LMU)

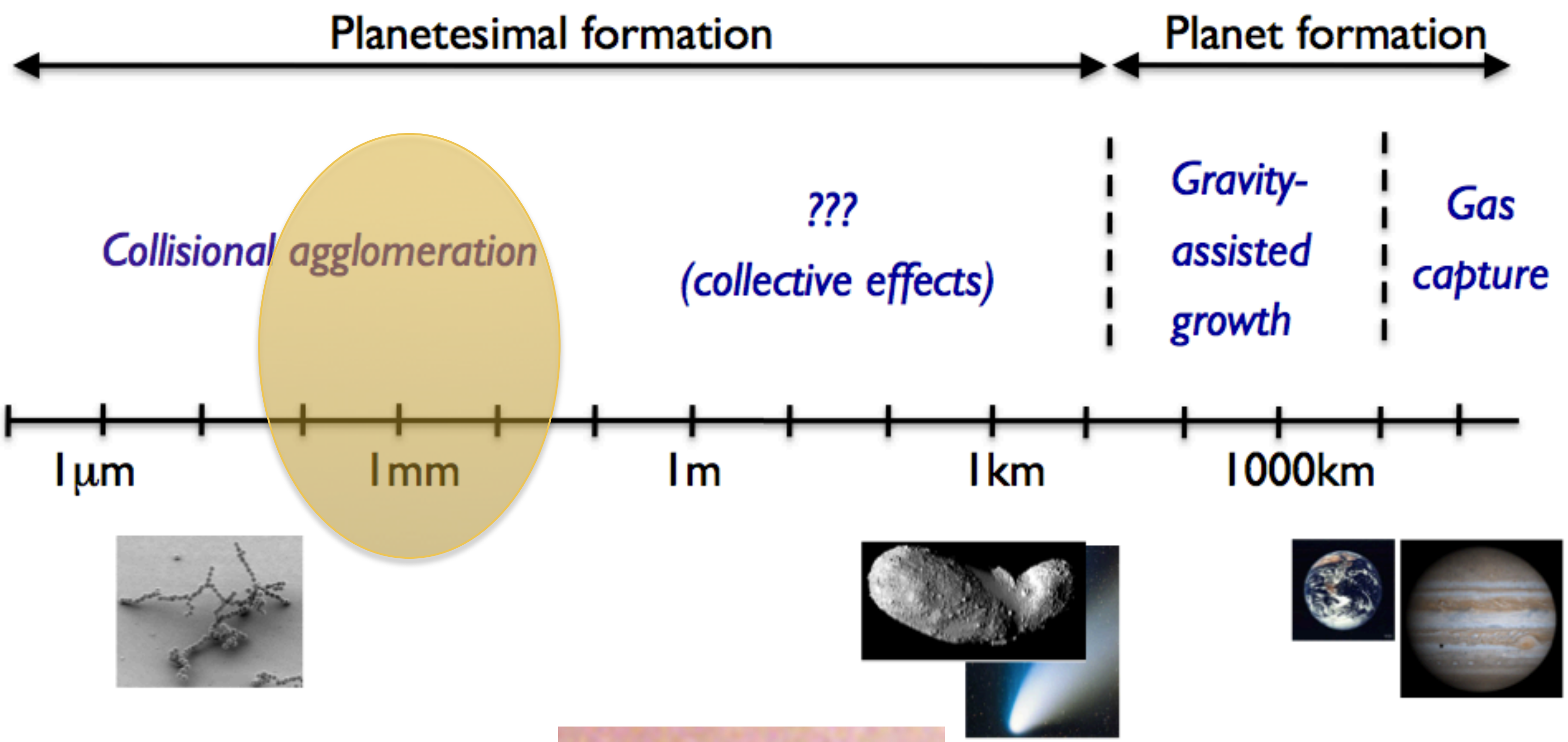
From dust to planets



Dullemond

NASA/ESA, L. Ricci

From dust to planets



Dullemond

NASA/ESA, L. Ricci

From dust to planetesimals

mm-grains with low sticking efficiency

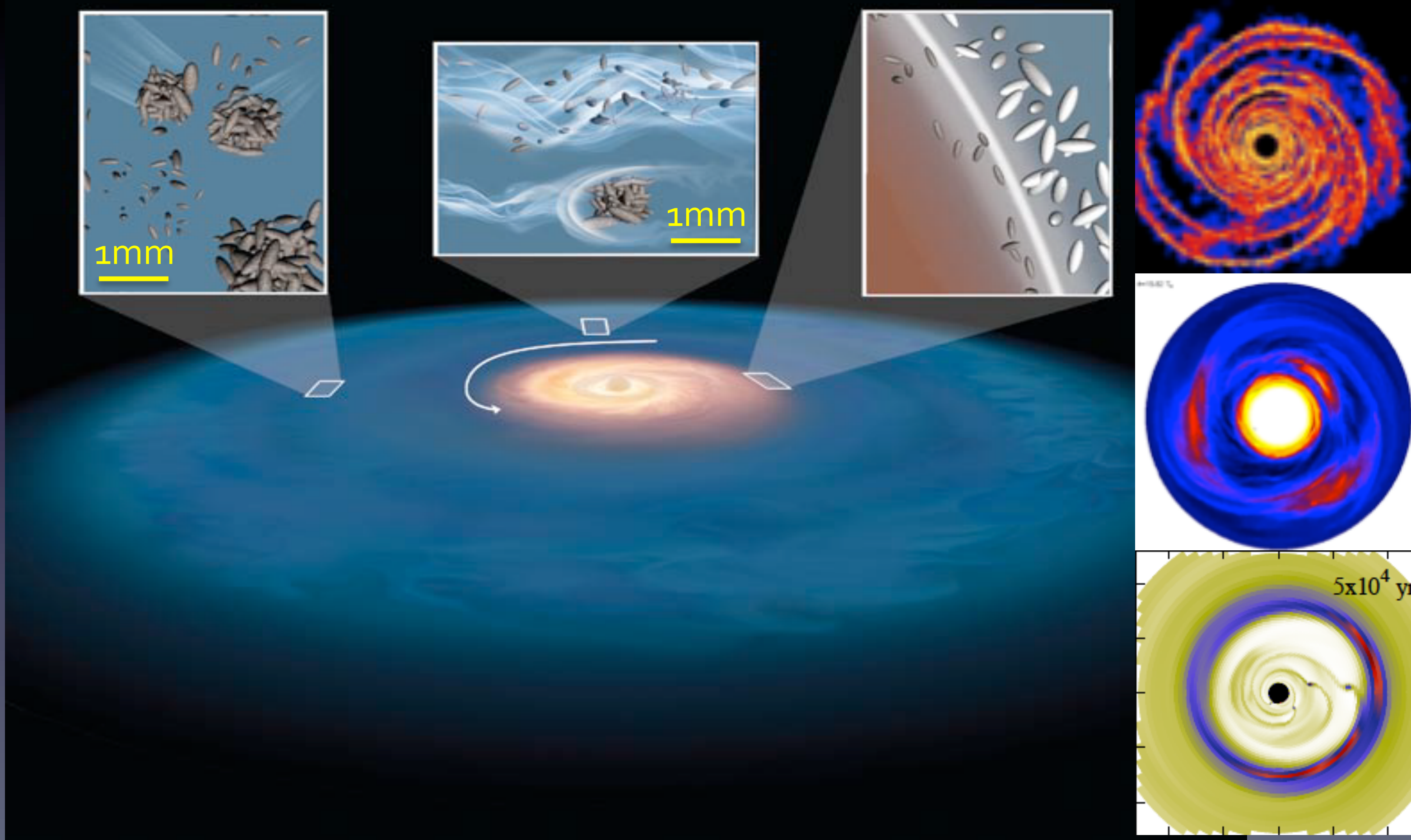
$dP_{gas} / dr < 0$:

$V_{gas} < V_{solids}$

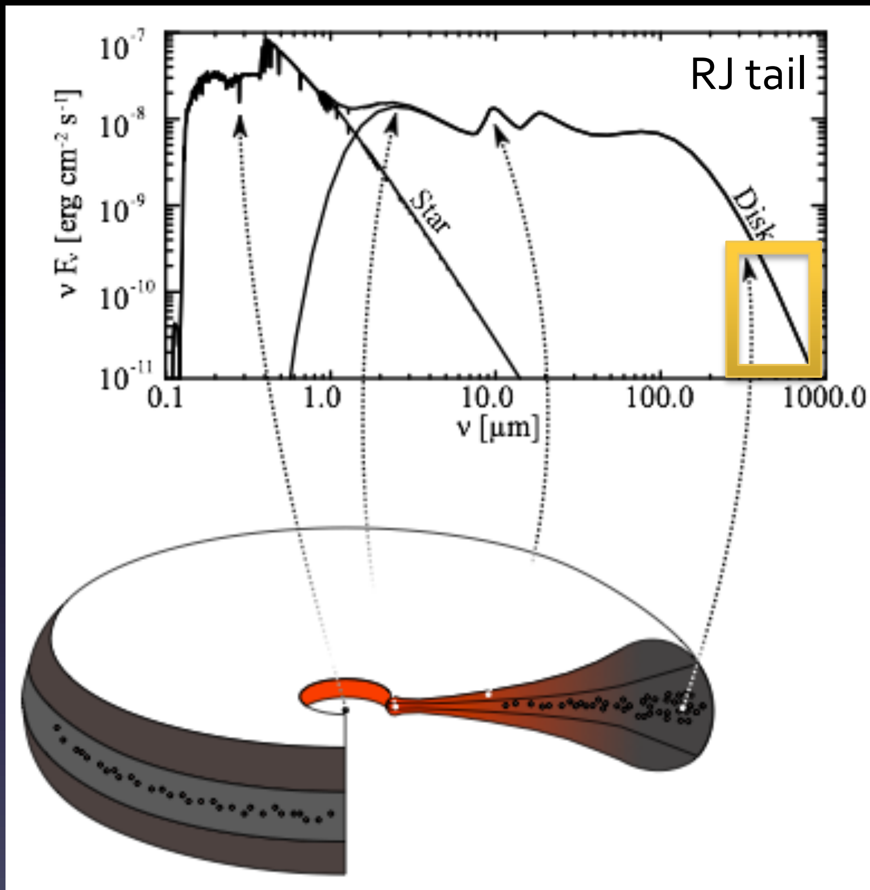
mm-grains drift fast toward the central star

$dP_{gas} / dr > 0$:

Reverse motion of solids, trapped at P-maxima



Grain sizing from mm-SED slope

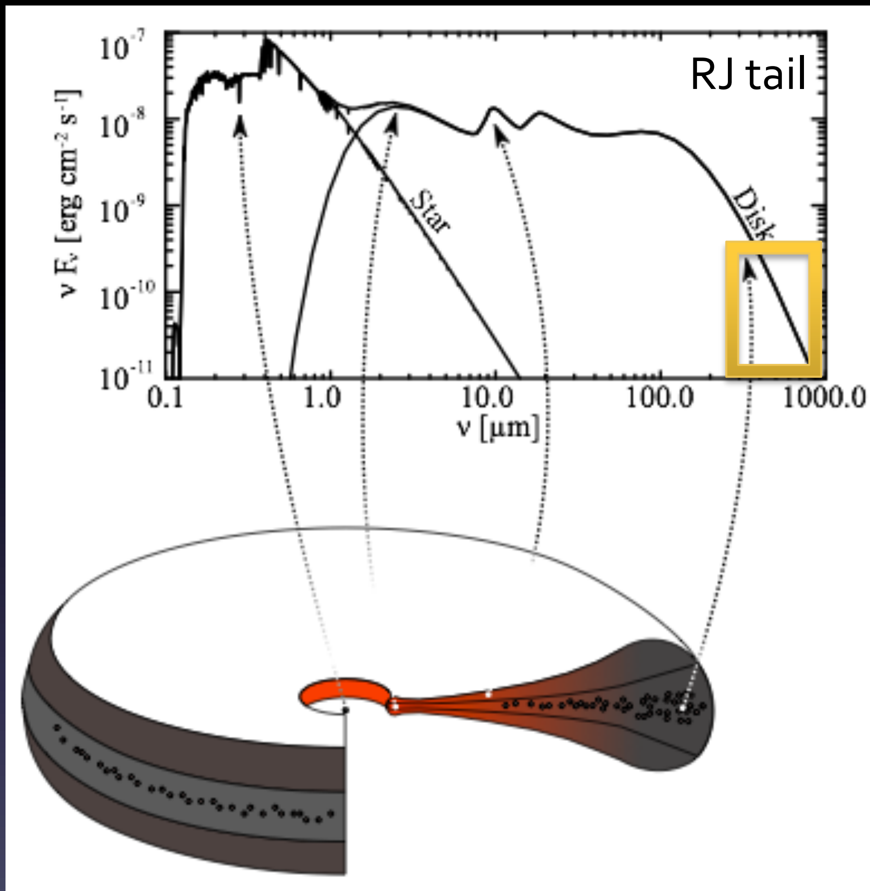


Dullemond, Birnstiel

$F_\nu \sim \nu^2 \kappa_\nu$; $F_\nu \sim \nu^\alpha$, $\kappa_\nu \sim \nu^\beta$

$\alpha \sim 2 + \beta$

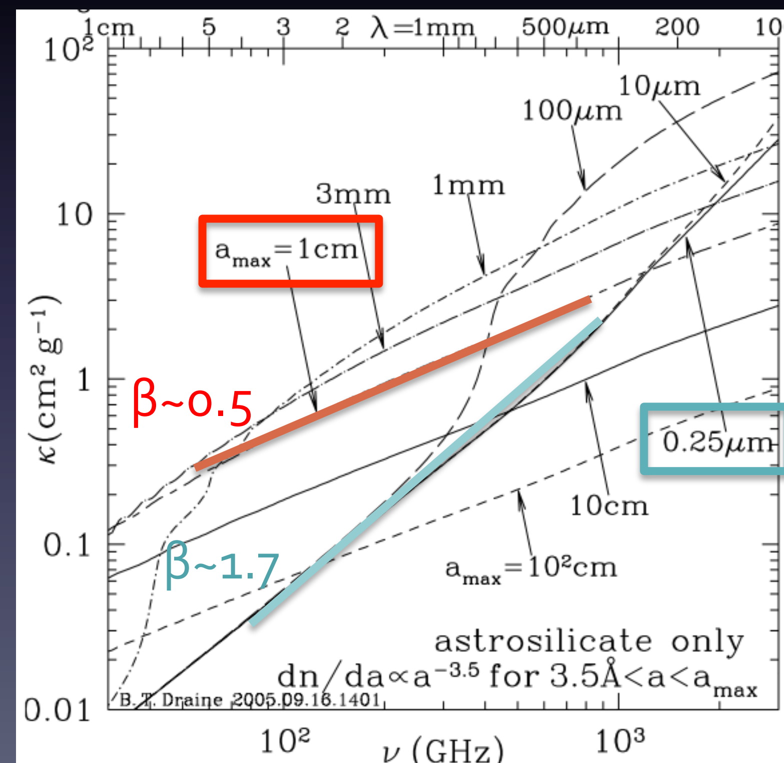
Grain sizing from mm-SED slope



Dullemond, Birnstiel

$\Rightarrow F_\nu \sim \nu^2 \kappa_\nu$; $F_\nu \sim \nu^\alpha, \kappa_\nu \sim \nu^\beta$

$\alpha \sim 2 + \beta$



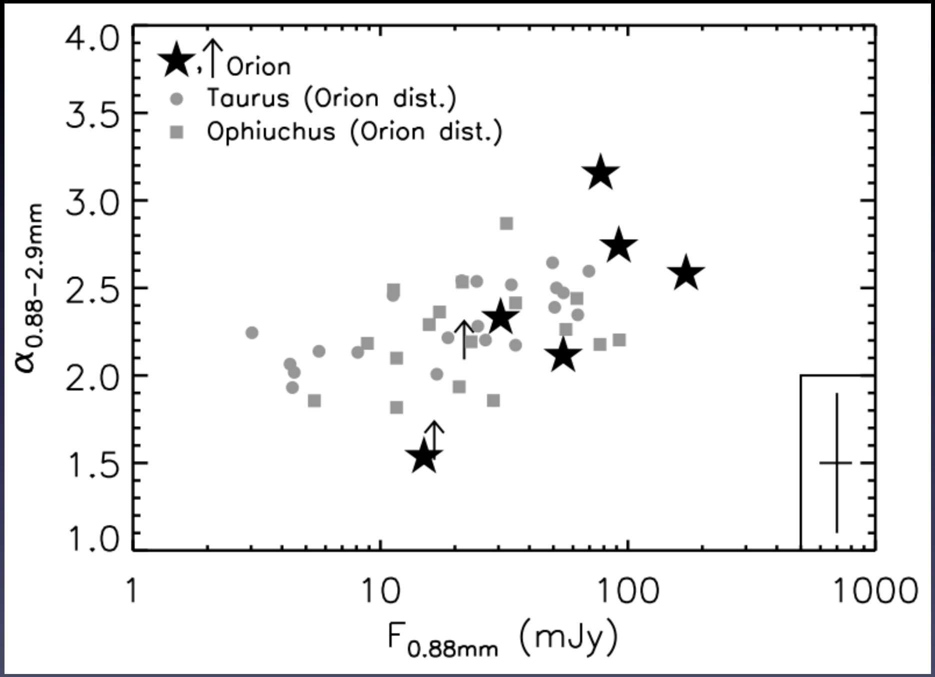
Draine 06

$\beta < 1$ ($\alpha < 3$) only if ~ mm pebbles in the outer disk (R > 10 AU)

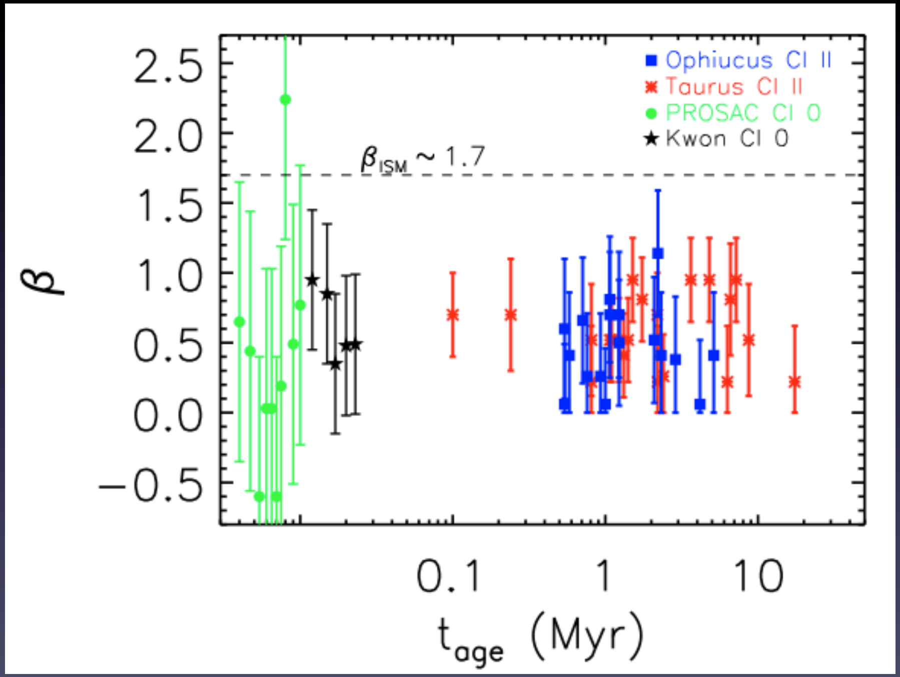
Grain growth: observational results

(Beckwith & Sargent 91, Testi+ 03, Wilner+ 05, Andrews & Williams 05, Rodmann+ 06, Lommen+ 07, Ricci+ 10a,10b,11,12, Guilloteau+ 11, Ubach+12, ...)

~ 100 Class II disks around young stars



Ricci+ 2011

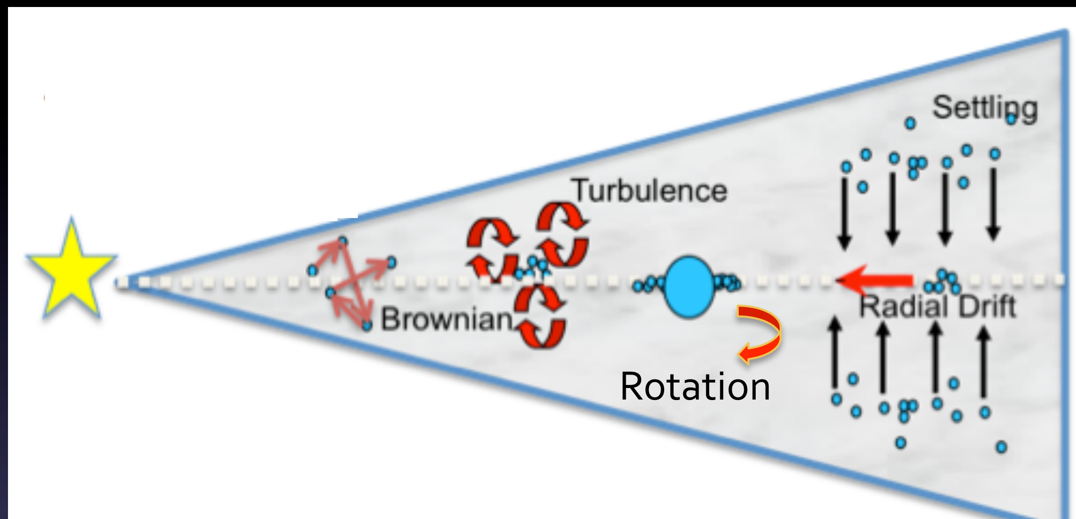


Ricci+ 2010

- mm-grains in the outer regions of nearly all disks: grain growth is fast even in the outer disk, i.e. < 1 Myr

Models of dust evolution in disks

- Time evolution of gas surface density & temperature



Brauer+ 08, Birnstiel+ 10

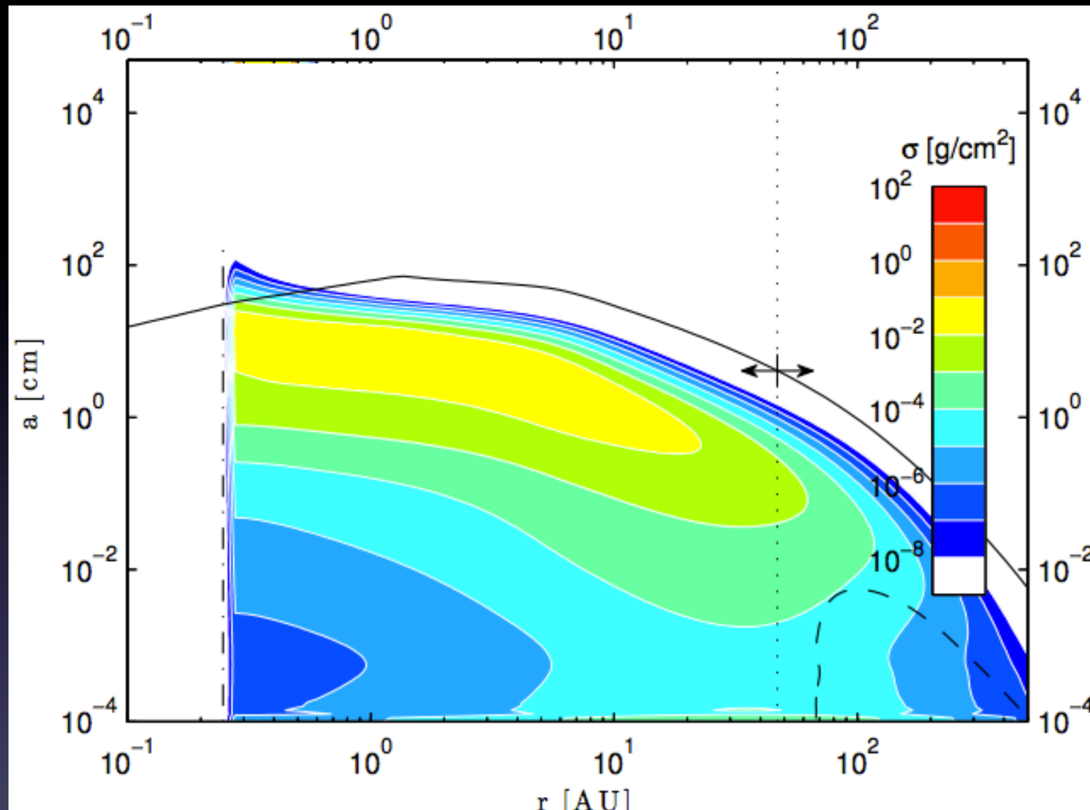
- Solids with different sizes acquire relative velocities, i.e. they collide

Collision outcome: Δv_{coll}

$> v_{frag}$ → fragmentation

$< v_{frag}$ → coagulation

Models of dust evolution in disks



Distance from the star

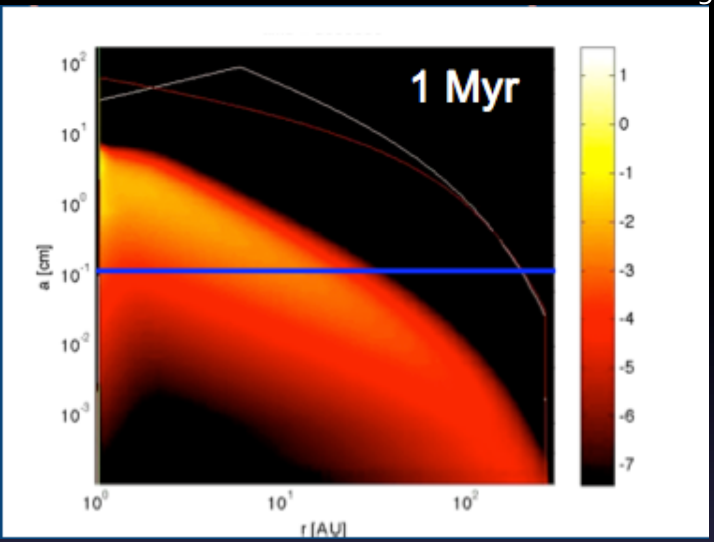
Dust composition (e.g. Pollack+ 94) → $\kappa_\lambda(r)$

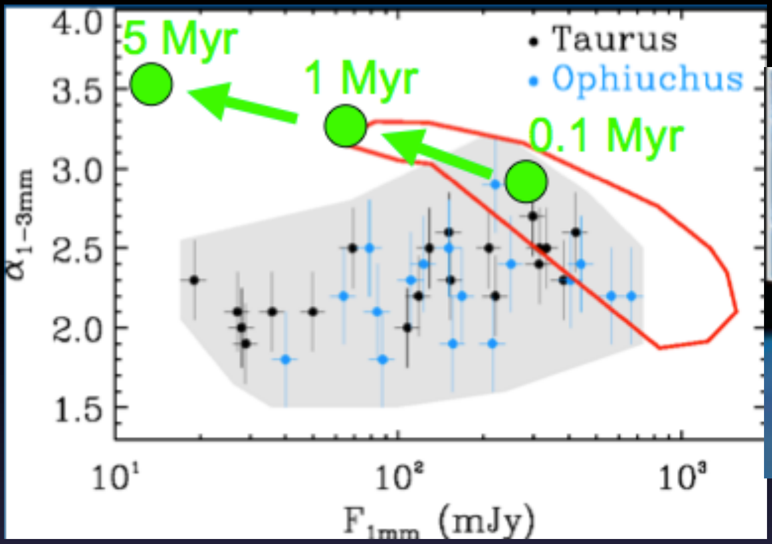
Disk structure ($\Sigma_d(r)$, $T(r)$) → Disk Fluxes

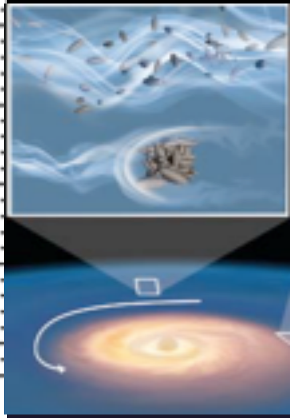
(dist, incl)

Data vs models: the role of drift

"SMOOTH" DISK, SELF-SIMILAR $\Sigma_{gas}(R)$



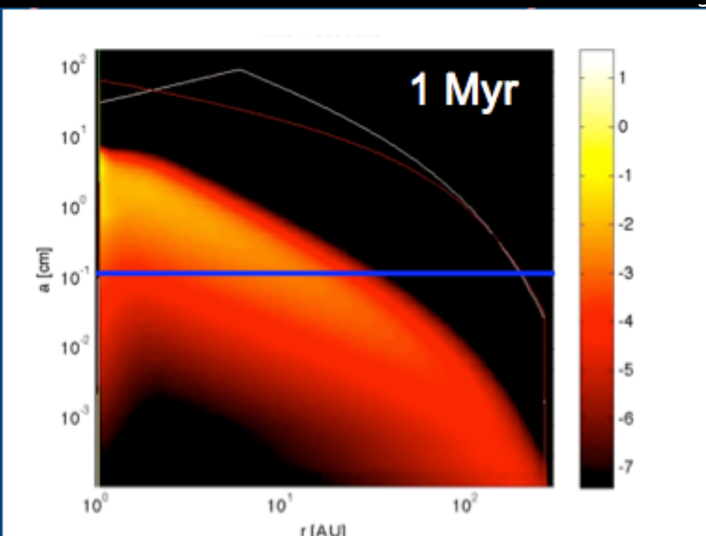


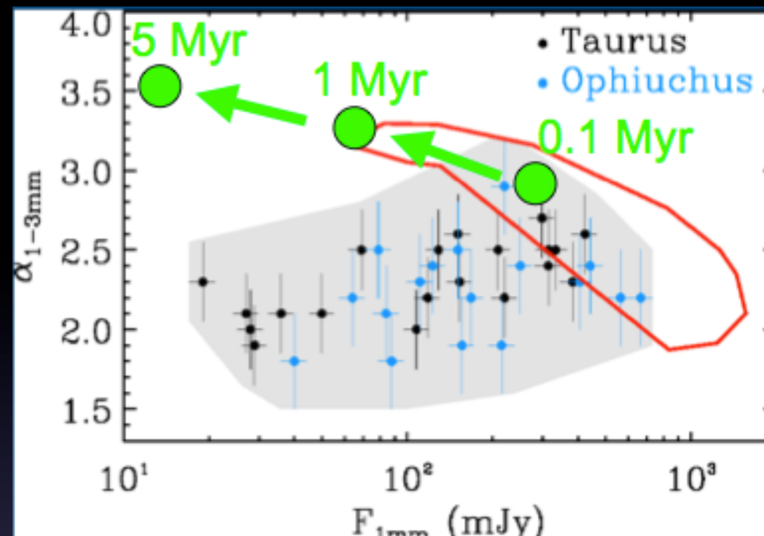


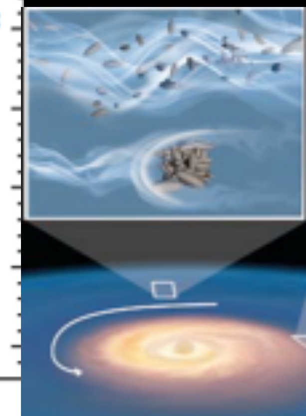
Pinilla, LR + 2012, Birnstiel, LR + 2010

Data vs models: the role of drift

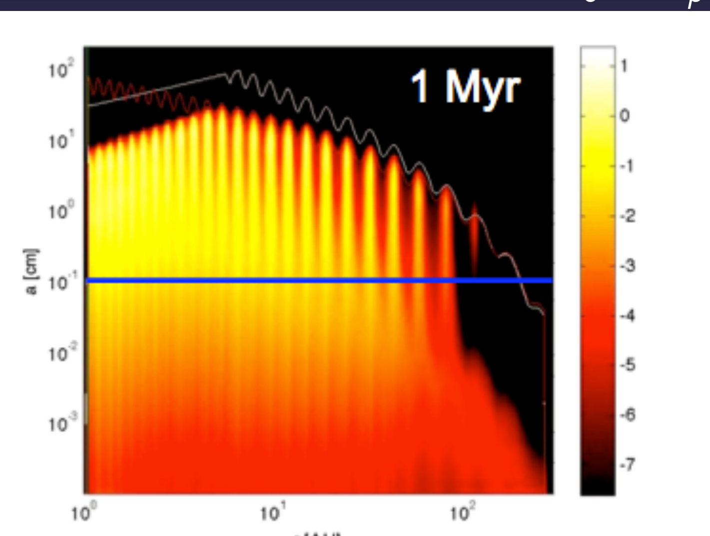
“SMOOTH” DISK, SELF-SIMILAR $\Sigma_{gas}(R)$

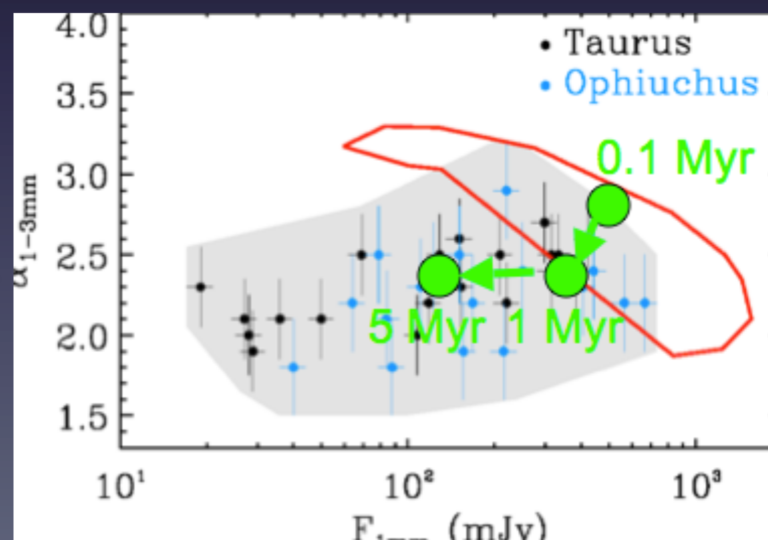






PRESSURE MAXIMA ($A \approx 0.3\Sigma_0$, $l \approx H_p$)

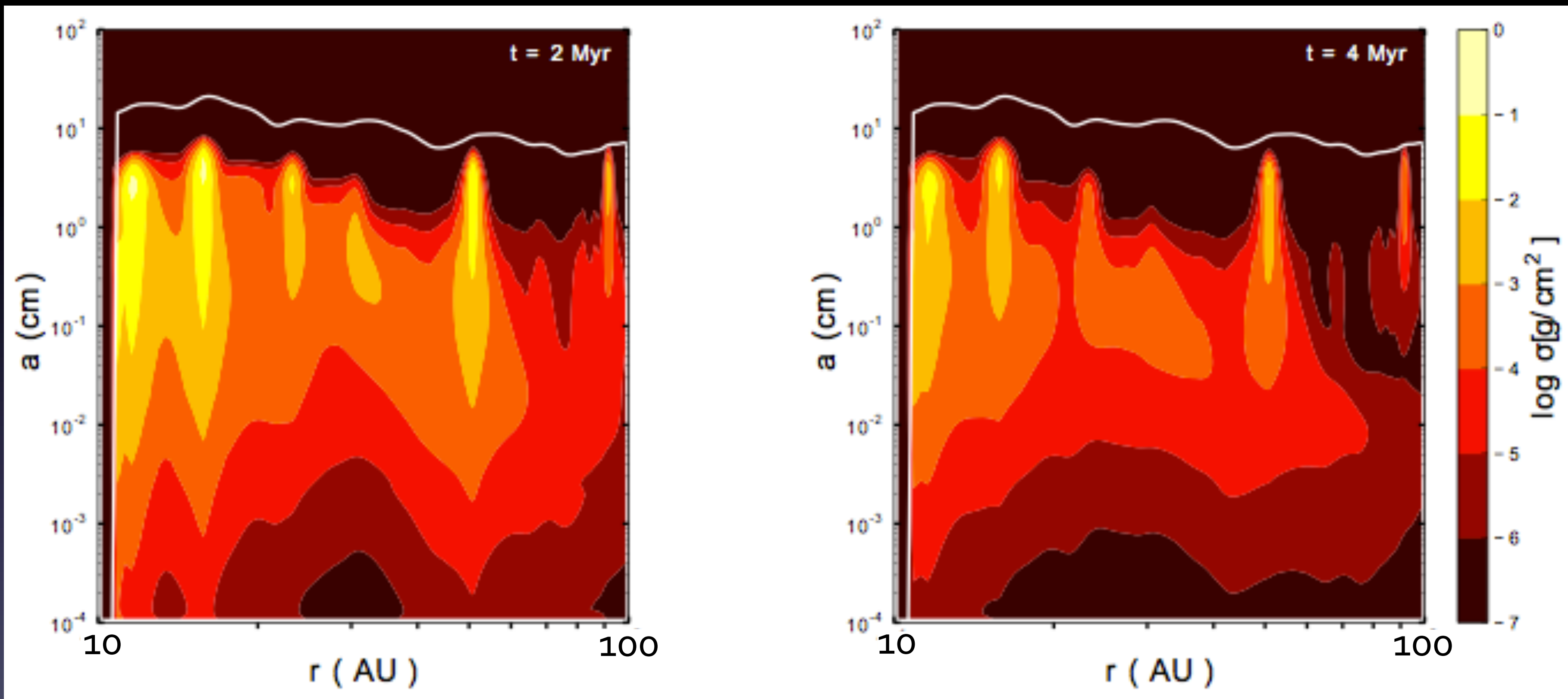




Pinilla, LR + 2012, Birnstiel, LR + 2010

Disks with P-maxima

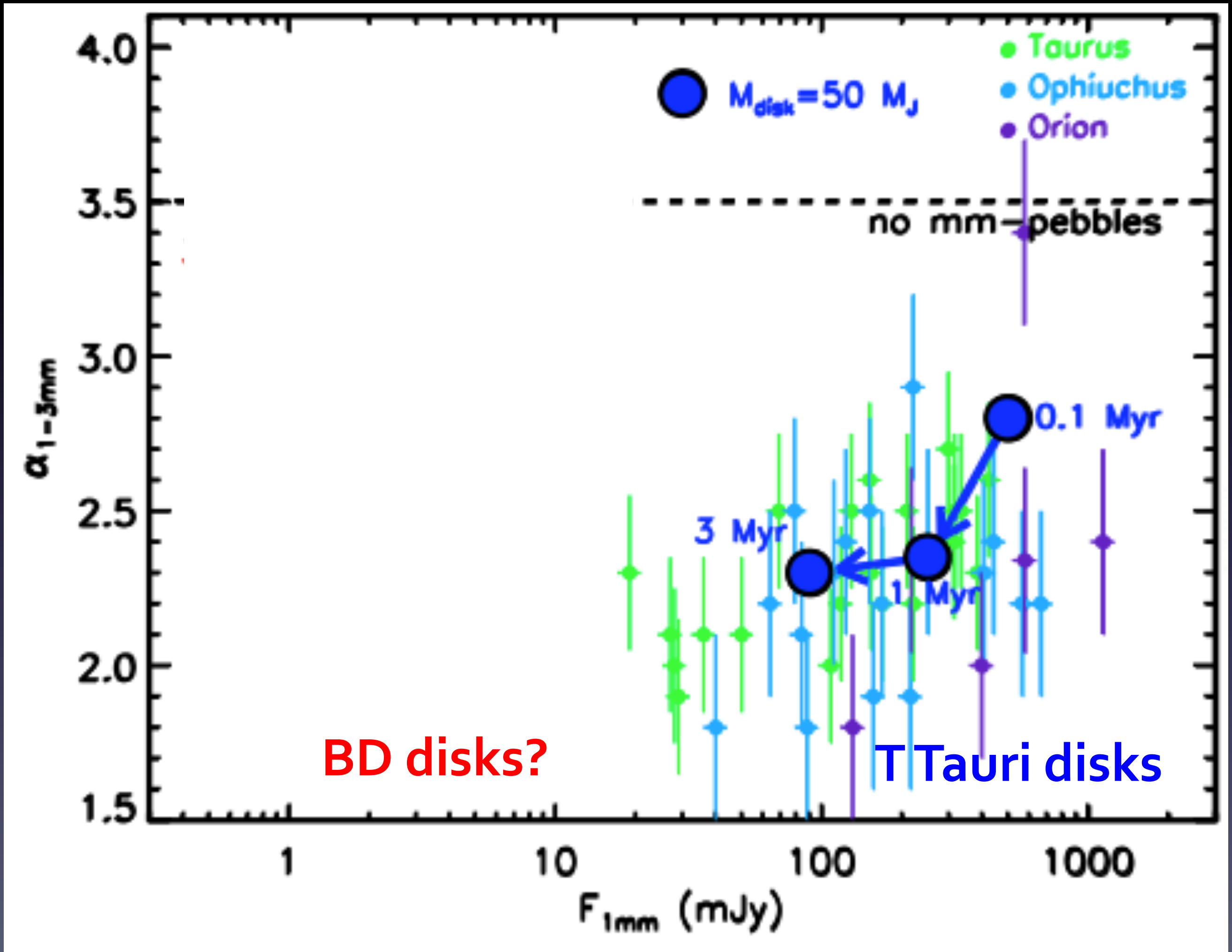
3D MHD simulations of MRI-turbulent disks (Uribe+ 2011)



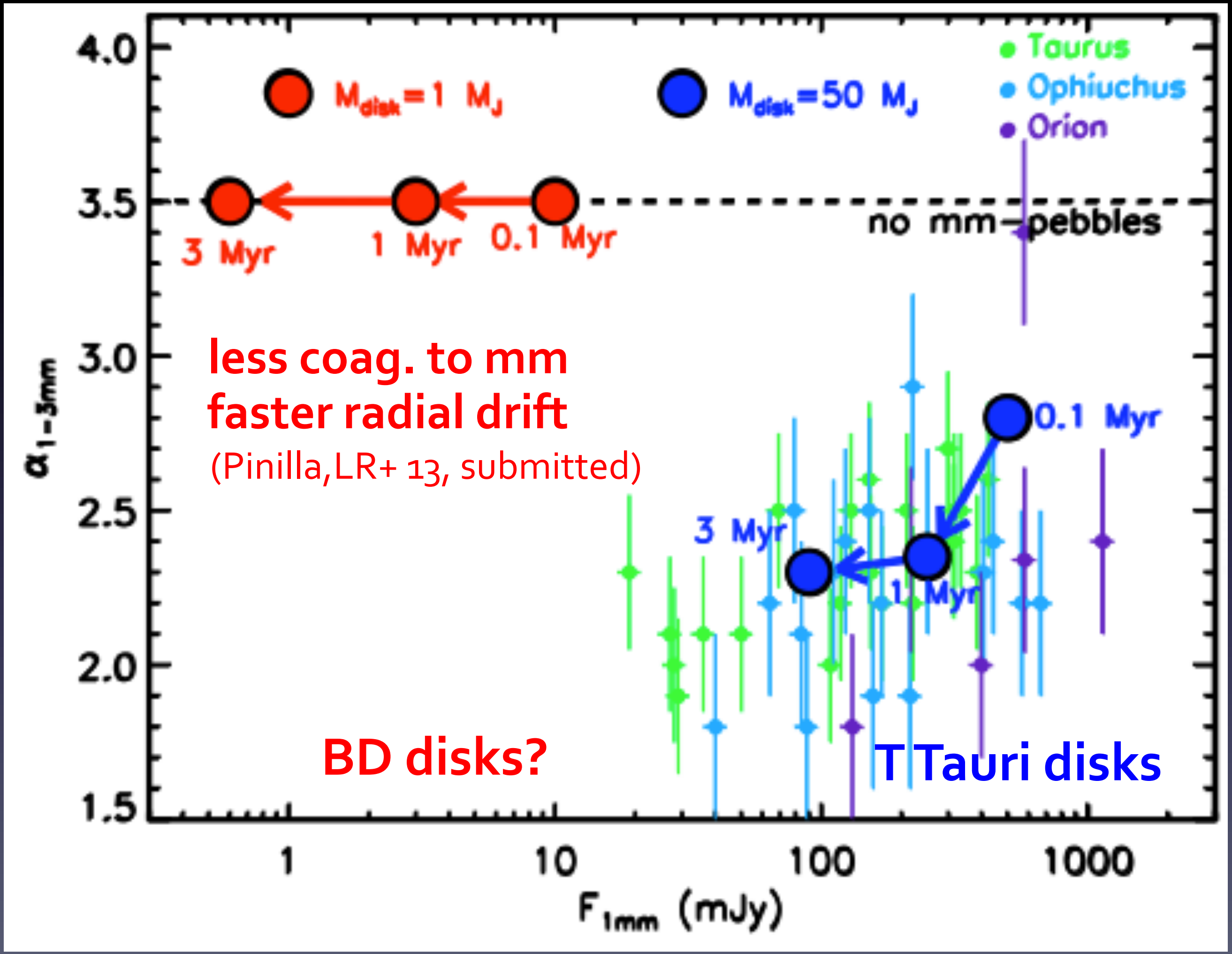
(are the required physical conditions met in real disks? stability?)

If there, ALMA should see them… (Pinilla, LR+ 2012)

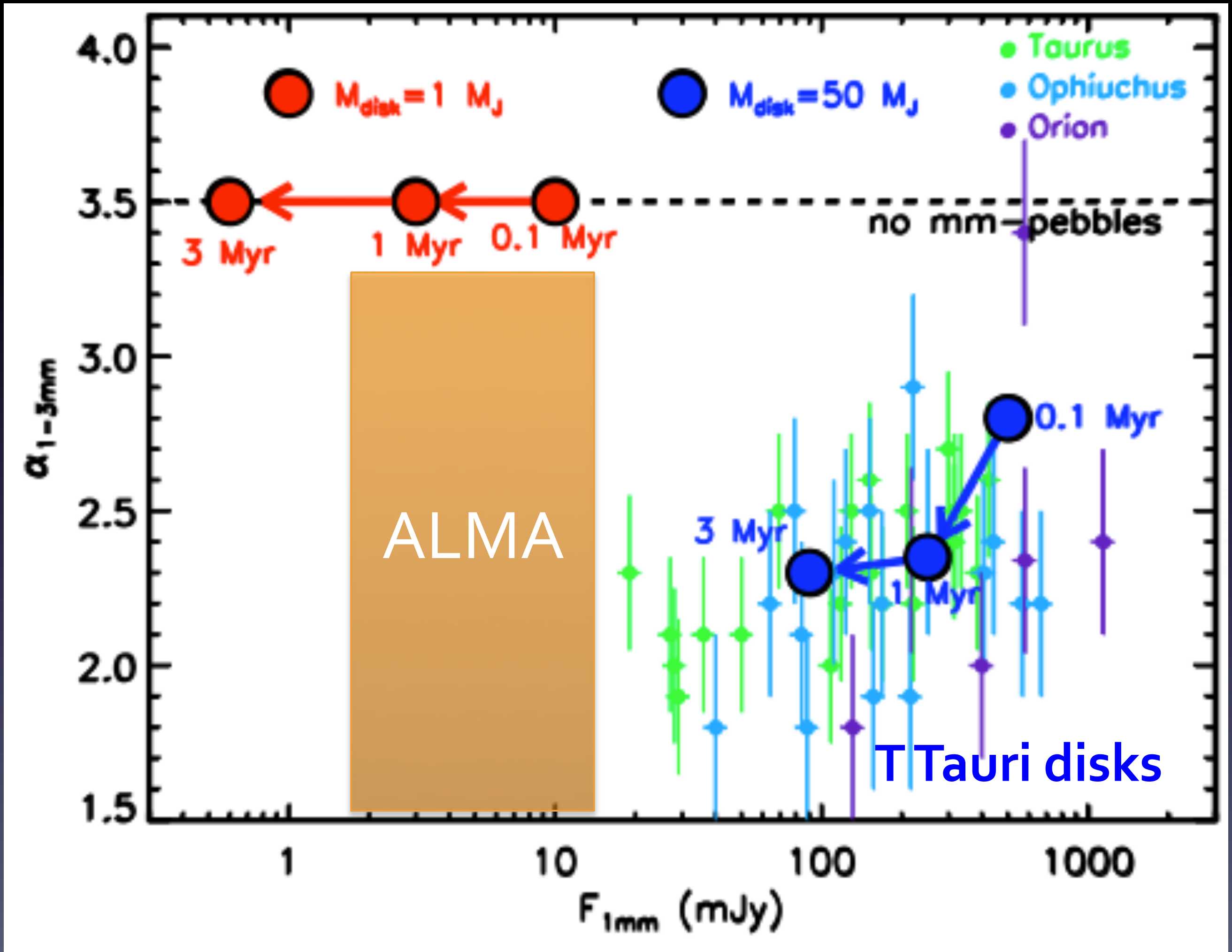
Disks with P-maxima: model predictions



Disks with P-maxima: model predictions



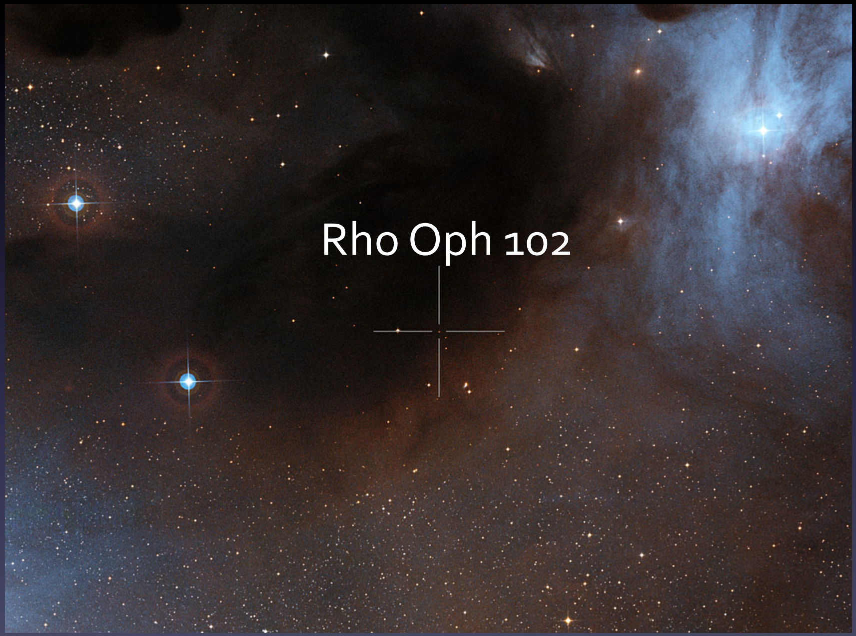
Disks with P-maxima: model predictions



4 disks with 1 < F_{1mm} < 10 mJy around BDs and VLMs

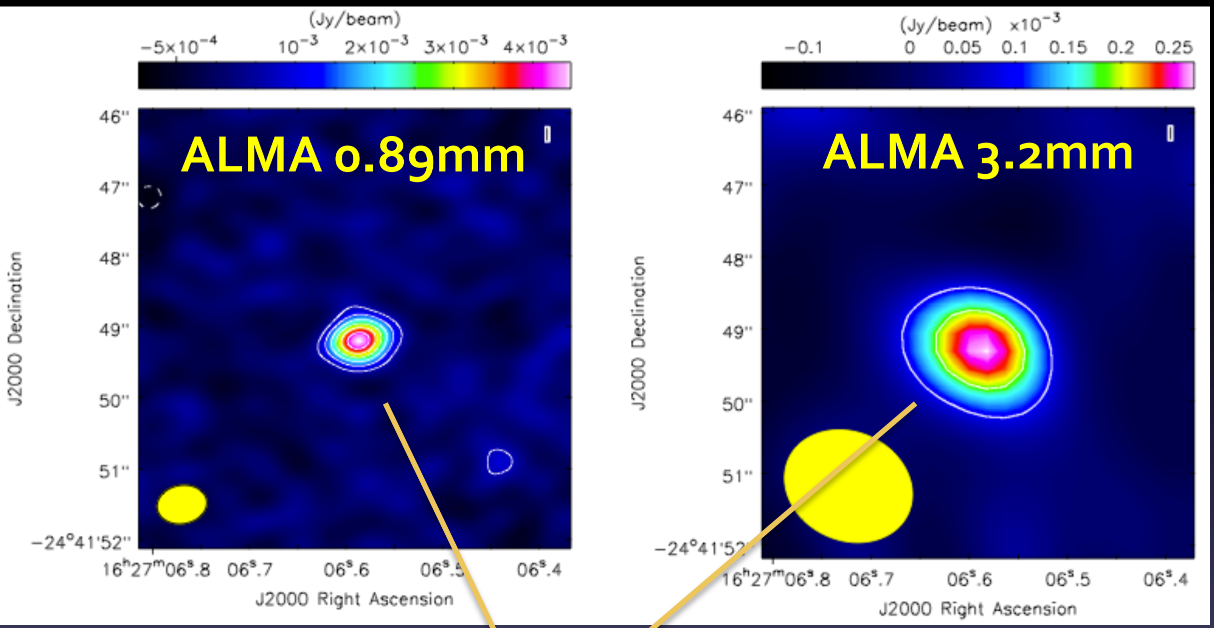
Rho Oph 102

ESO/Digitized Sky Survey 2



$M_{BD} \approx 60\ M_{Jup}$, $Age \sim 1$ Myr

The disk around the young BD rho Oph 102

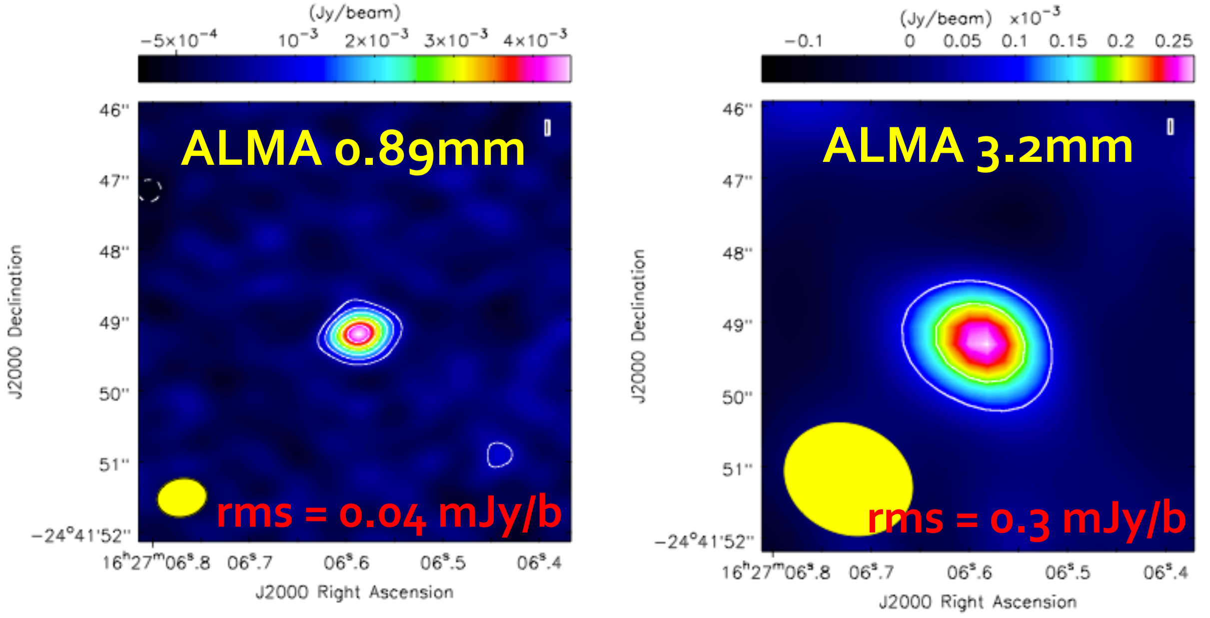


α

ALMA
ATACAMA LARGE MILLIMETER ARRAY

Ricci + 12

The disk around the young BD rho Oph 102



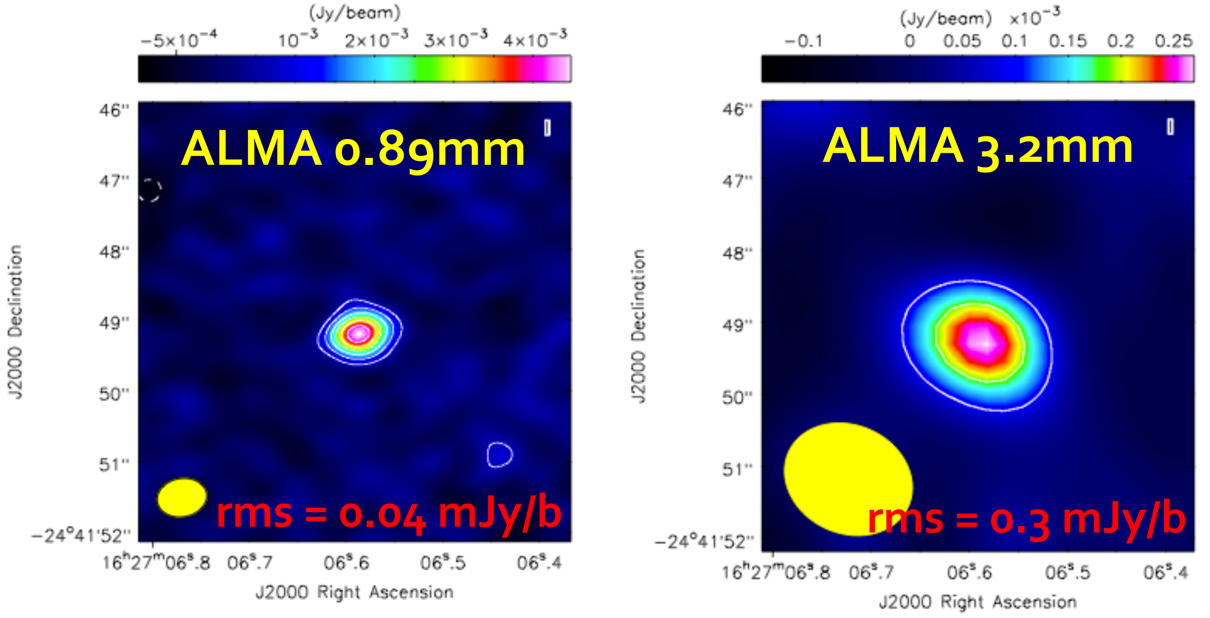
~ 15 min ALMA time

~ 30 min ALMA time

ALMA
ATACAMA LARGE MILLIMETER ARRAY

Ricci + 12

The disk around the young BD rho Oph 102

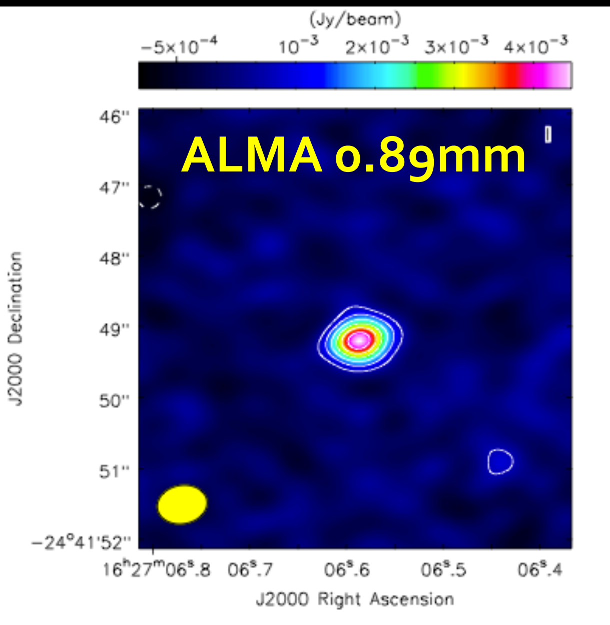


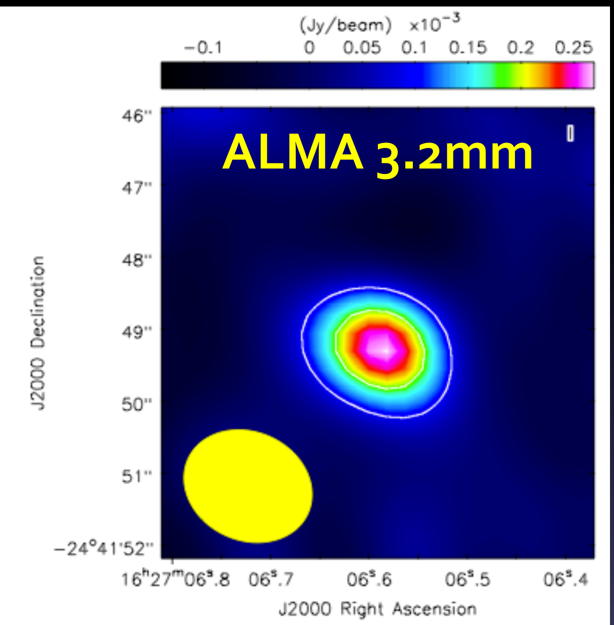
~ 15 min ALMA time
vs ~ 500 hrs SMA time!

~ 30 min ALMA time
vs ~ 120 hrs CARMA time!

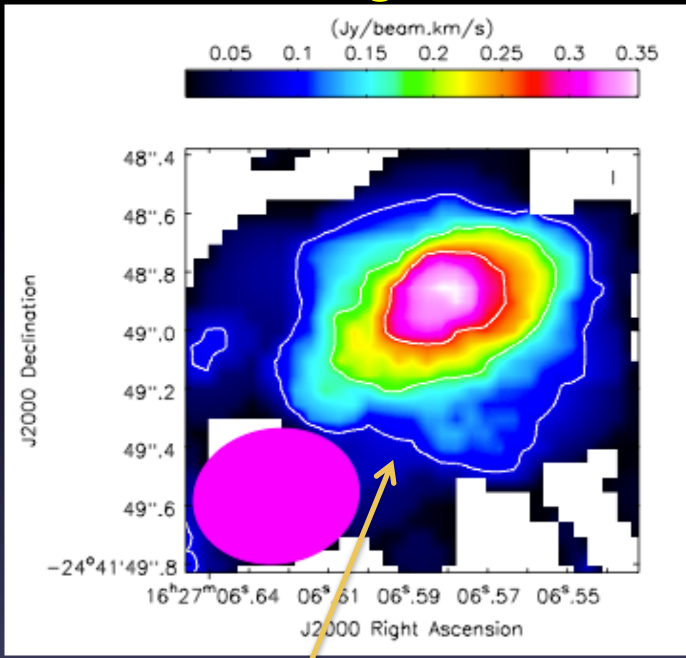
Ricci + 12

The disk around the young BD rho Oph 102





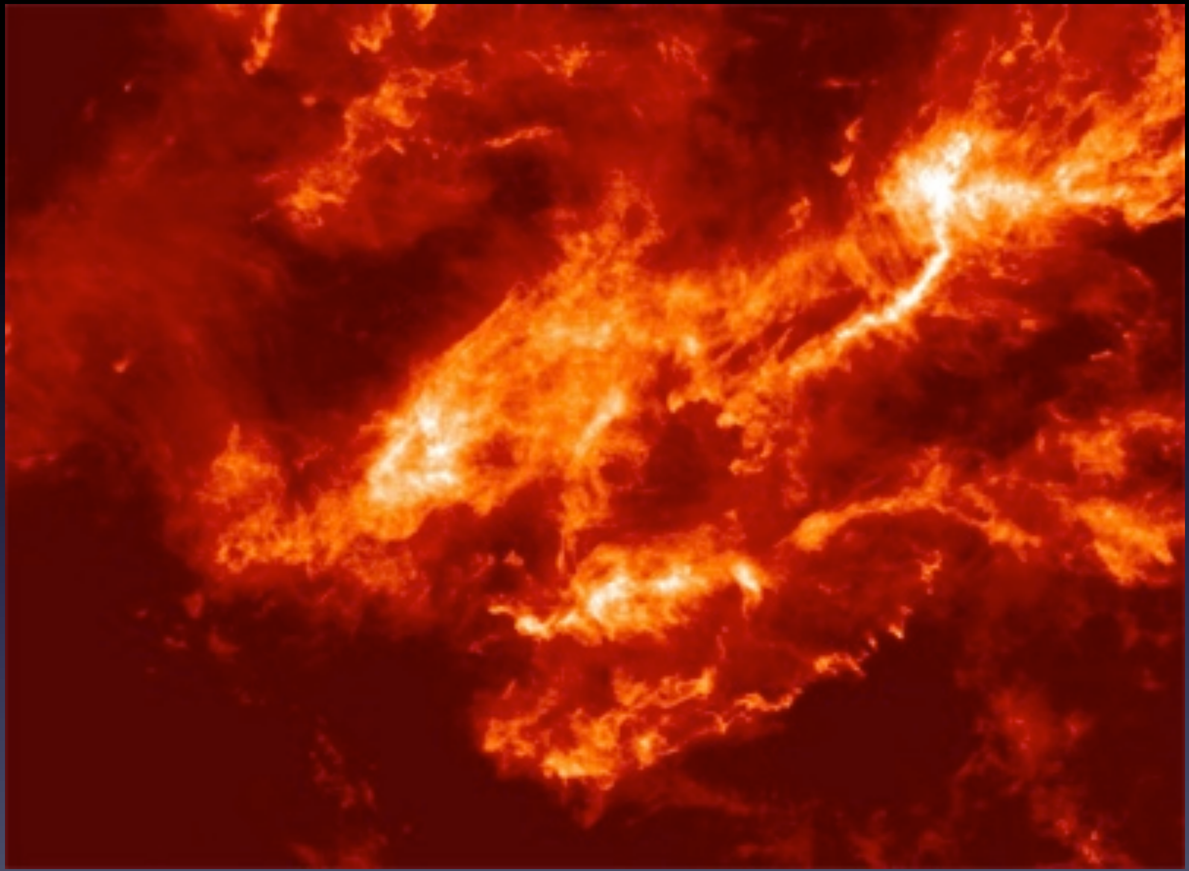
CO (J = 3 - 2)



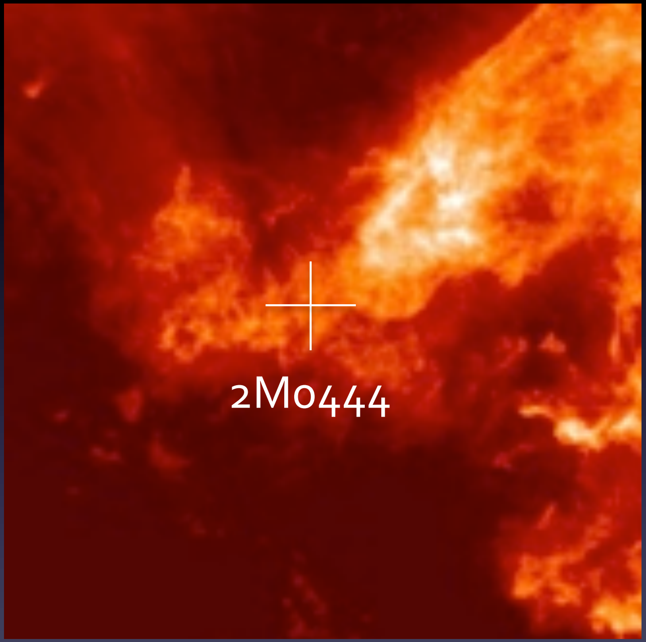
Cold Molecular gas from the disk
gas-rich disk as in T Tauri disks

Ricci + 12

2M0444+2512

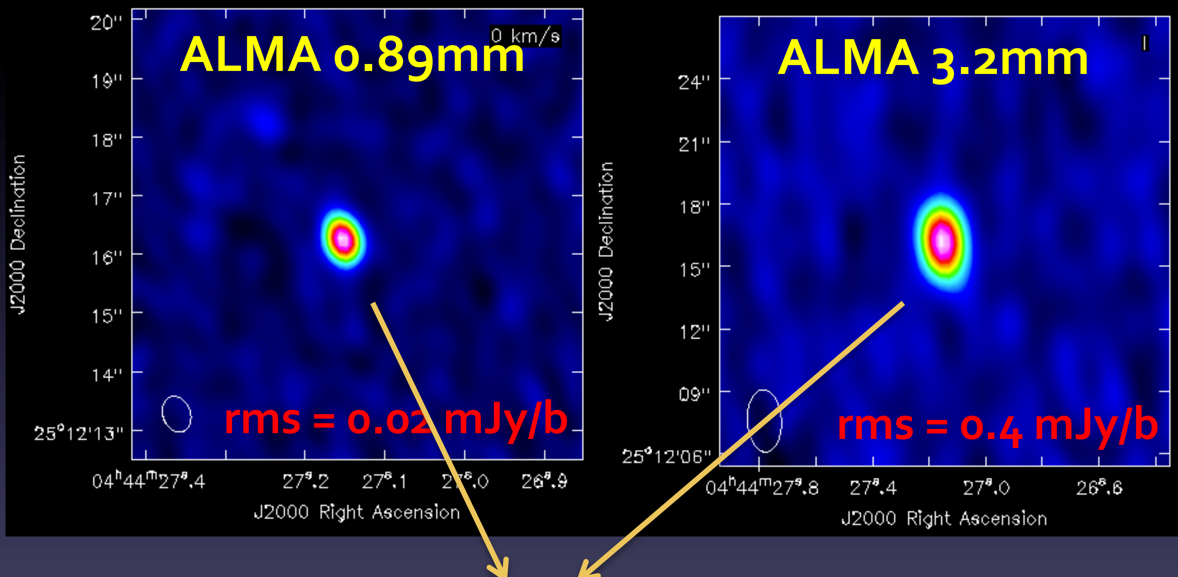


FCRAO, G. Narayanan / M. Heyer



$M_{BD} \approx 50\ M_{Jup}$, $Age \sim 1$ Myr

The disk around the young BD 2M0444

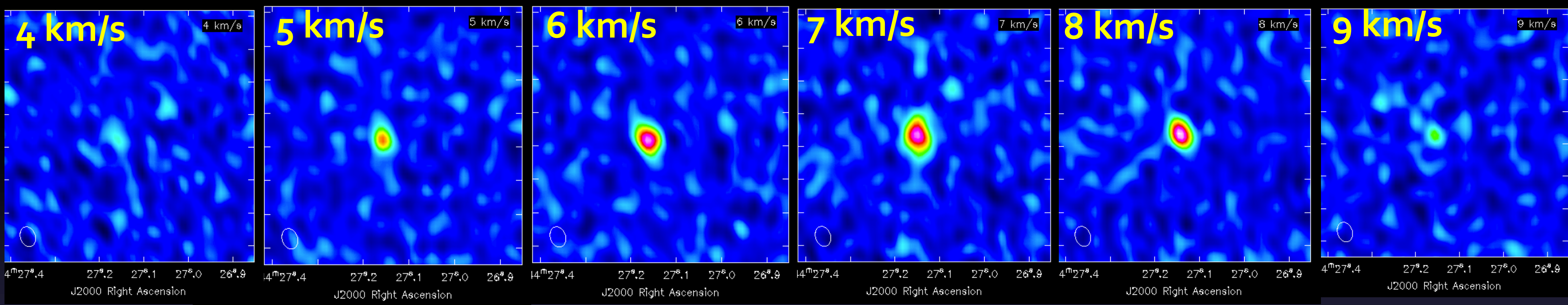


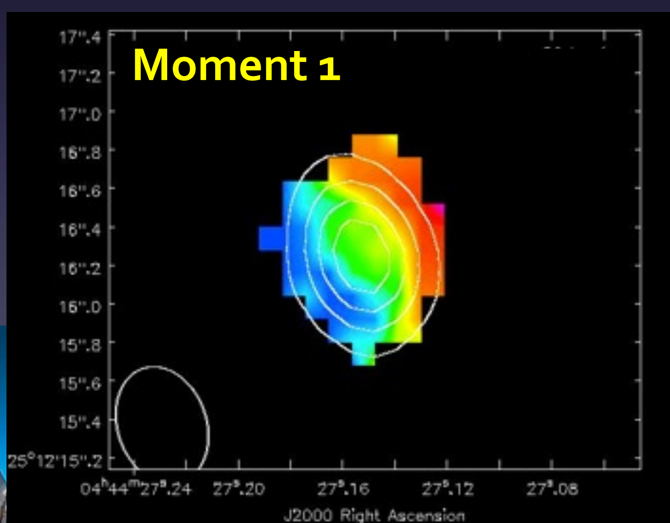
α

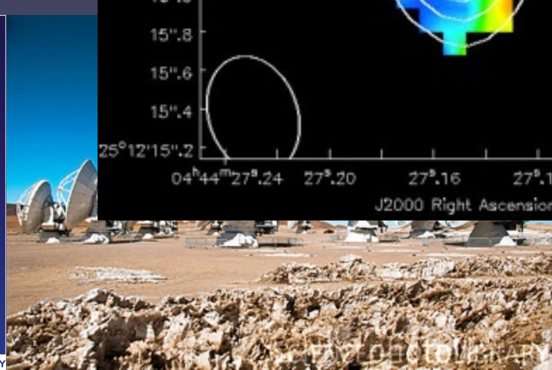
Ricci + 13b, in prep

The disk around the young BD 2M0444

CO (J = 3 - 2)



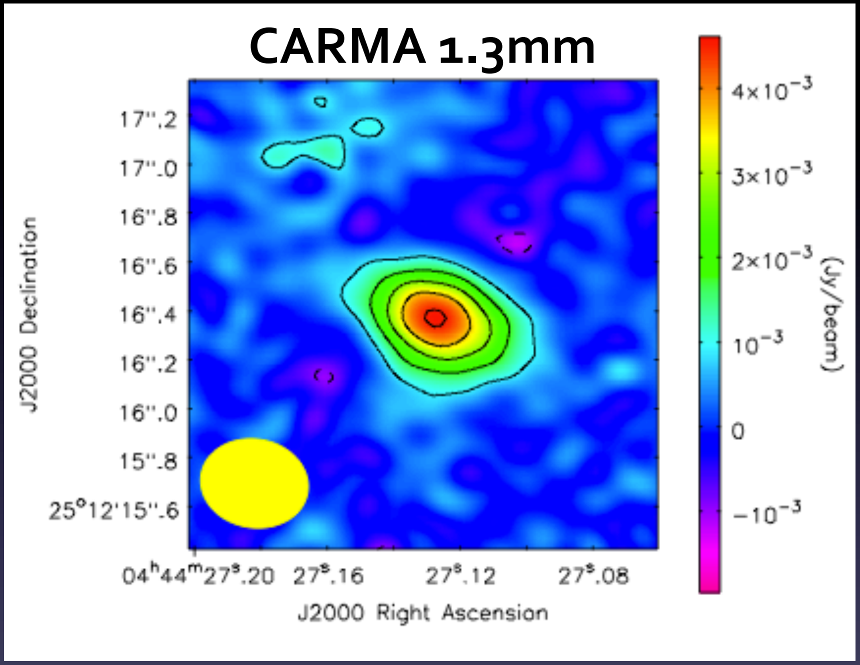


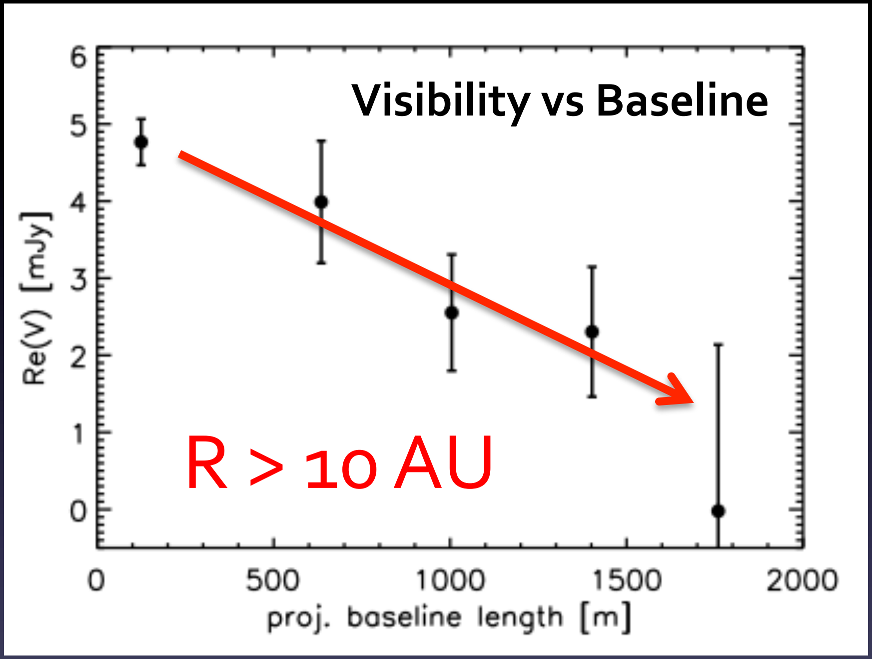


Gas in rotation around the BD

Ricci + 13b, in prep

The disk around the young BD 2M0444



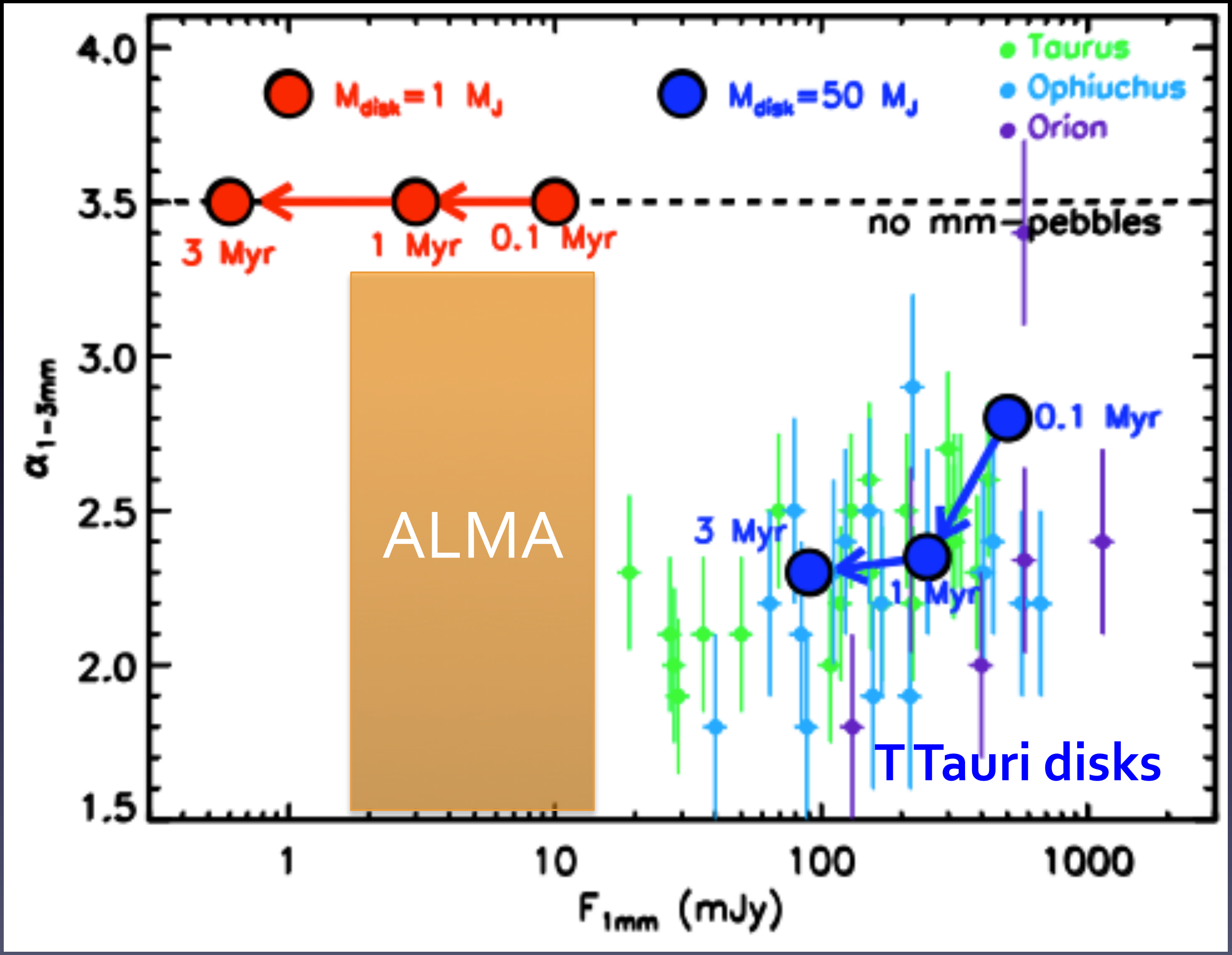


θ ≈ 0.15 arcsec, 10 AU in R

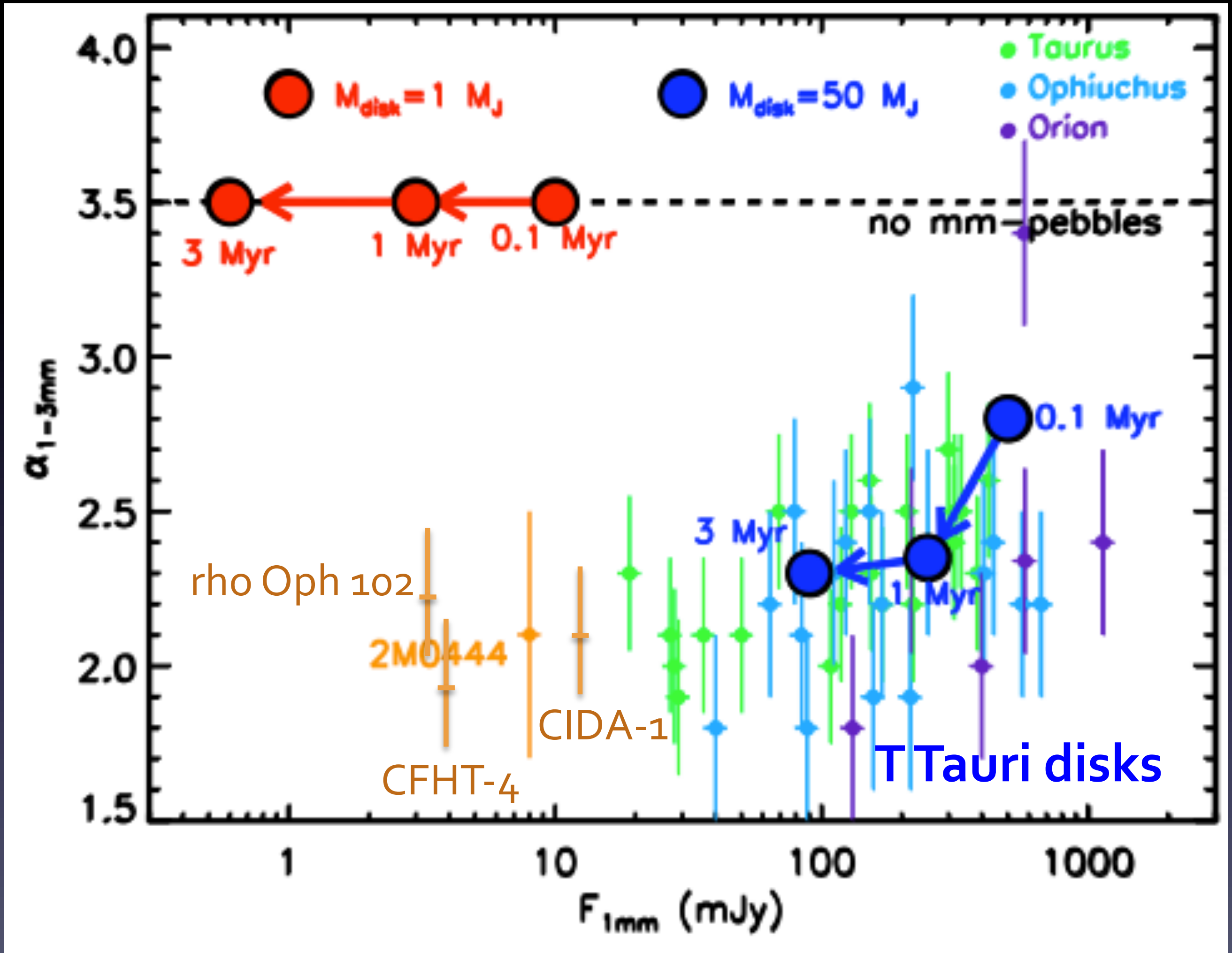
Dust optically thin: $\alpha \sim 2 + \beta$

Ricci + 13a

Disks with P-maxima: model predictions

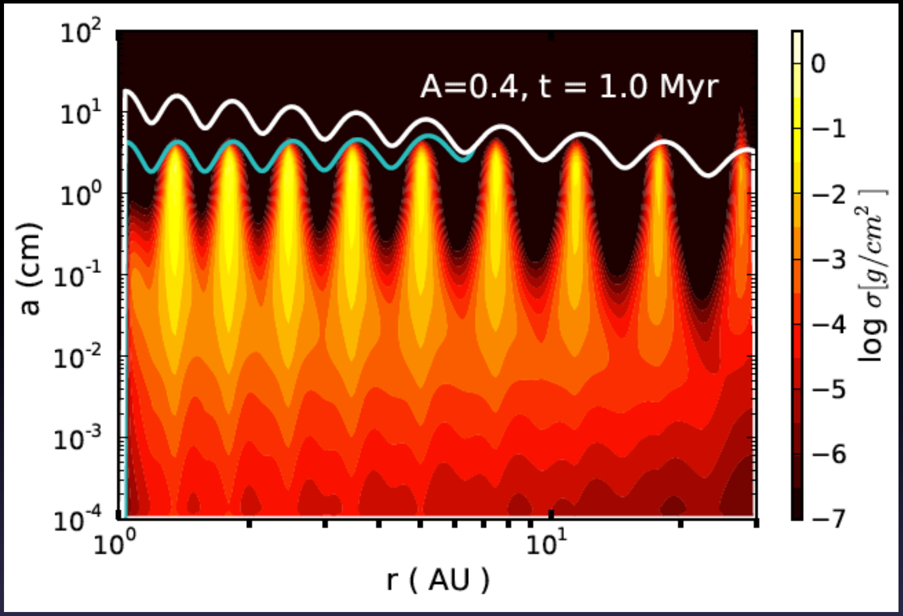


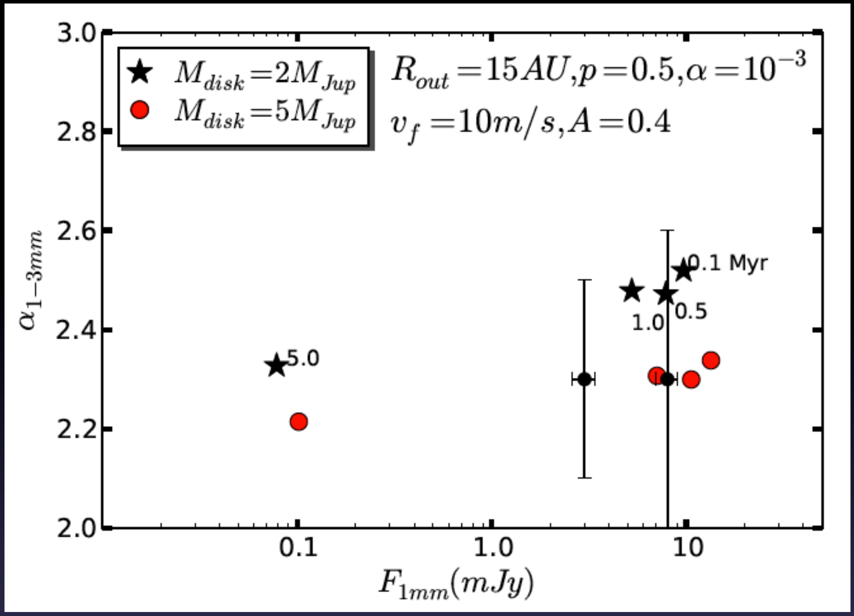
Disks with P-maxima: model predictions



Grain growth even in the outer regions of BD disks

Grain growth in BD disks: possible solution





- Disk outer radii ~ 15 – 30 AU

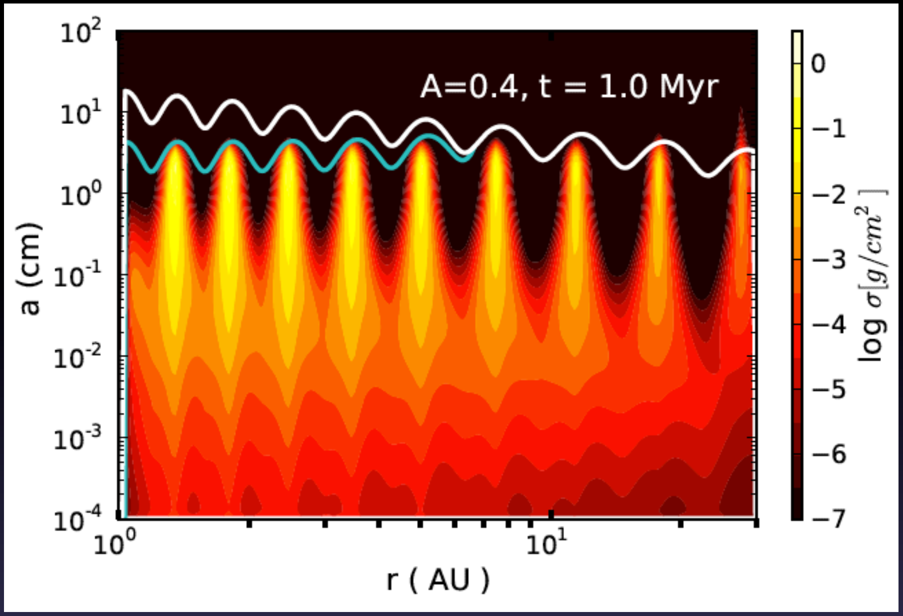
- Low turbulent velocities $\alpha < 10^{-3}$

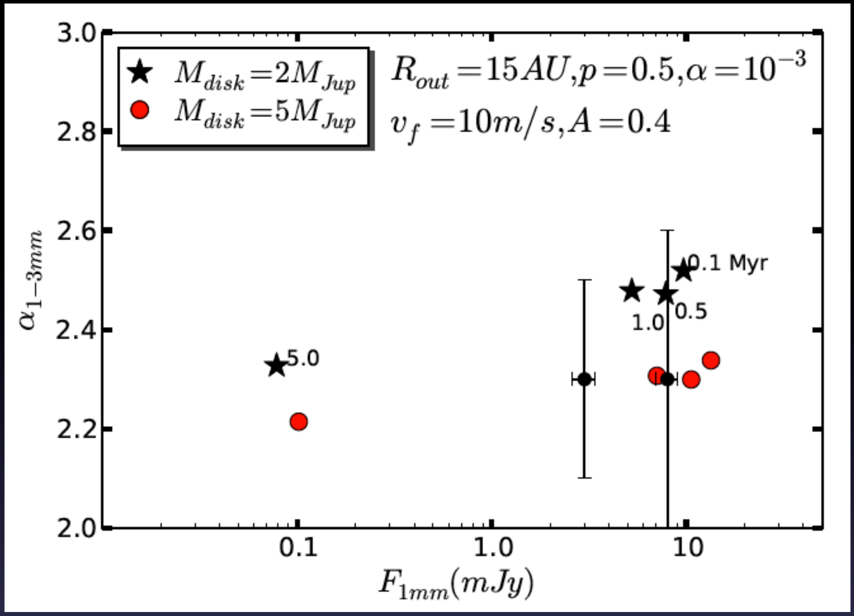
- Strong pressure bumps

(see also F. Meru's poster)

Pinilla, LR + 13, submitted

Grain growth in BD disks: possible solution





- Disk outer radii ~ 15 – 30 AU

ϑ ~ 0.2 – 0.4″

- Low turbulent velocities $\alpha < 10^{-3}$

Modeling of molecular lines
(see Dartois+03 Hughes+ 11, Guilloteau+ 12)

- Strong pressure bumps

B > 10 km

(see also F. Meru's poster)

Pinilla, LR + 13, submitted

Take away messages

- Grain growth to mm-sizes is fast (< 1 Myr) in both T Tauri and BD disks [see Perez review talk on radial variation of β]

- Dust trapping to explain mm-data of disks, ALMA should see the traps [trapping in transitional disks is from the P bump in the inner disk, here we are invoking trapping in the outer regions of primordial disks]

- BD disks to test dust evolution models

- We started to probe dust properties and CO in BD disks: more to come in ALMA-Cycle 1 [see also Van der Plas poster]