Disk evolution and the initial steps towards planet formation

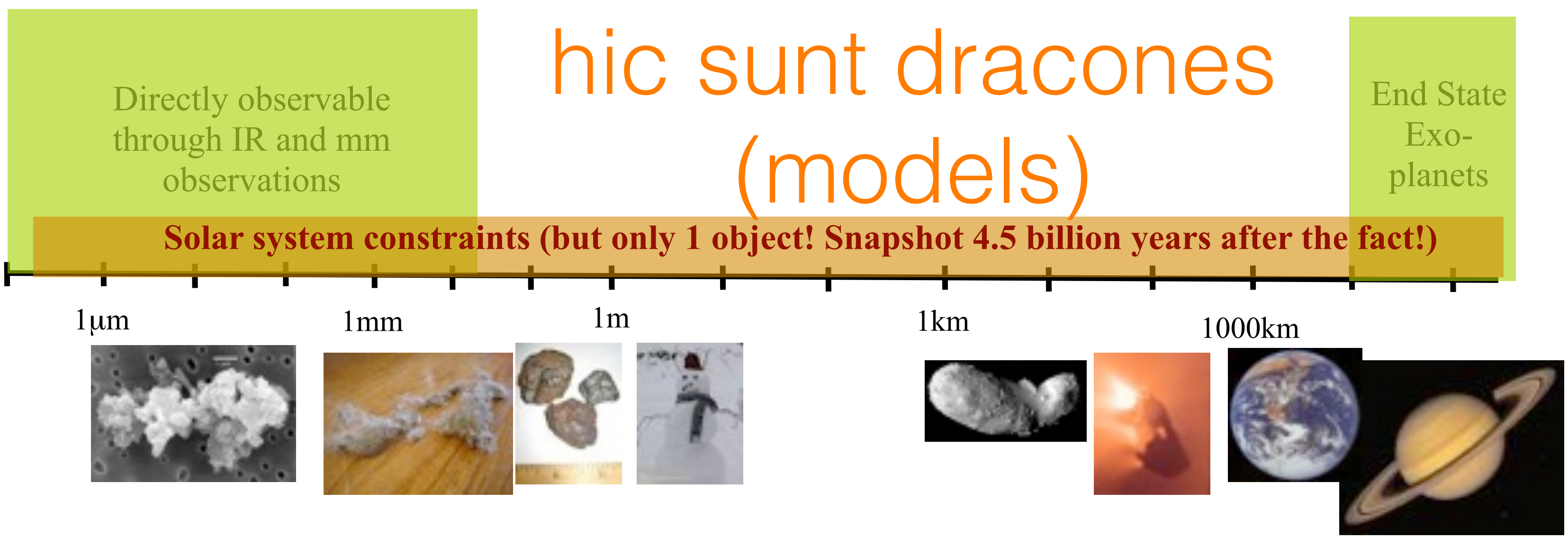
Leonardo Testi (ESO/Arcetri)

L. Ricci (ESO), T. Birnstiel (MPA), P. Pinilla (Heidelberg), F. Trotta (Arcetri/ESO), A. Natta (Arcetri), K. Dullemond (Heidelberg)

- Observational evidence for grain growth in disks
- A possible solution for the migration/fragmentation barrier
- Successes, shortcomings and future directions

From dust to planets

- The core-accretion scenario
  - Dust growth and planetesimals formation
  - Formation of rocky cores
  - Gas accretion from disk



(sub)mm continuum emission

$$F_\nu = \frac{\cos\theta}{D^2}\int_{r_i}^{r_o} B_\nu(T_d)(1-e^{-\tau_\nu})2\pi r\,dr$$

$$T_d \sim r^{-q}$$

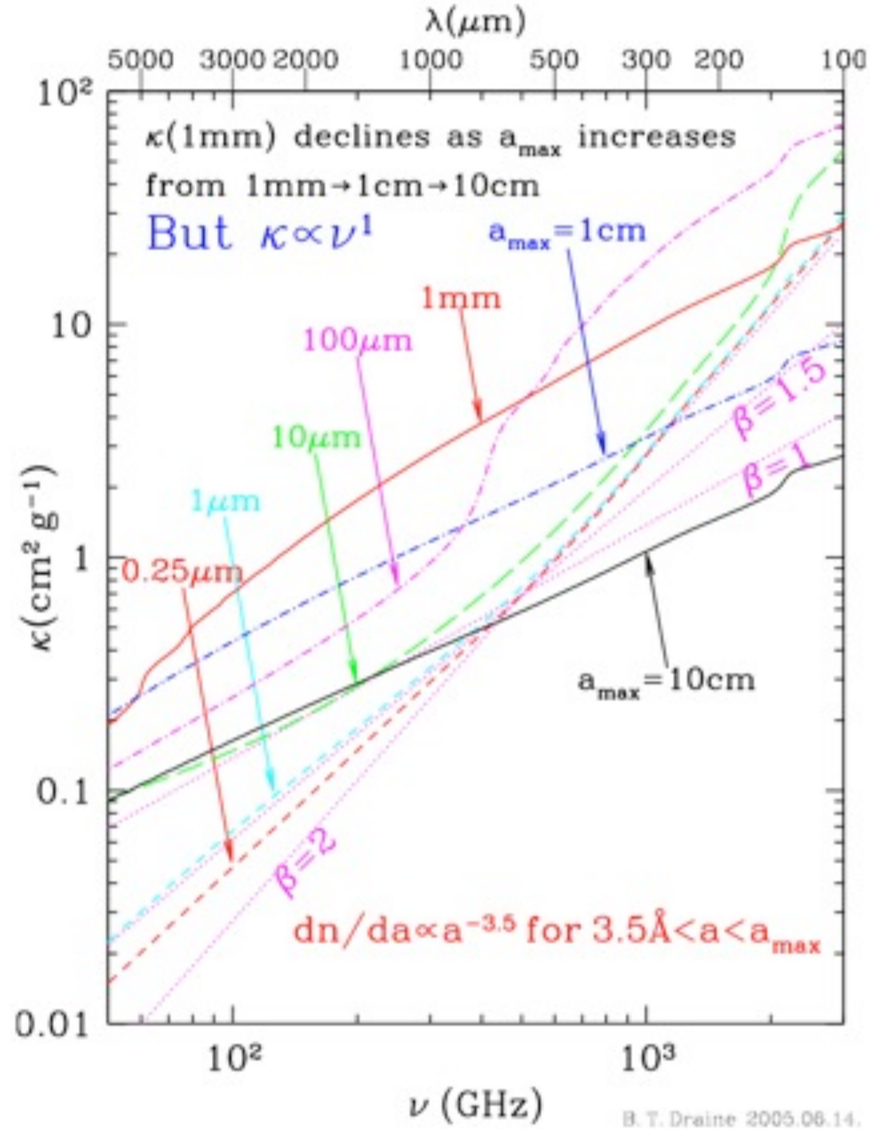
$\tau_\nu \propto \Sigma(r)\kappa_\nu$ $\Sigma(r) \propto r^{-p}$ $\kappa_\nu \propto \kappa_o \nu^\beta$

$\tau_\nu \ll 1$ $T_d \approx$ const.

$F_\nu \sim \kappa_\nu B_\nu(T_d) M_d$ ⇒ $F_\nu \sim \kappa_\nu \nu^2 T_d M$

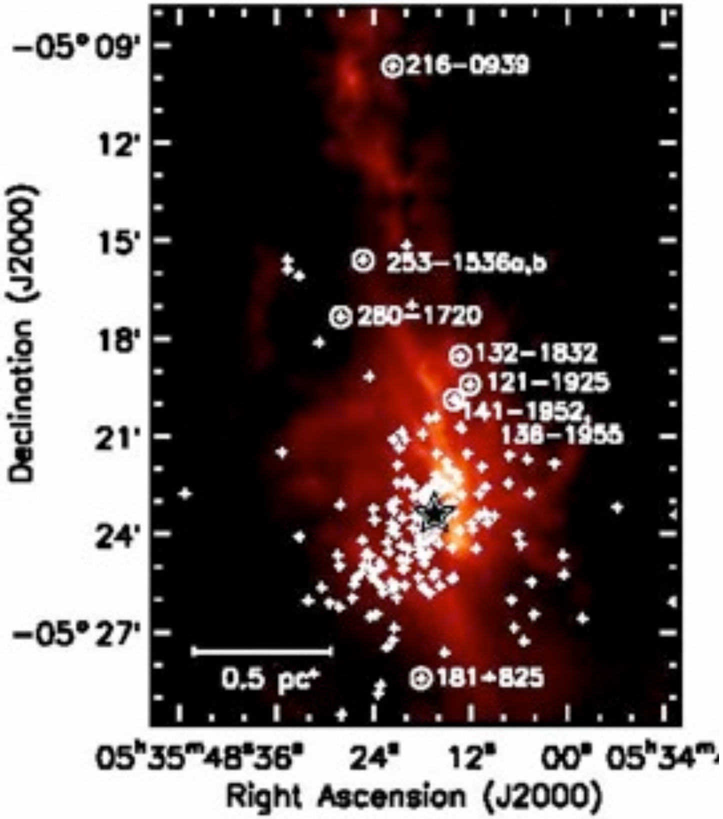
$F_\nu \sim \nu^{2+\beta}$

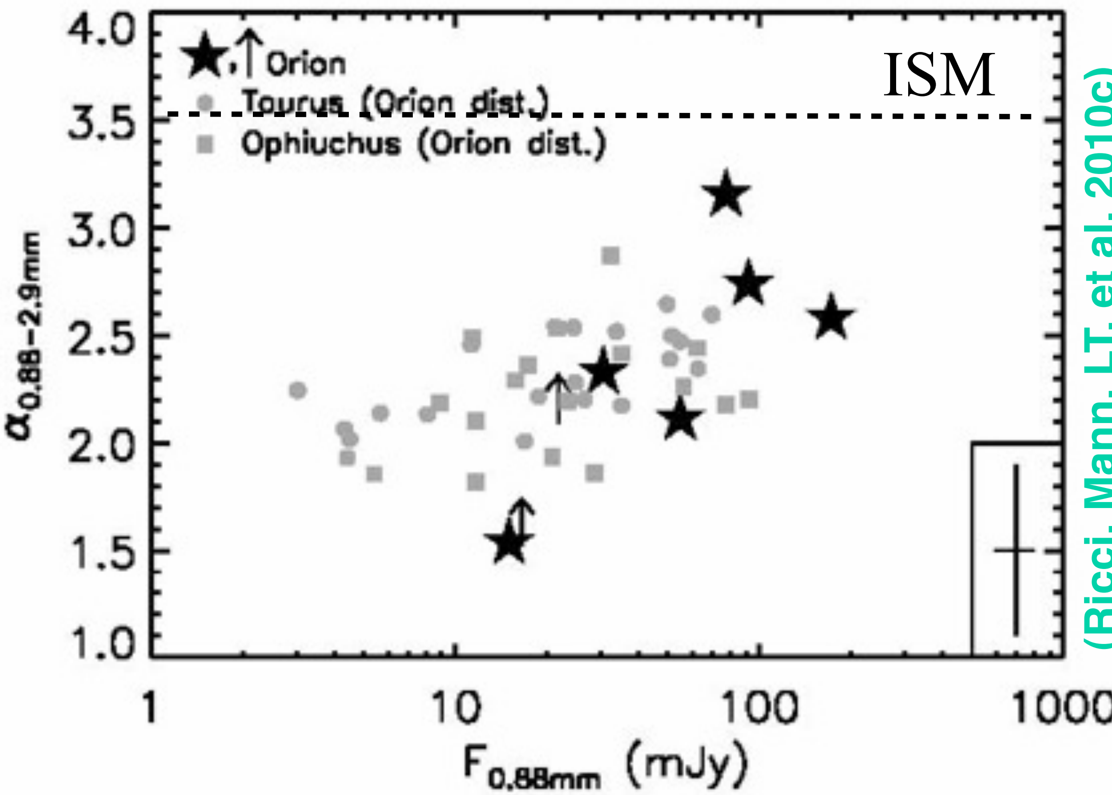
Not a new idea:
Beckwith & Sargent (1991)
Wilner et al. (2000; 2005)
Testi et al. (2001; 2003)
Natta et al. (2004; 2007)
Rodmann et al. (2006)
etc...



(Draine 2005)

Deep survey for large grains in nearby SFRs



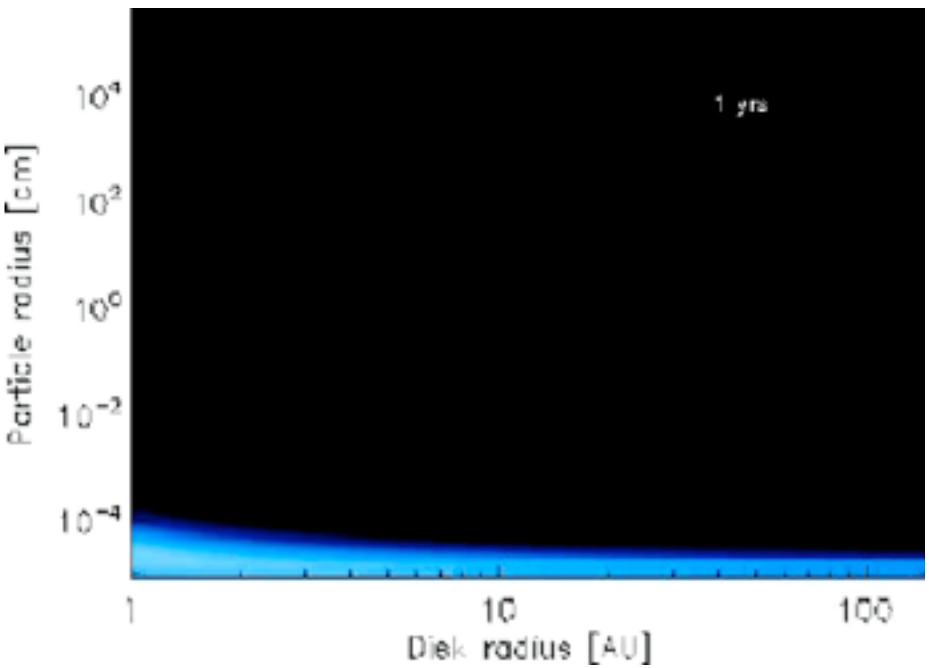


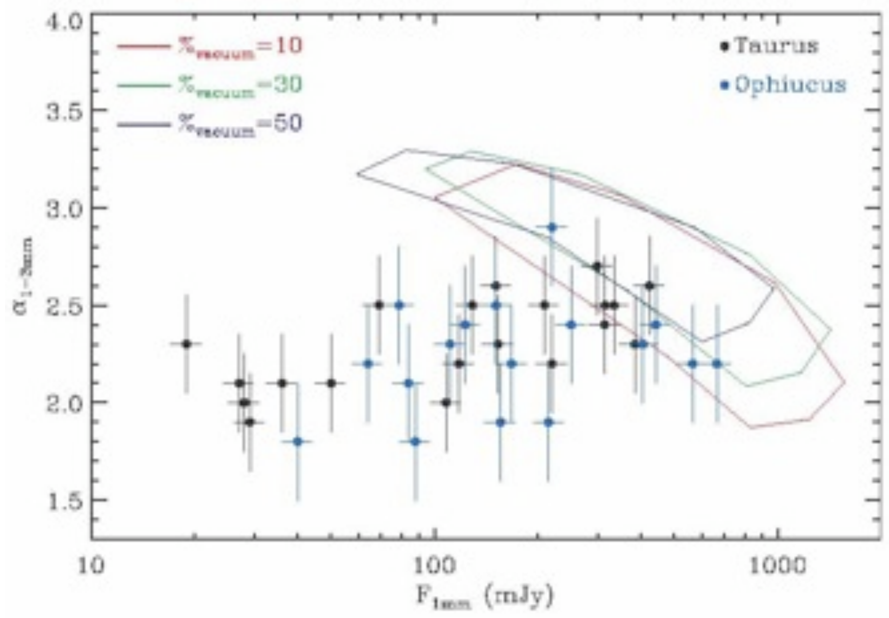
(Ricci, Mann, LT, et al. 2010c)
(Ricci, LT, et al. 2010ab)

- Large SMA, PdBI, ATCA & VLA survey to measure the long wavelengths emission from disks; >50 single, well characterized young stars
- Most disks have low values of β: early growth, slow evolution
- No correlation with other properties

Grain growth in disks: model predictions

(Brauer et al. 2008; Birnsiel et al. 2009)



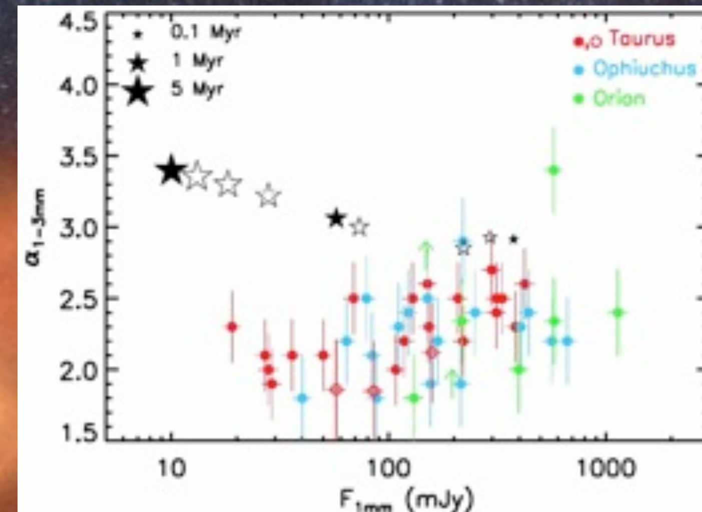


(Birnsiel, Ricci, Trotta, et al. 2010)

- Models predict a radial dependence of the grain growth
- Larger grains at small R, smaller (but still large) grains at large R
  - Qualitative agreement with data (...but...)

Migration & Fragmentation

- Large grains migrate fast, are drained towards the central star, collide with other grains and fragment



(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)

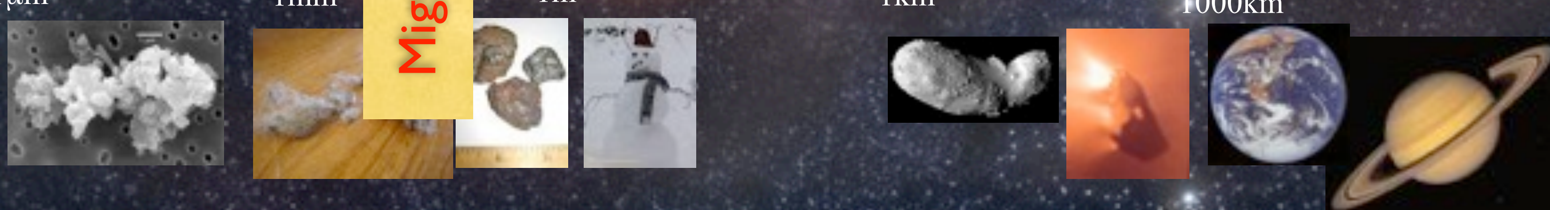
Millimetre and infra[...]
observations

Migration + Fragmentation

Models

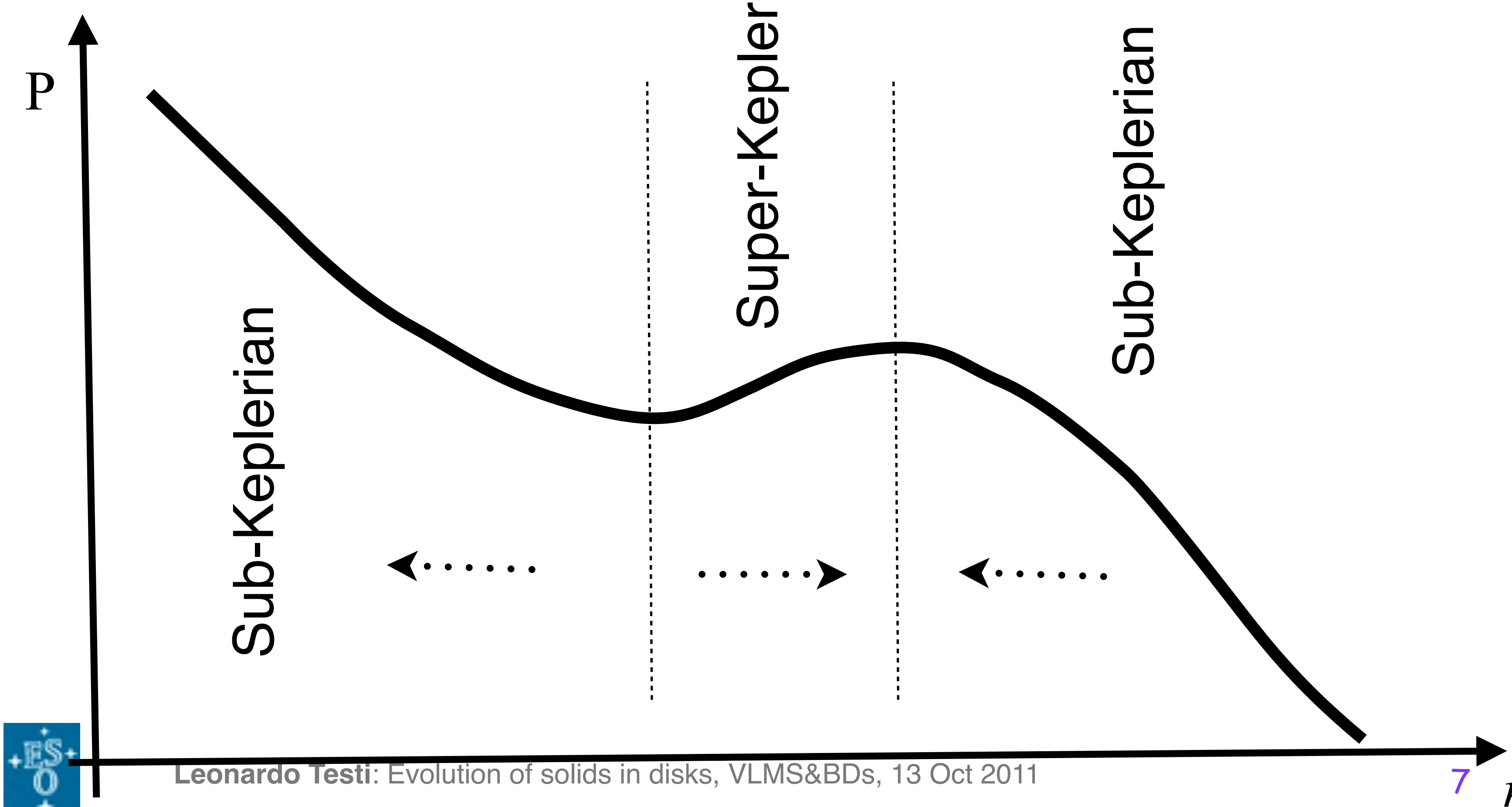
Extrasolar planetary systems

1µm 1mm 1m 1km 1000km



Pressure confinement of pebbles

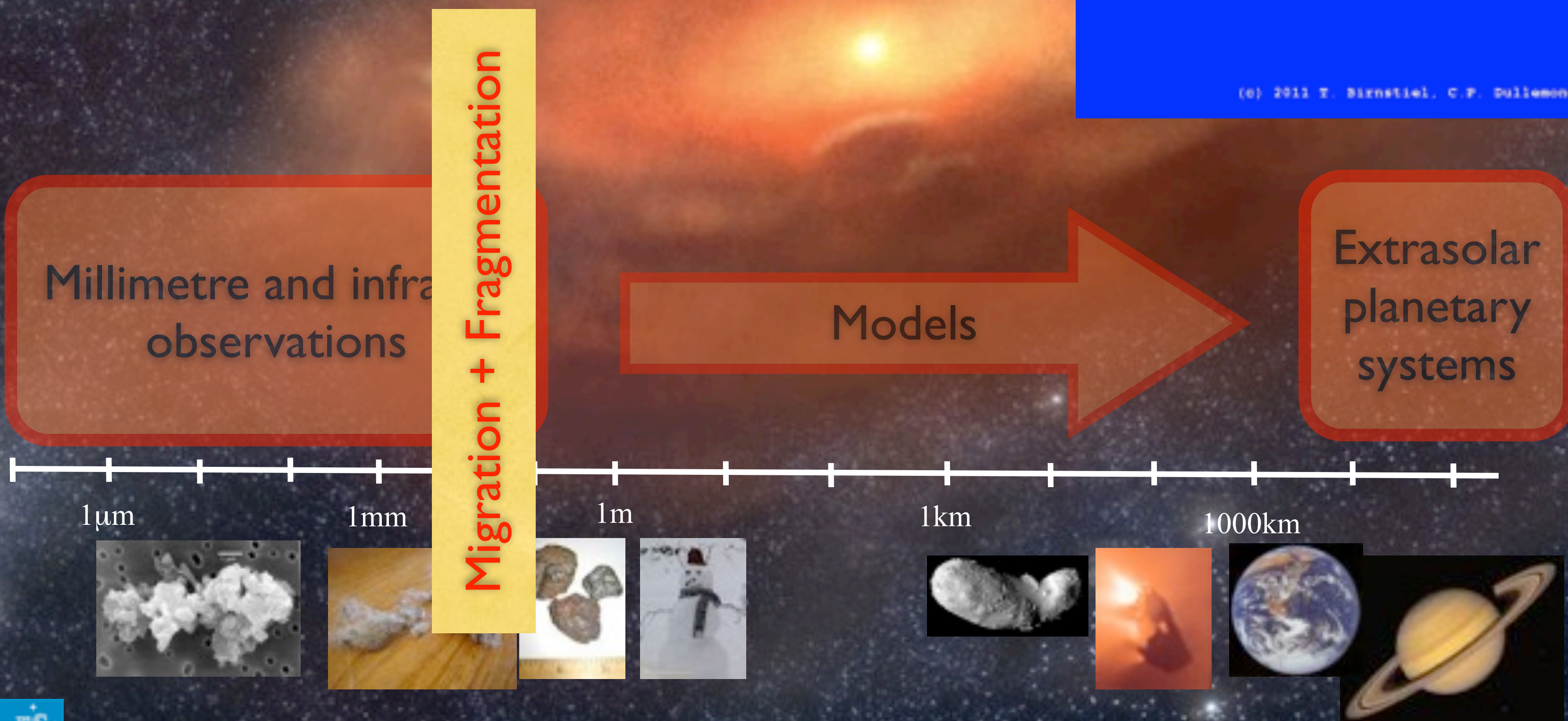
- Local pressure maxima in the gas efficiently confine large grains



Dust trapping in pressure maxima

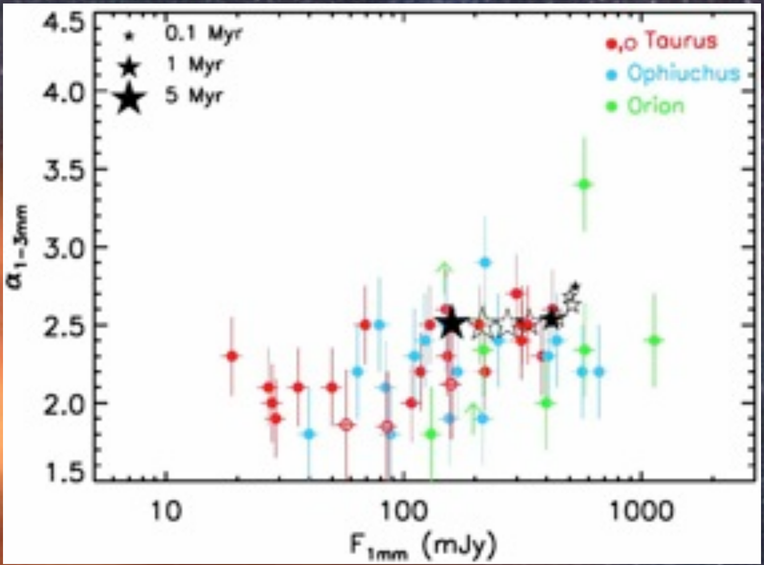
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times

(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)

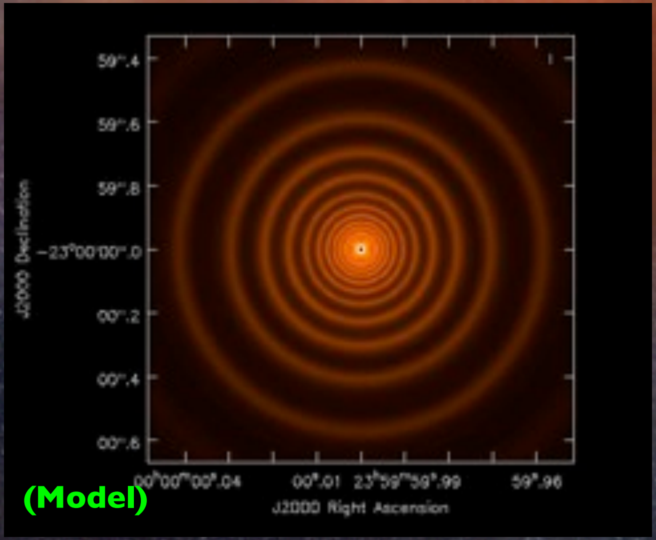


Dust trapping in pressure maxima

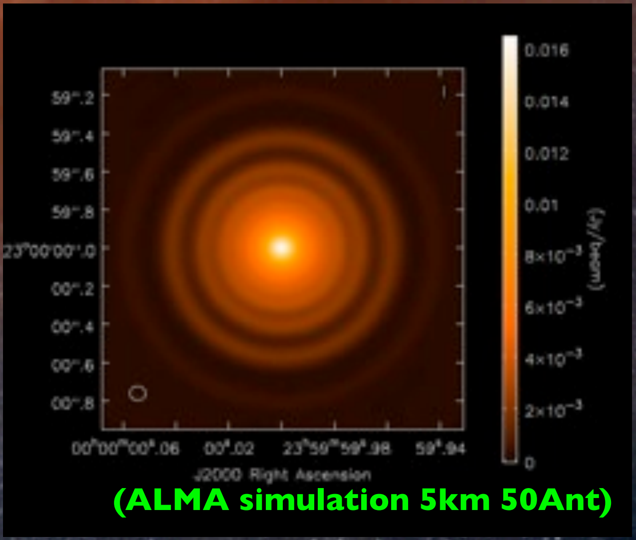
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times
- Observable with ALMA!



(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)

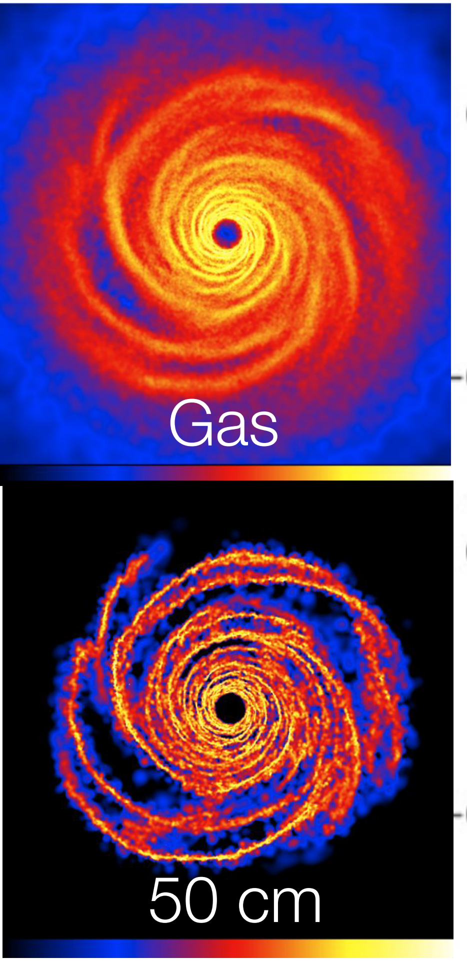


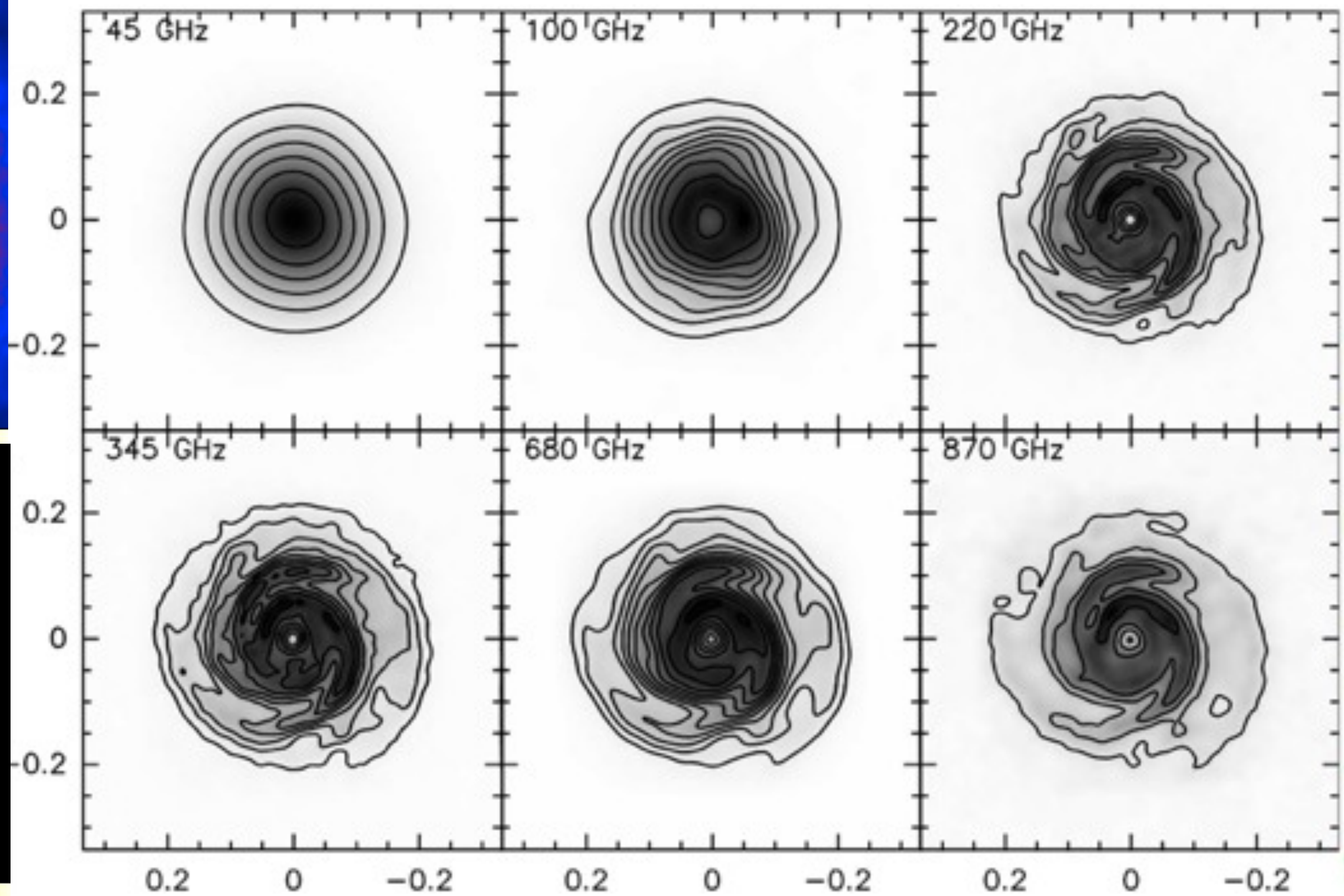
(Model)



(ALMA simulation 5km 50Ant)

Slowing down radial drift: grain trapping



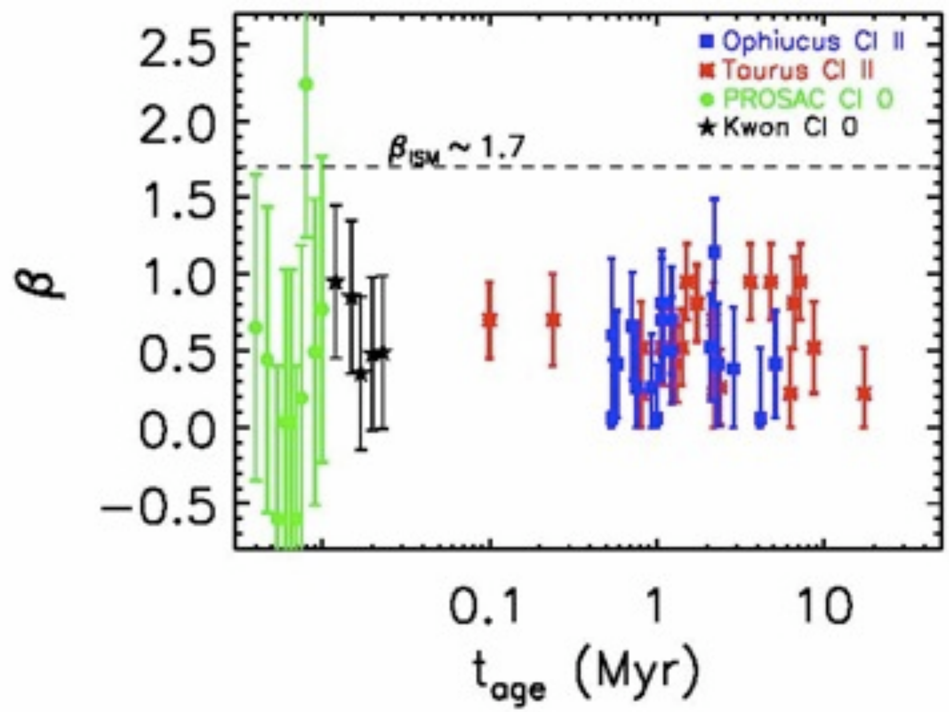


(Cossins, Lodato, Testi 2010)

- <u>Grain Trapping</u>: e.g. spiral arms, vortices, density enhancements
- <u>Predictions will be tested observationally</u>

State of the Art & Future Directions

- Grains grow and settle in disks around all type of PMS objects
- Grain evolution can be very fast as we see highly processed grains around objects of all ages between 1 and 10 Myr
- Plausible physical structures in the disk can stop migration



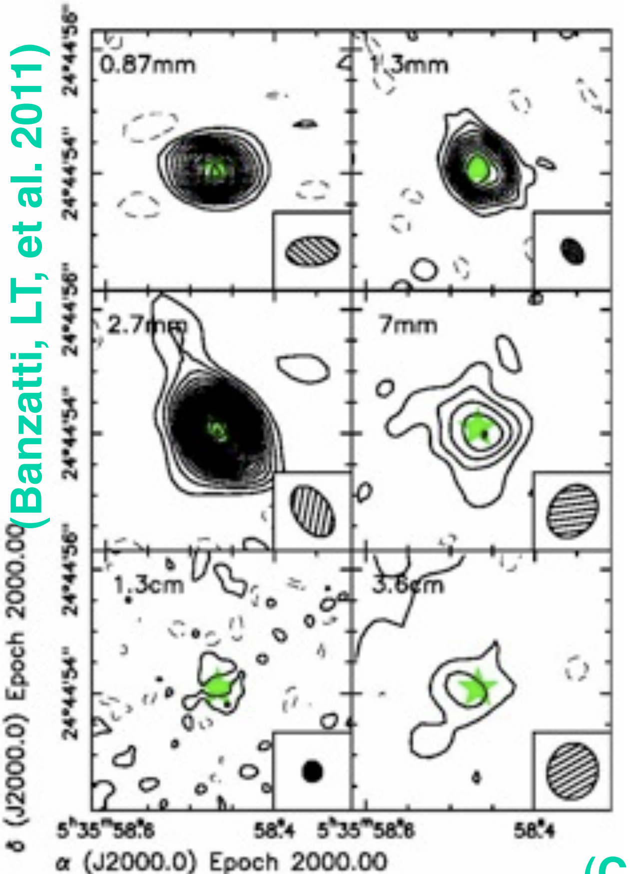
(Ricci, LT, et al. 2010ab)

State of the Art & Future Directions

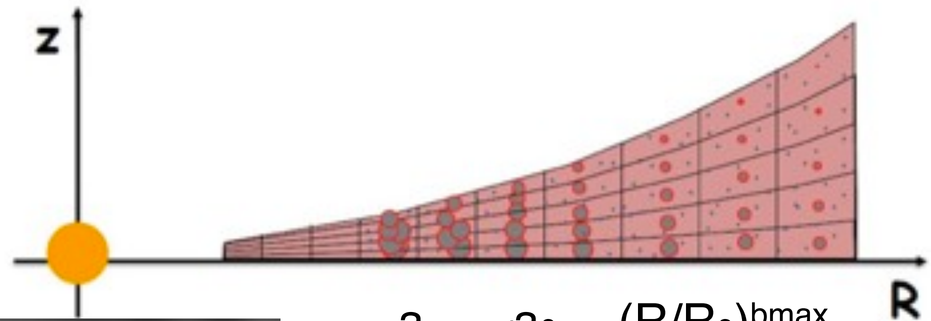
- Grains grow and settle in disks around all type of PMS objects
- Grain evolution can be very fast as we see highly processed grains around objects of all ages between 1 and 10 Myr
- Plausible physical structures in the disk can stop migration

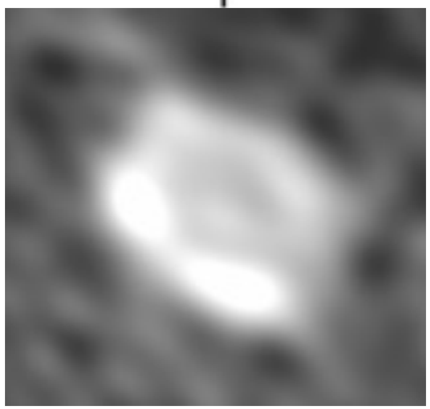
- **Key predictions and tests:**
  - Grain growth in Class 0 and I
  - Radial gradient of dust properties (Guilloteau et al. 2011; Trotta et al. 2011; Poster by Miotello)
  - Small-scale segregation of large grains (full ALMA resolution needed)
  - Disks need high gas densities for grains to grow: faint disks should be a late evolutionary stage disks around BDs should not grow grains (to be tested with ALMA Early Science)

The case of the CQ Tau disk

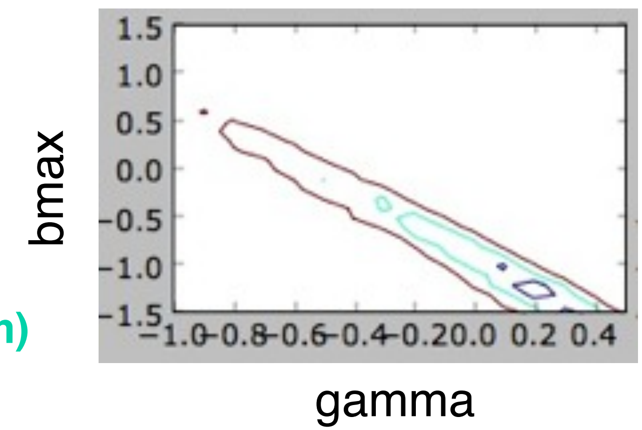


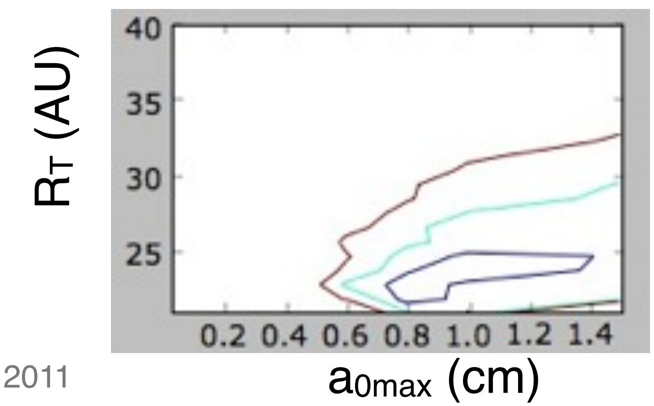
(Banzatti, LT, et al. 2011)





(Chandler et al. EVLA, 1.3cm)

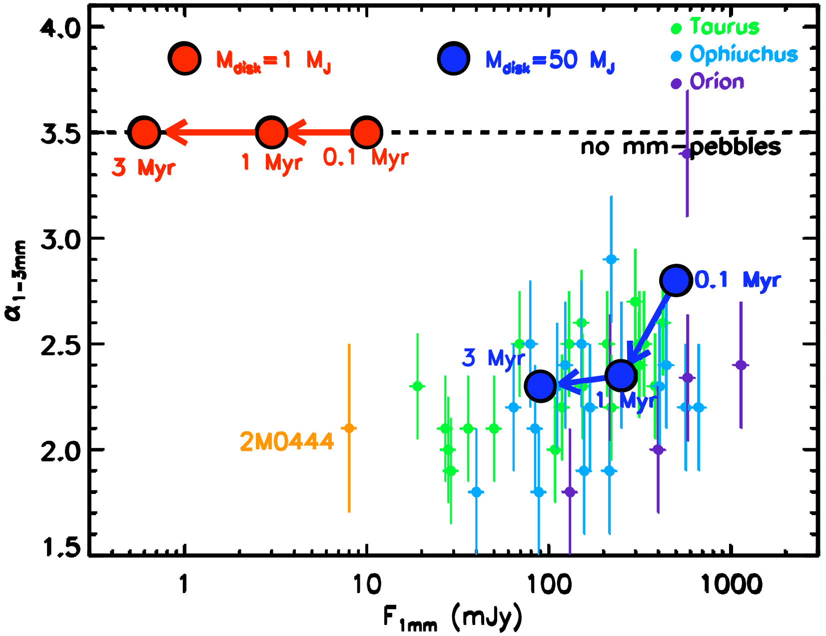




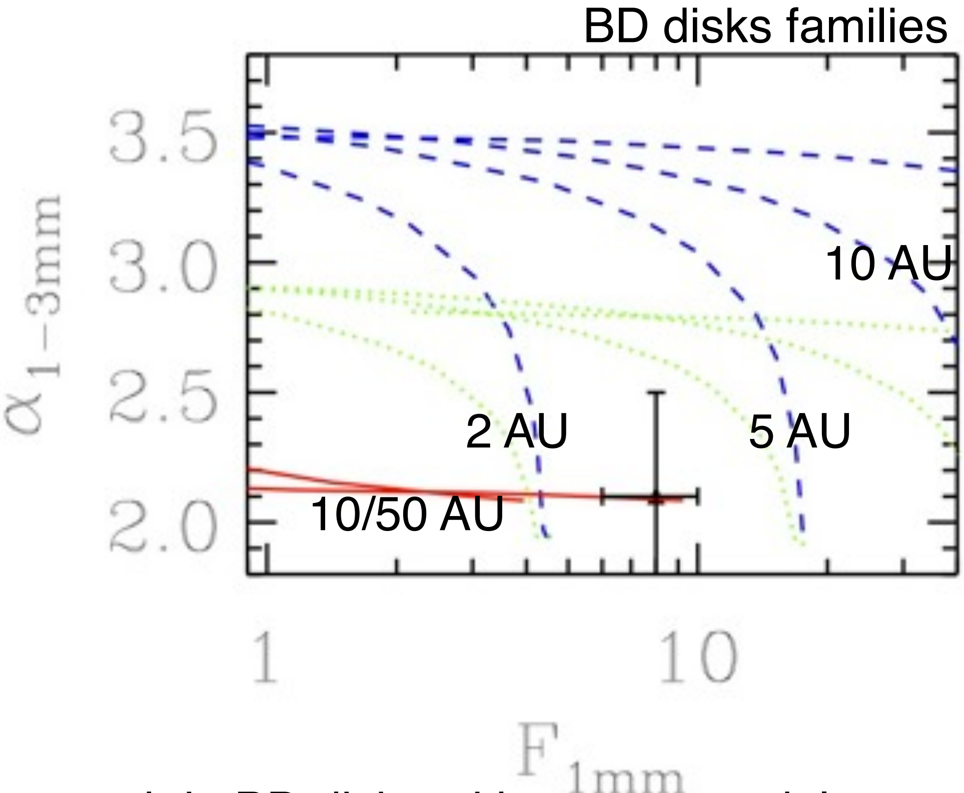
(Trotta, LT, et al. in prep)

- Dusty disk detected down to very long wl
- Possible evidence for variation of dust properties with radius
- Analysis limited by S/N and resolution
- New EVLA data, new analysis methodology

Disks around BDs and VLMS



(Poster Ricci, talk Mohanty)



(adapted from Testi et al. 2001)

- Very difficult to understand grain growth in BD disks with current models
- Although it is possible to have optically thick disks, it seems plausible that the disk is optically thin and contains large grains
- Measure a sample (of even fainter disks) and possibly resolve the brightest ones -> ALMA Early Science + ALMA full science
- => goal is to properly test the limits of grain evolution models

State of the Art & Future Directions

- Grains grow and settle in disks around all type of PMS objects
- Grain evolution can be very fast as we see highly processed grains around objects of all ages between 1 and 10 Myr
- Plausible physical structures in the disk can stop migration

- **Key predictions and tests:**
  - Grain growth in Class 0 and I
  - Radial gradient of dust properties (Guilloteau et al. 2011; Trotta et al. 2011; Poster by Miotello)
  - Small-scale segregation of large grains (full ALMA resolution needed)
  - Disks need high gas densities for grains to grow: faint disks should be a late evolutionary stage disks around BDs should not grow grains (to be tested with ALMA Early Science)

- **We thought we had finally started to solve the problem to understand how grain grow and are kept in the disk... and now we find large grains where we were not expecting them! ... life is interesting ...**