Probing the first stages of planet formation from (sub-)mm interferometry

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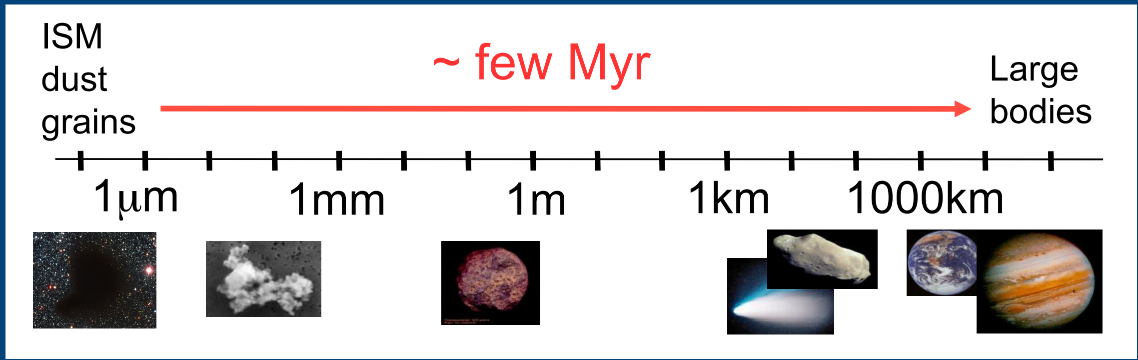
"Evolution of Solar-mass Stars", Garching, March 2 2010

IMPRS

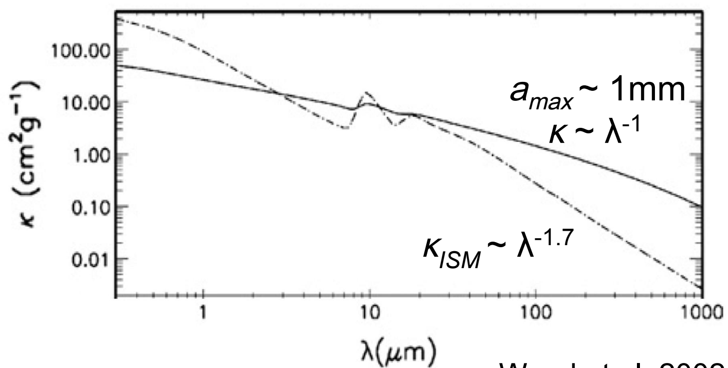
Planet formation: a question of sizes



➡ **Growth of solids by > 12 o.o.m. in size (!)**

Three main stages:

1) planetesimal formation (~10 km, aerodynamic coupling to gas)
2) terrestrial planet formation (Newtonian gravity)
3) giant planet formation (gravity + coupling to gas)



Wood et al. 2002

$\kappa_{dust}(\lambda) \sim \lambda^{-\beta}$

➡ β **proxy for dust grain growth**

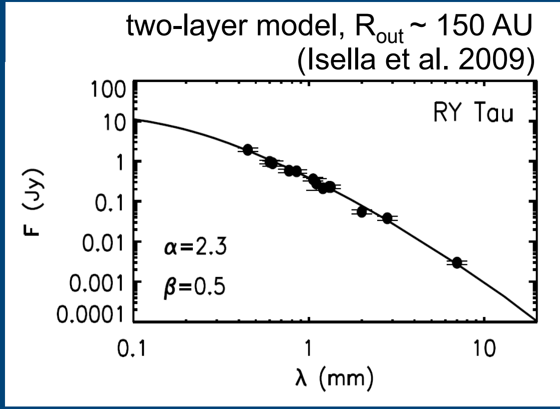
Dust grain growth from mm-SED slope

Emission at mm-λ from completely optically thin disk in RJ regime:

$$F(\lambda) \sim (M_{dust}\, T_{dust})\, \lambda^{-2} \kappa_{dust}(\lambda)$$

spectral index α ($F(\lambda) \sim \lambda^{-\alpha}$) ➡ $\beta = \alpha - 2$

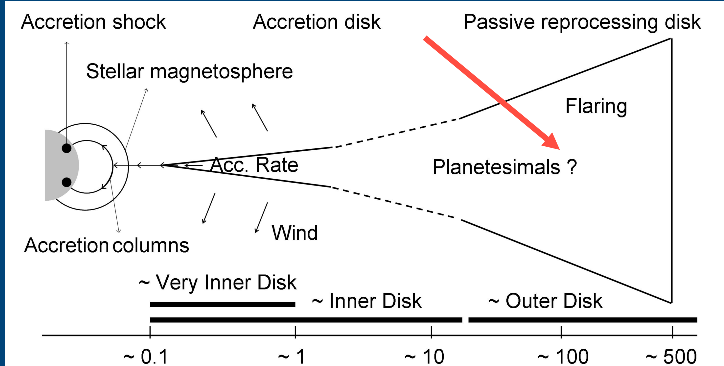
optically thick inner regions
+
deviations from RJ regime ➡ $\beta > \alpha - 2$



Ricci et al. 2010, A&A in press

IF $\beta < 1$ ➡ DUST GRAIN GROWTH to sizes > 1 mm

Diagnostic of grain growth:
- up to ~cm-sized grains ($a_{max} \sim \lambda$)
- in the disk midplane (low optical depth)
- in the disk outer regions (R > 50 AU)



Dutrey 2008

Goals and Sample

Extend *β*-estimates to

- longer λ (λ>1mm, to minimize emission from opt. thick inner regions)
- increase the statistics (investigate trends over a homogeneous sample)
- "fainter" disks (F_{1mm} < 100 mJy, more representative of the whole disk pop.)
- different SFRs (dependence on environment)

New data @3mm:

PdBI: 17 YSOs in Taurus-Auriga (rms ~ 0.3 mJy)

ATCA: 25 YSOs in *ρ*-Oph (rms ~ 0.4 mJy)

PdBI (French Alps)

ATCA (Narrabri, AUS)

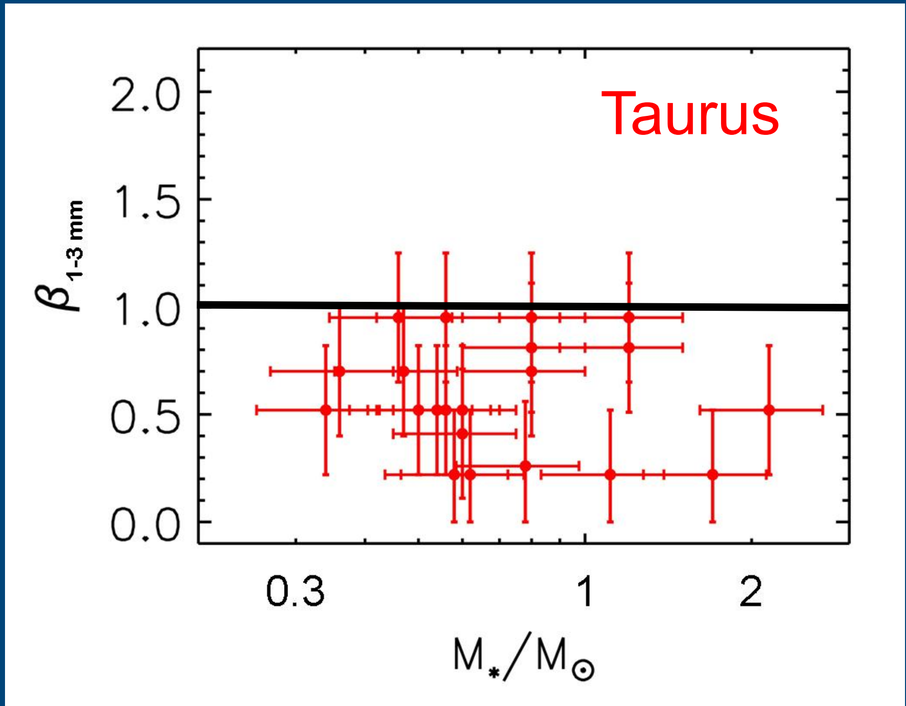
Sample selection criteria:

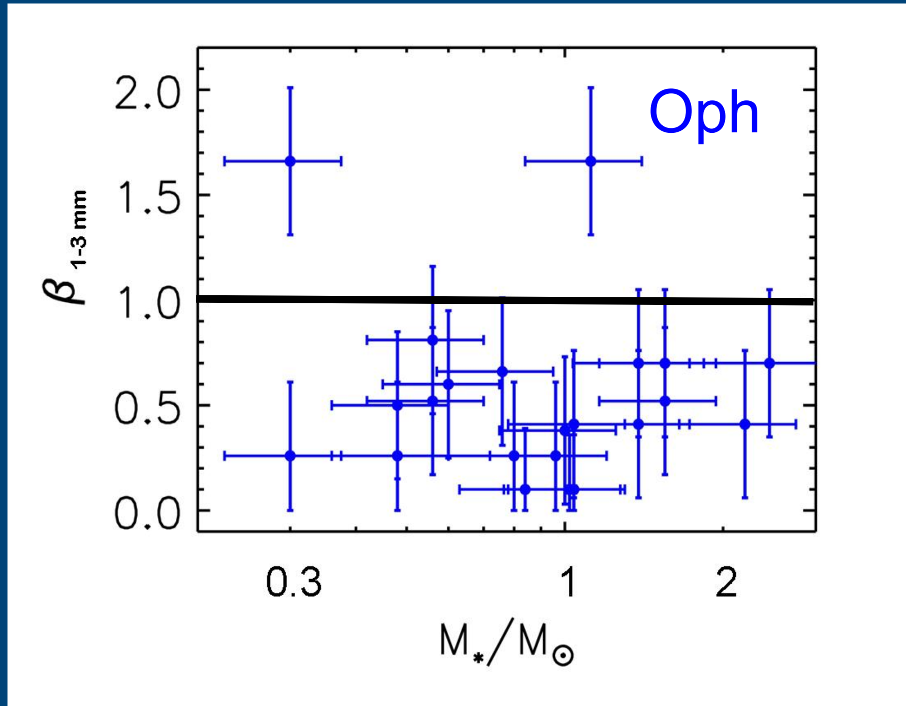
- class II YSOs (no or very little envelope)
- literature (sub-)mm data + 3mm
- isolated disks (no gravitational tidal effects)

➡ 43 disks (21 Taurus, 22 *ρ*-Oph)

(R_{out} from Isella et al. 2009, Andrews et al. 2009)

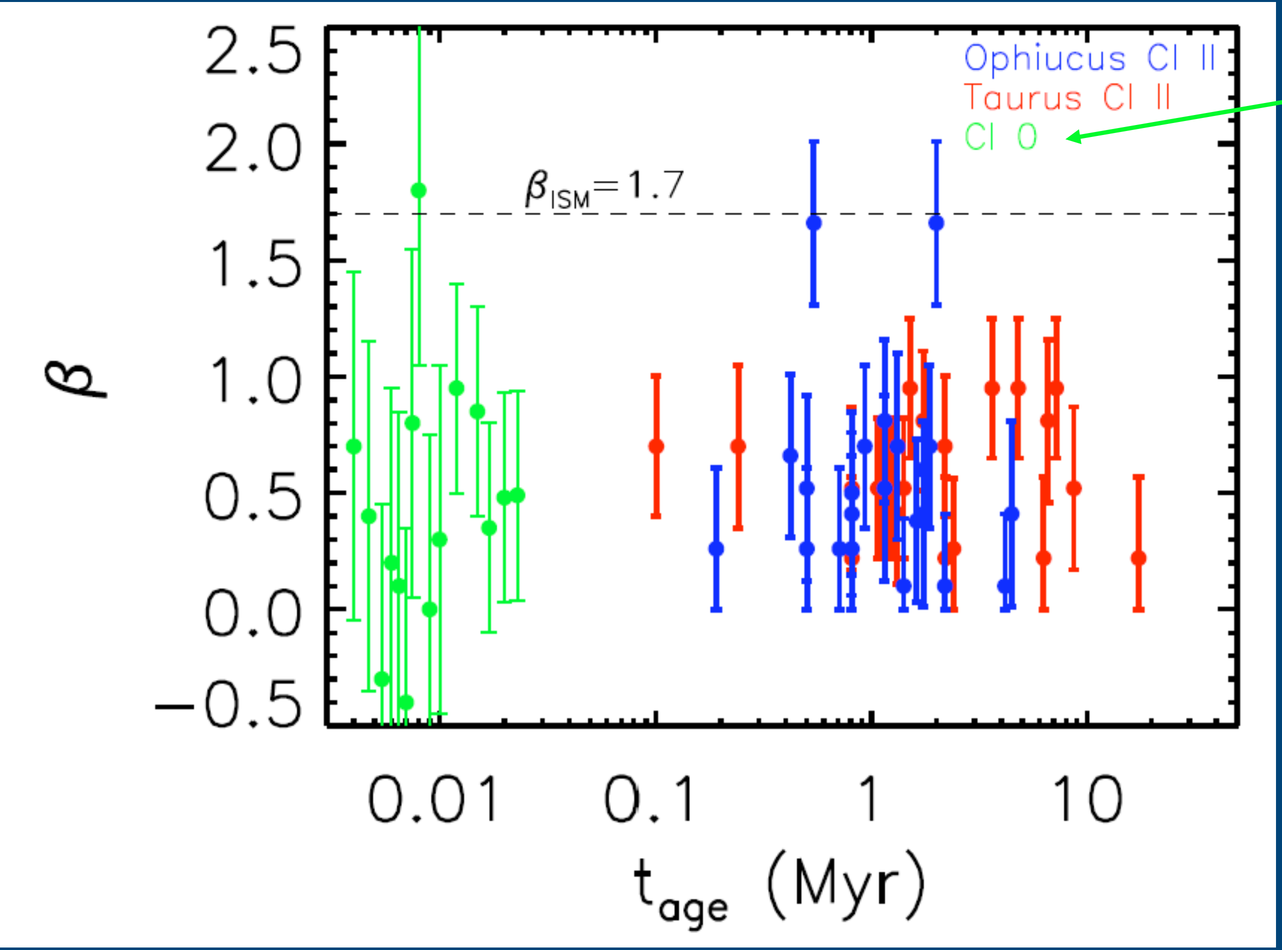
β vs stellar properties





- Grain growth to ~mm/cm-scales for (nearly) all the disks around Solar-like young stars
- no trends between β and stellar properties (e.g. M_{Star}, L_{Star}, $\dot{M}$) for 0.3 < M_{Star} < 2 M_{Sun}

β vs age



Jorgensen et al. 2007
Kwon et al. 2009

Ricci et al., in prep.

- grains grown to >mm sizes very early on
- presence of large grains stationary vs short timescale of inward radial drift

"Radial drift problem"

Gas feels pressure gradient (while dust does not)

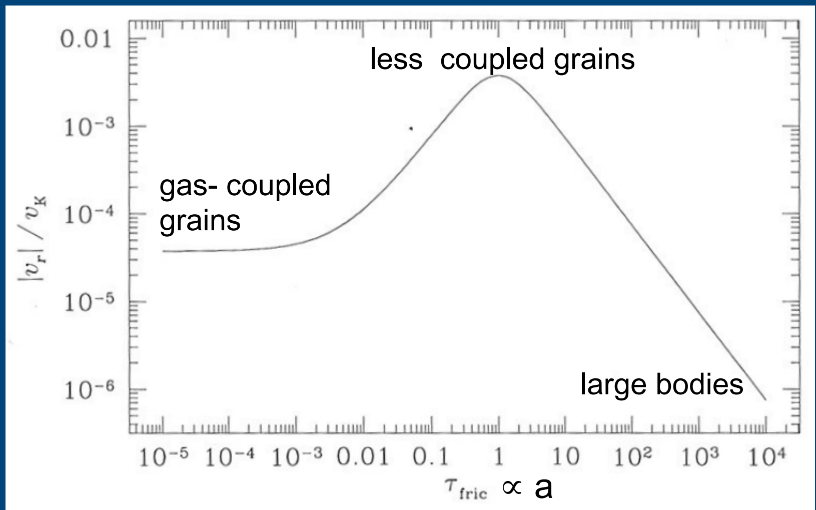
➡ $V_{\phi,gas}(r) < V_K(r)$

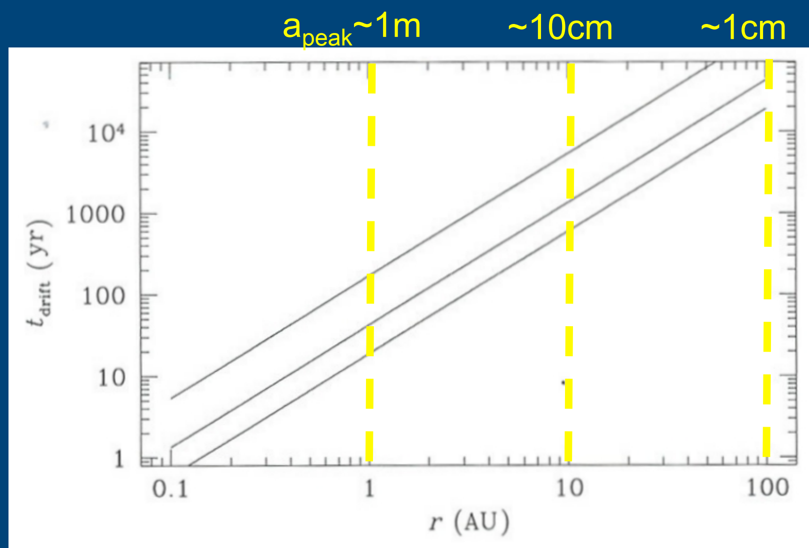
"Small" grains (well coupled to gas): $V_\phi(r) \approx V_{\phi,gas}(r) < V_K(r)$

Centrif. force < gravity ➡ inward radial drift

"Larger" grains (less coupled to gas): $V_\phi(r) \approx V_K(r) > V_{\phi,gas}(r)$

Gas headwind ➡ inward radial drift



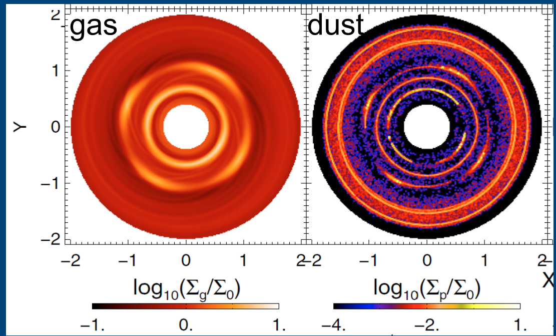


At each r: $t_{drift} \ll t_{life}$ (≈5 Myr)

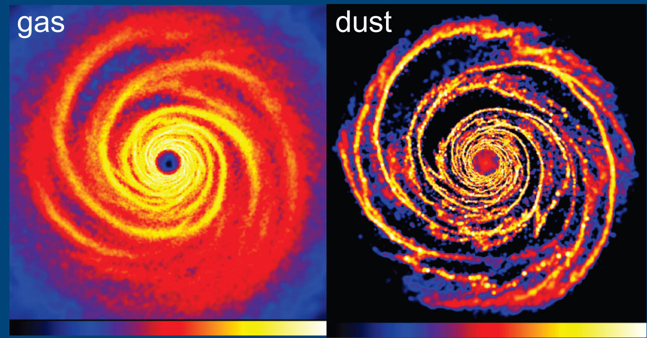
"Radial drift problem": possible solutions

Possible solutions:

- t_{growth} (a>>1m) < t_{drift}
- radial drift halted by local pressure maxima



Turbulent vortices, Lyra et al. 2009



Spiral arms (self-gravity), Rice et al. 2006

Ongoing work (with C. Dullemond group)

1) how would such local disomogeneities affect the disk emission?
2) how does grain growth varies with distance to the star?

two-layer disk model (Dullemond et al. 2001)

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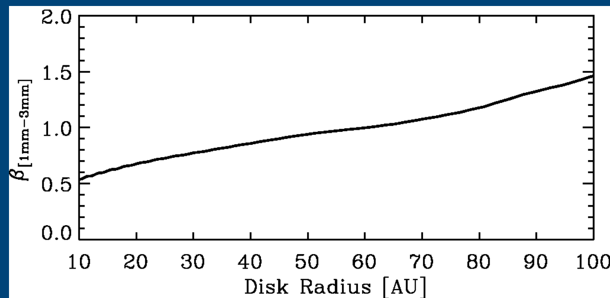
dust evolution (Birnstiel et al. 2010, in press)



F. Trotta's poster (P-5/S-1)

Summary

Investigation of β over a homogeneous sample of 43 isolated Class II disks in Taurus-Auriga and ρ-Ophiucus

- evidence for ~mm/cm-size dust grains in outer regions of nearly all the young disks around Solar-like PMS stars
- their presence is stationary throughout the Class II evolutionary stage
- Mapping spatial distribution of large grains to shed light into the radial drift problem (key for planetesimal formation): need for both high-angular resolution & sensitivity

⇨ Interesting case for ALMA, EVLA!