# Disks with ALMA

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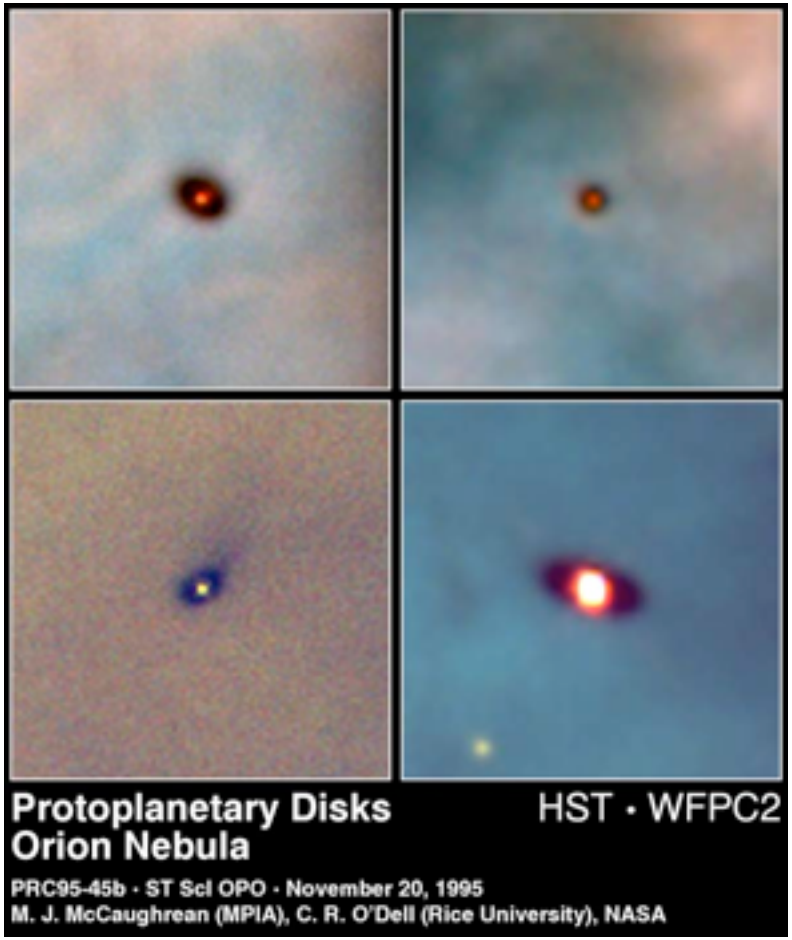
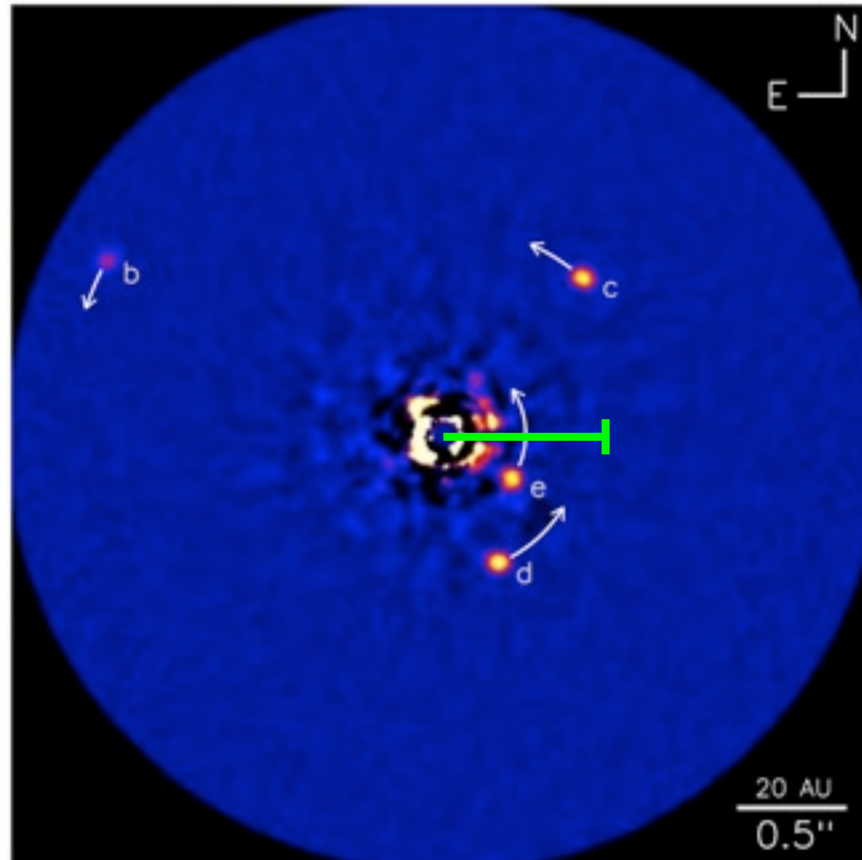
# Origins of Planetary Systems

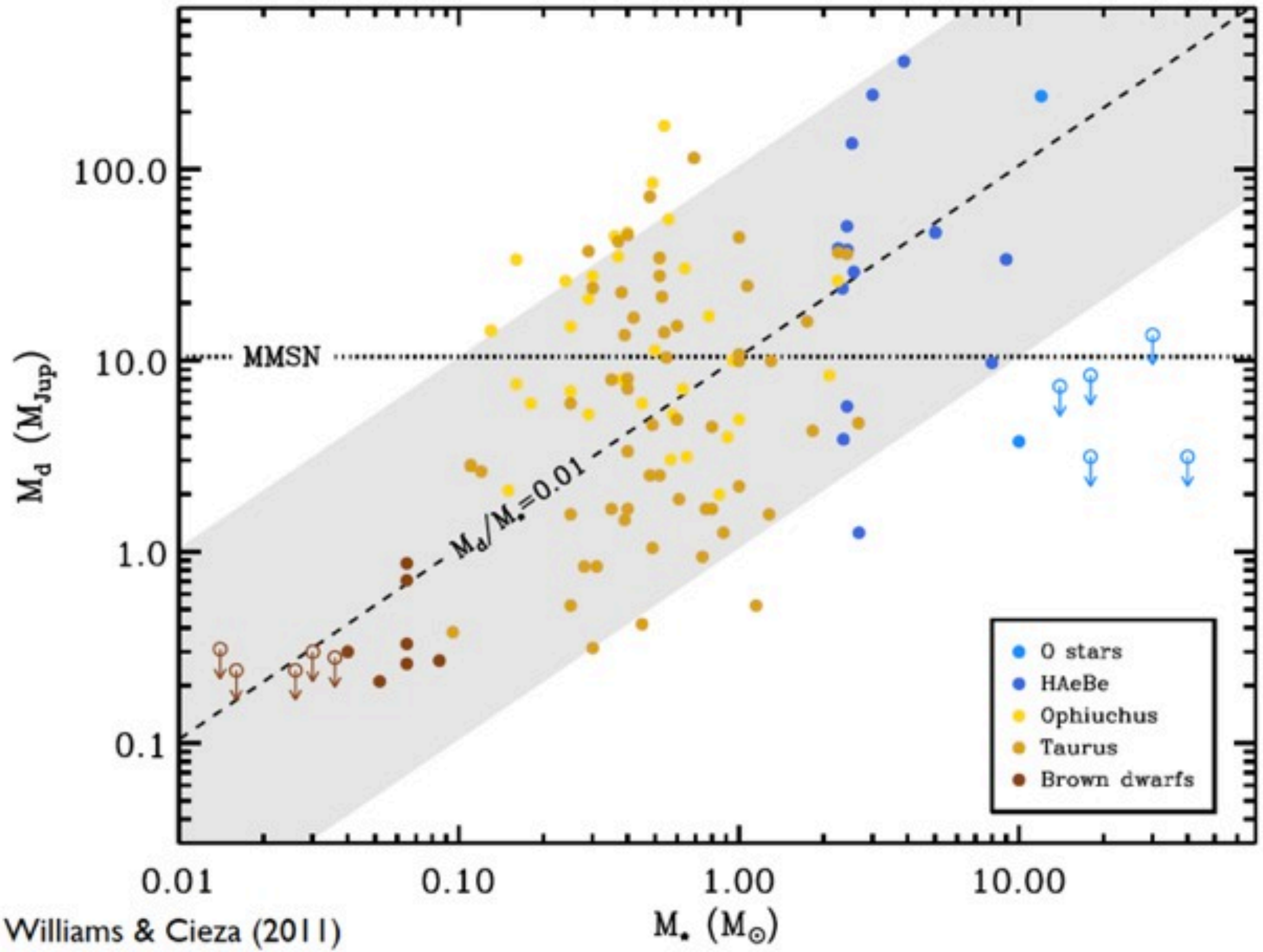
(McCaughrean & O'Dell 1995)



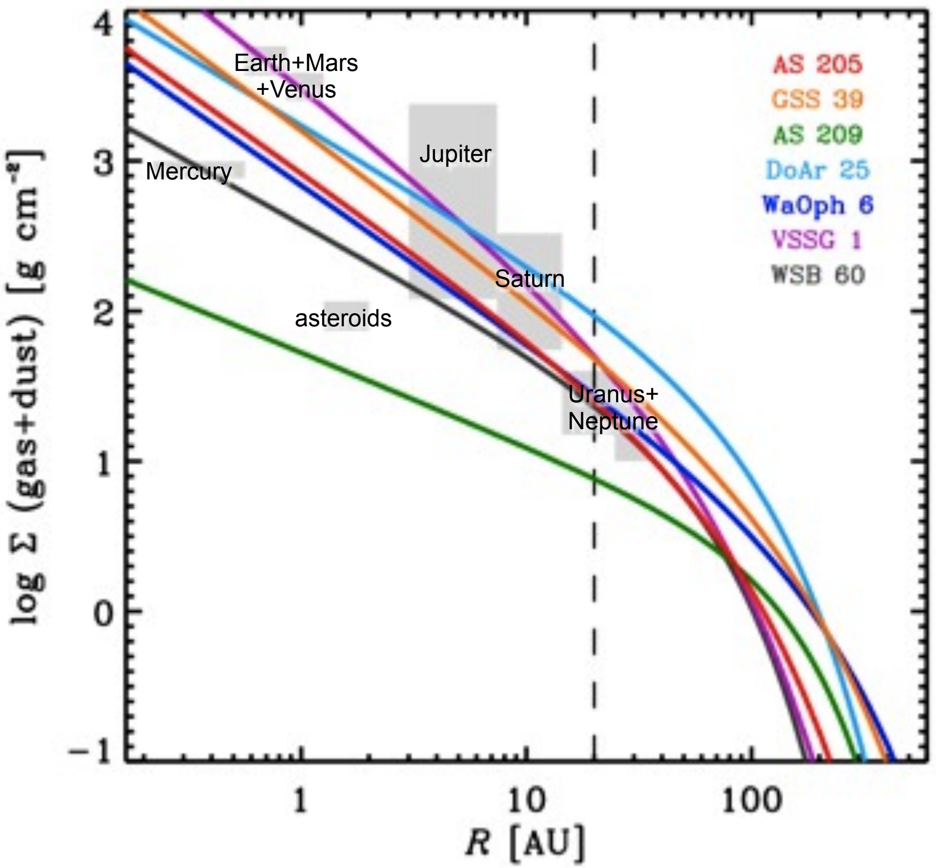

(Marois et al. 2010)

# Disk Masses



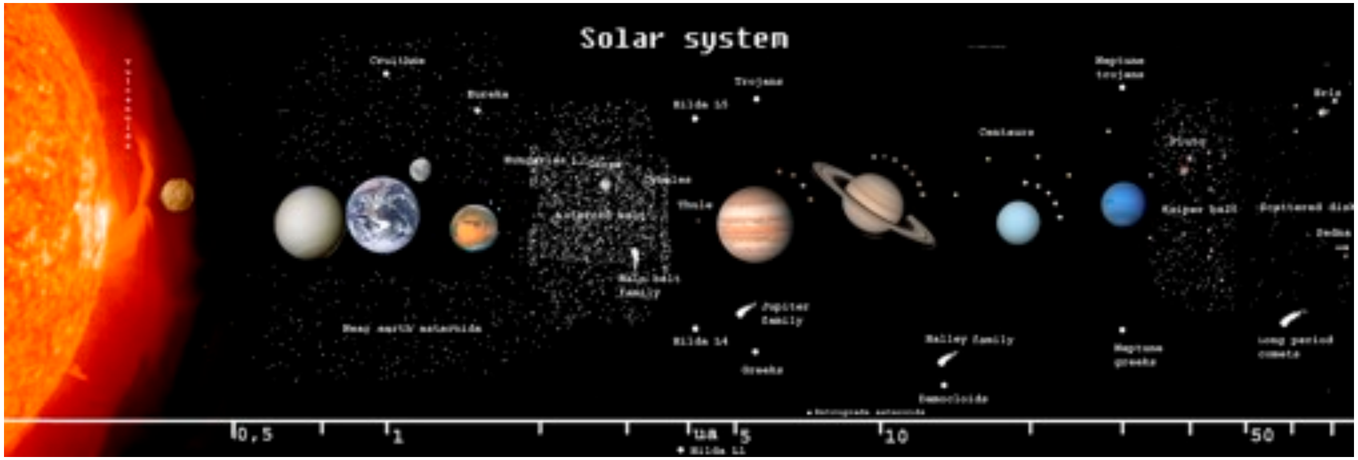

Williams & Cieza (2011)

# Disks Structure

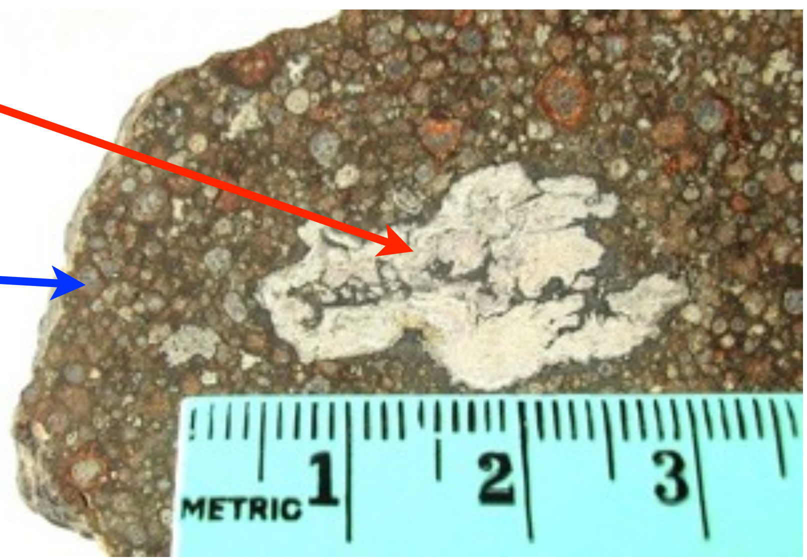


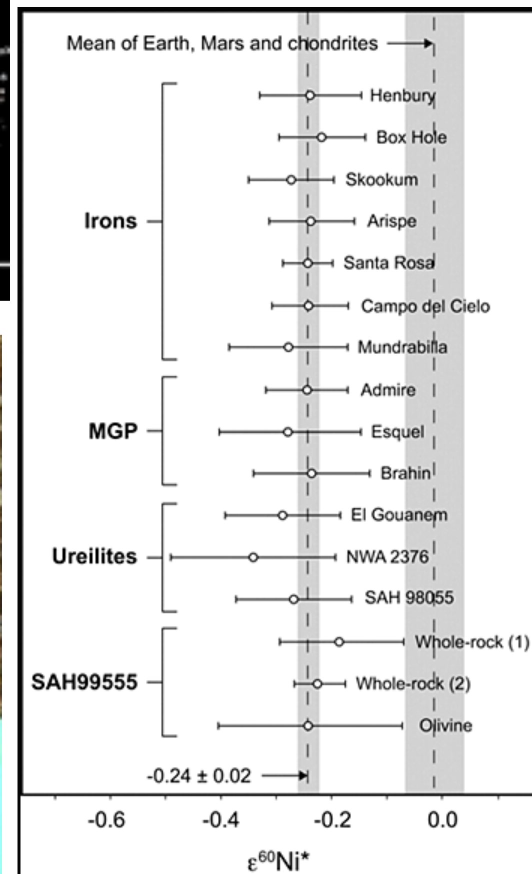

(Andrews et al. 2009;
Hughes et al. 2007; Isella et al. 2009)

# Our own Solar System



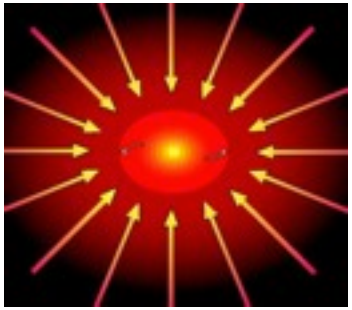

- CAI
  - Formed early
  - Survived 3-5 Myr
- Condrules
  - After 3-5 Myr
- Matrix
  - Sub-um particles
  - Cement the body

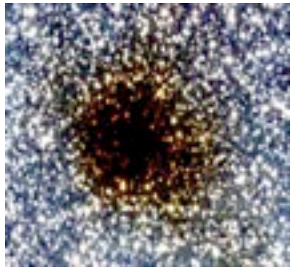


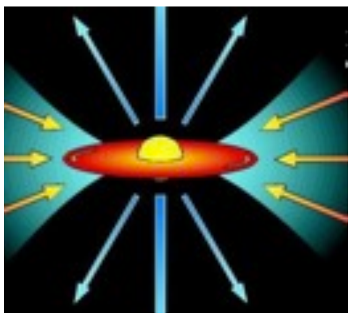

(From Bizzarro *et al.*, 2007, *Science*, v. 316, p.1178-1181.)

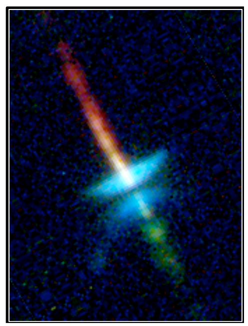
# From Cores to Planetary Systems



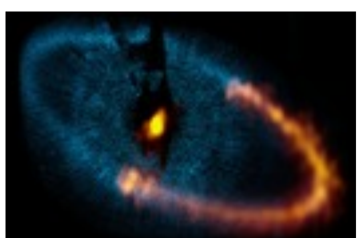


Core

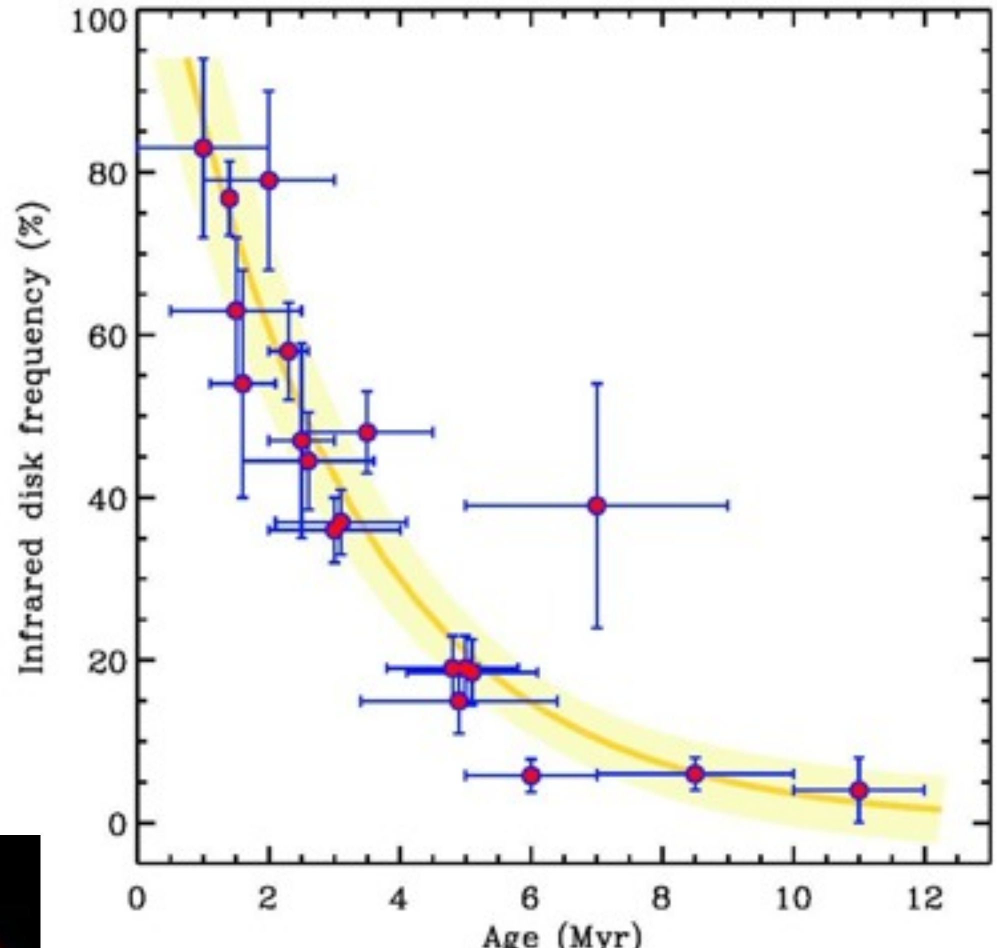




Disk



Debris Disk

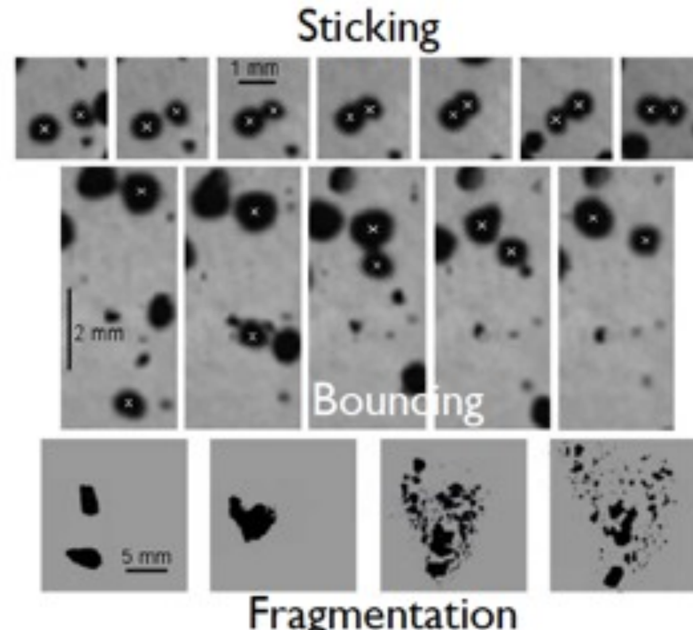


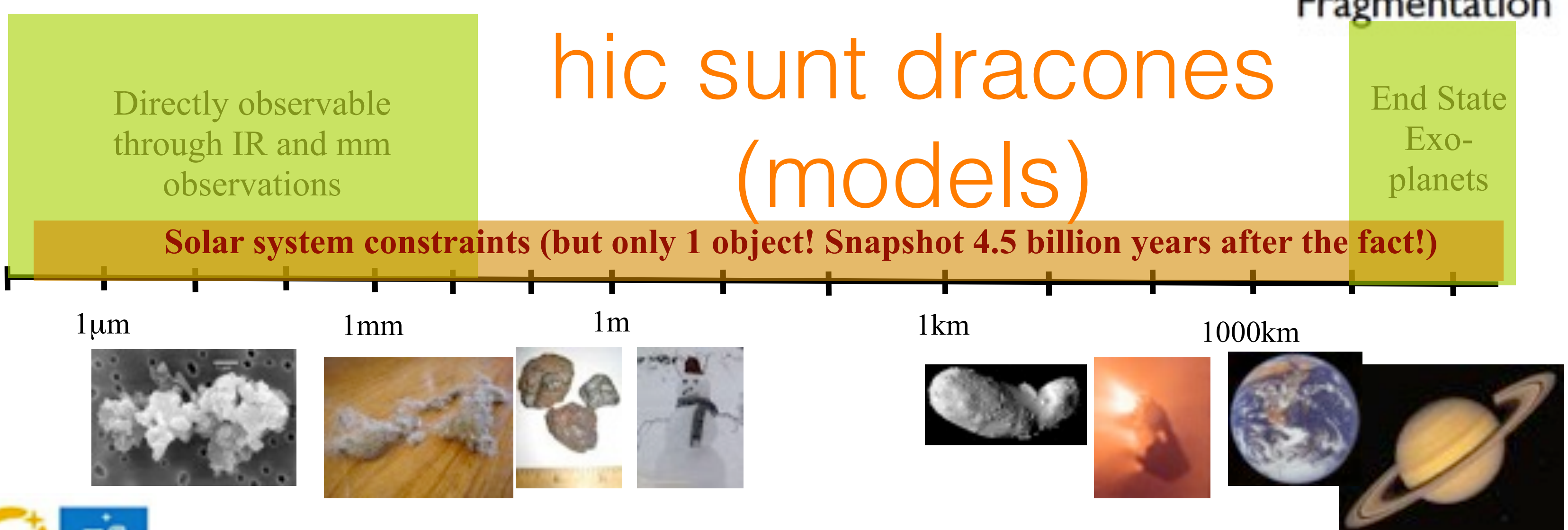

(Hernandez et al. 2007)

Inner disk clearing:
e-folding time t~2-3 Myr

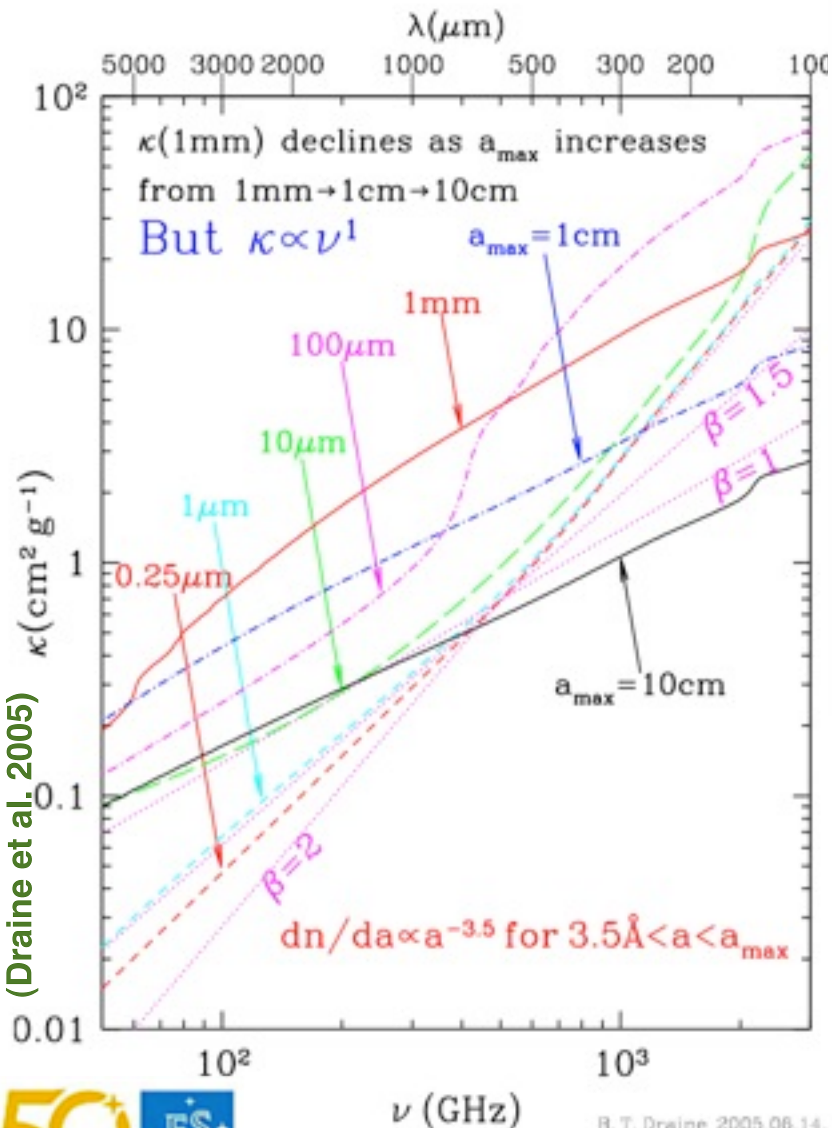
# Grain Growth the Dawn of Planets

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

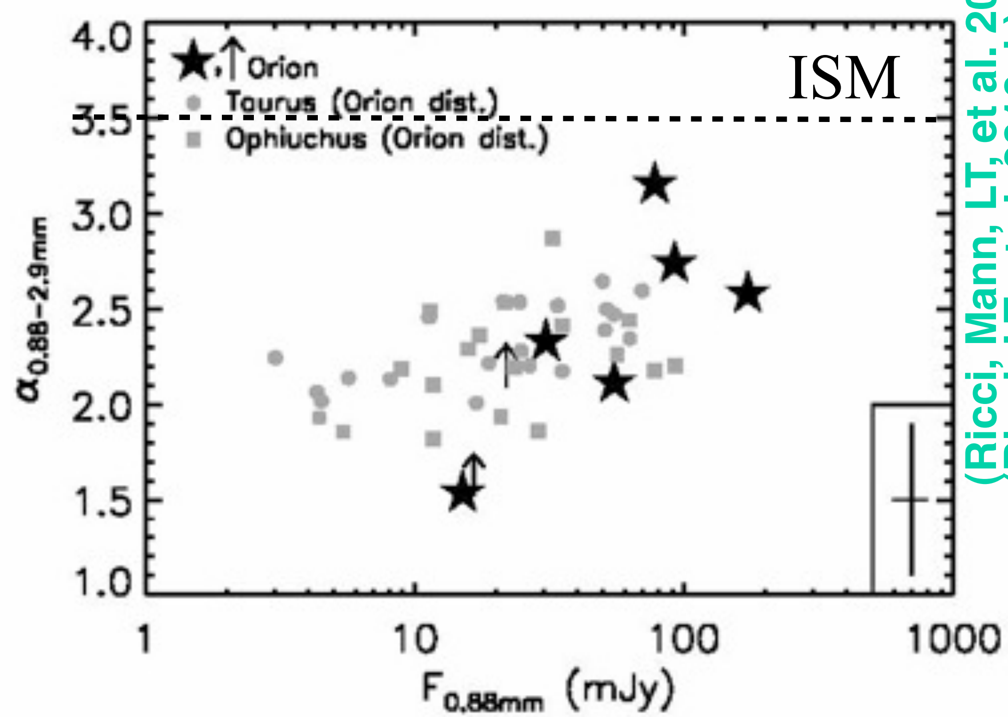


# Dust and Pebbles from mm observations

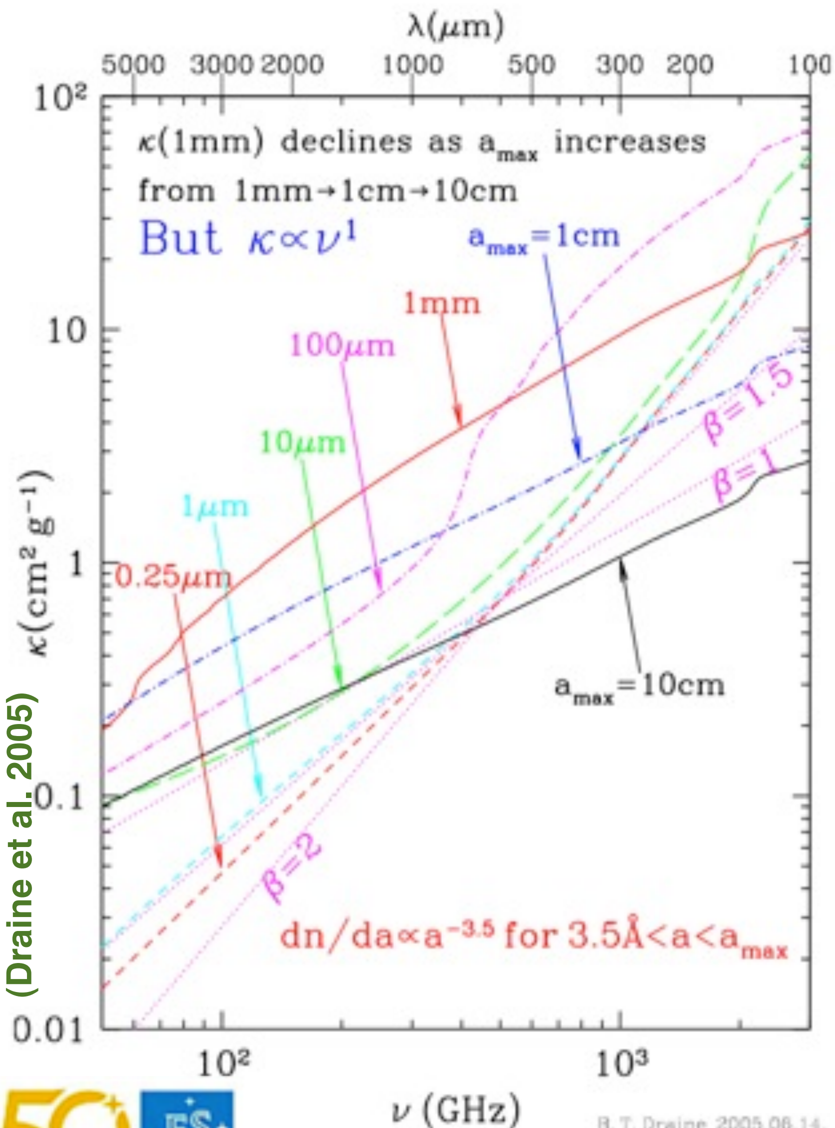



(Draine et al. 2005)

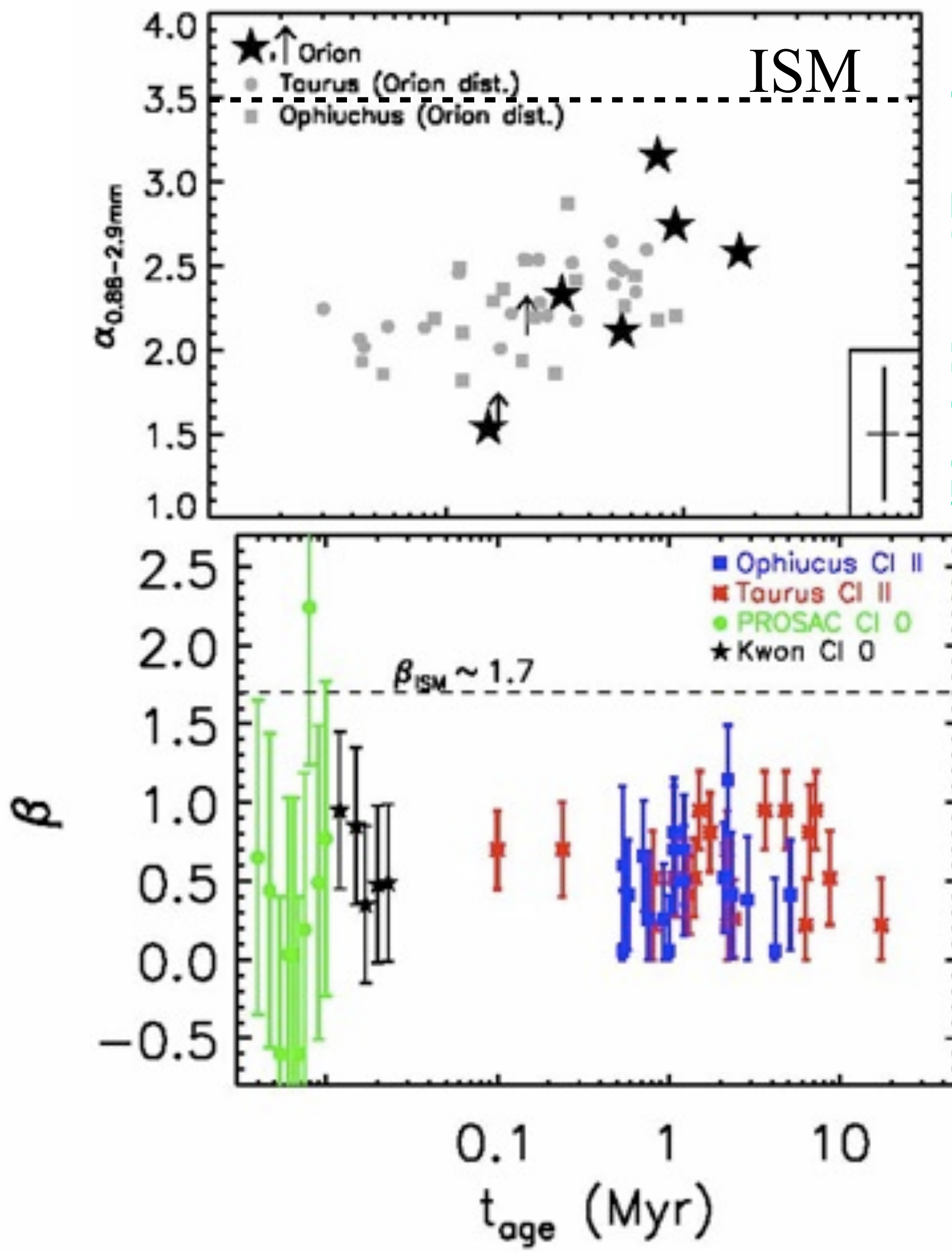



(Ricci, Mann, LT, et al. 2011c)
(Ricci, LT, et al. 2010ab)

# Dust and Pebbles from mm observations



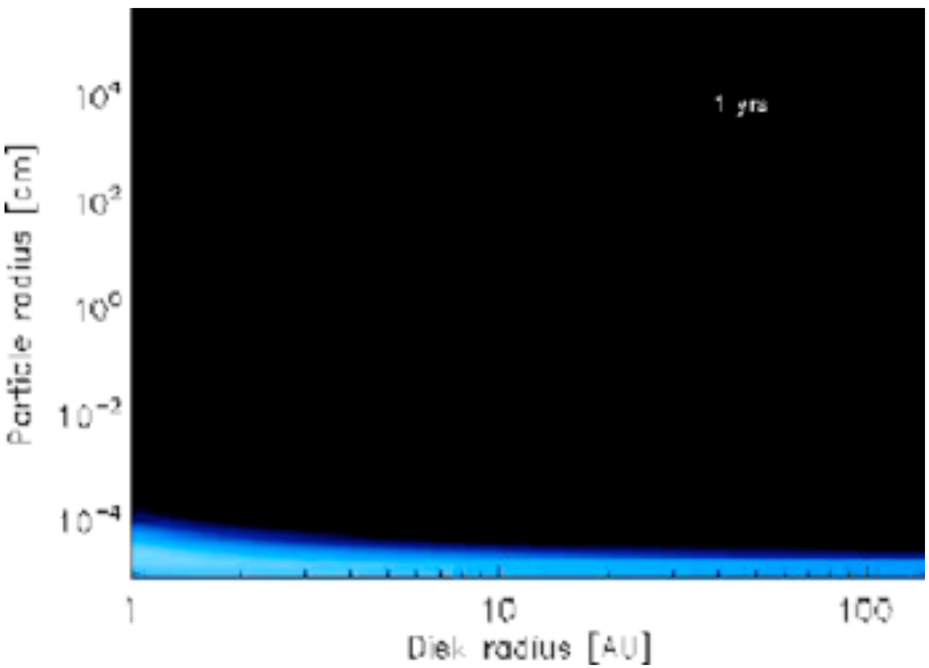

(Draine et al. 2005)

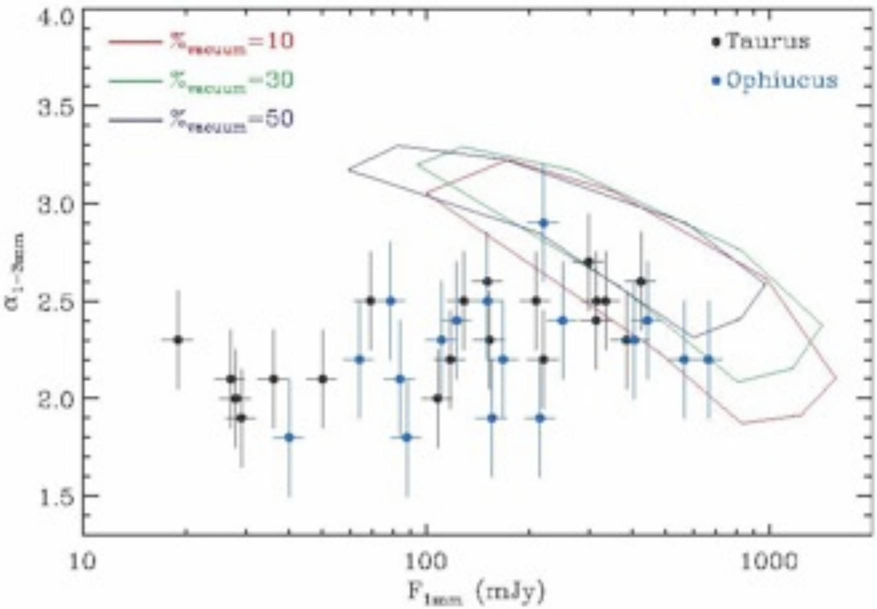



(Ricci, Mann, LT, et al. 2011c)
(Ricci, LT, et al. 2010ab)

# Grain growth in disks: model predictions

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



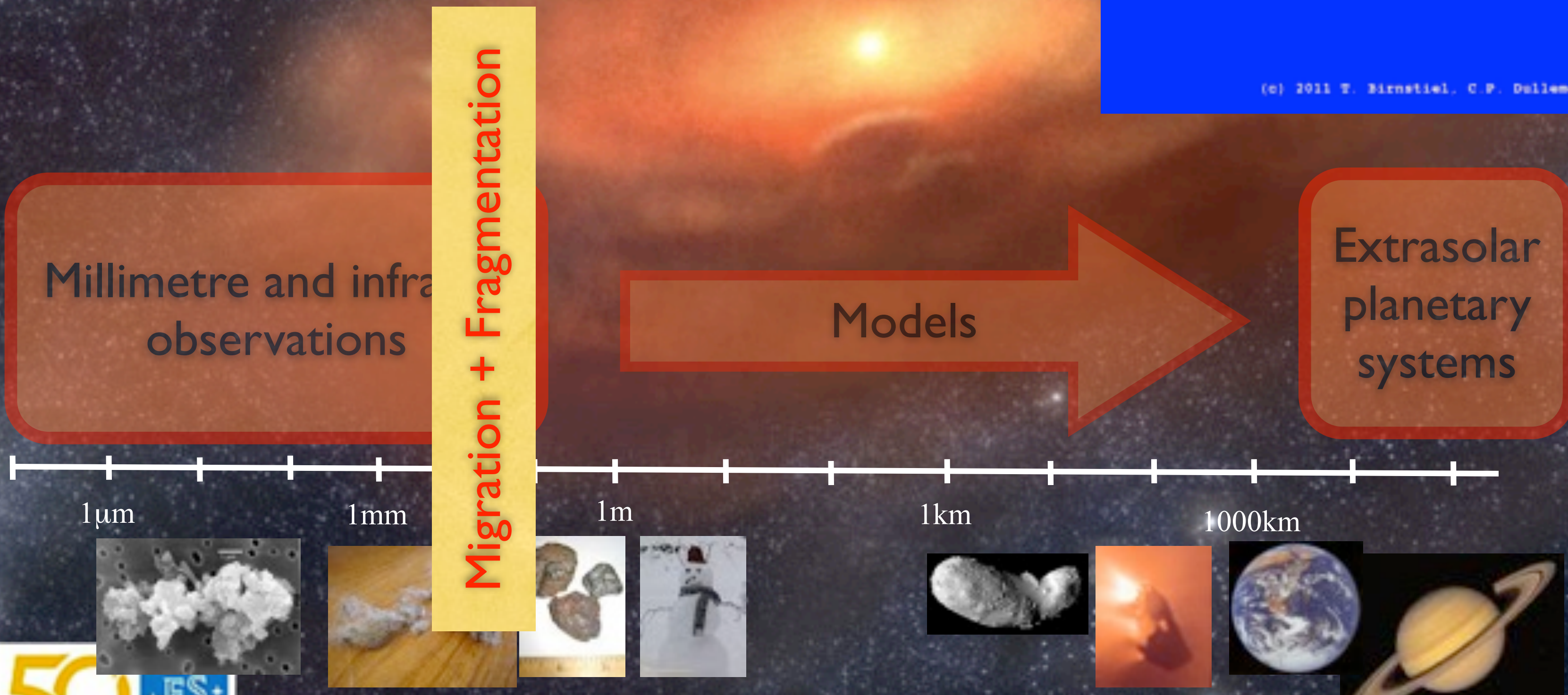

(Birnsiel, Ricci, Trotta, et al. 2010)

- ✦ 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 need to stop migration
  - ➢ Need to understand faint disks

# Migration & Fragmentation

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

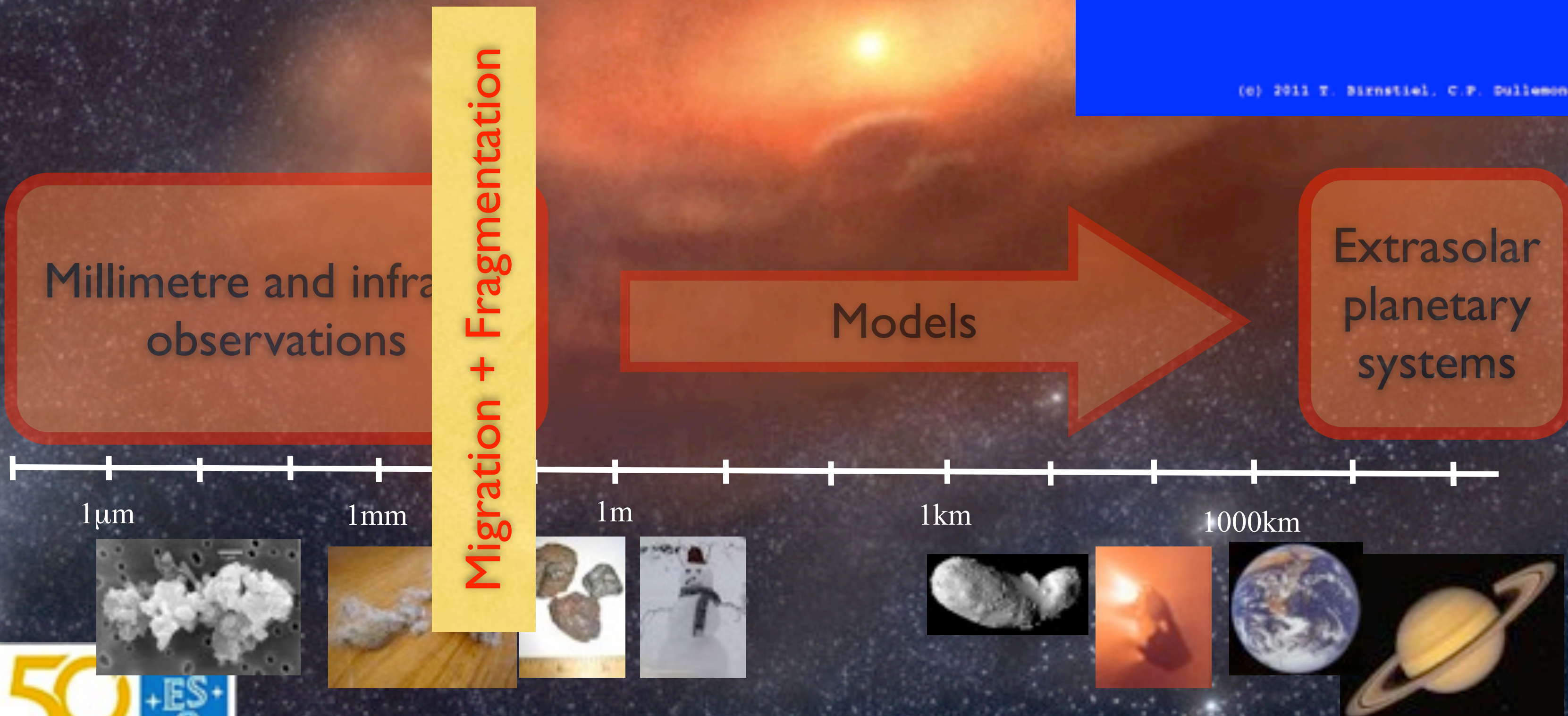

(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)



# Dust trapping in pressure maxima

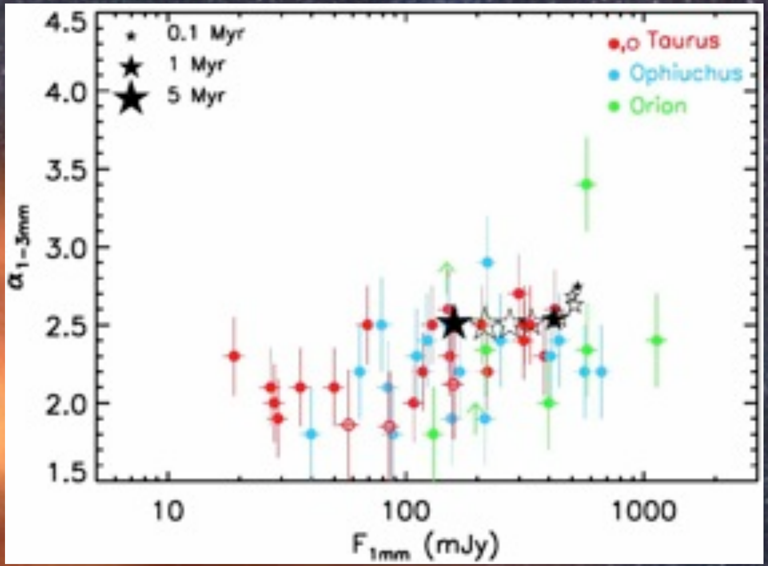
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times


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

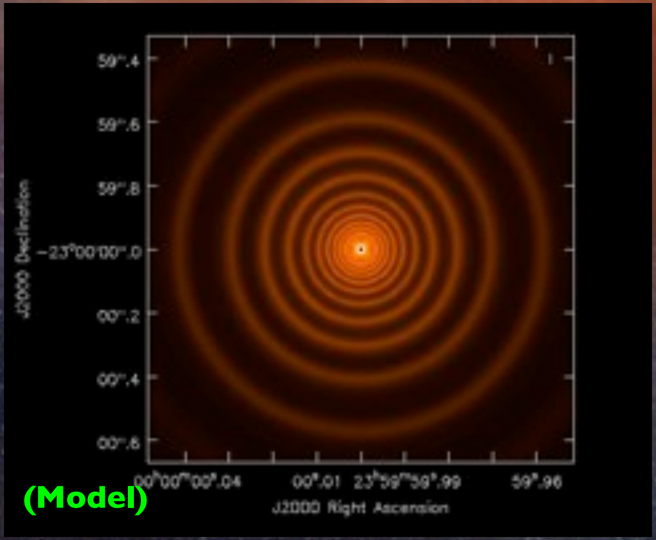


# Dust trapping in pressure maxima

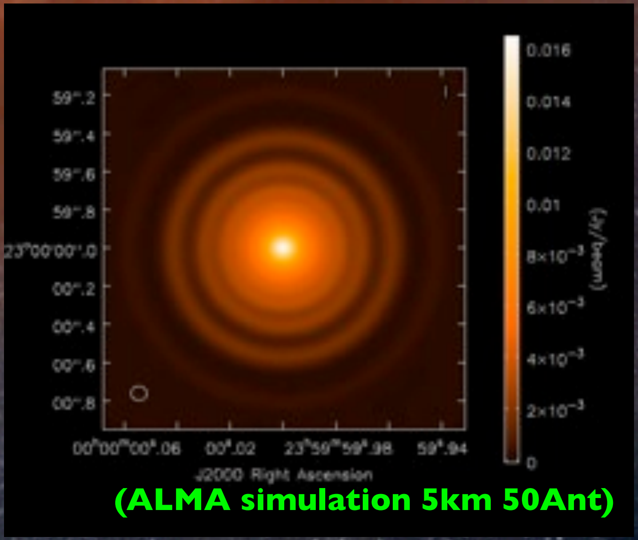
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times
- Observable with ALMA!




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

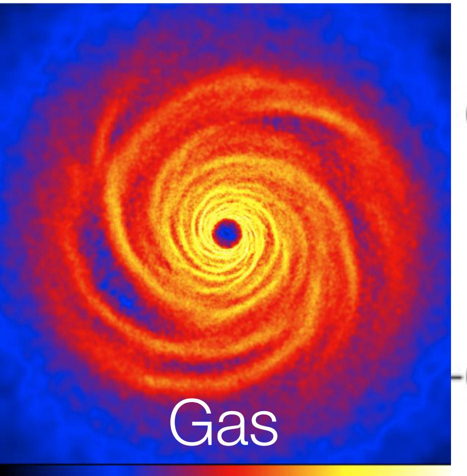


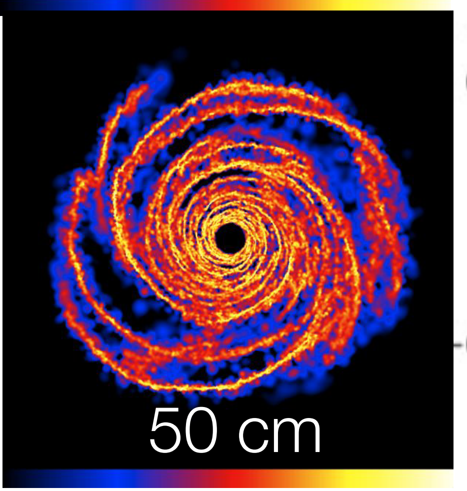

(Model)

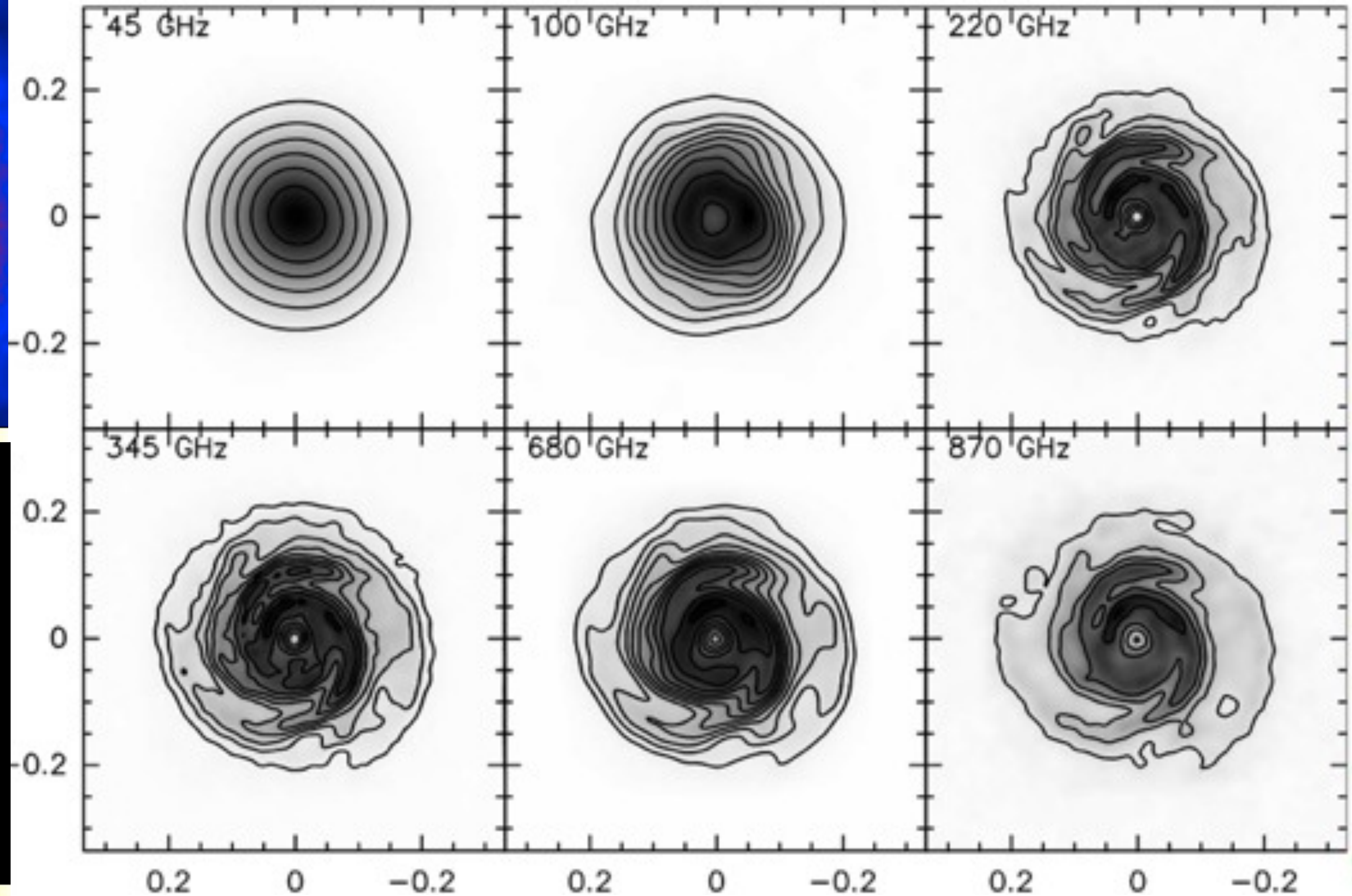



(ALMA simulation 5km 50Ant)

# Slowing down radial drift: grain trapping



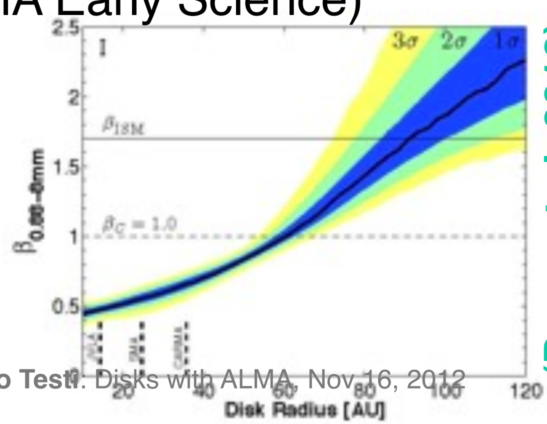

(Cossins, Lodato, Testi 2010)

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

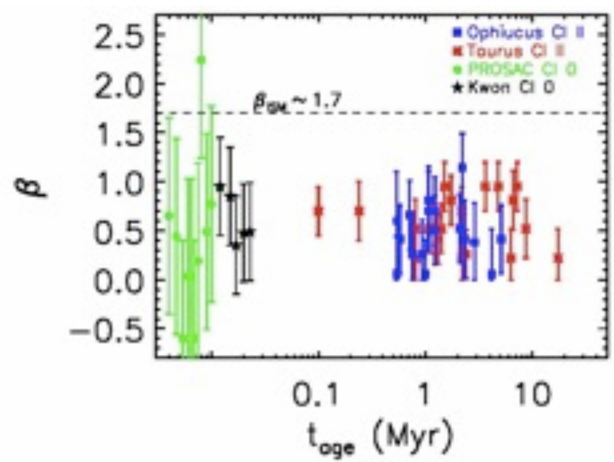
# State of the Art & Future Directions

- 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. 2012)
  - 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)



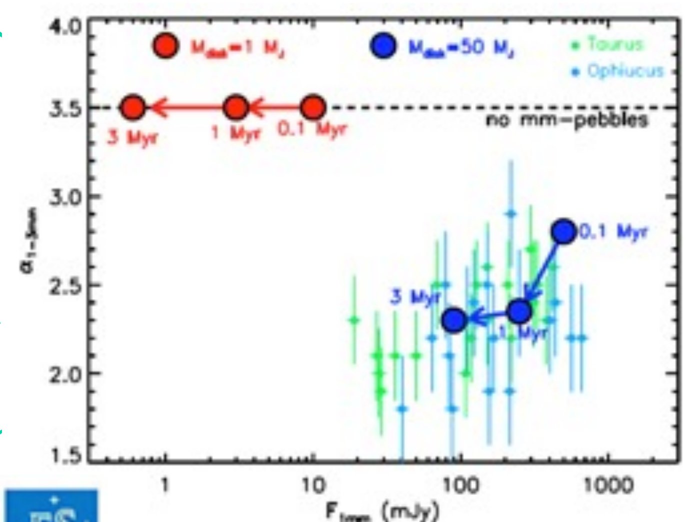

(Perez et al. 2012)

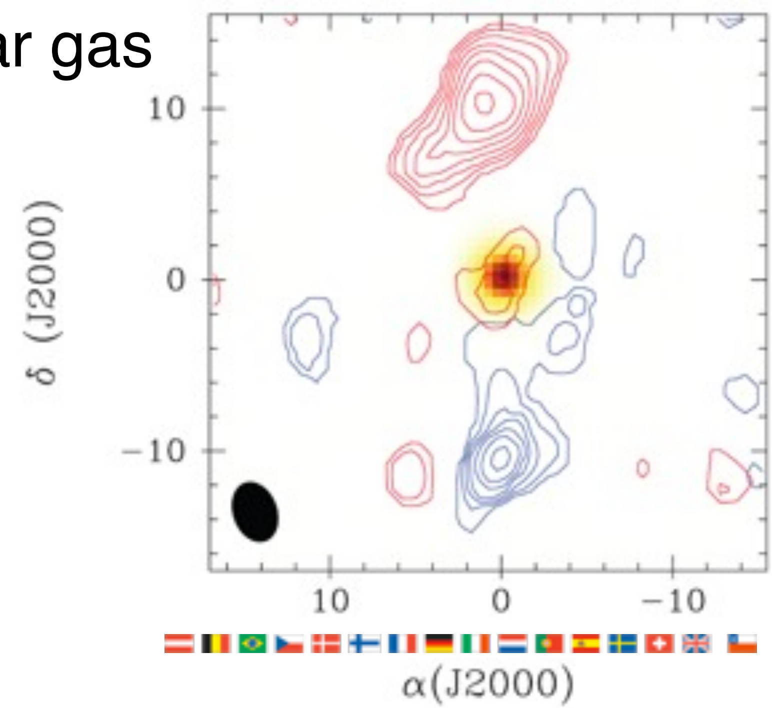


# ALMA Observations Goals

- ✦ Target known BDs disks in nearby SFR
- ✦ Estimate disk mass, size (mm flux, resolve disk)
- ✦ Constraint dust properties (mm spectral index)
- ✦ Attempt detection of molecular gas

(Ricci, LT et al. 2012)

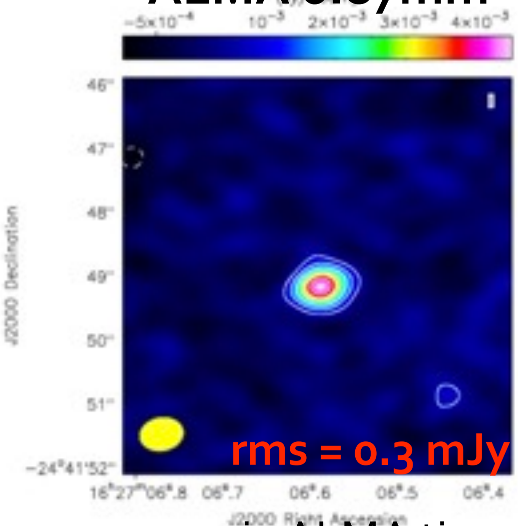



(Phan Bao et al. 2008)

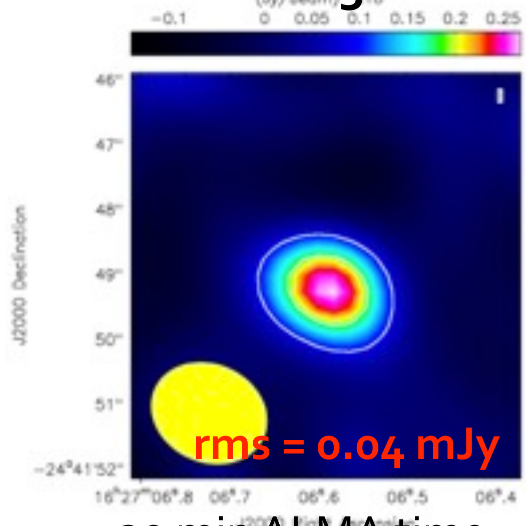
# ALMA Results on rho-Oph 102

**ALMA 0.87mm**



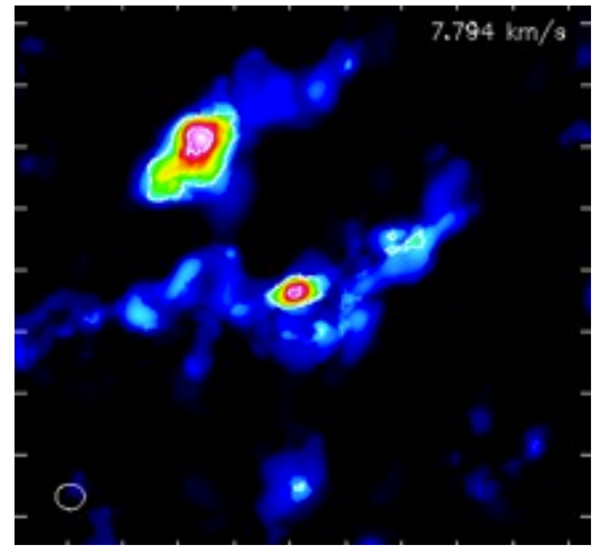

~ 15 min ALMA time
vs ~ 500 hrs SMA time!

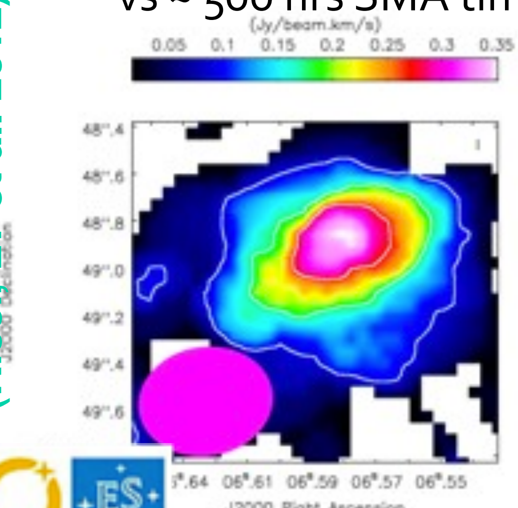
**ALMA 3mm**

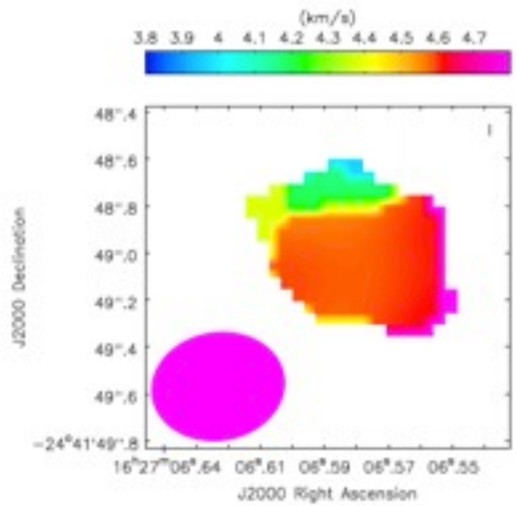


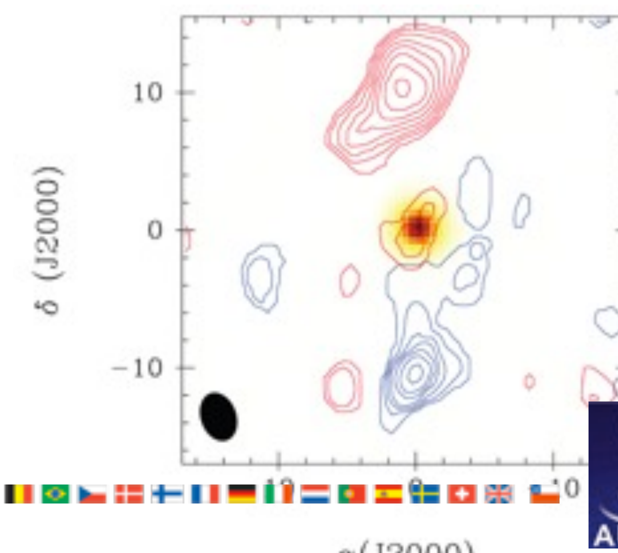

~ 30 min ALMA time
vs ~ 120 hrs CARMA time!

**ALMA CO ($J = 3 - 2$)**



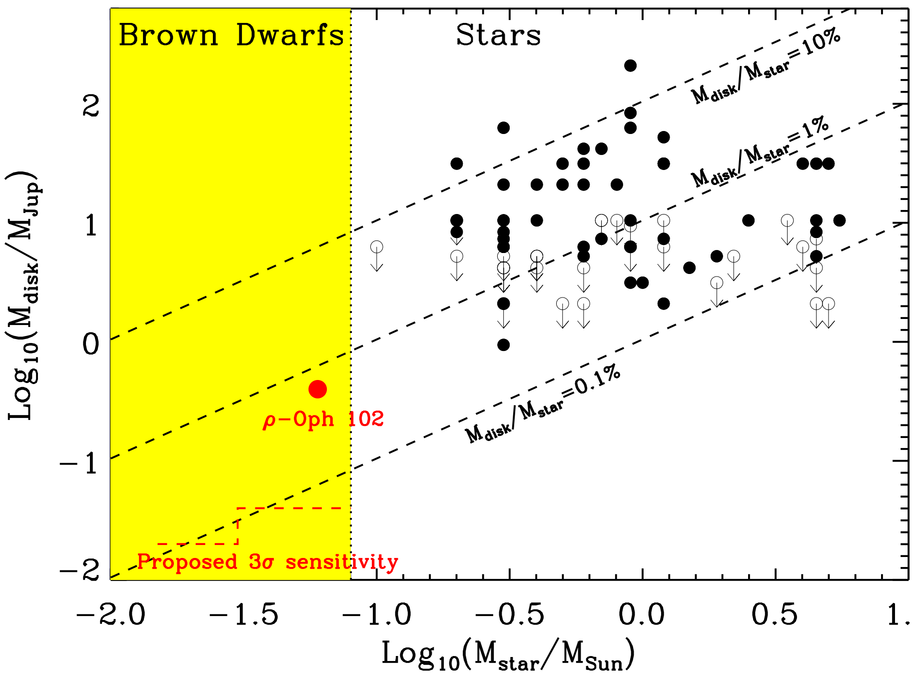



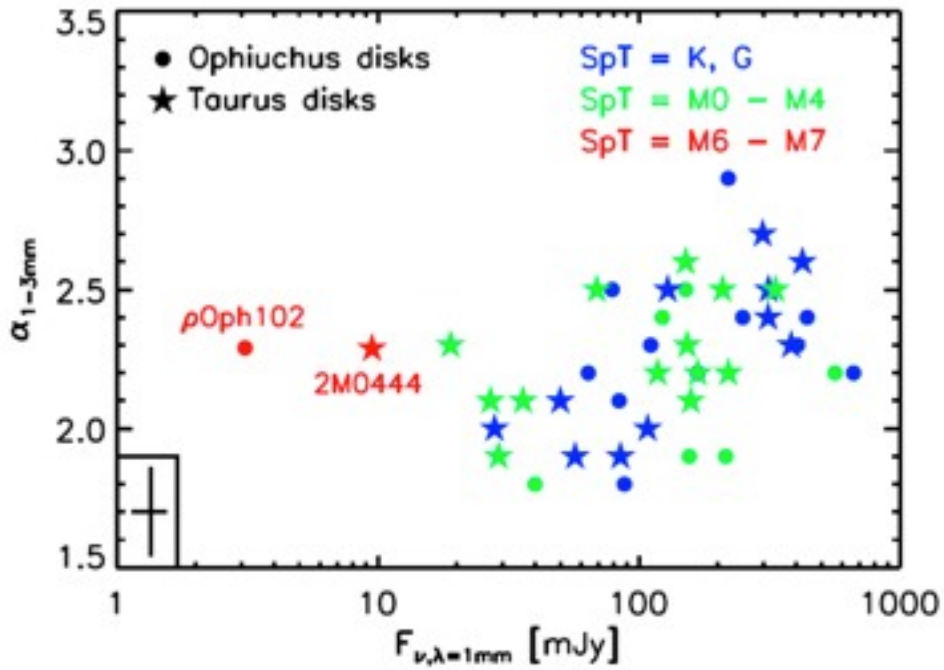



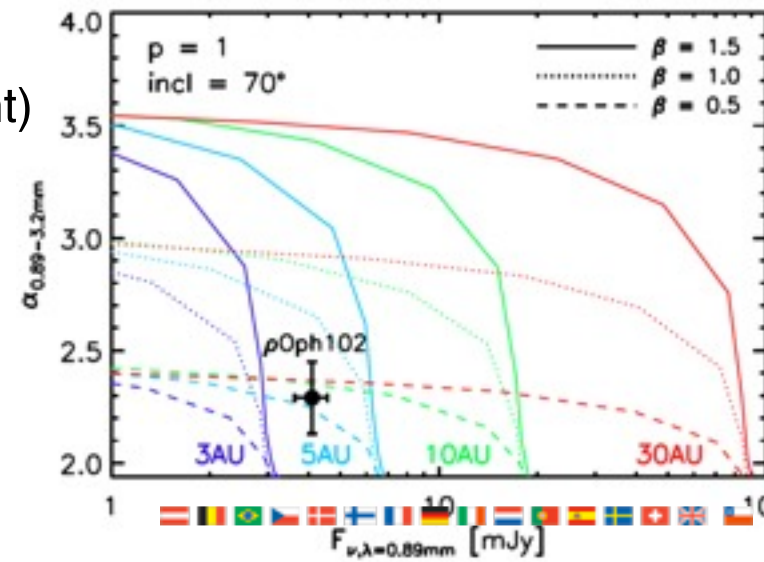

(Ricci, LT et al. 2012)

(Phan Bao et al. 2008)

# Disks around BDs and VLMS



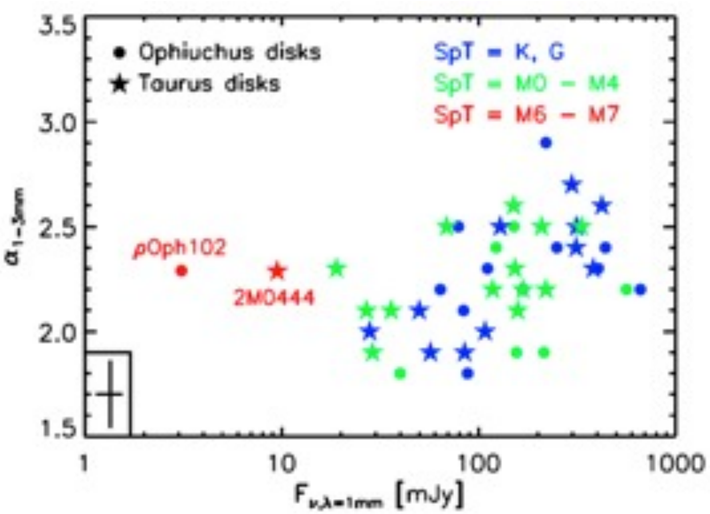

(Ricci et al. 2012)

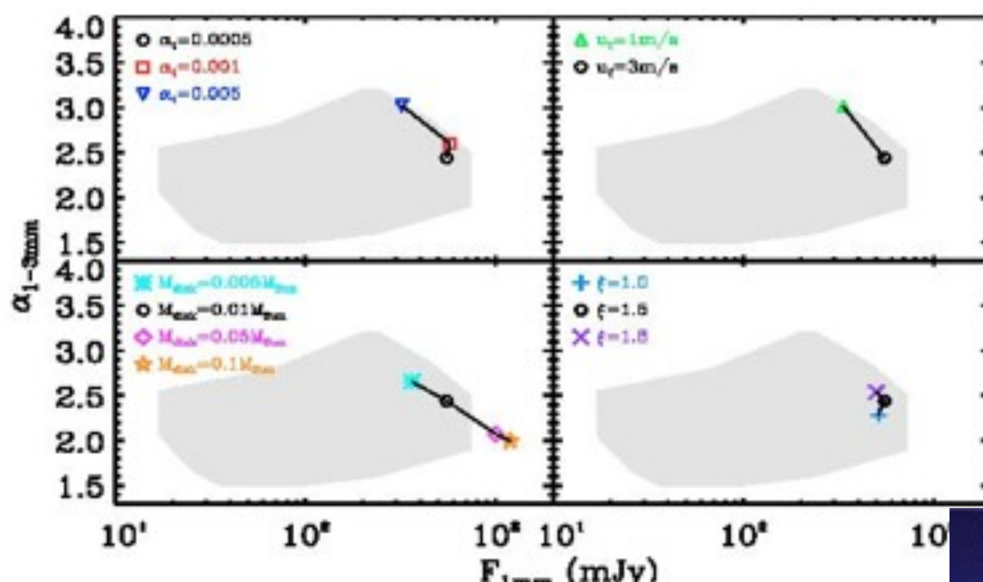
- Disk Size: 10AU (CO) <~ R <~ 30AU (cont)
- Disk Mass: ~0.3-1% of central BD
- Gas rich disk
- Evidence for large (>~ mm-size) grains

# Comparison with models

- Can we reconcile grain growth in young BDs with dust evolution models in disks?
- Main parameters
  - Gas surface density (disk mass/size)
  - Fragmentation velocity
  - Turbulence

$$a_{\rm max} \simeq \frac{2\Sigma_{\rm g}}{\pi \alpha_{\rm t} \rho_{\rm s}} \cdot \frac{u_{\rm f}^2}{c_{\rm s}^2}.$$



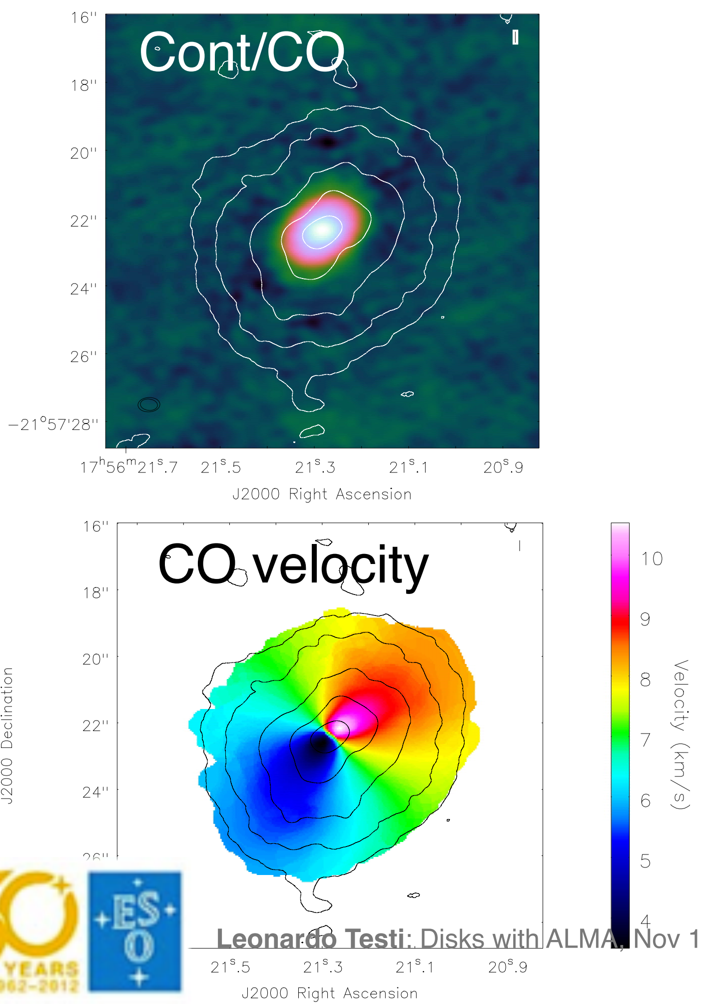



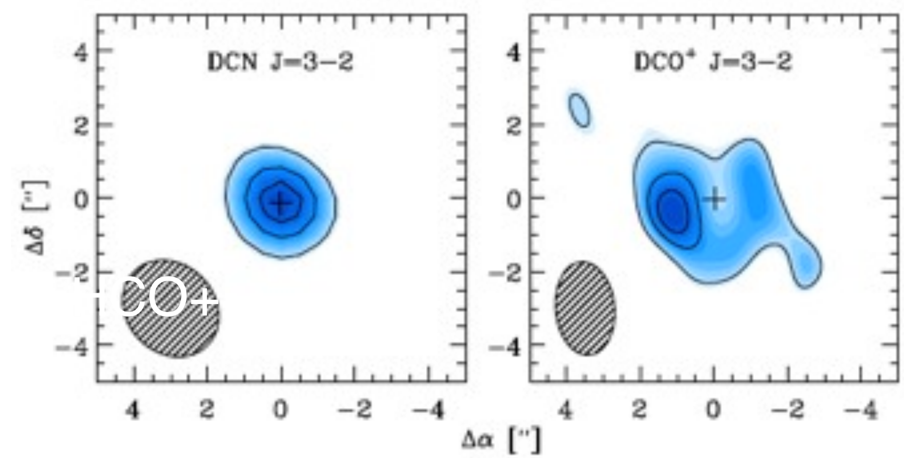

(Birnstiel et al. 2010)

# Role of gas

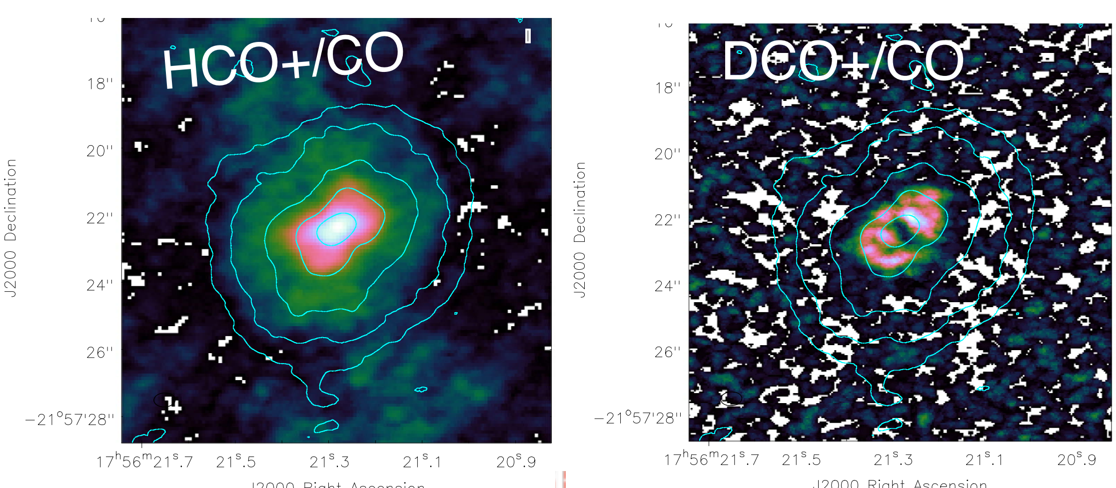
- Gas contains most of the mass and is critical for the stability of the disk, the viscous evolution and the chemical evolution

(de Gregorio Monsalvo et al.2012)




(Oeberg et al.2012)



# Summary

- Grains grow fast to pebbles and stay there for a while
  - We are starting to assemble a consistent picture for solids evolution

- Grain growth process in protoplanetary disks
  - Need to solve the “trapping” problem
  - ALMA observations are providing unique tests
  - Look at the odd objects: they will provide key tests and insights

- Are we looking at the wrong objects?
  - Solar System likely formed in a more clustered environment
  - Is the SS the product of one of the (few) long lived disks?
  - At any given time the fraction of “diskless” stars is relatively high: can planet formation occur on very short timescales?

- We are just starting to explore in detail the gas content and the disk chemical processes