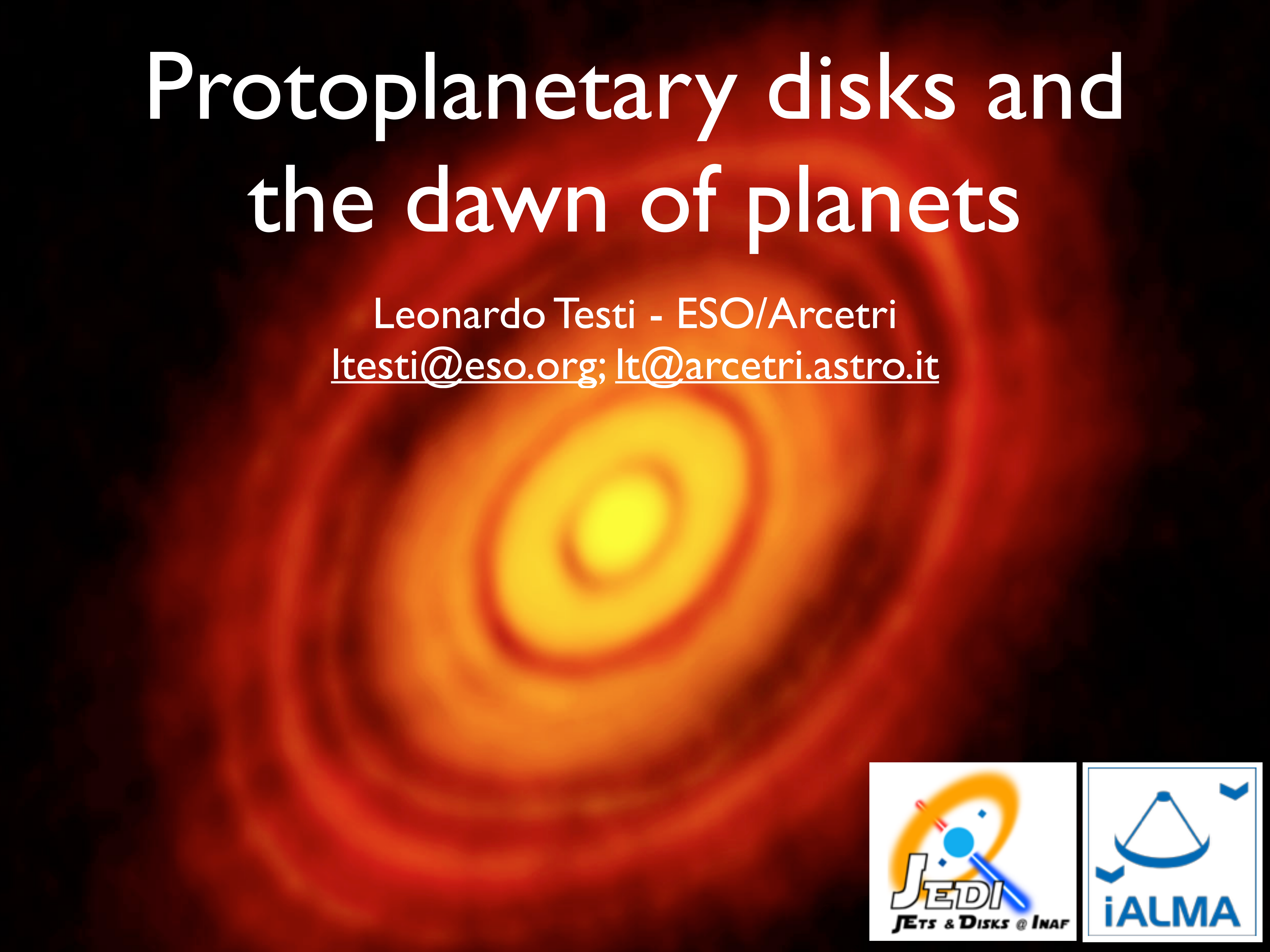
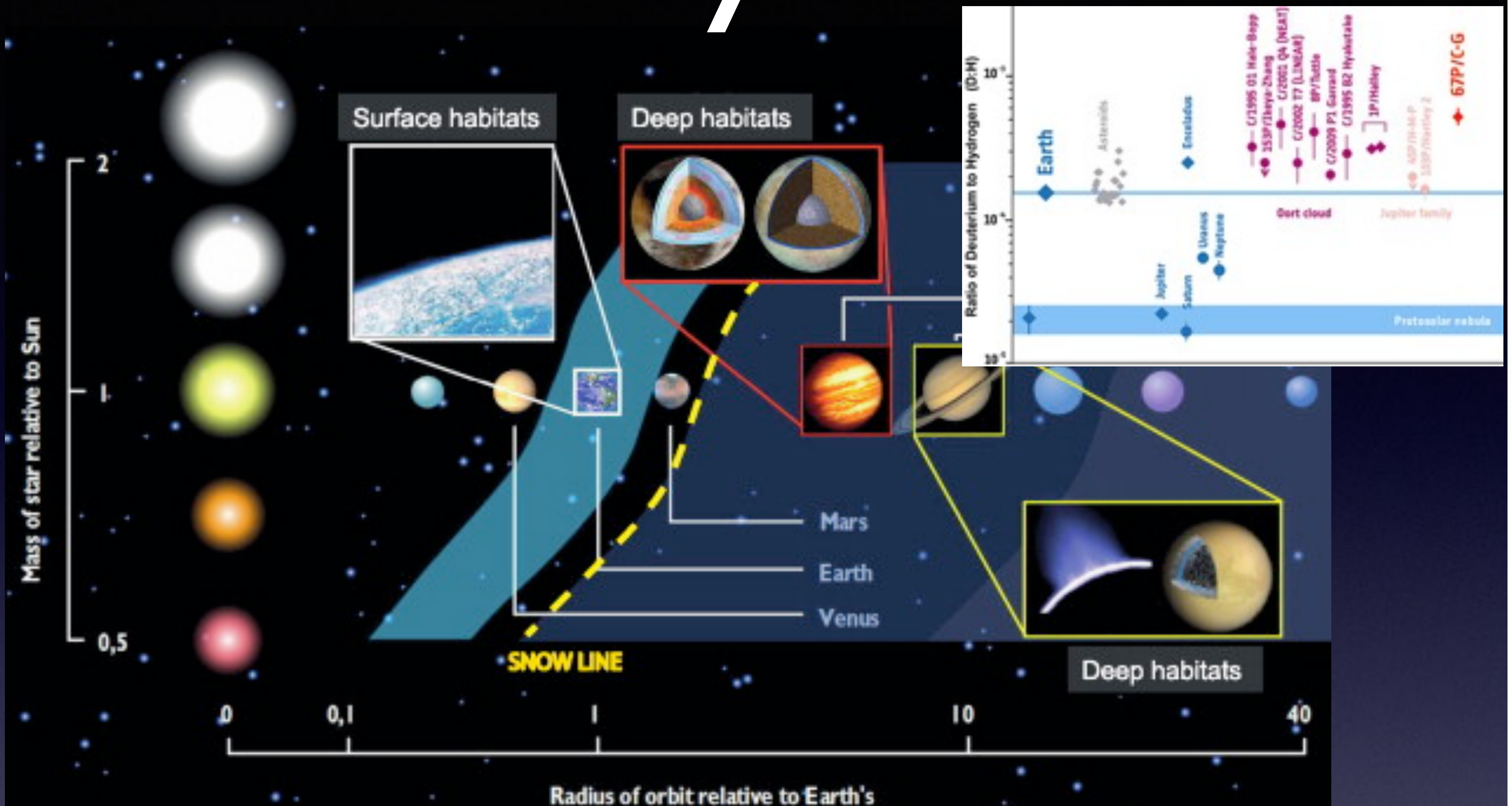
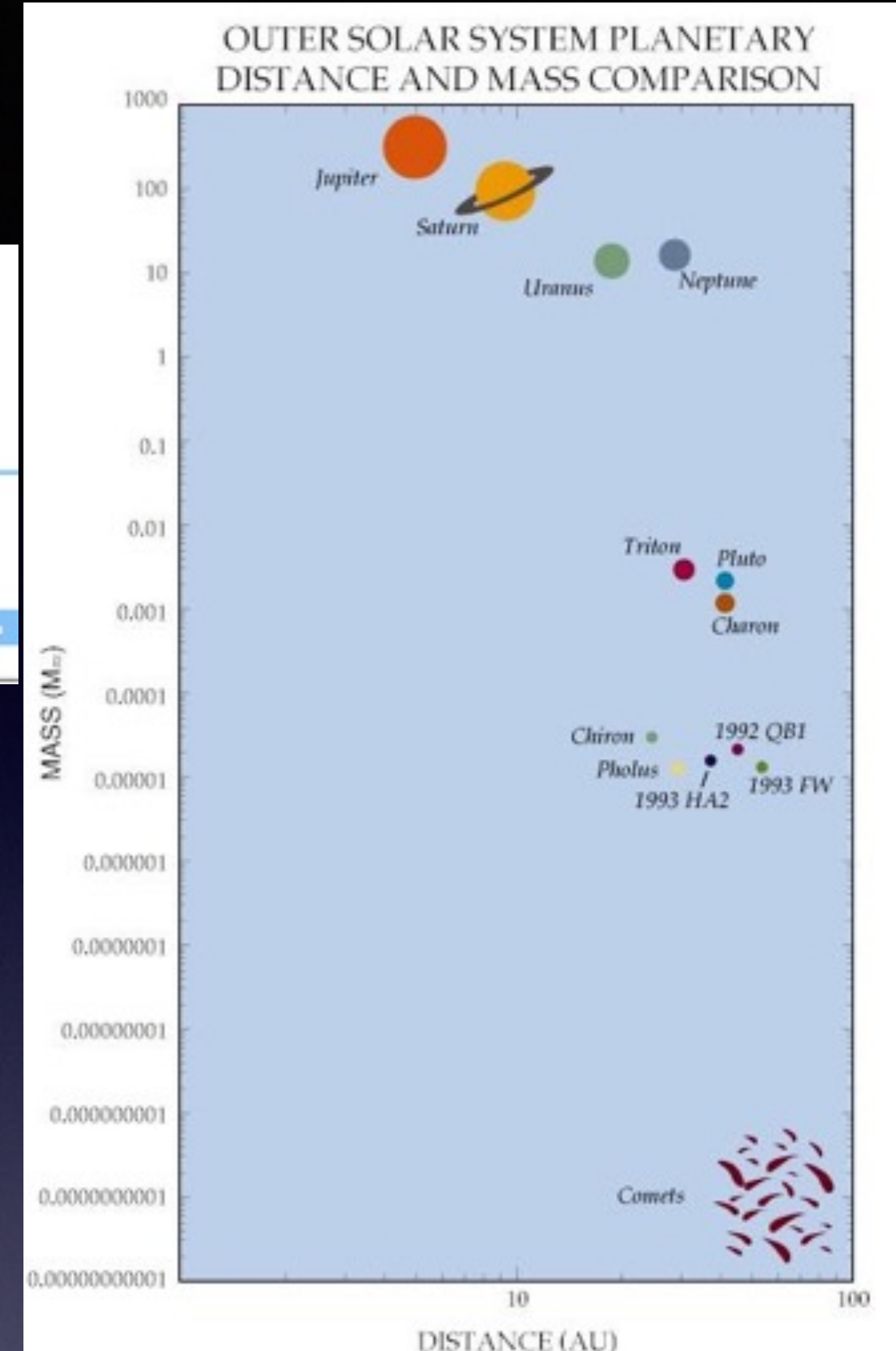
Protoplanetary disks and the dawn of planets

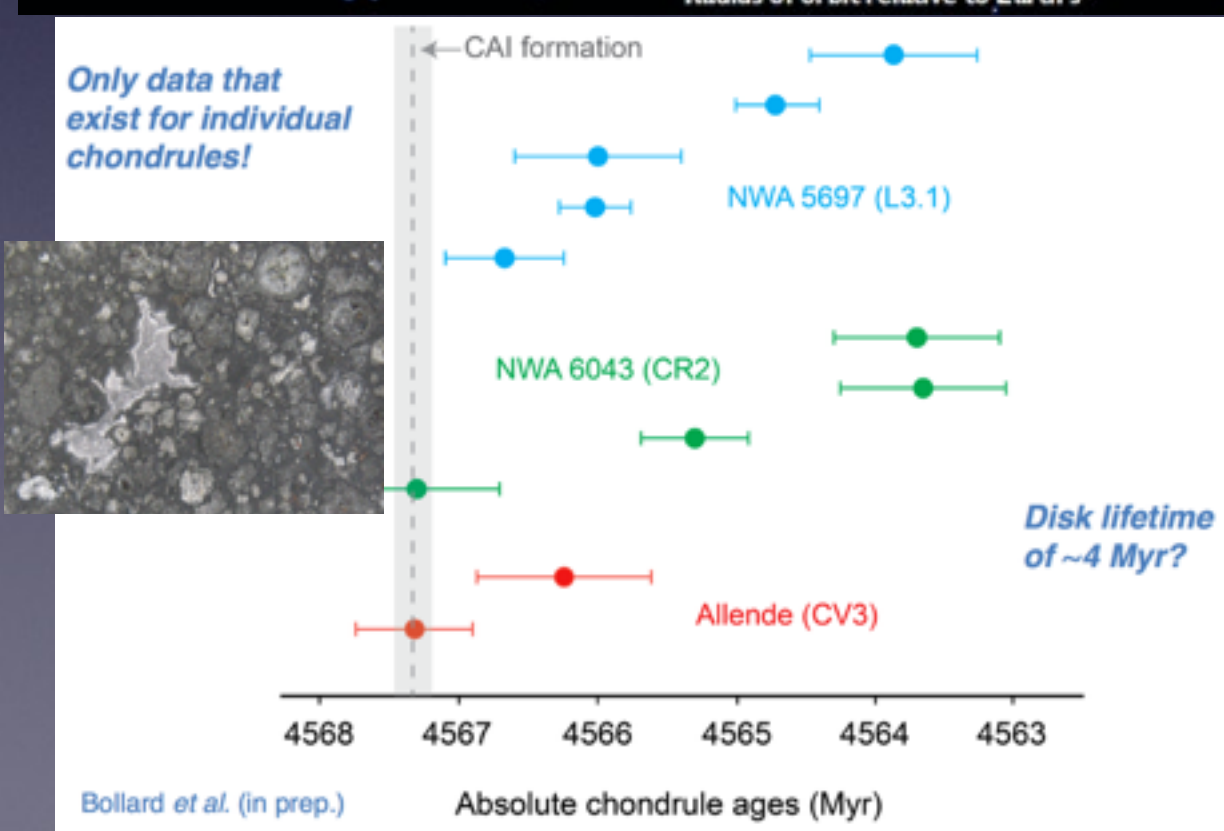
Leonardo Testi - ESO/Arcetri
ltesti@eso.org; lt@arcetri.astro.it

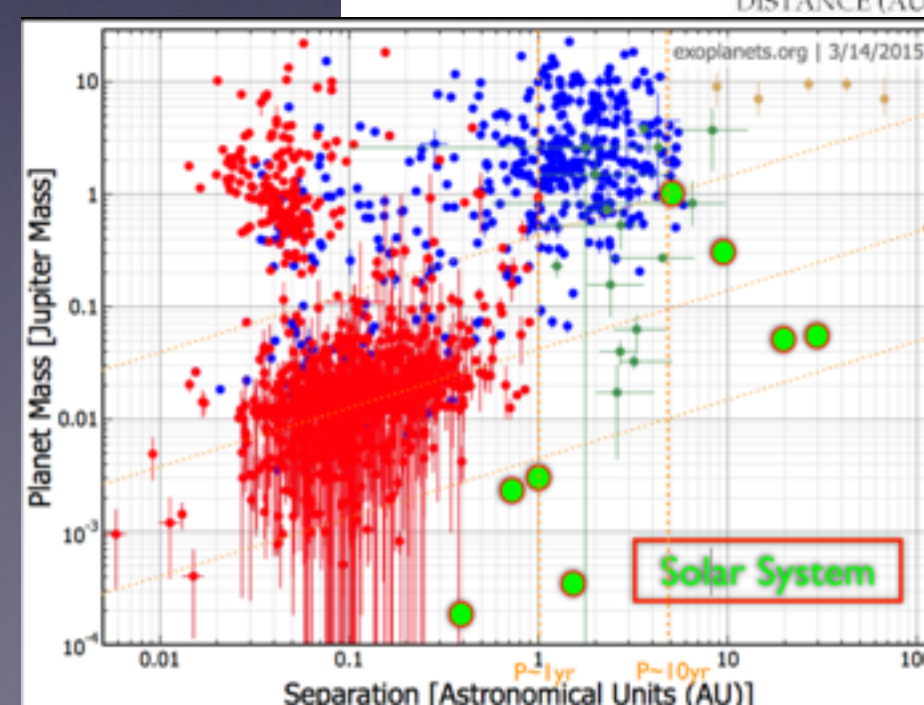


Solar System

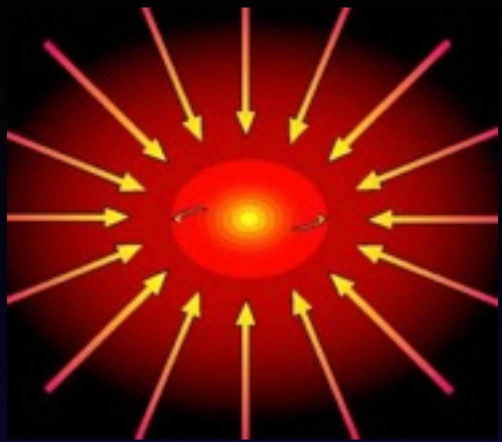
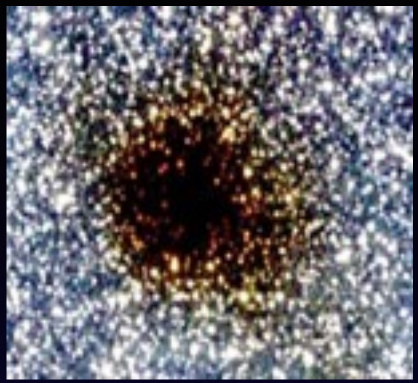




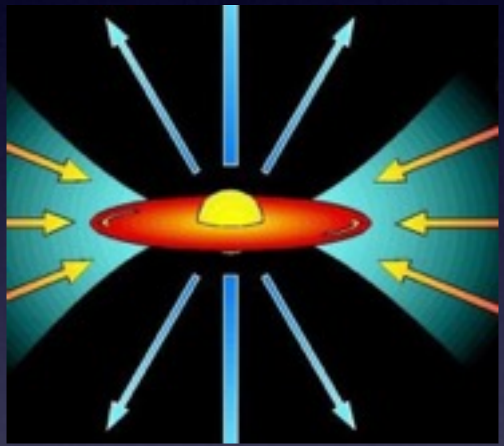
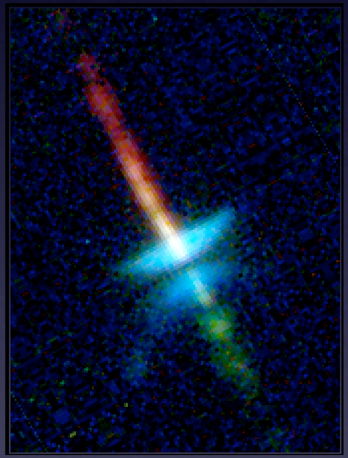




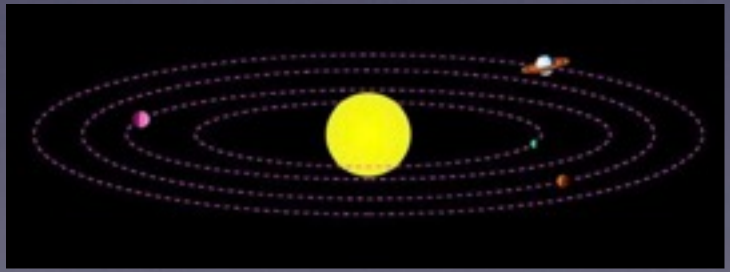
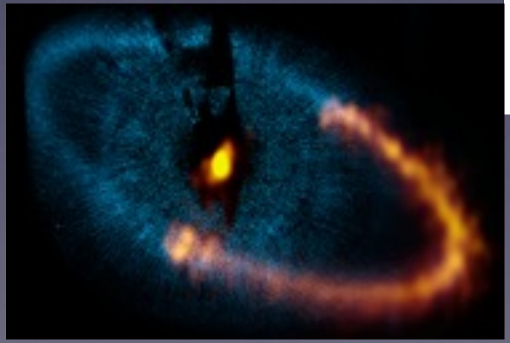
From Cores to Planetary Systems

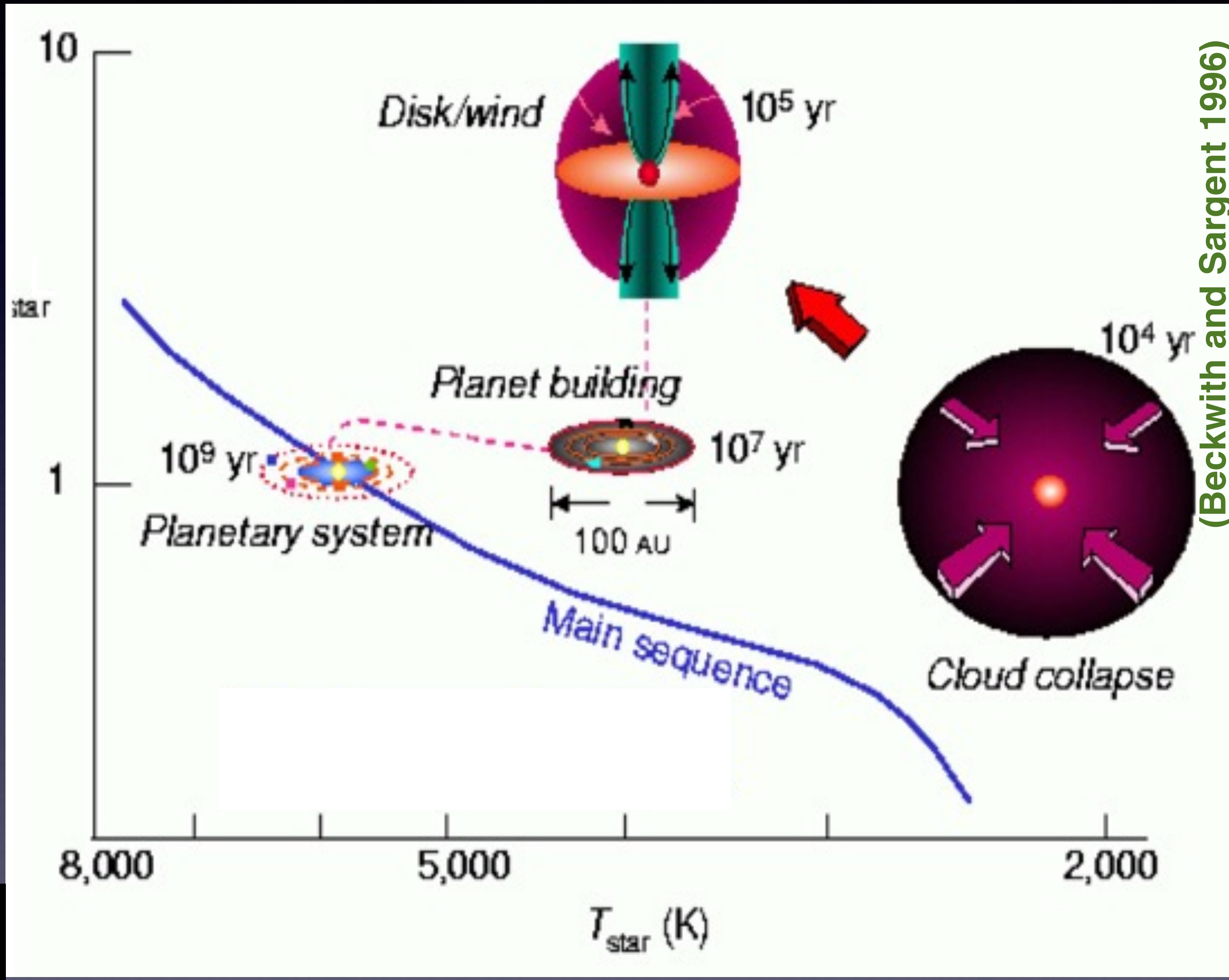
Core

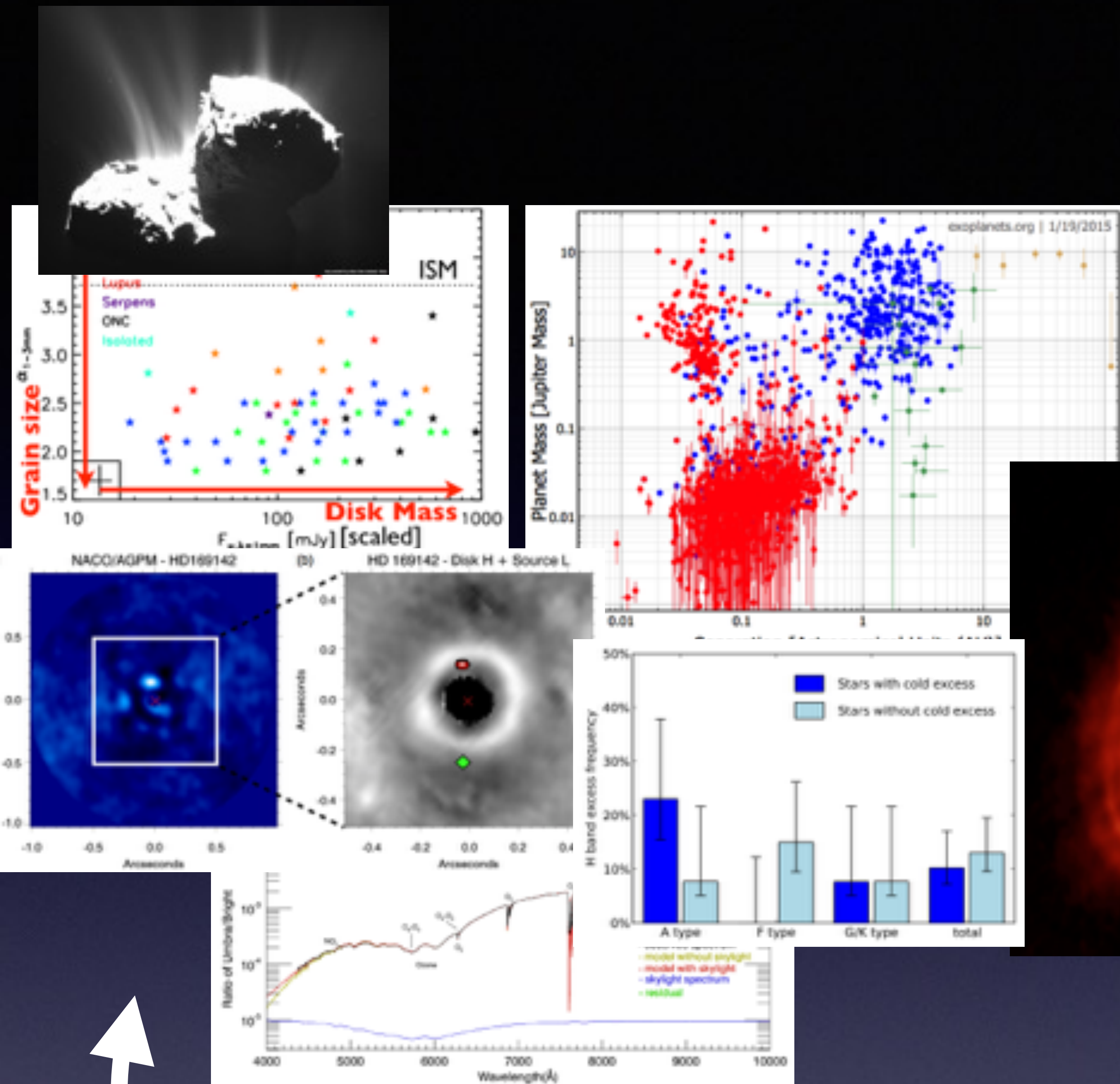



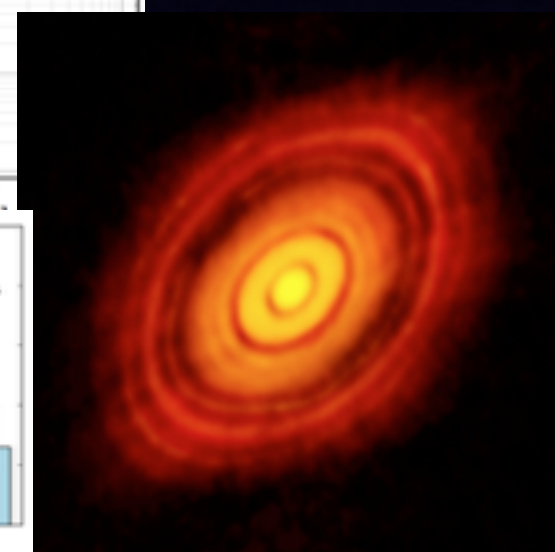
Disk

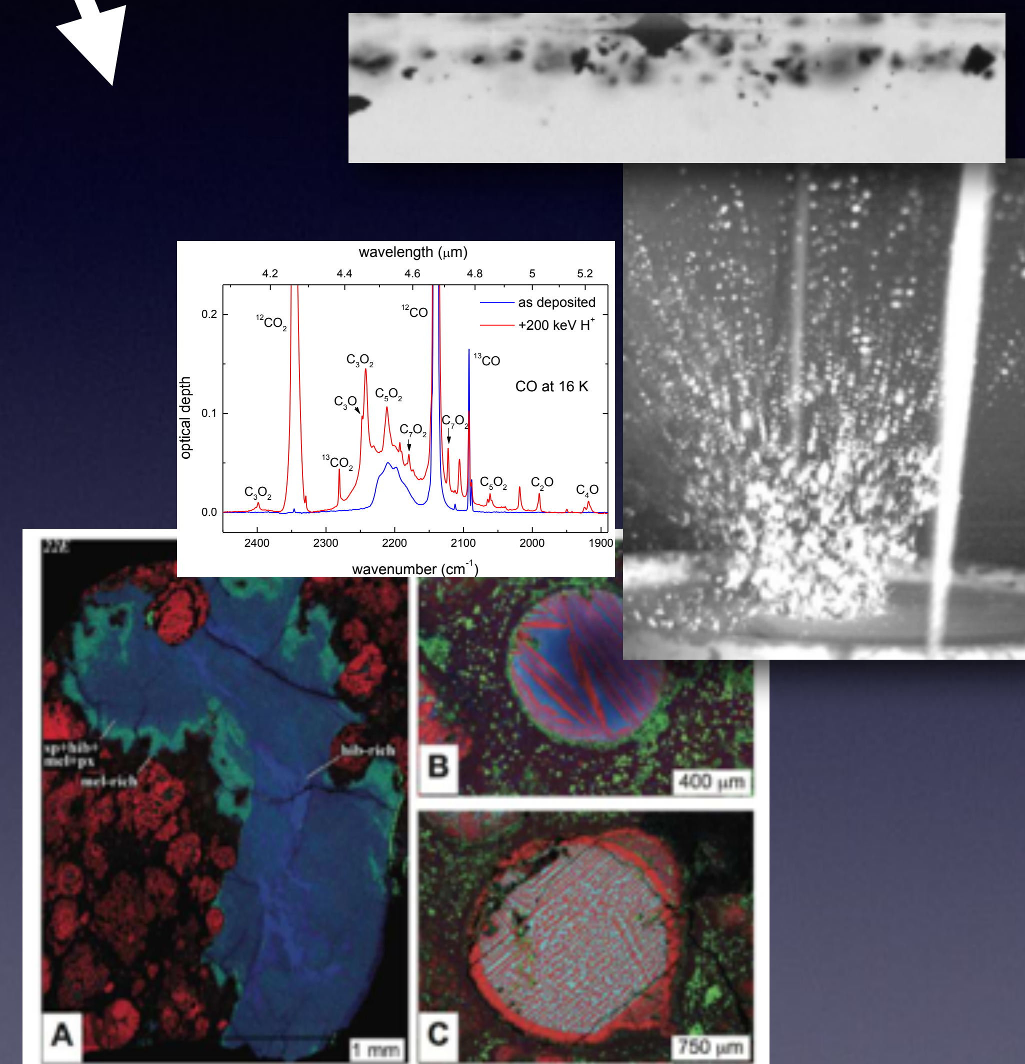




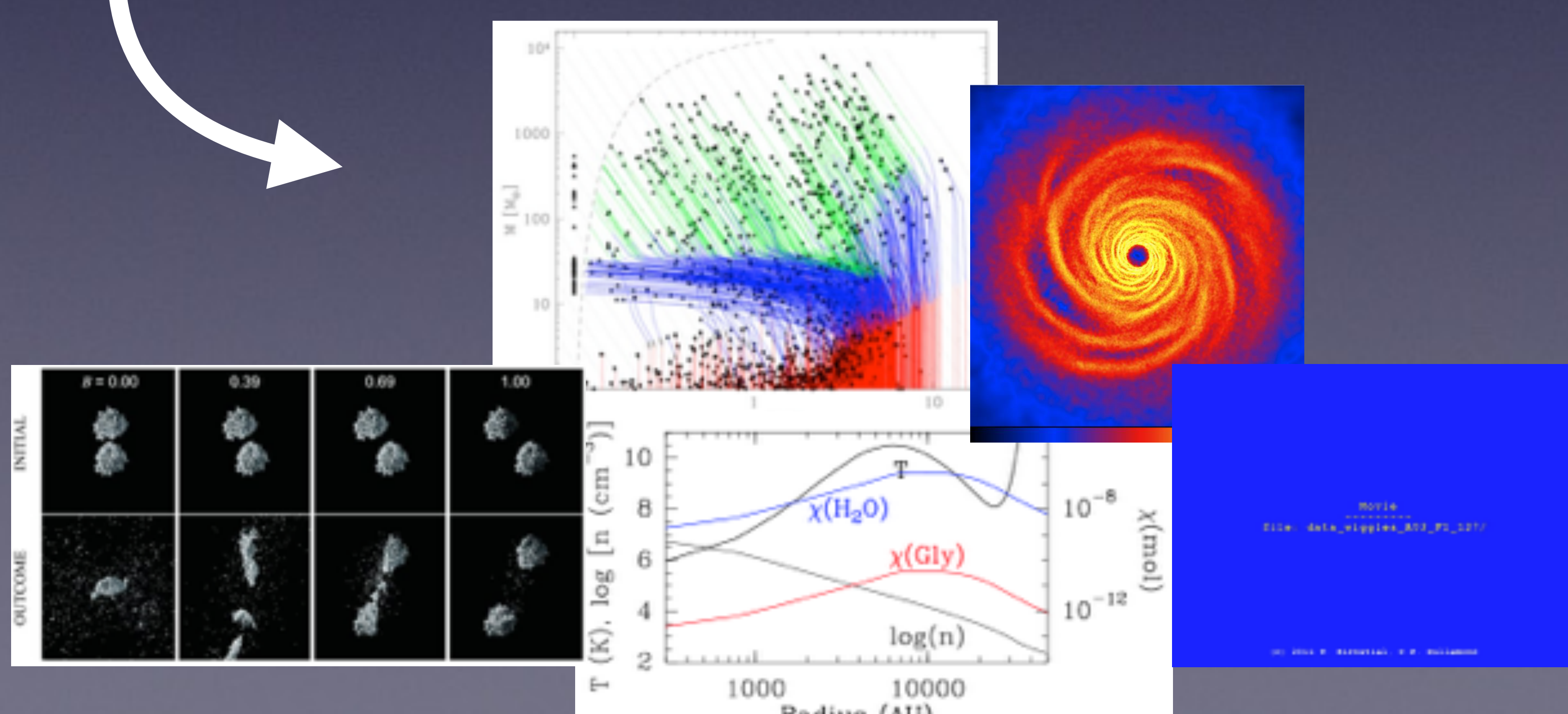
Debris Disk











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JEts & Disks @ INAF
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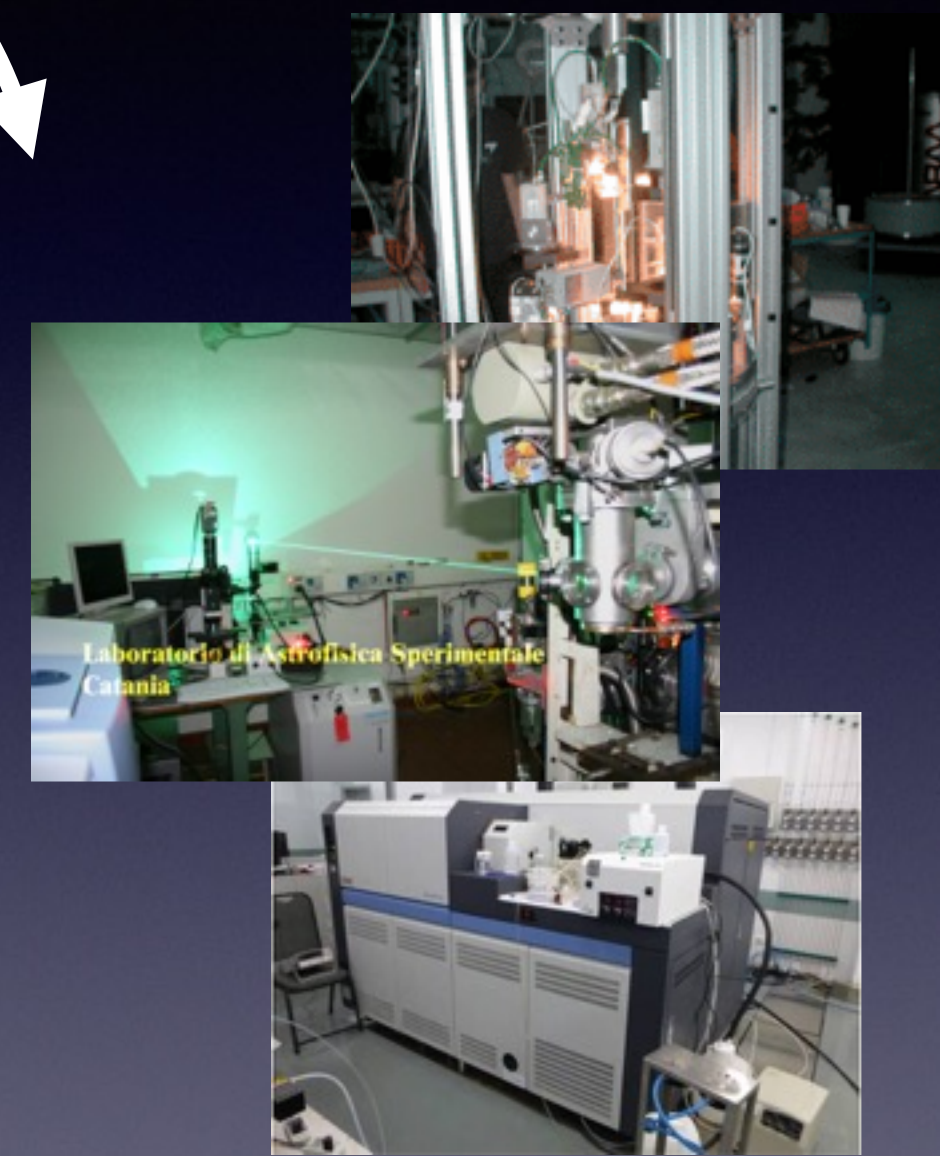
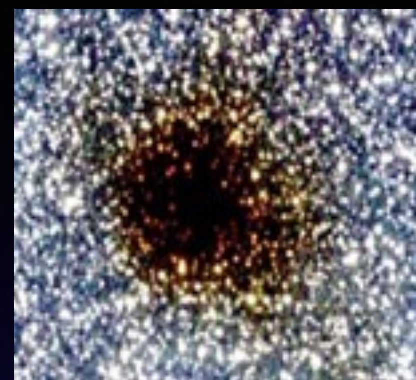
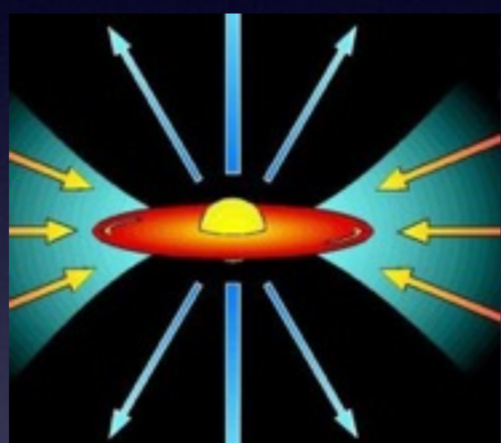
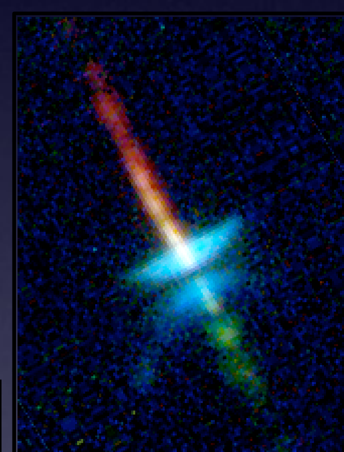


From Cores to Planetary Systems

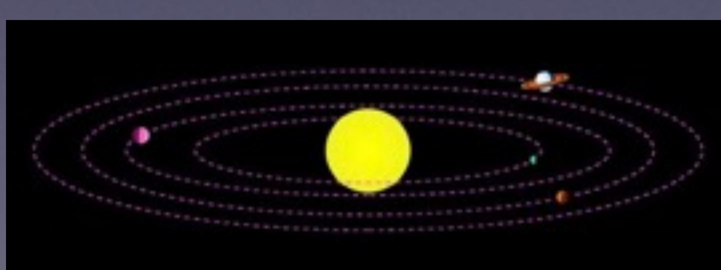


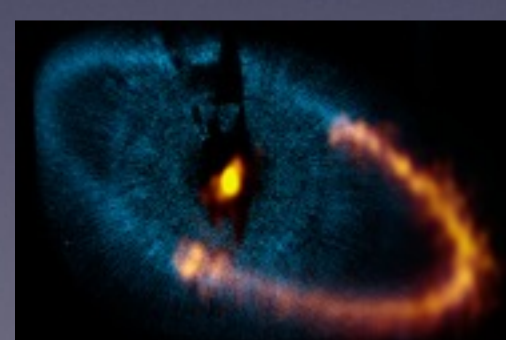
Core



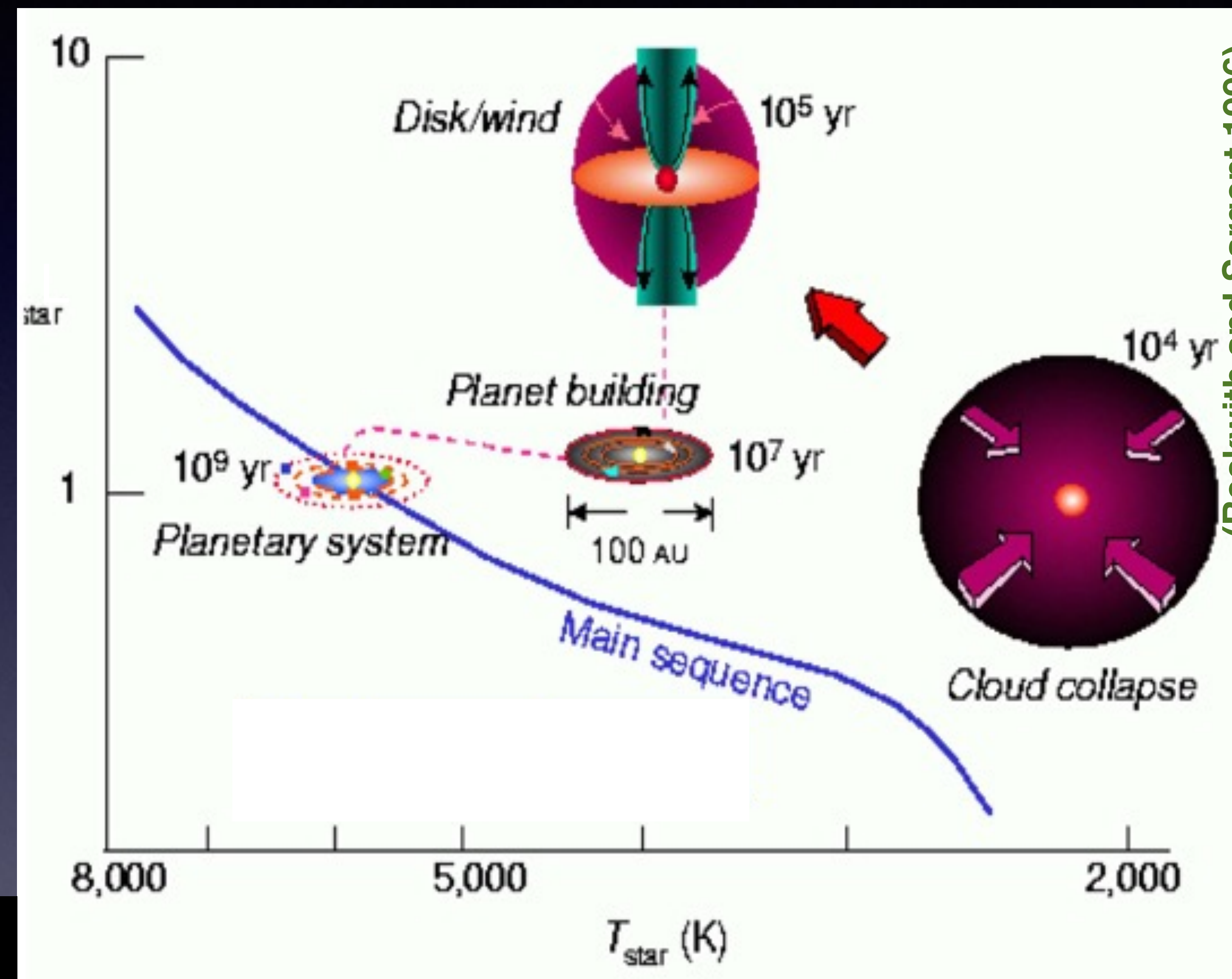


Disk

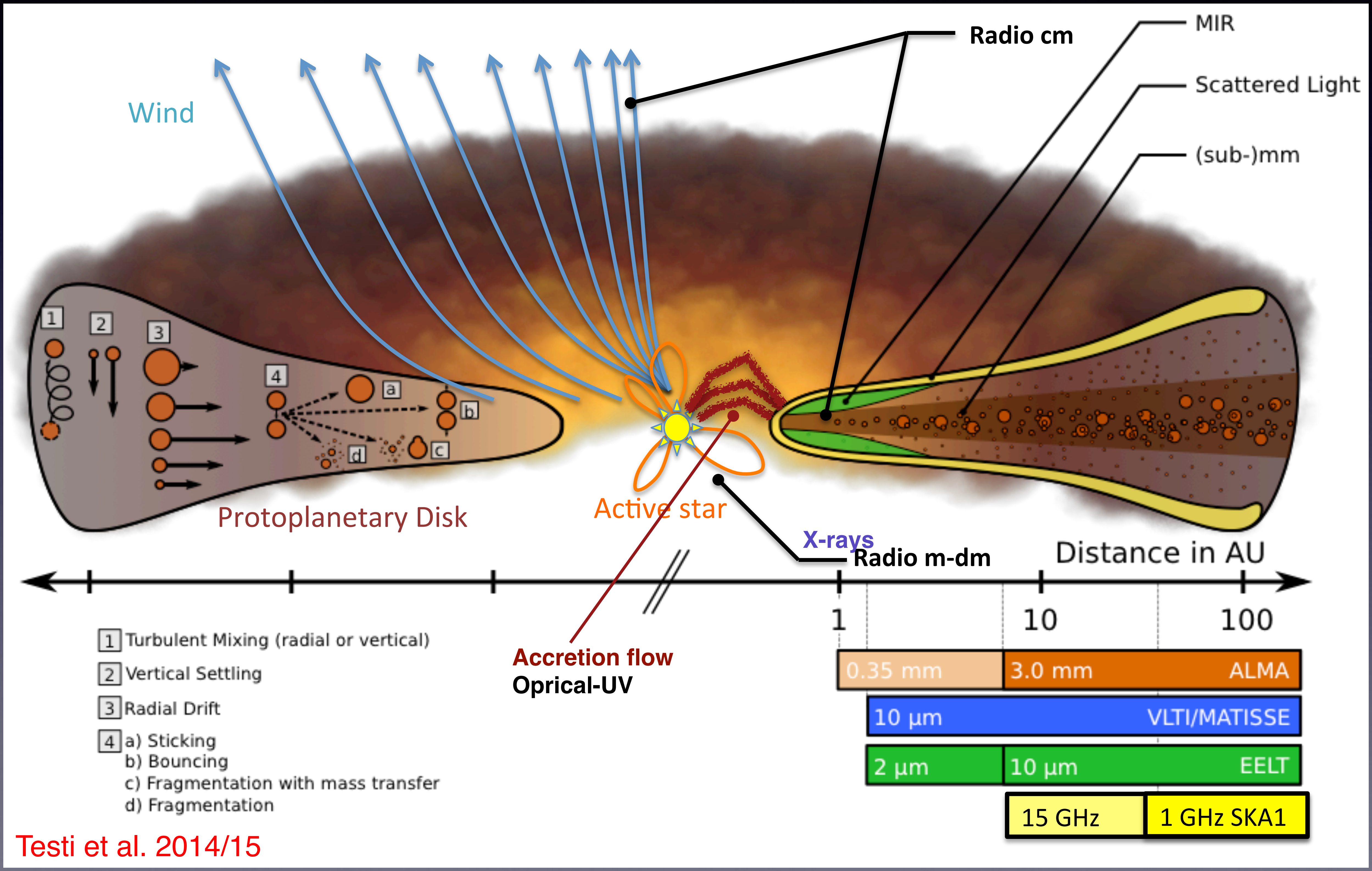




Debris Disk

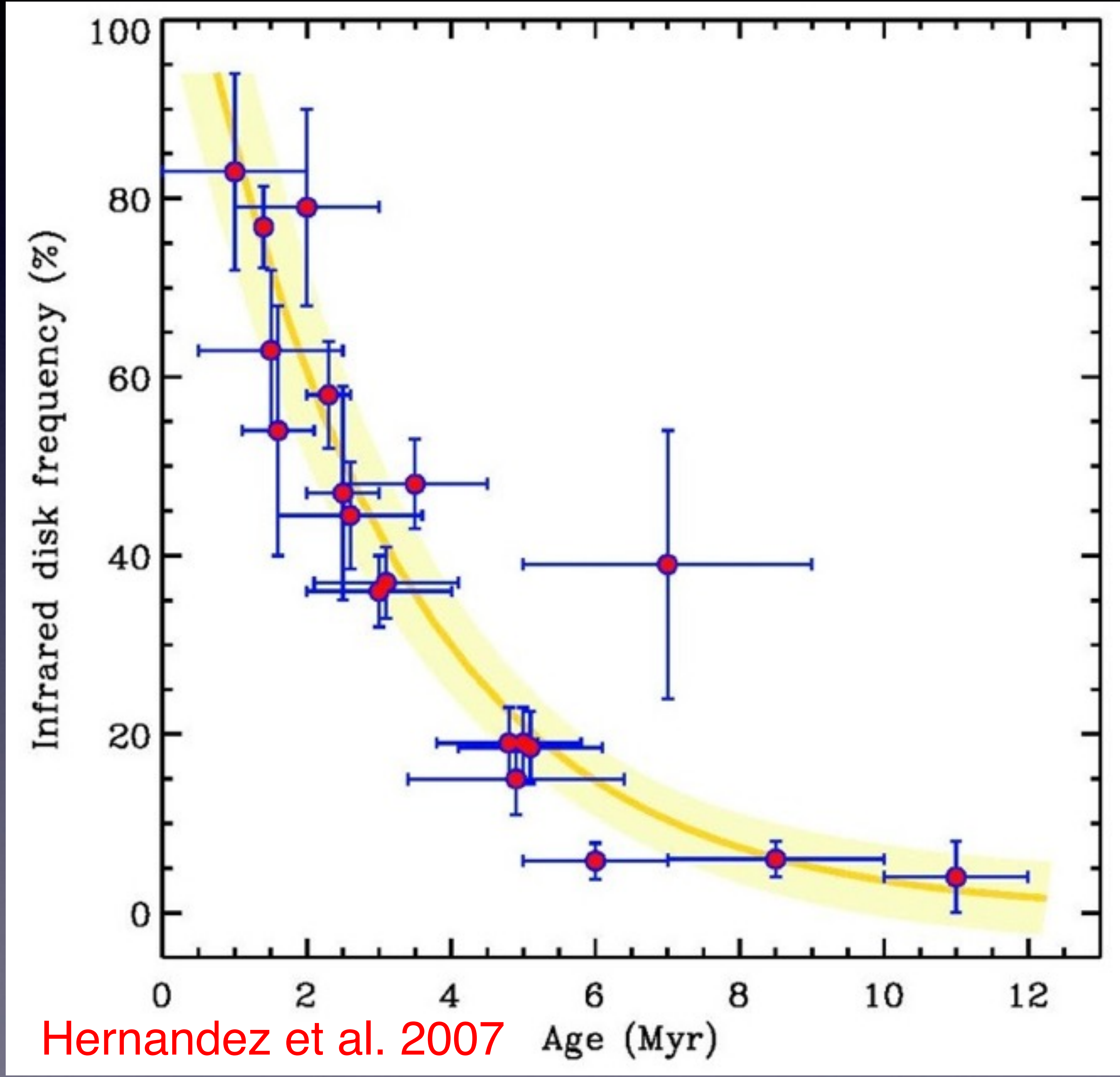


Disk-star system

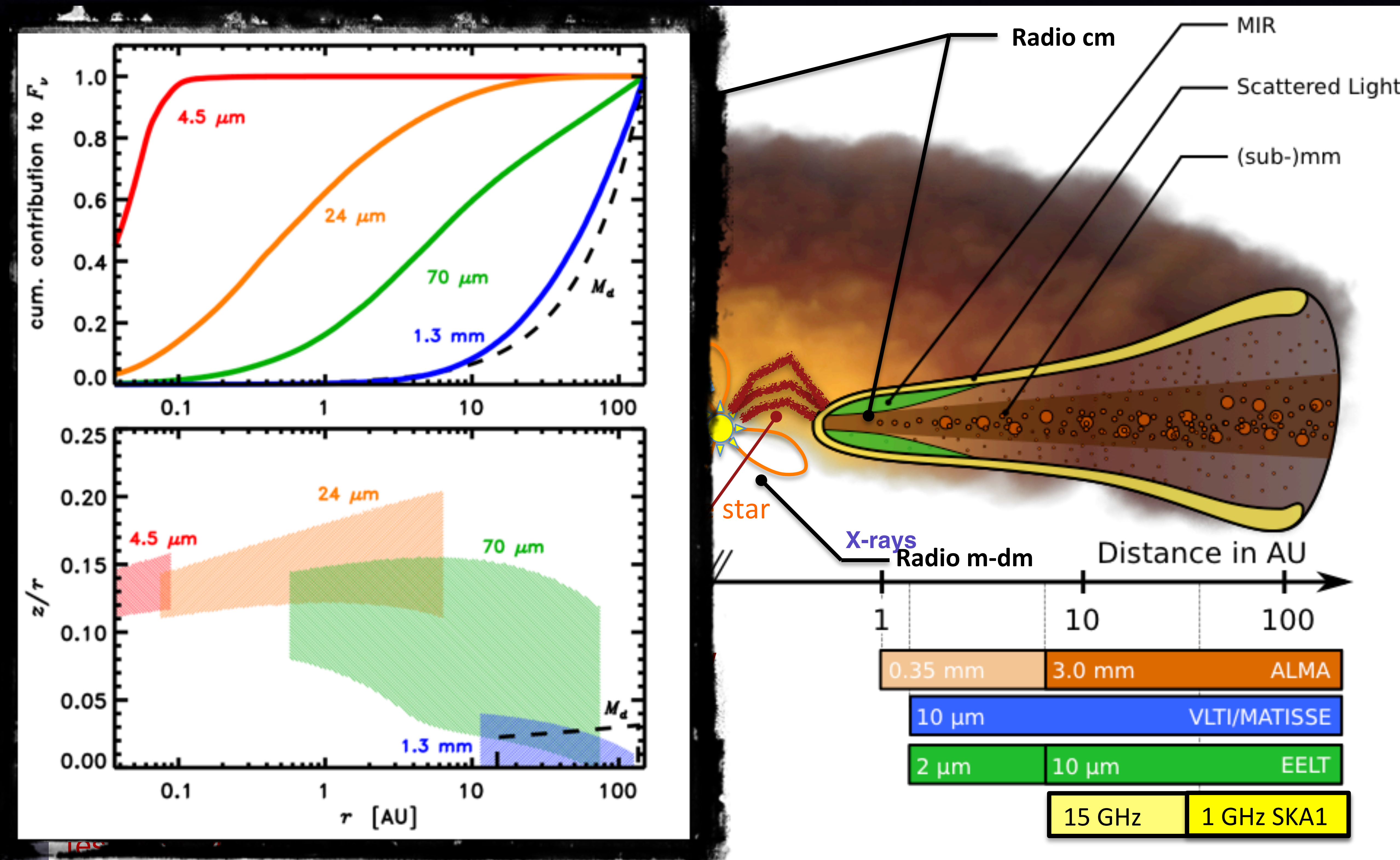


Timescales for inner disk

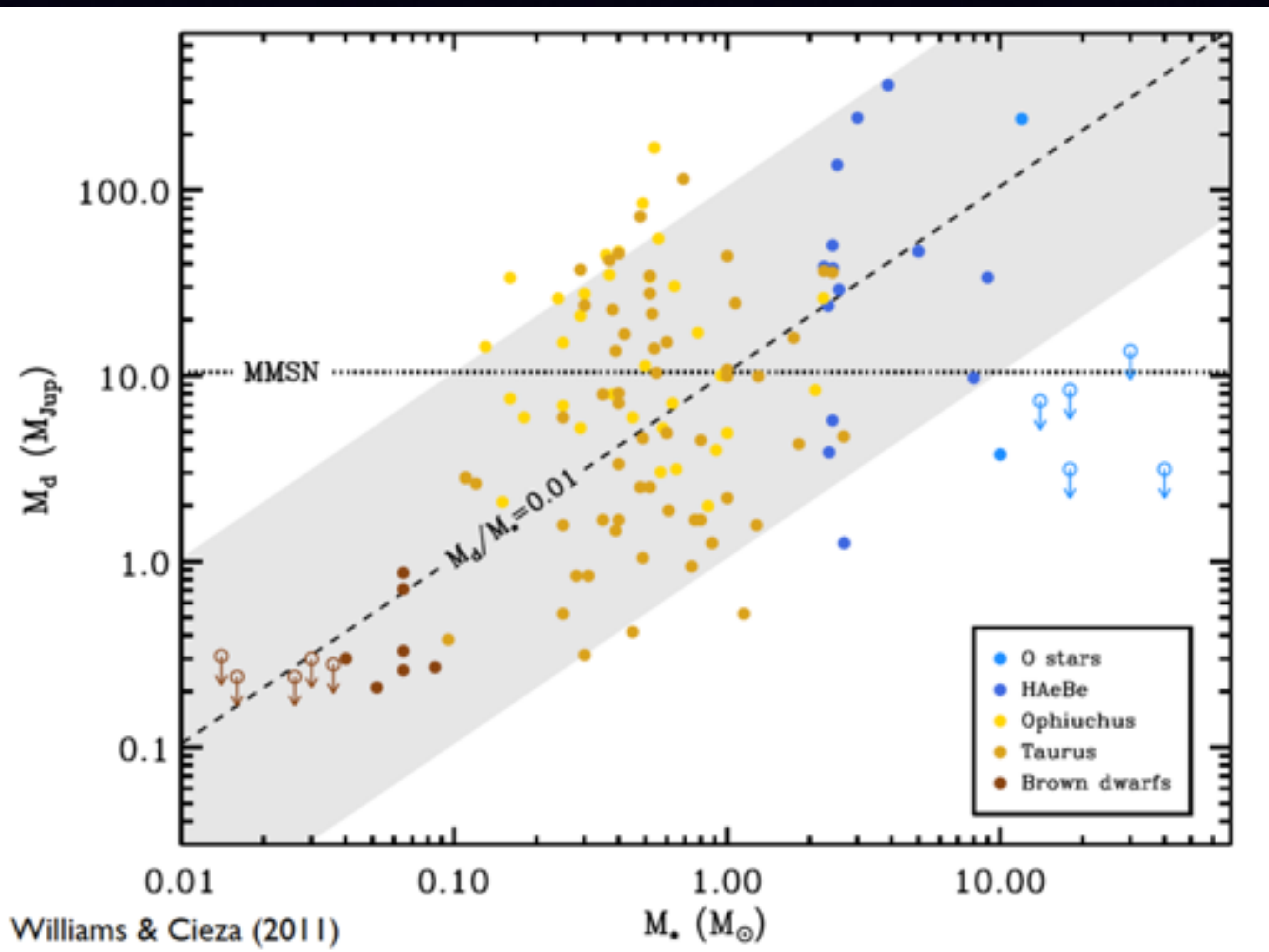
- Mesuring the fraction of objects that show disk-like infrared excess
- Uncertainties:
  - ages (computed from pms-tracks
  - tracing only hot dust very close to the star
  - whole population is difficult to probe

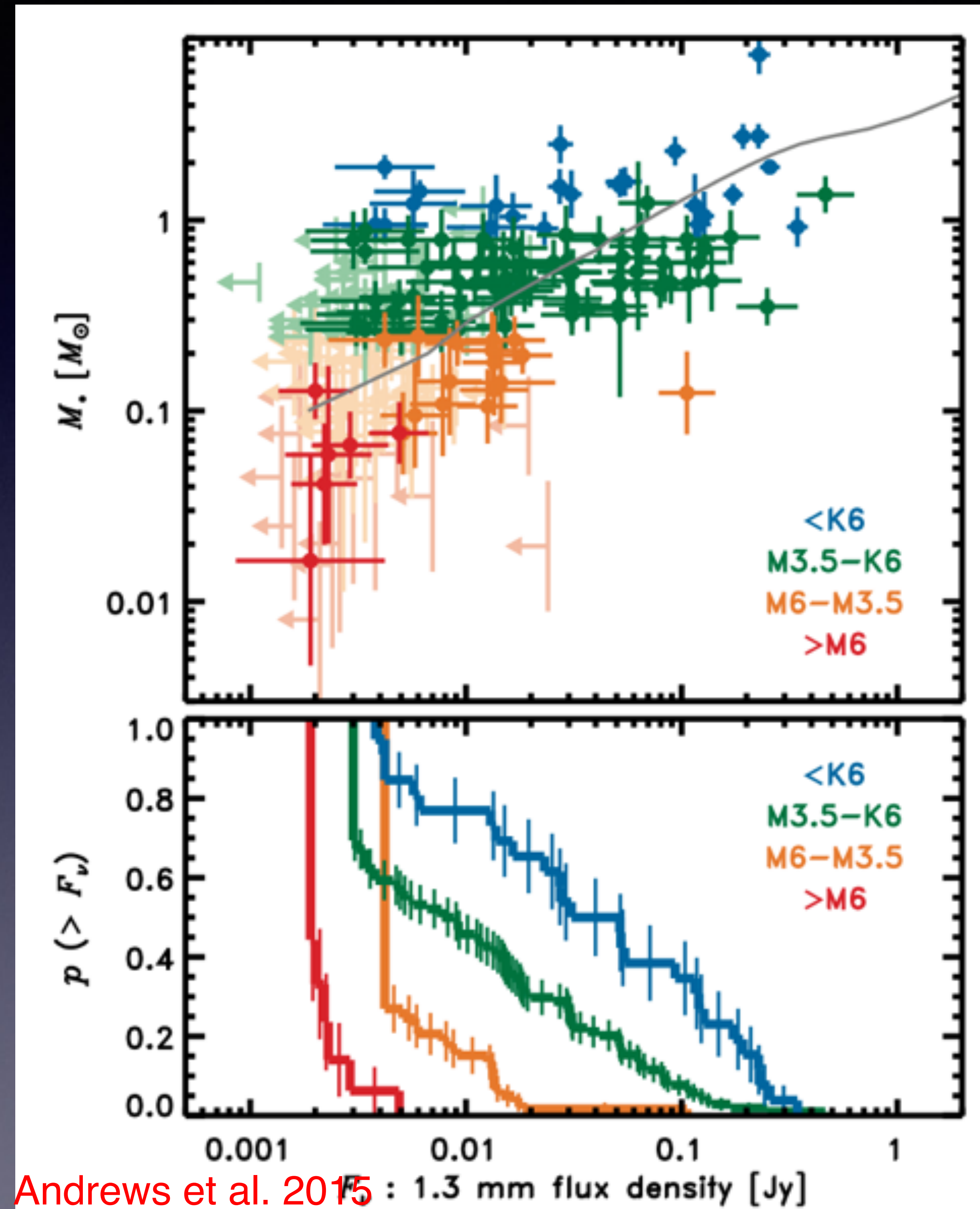


Disk-star system



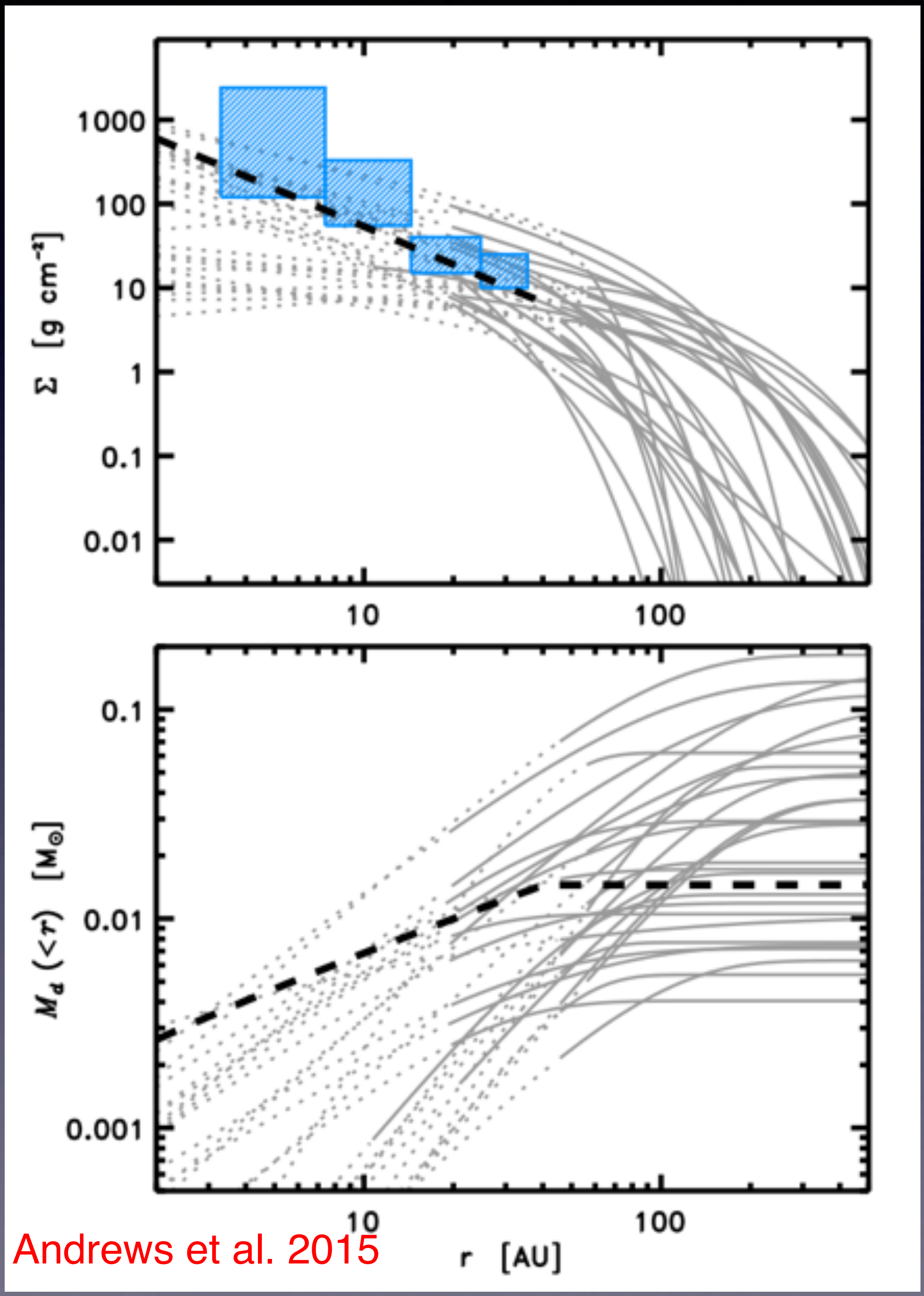
Disk masses

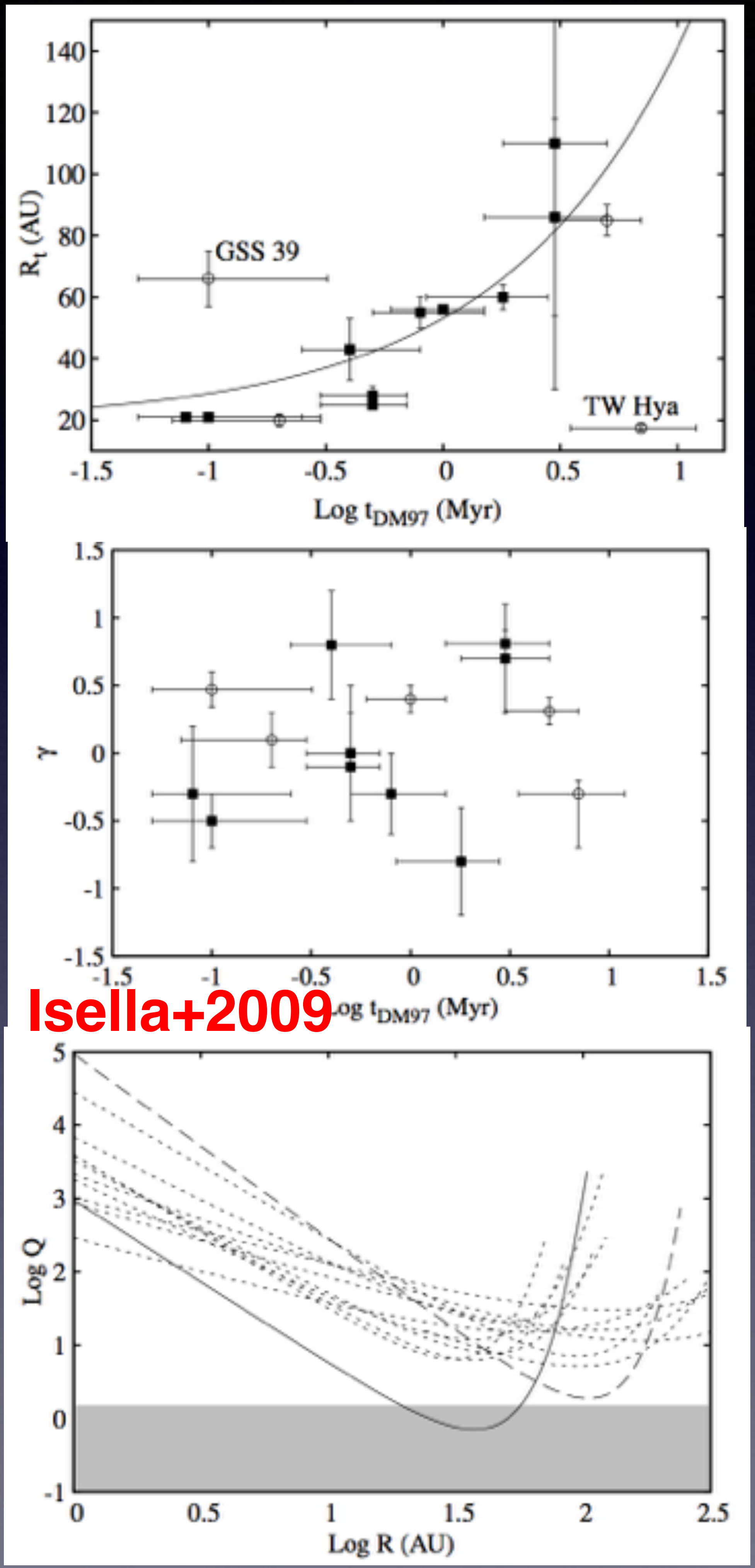




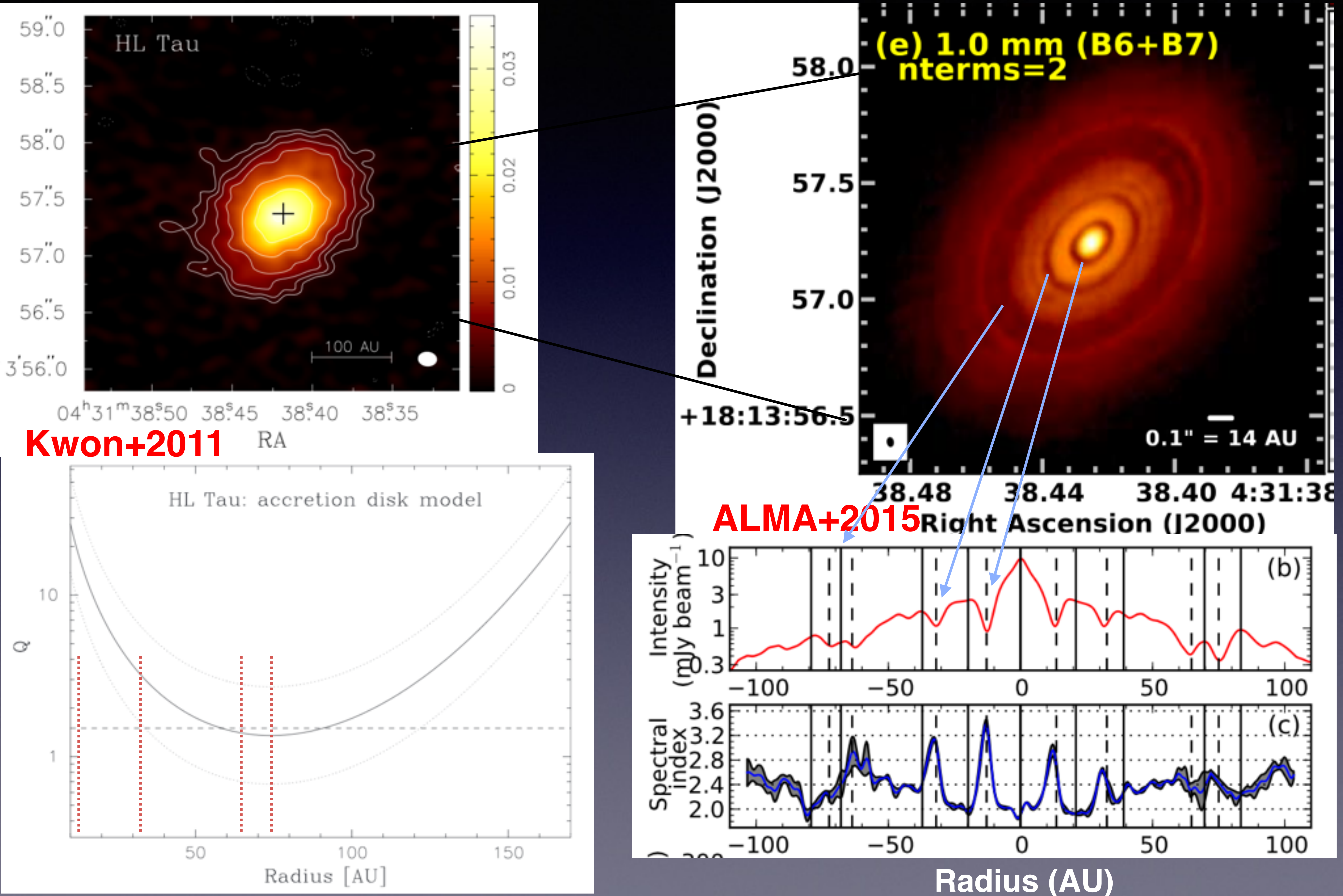
- $F_{1mm} \sim B_\nu(T)\, k_{1mm}\, M_d$

Mass distribution

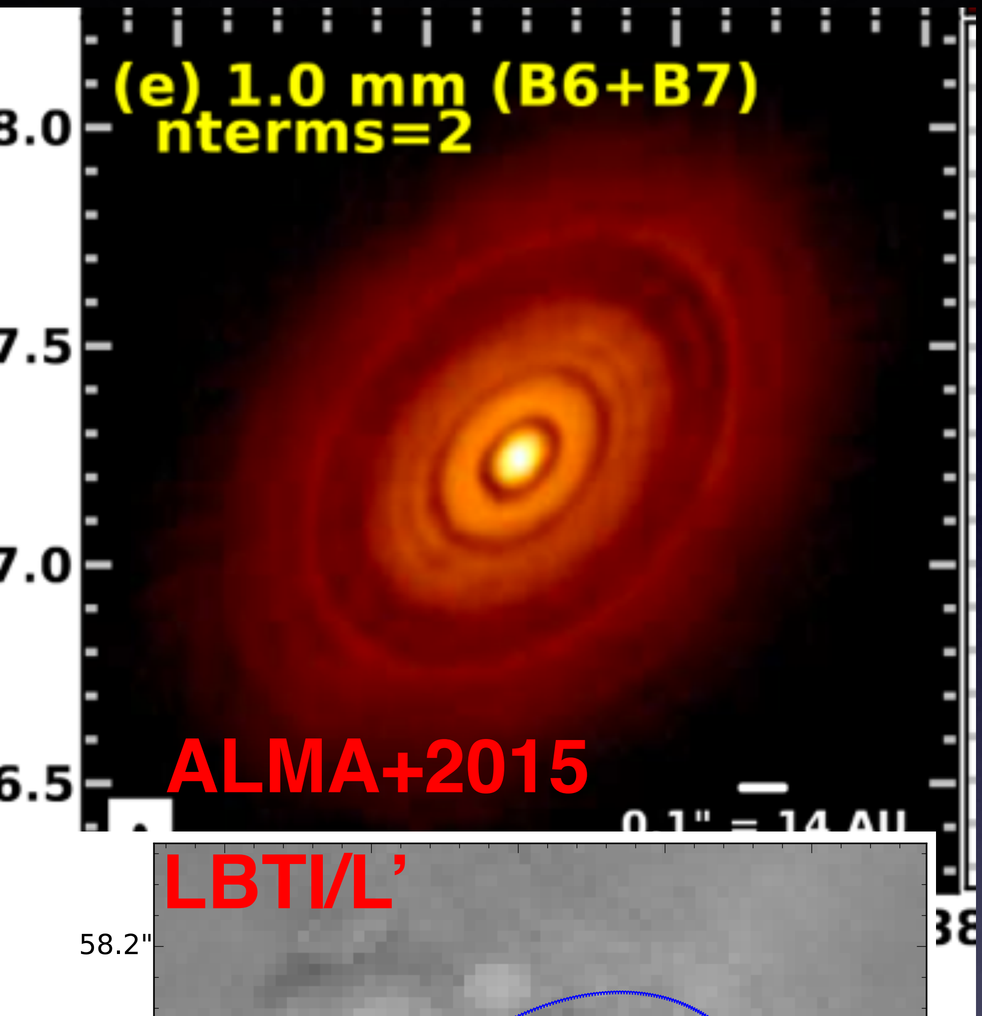


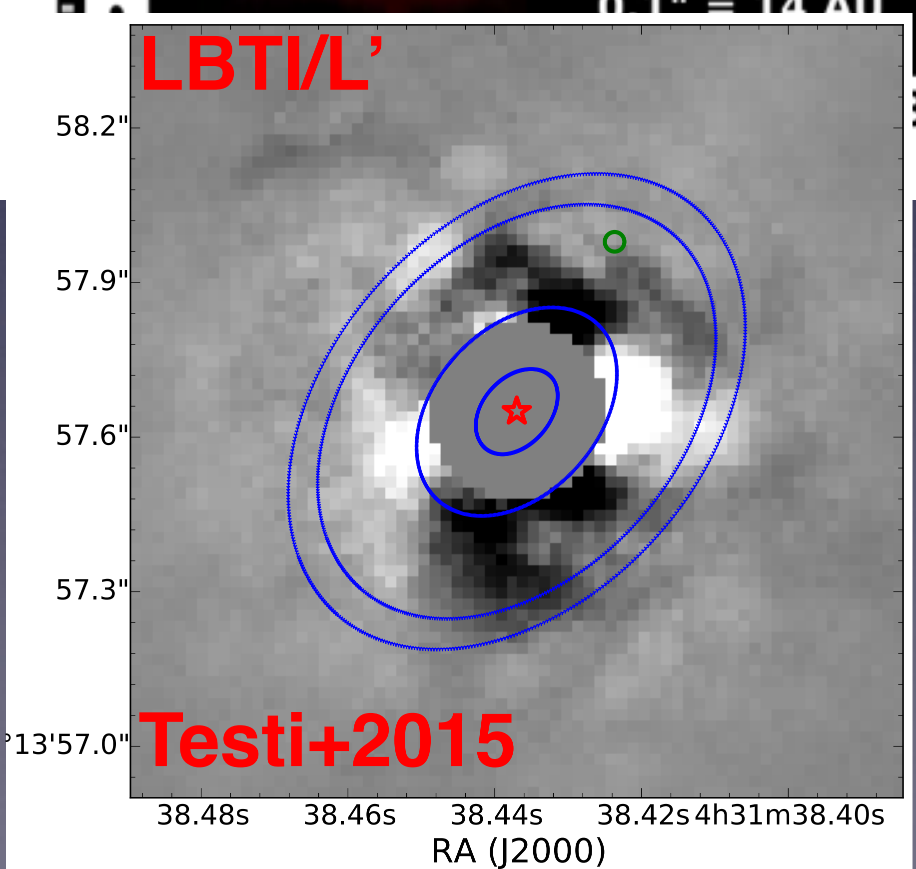


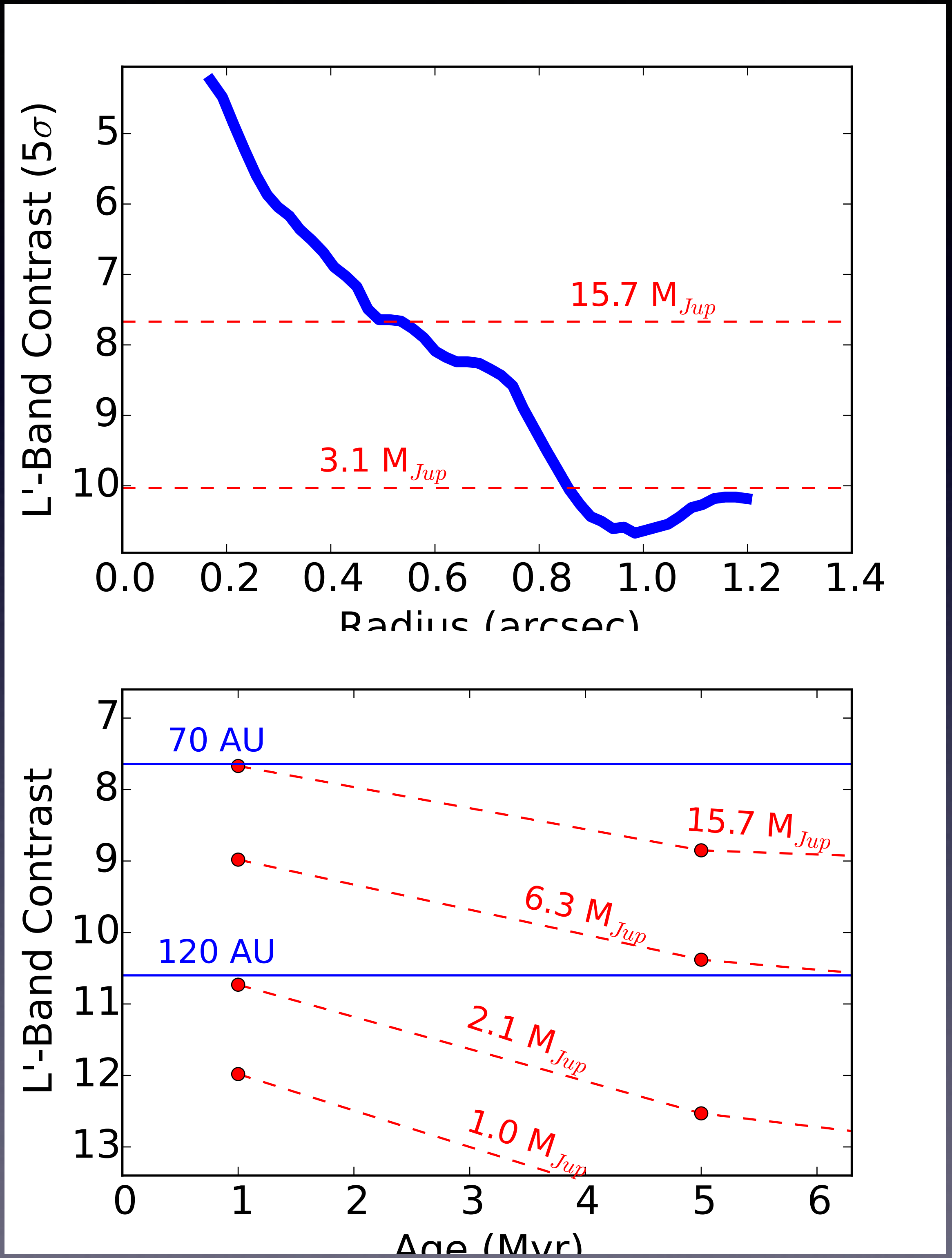
The ALMA Revolution



Are there planets formed(/ing)?



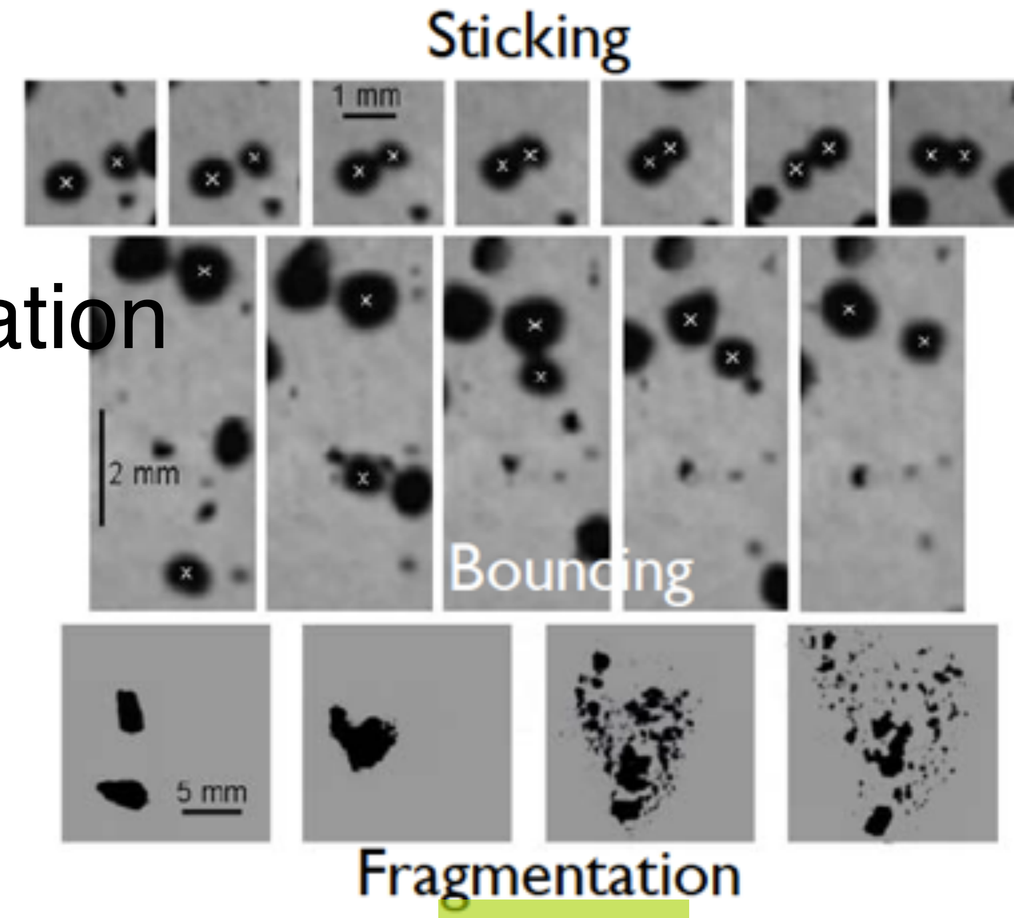


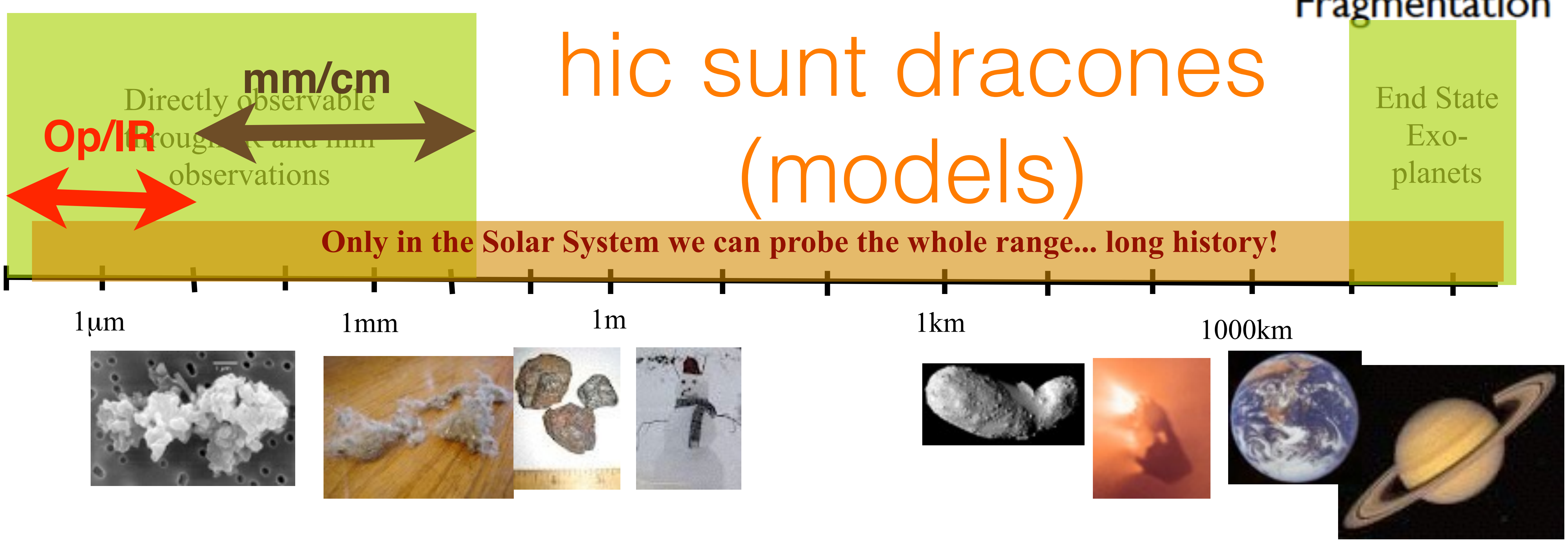


- No large planets in the system

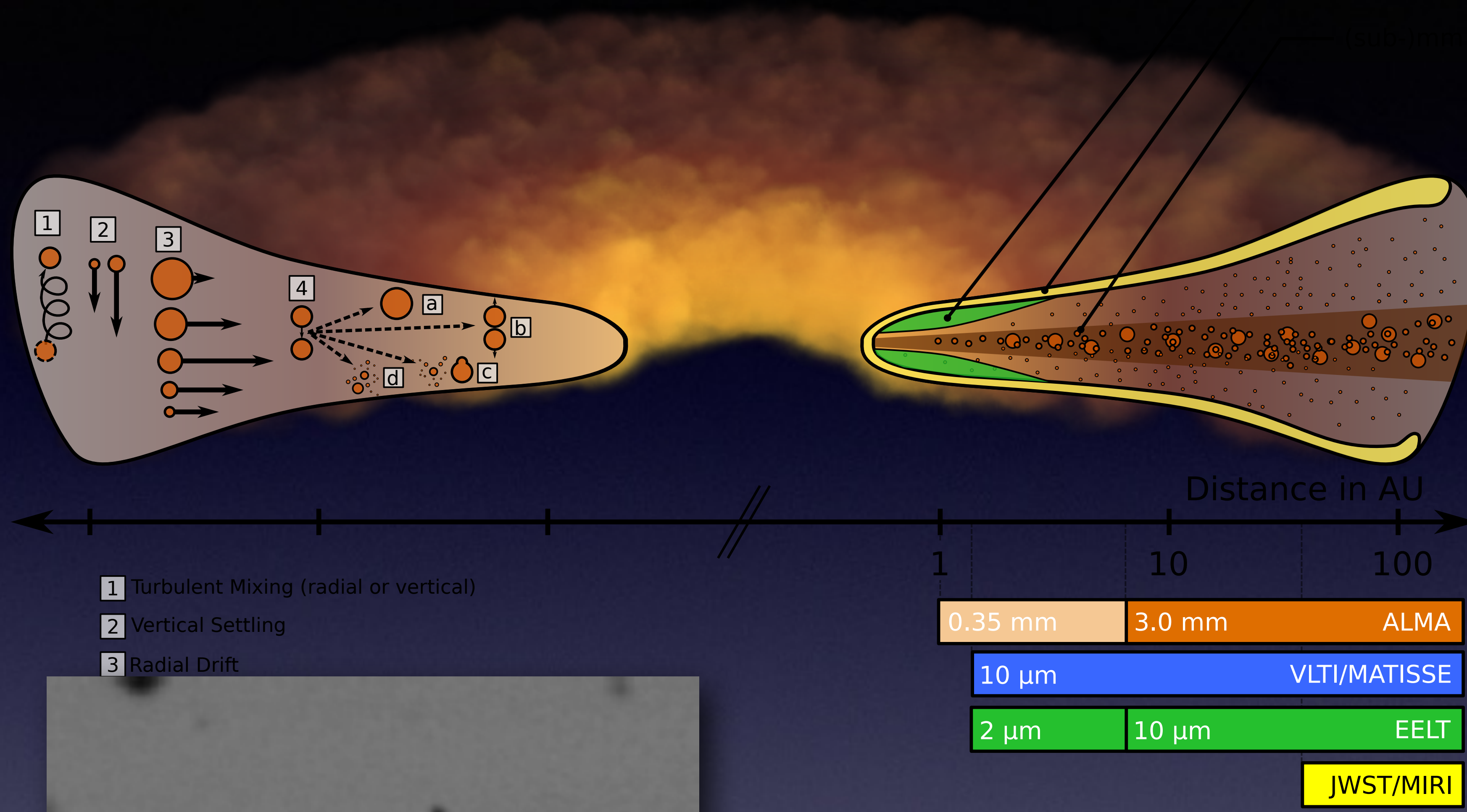
Grain Growth the Dawn of Planets

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

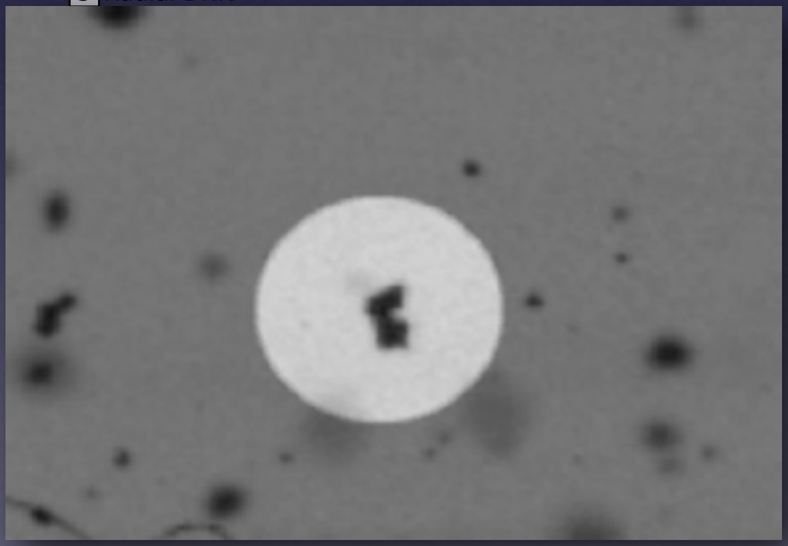


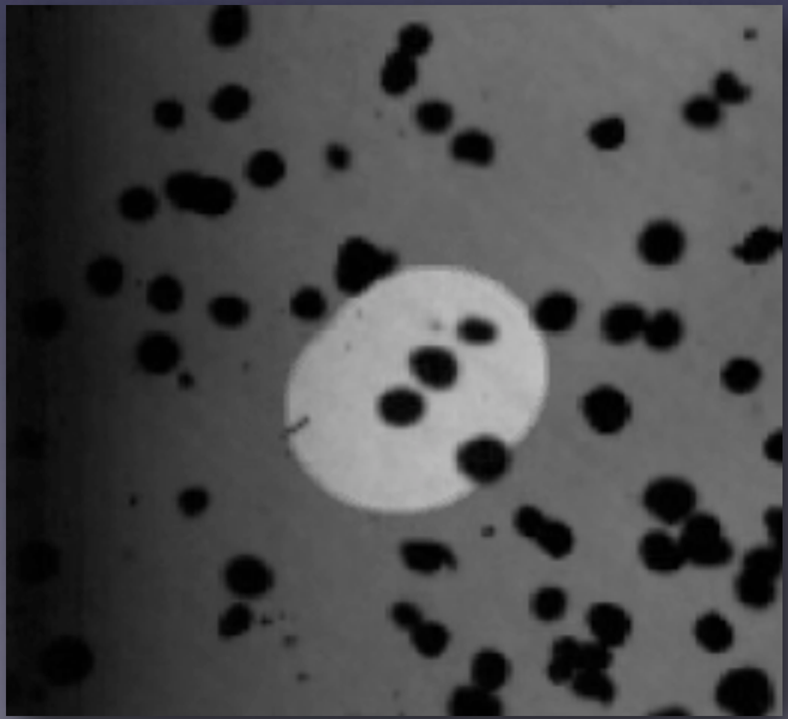


Grain Growth Processes

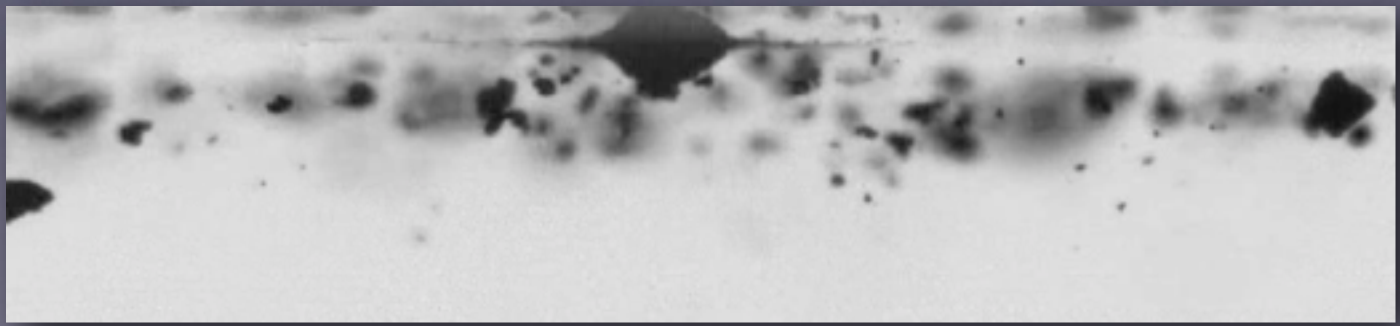


(Testi et al. 2014)

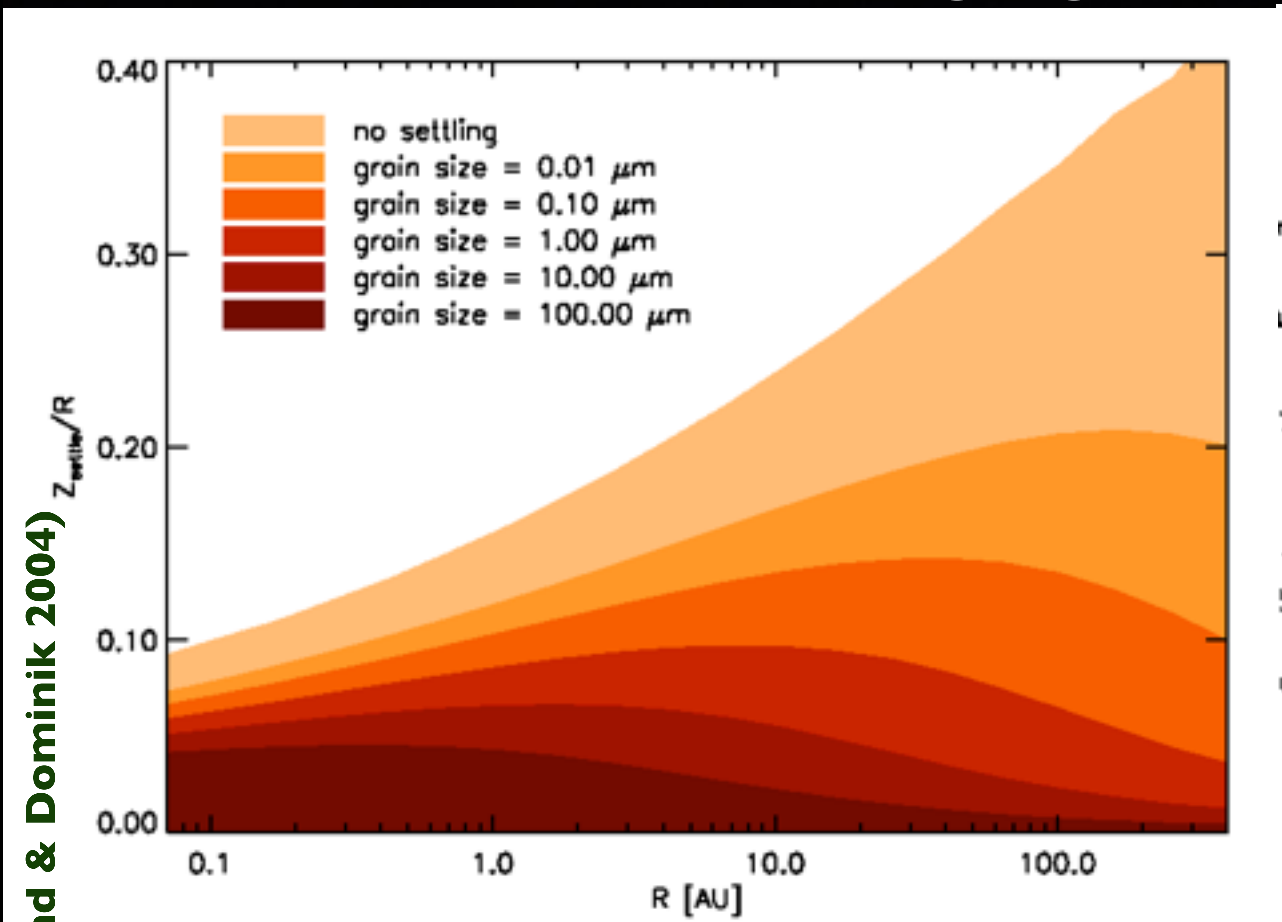


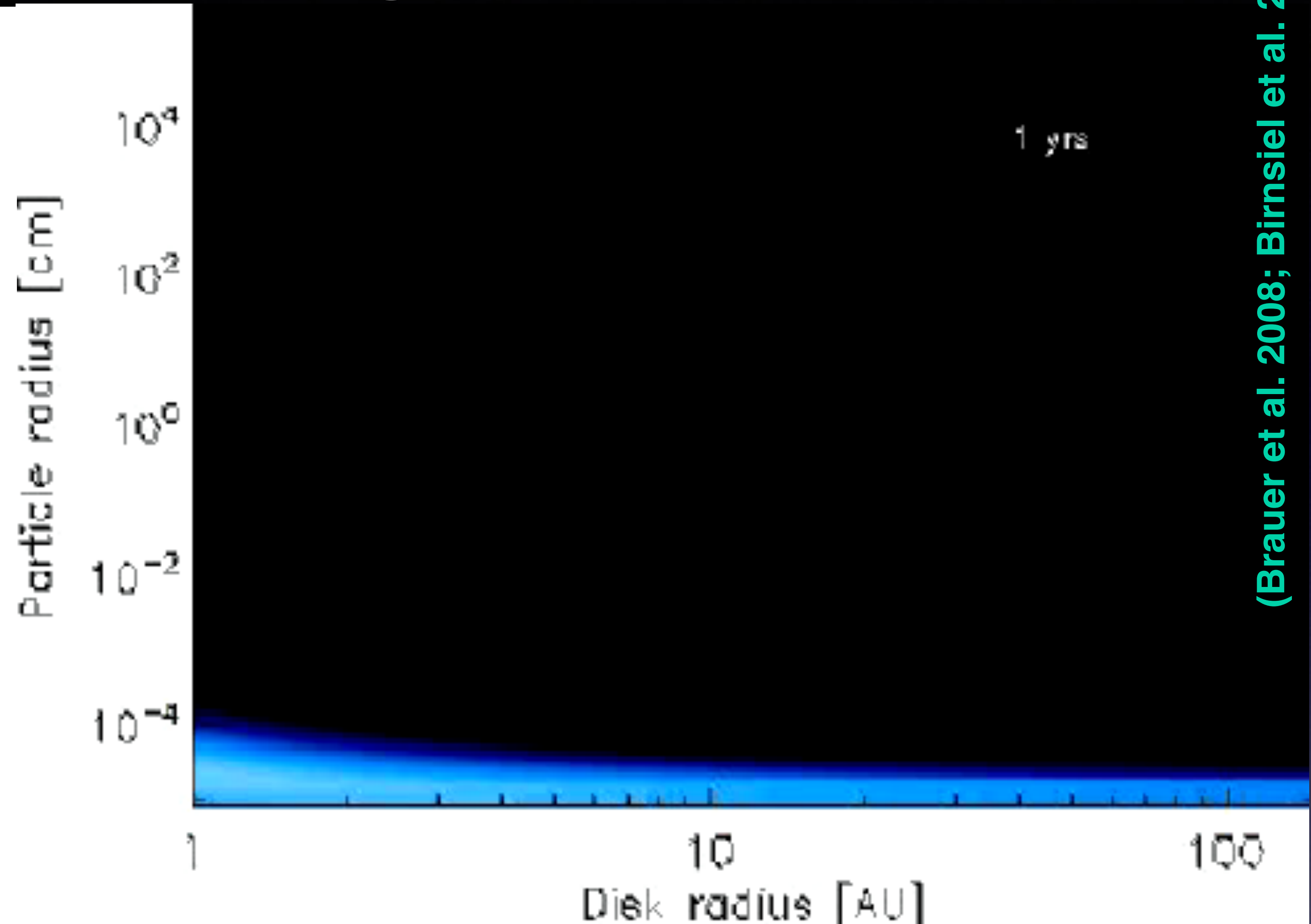


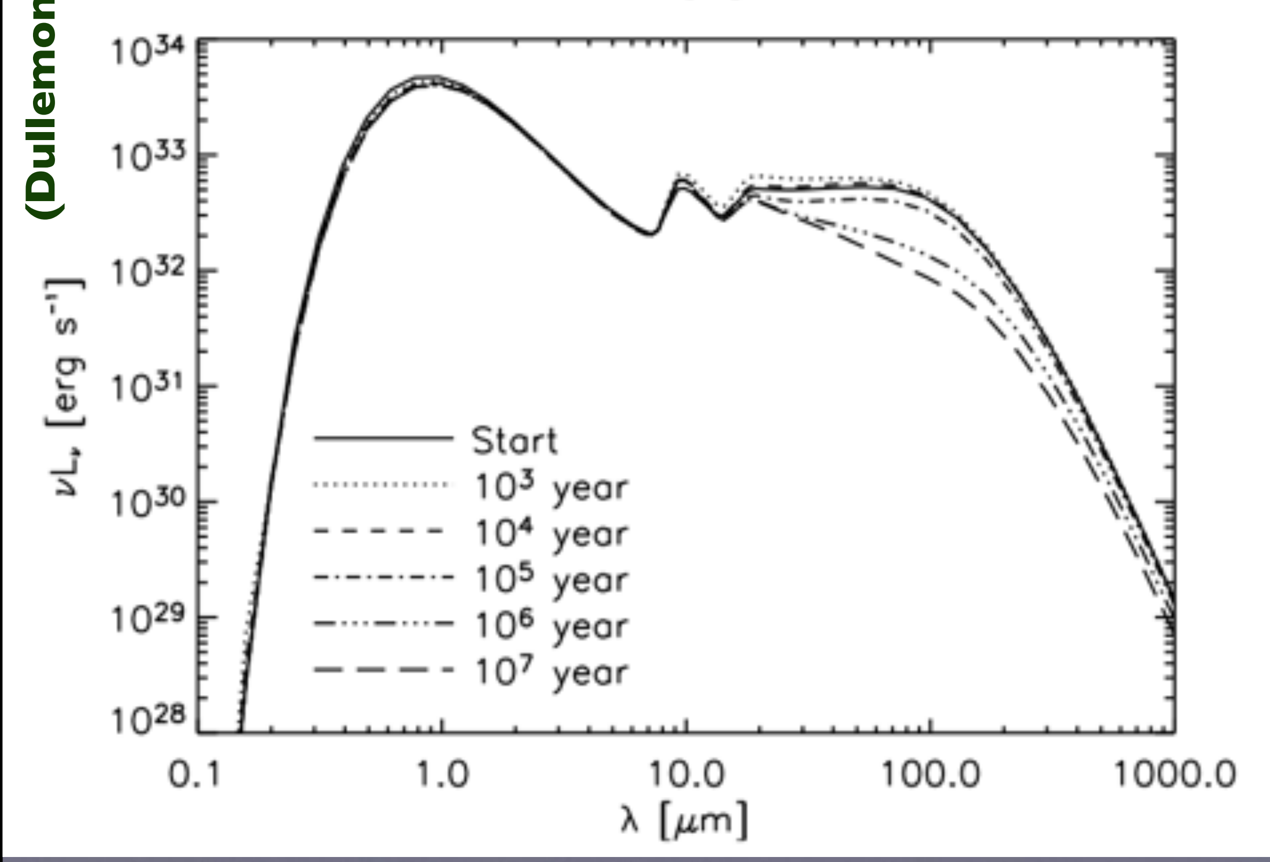
Movies from J. Blum and collaborators:
Weidling et al. 2012
Schraepler et a. 2012
Guettler et al. 2010

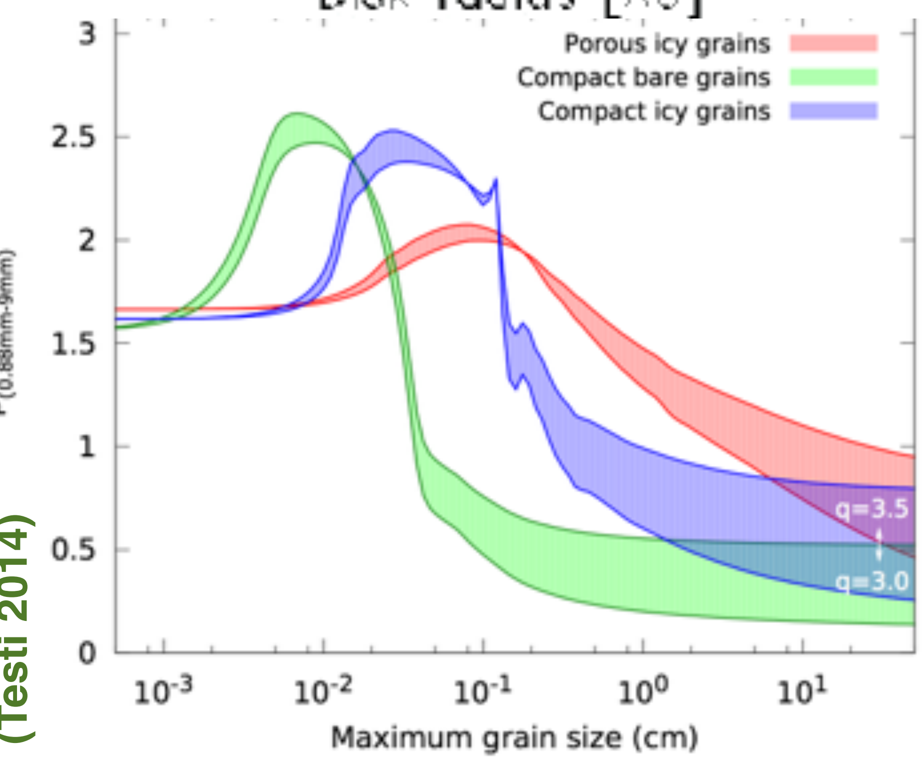


Settling/growth signatures









(Dullemond & Dominik 2004)

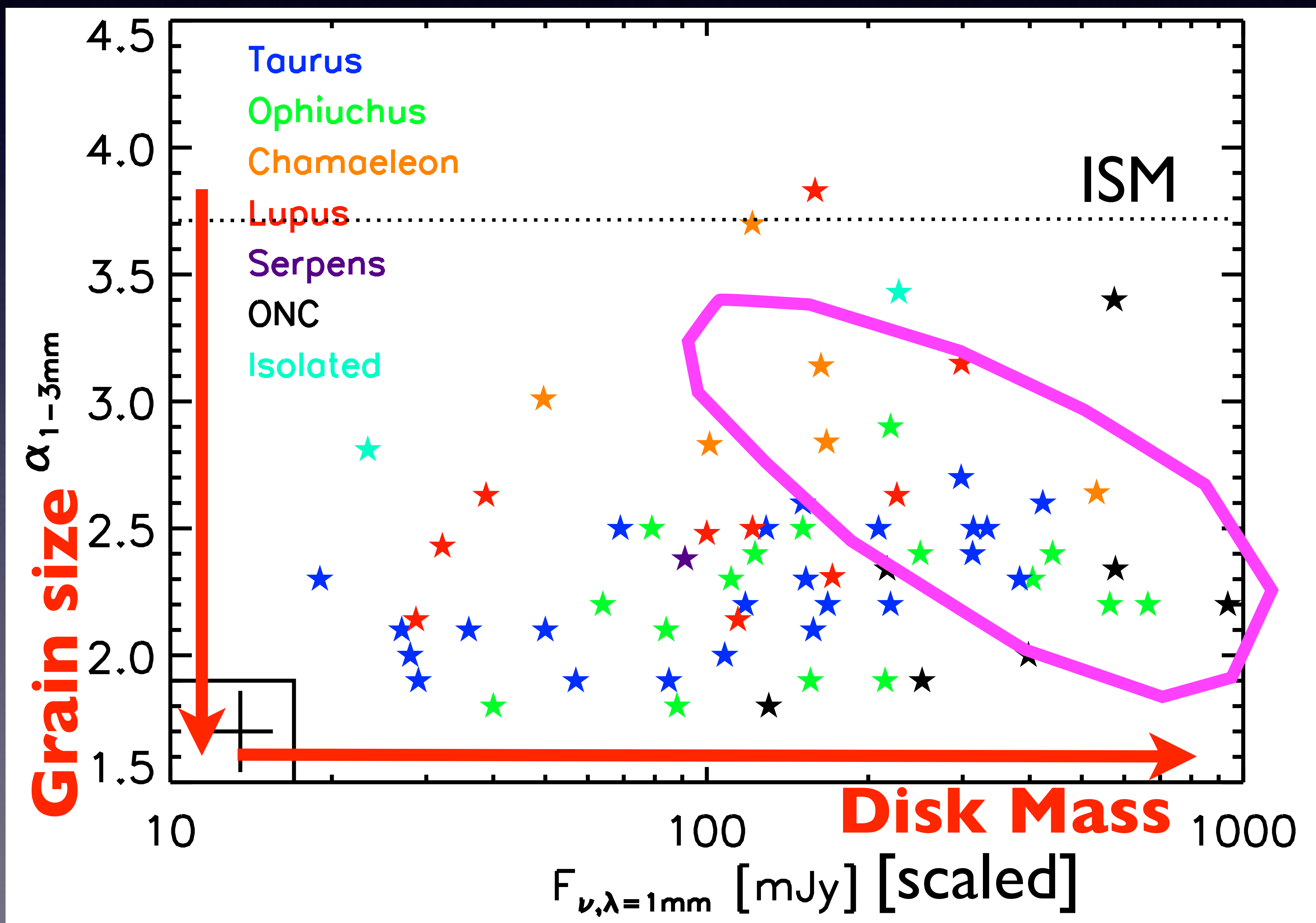
(Brauer et al. 2008; Birnsiel et al. 2009)

(Testi 2014)

Grain growth in disks

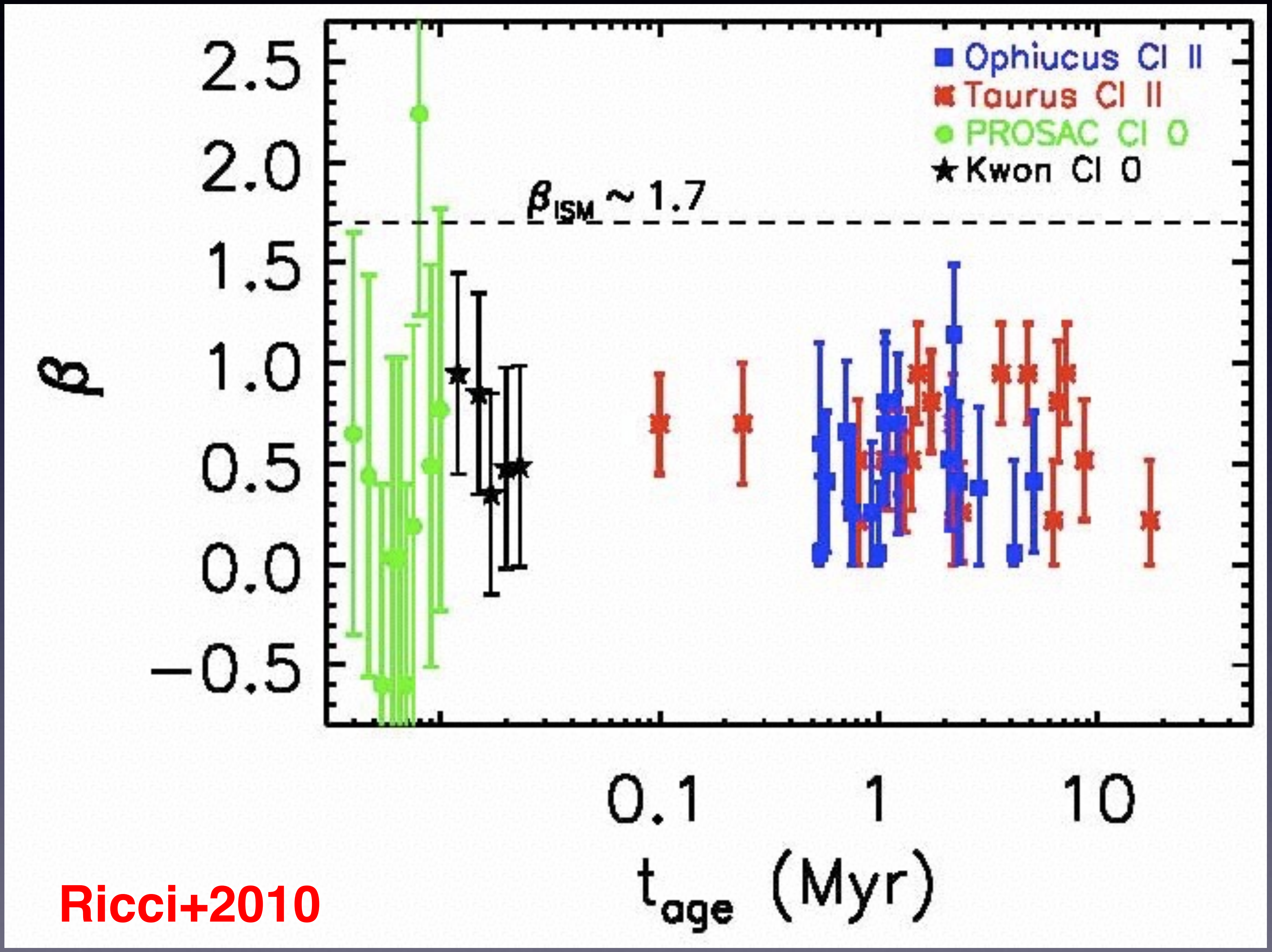
- Widespread evidence for grain growth
- K-M stars (no BDs), "single" class II YSOs

Models from:
Birnstiel et al. 2010



Data from:
Ricci et al. 2010a,b,c,
Lommen et al. 2007, 2009, 2010,
Ubach et al. 2012

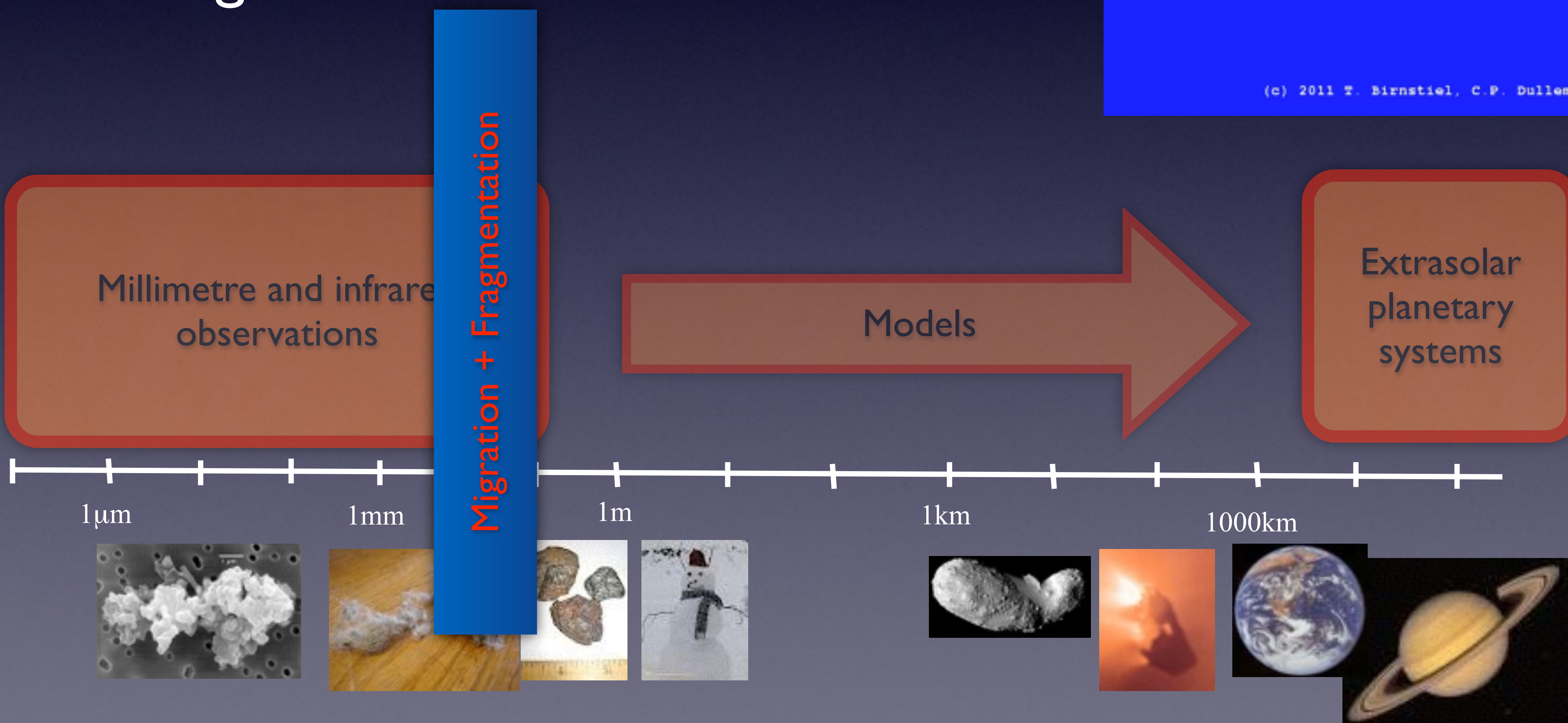
When is grain growth occurring?



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)



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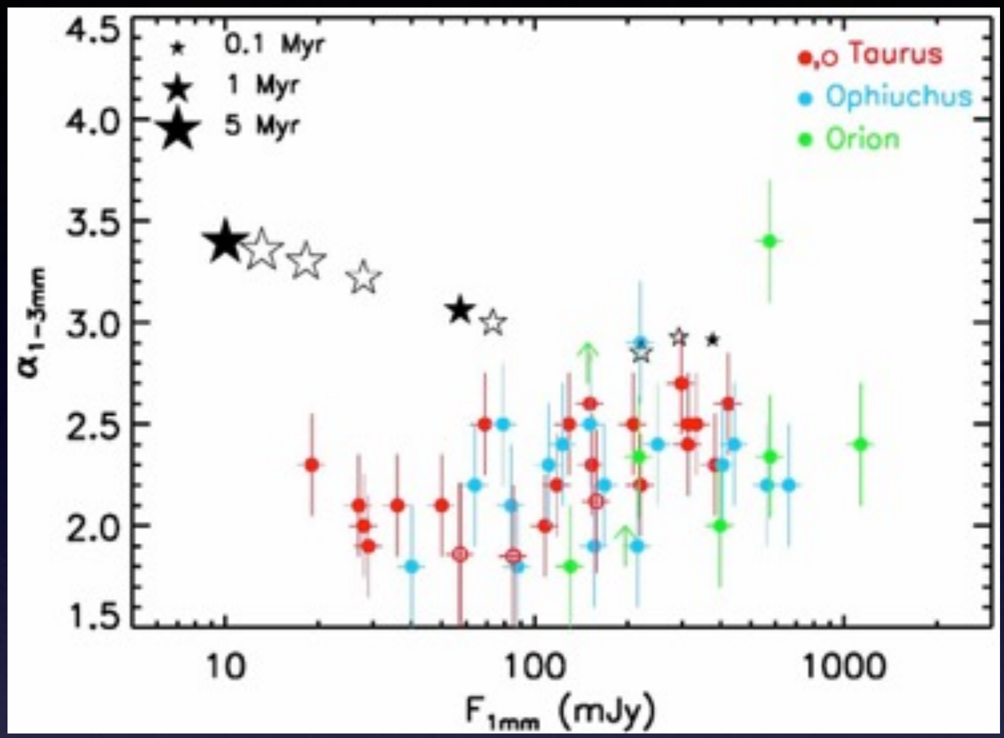
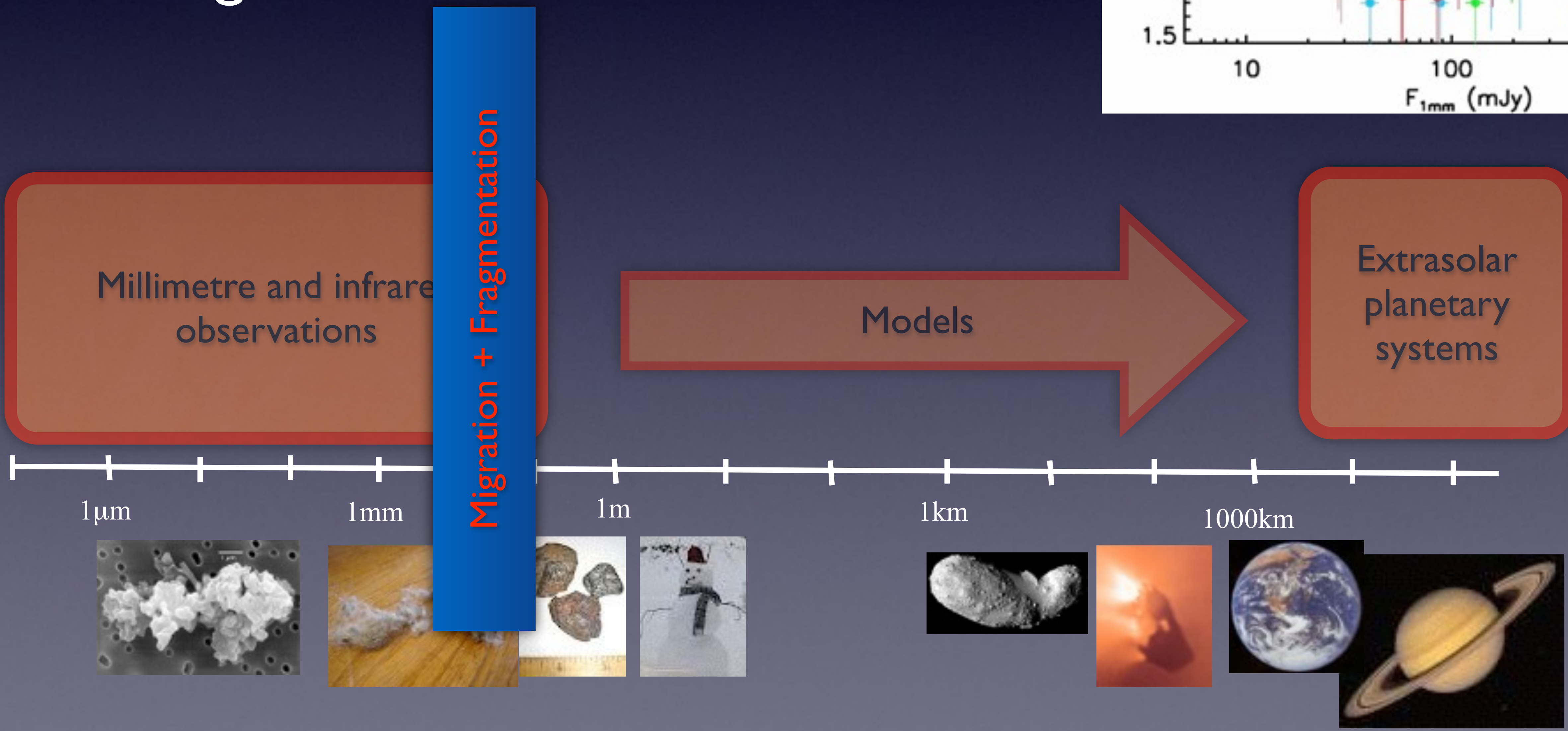
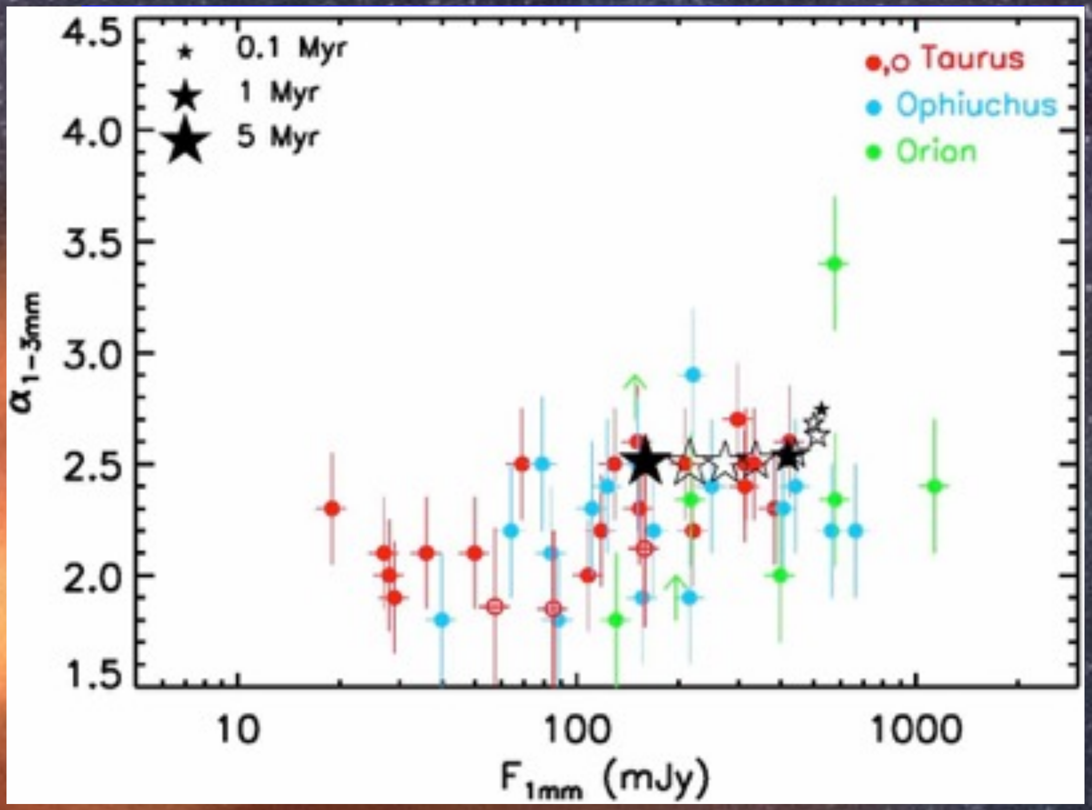


(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)



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)

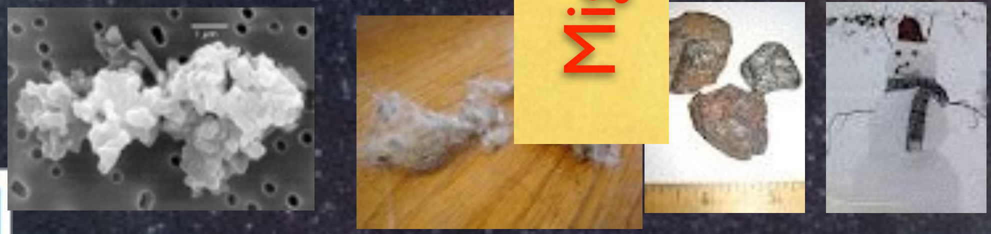
Millimetre and infra[red] observations

Migration + Fragmentation

Models

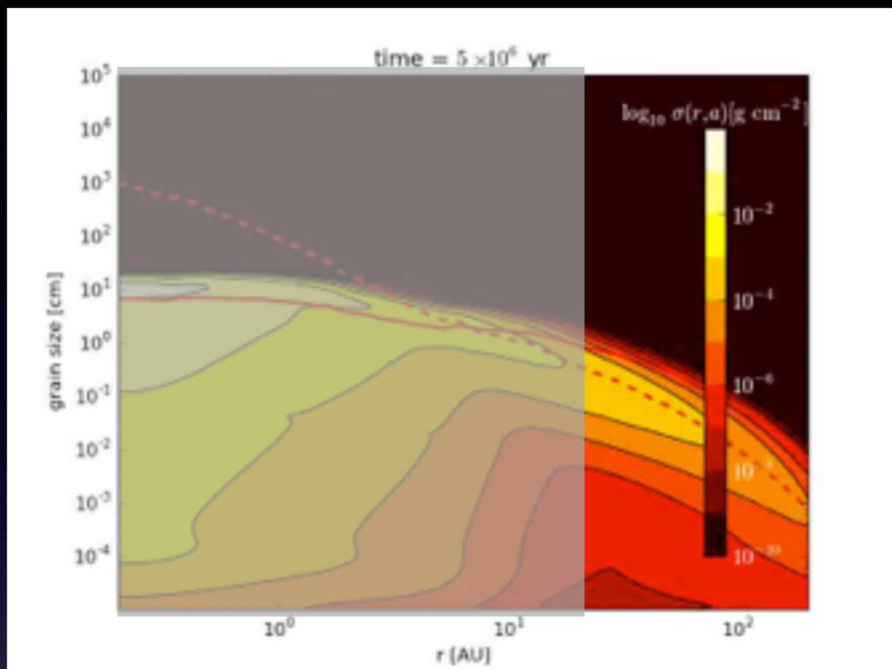
Extrasolar planetary systems

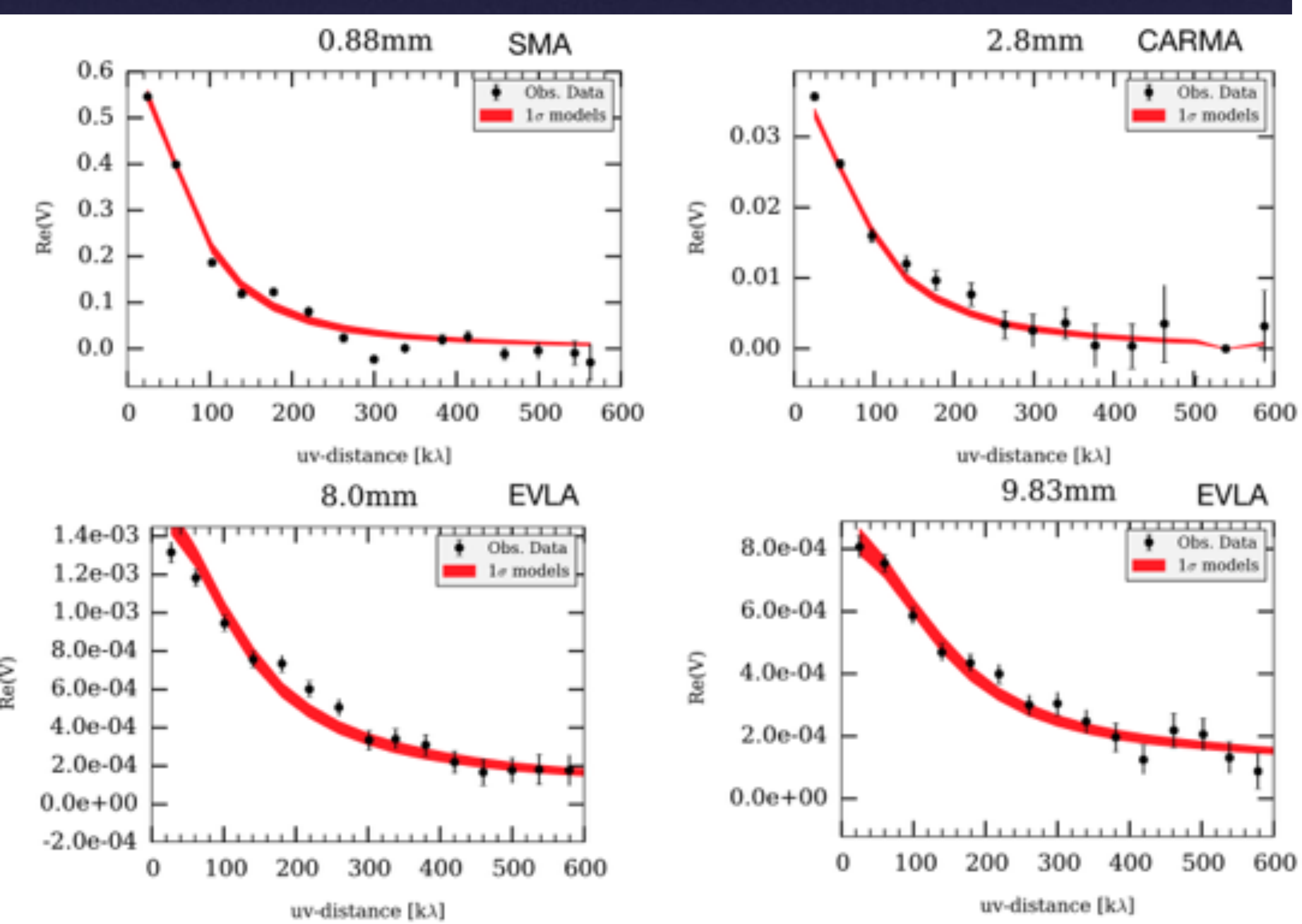
1μm — 1mm — 1m — 1km — 1000km

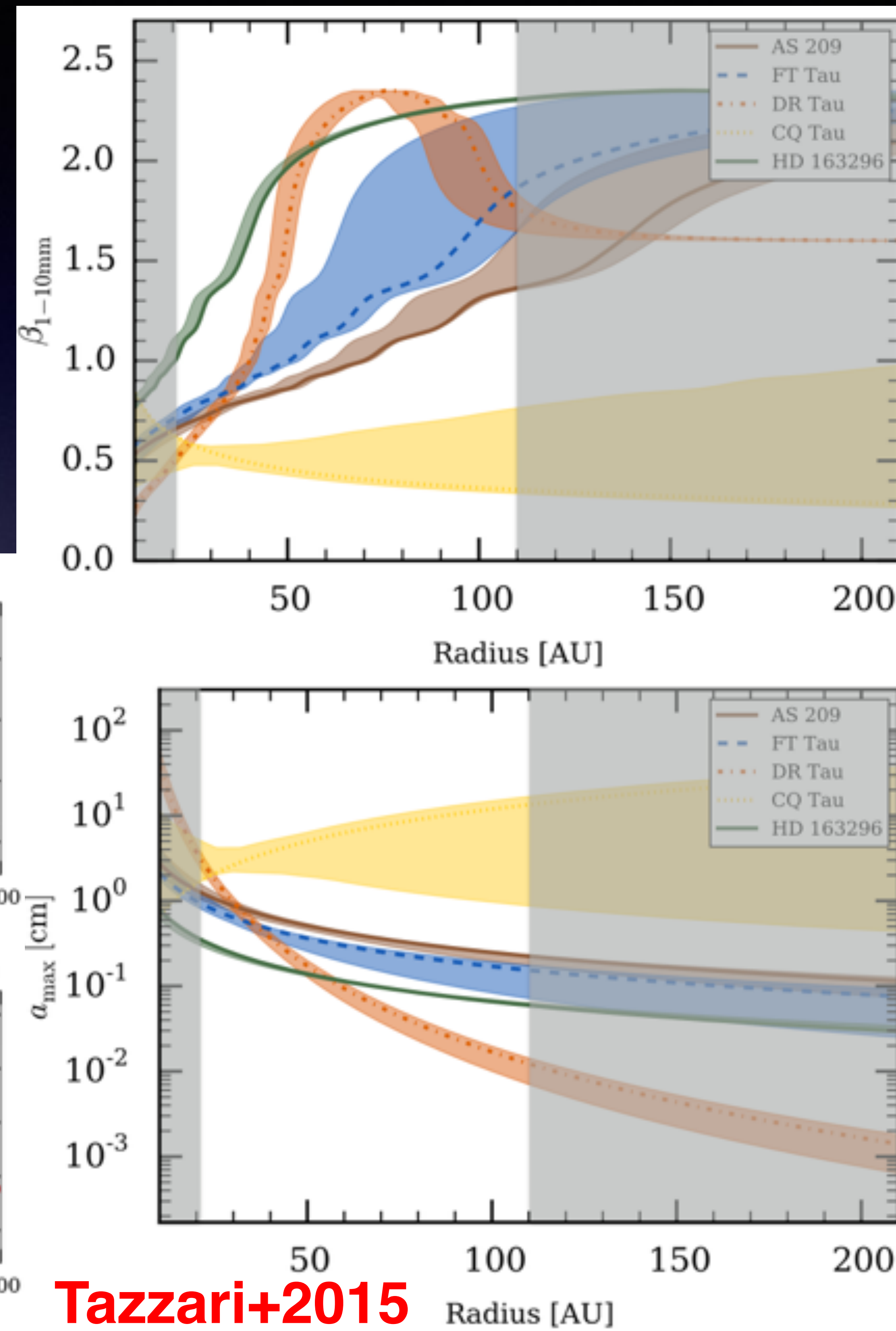


Radial stratification

Birnstiel et al. 2012



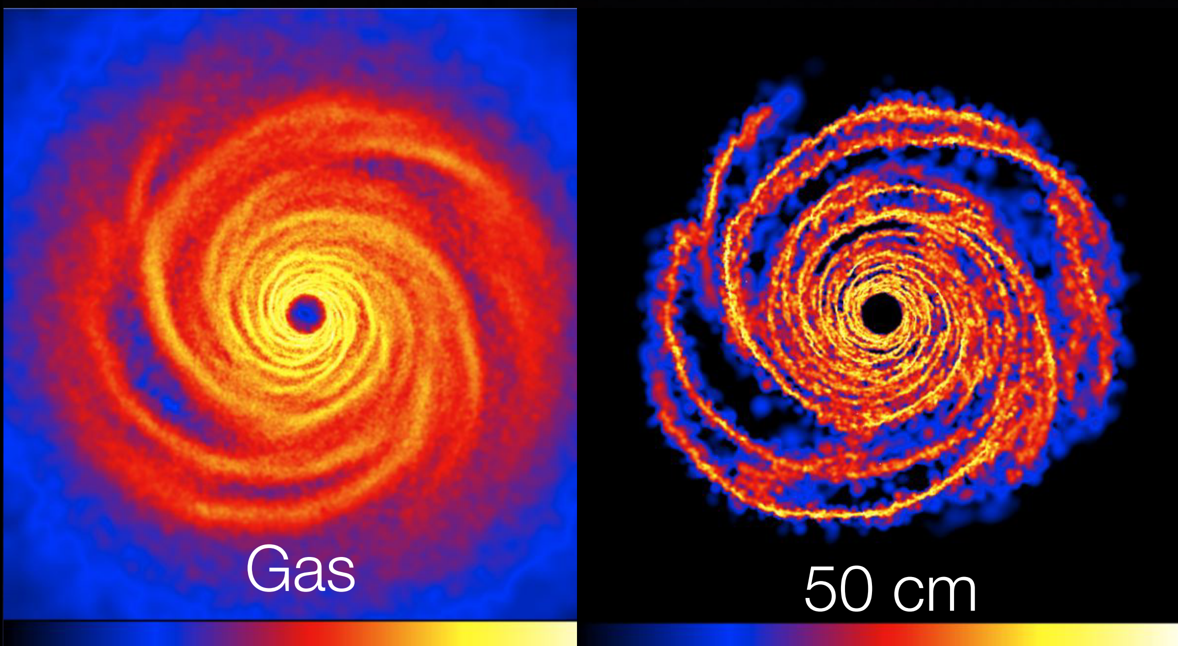




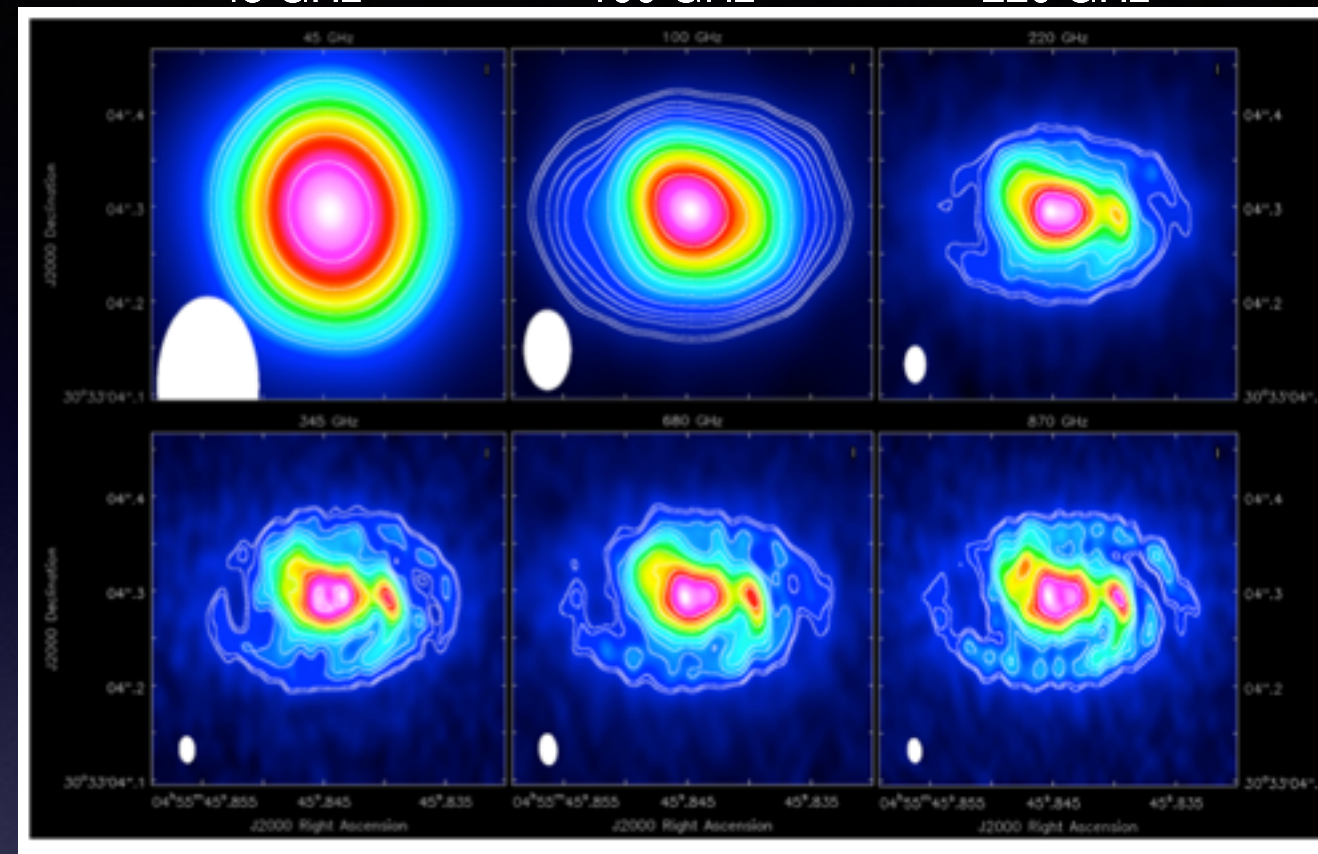
Tazzari+2015

See also: Testi+2014, PPVI: Perez et al. 2012

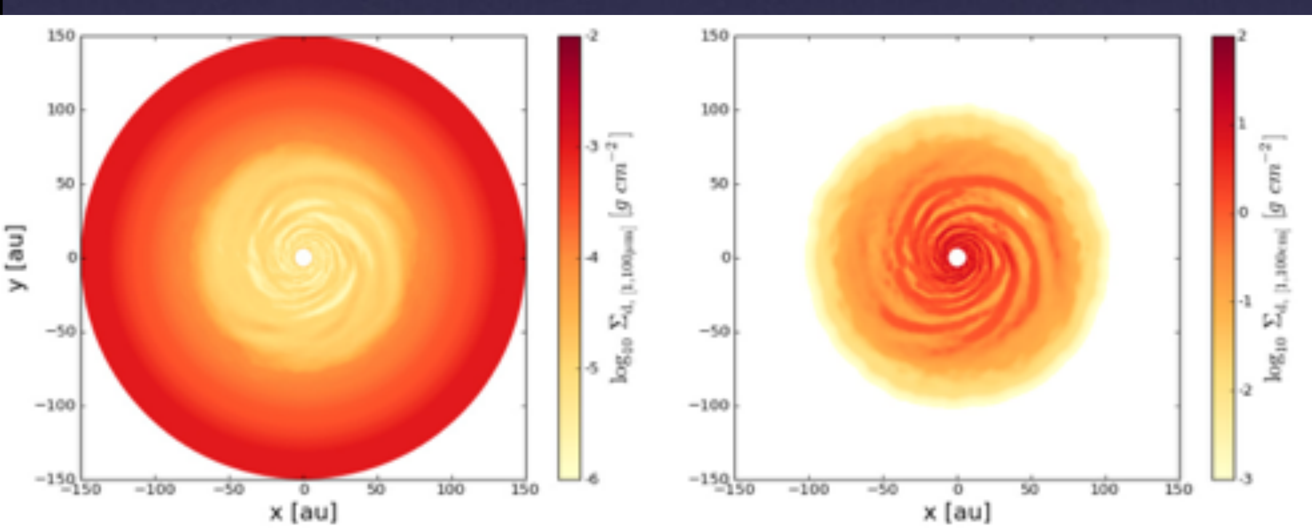
Can we detect the traps?

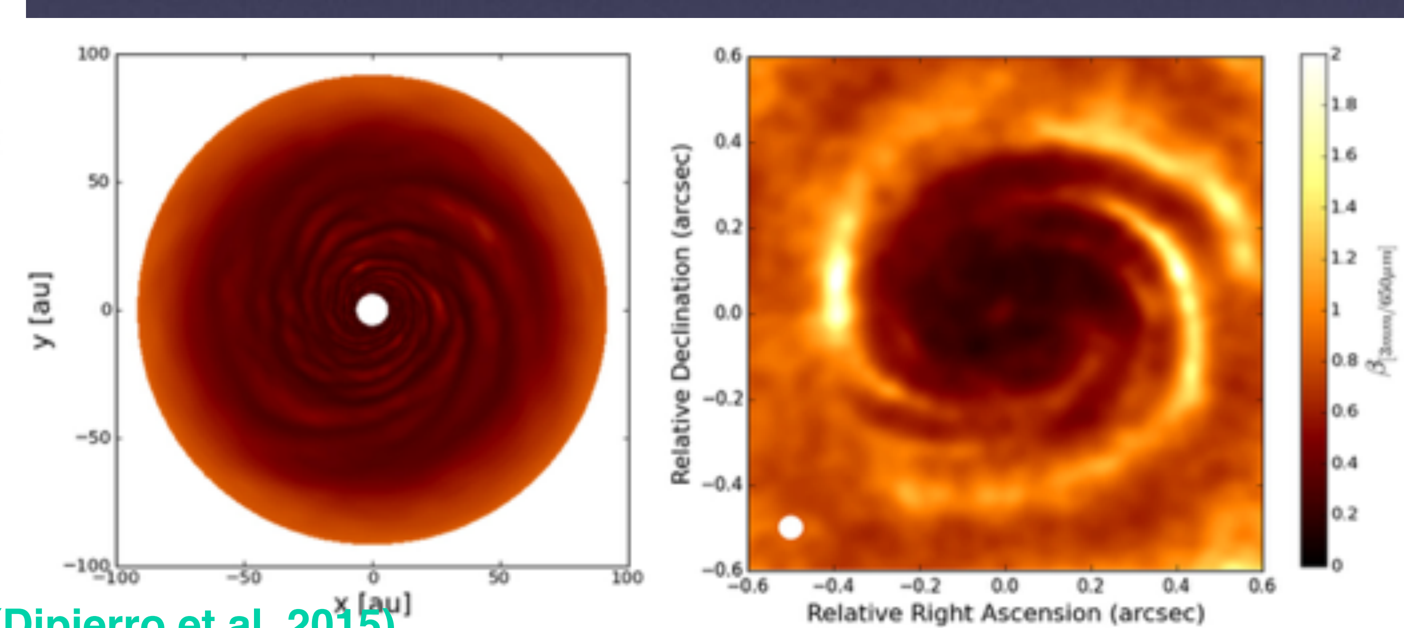


(Lodato & Rice 2005)



(Cossins, Lodato, Testi 2010; Dipierro et al. 2014)

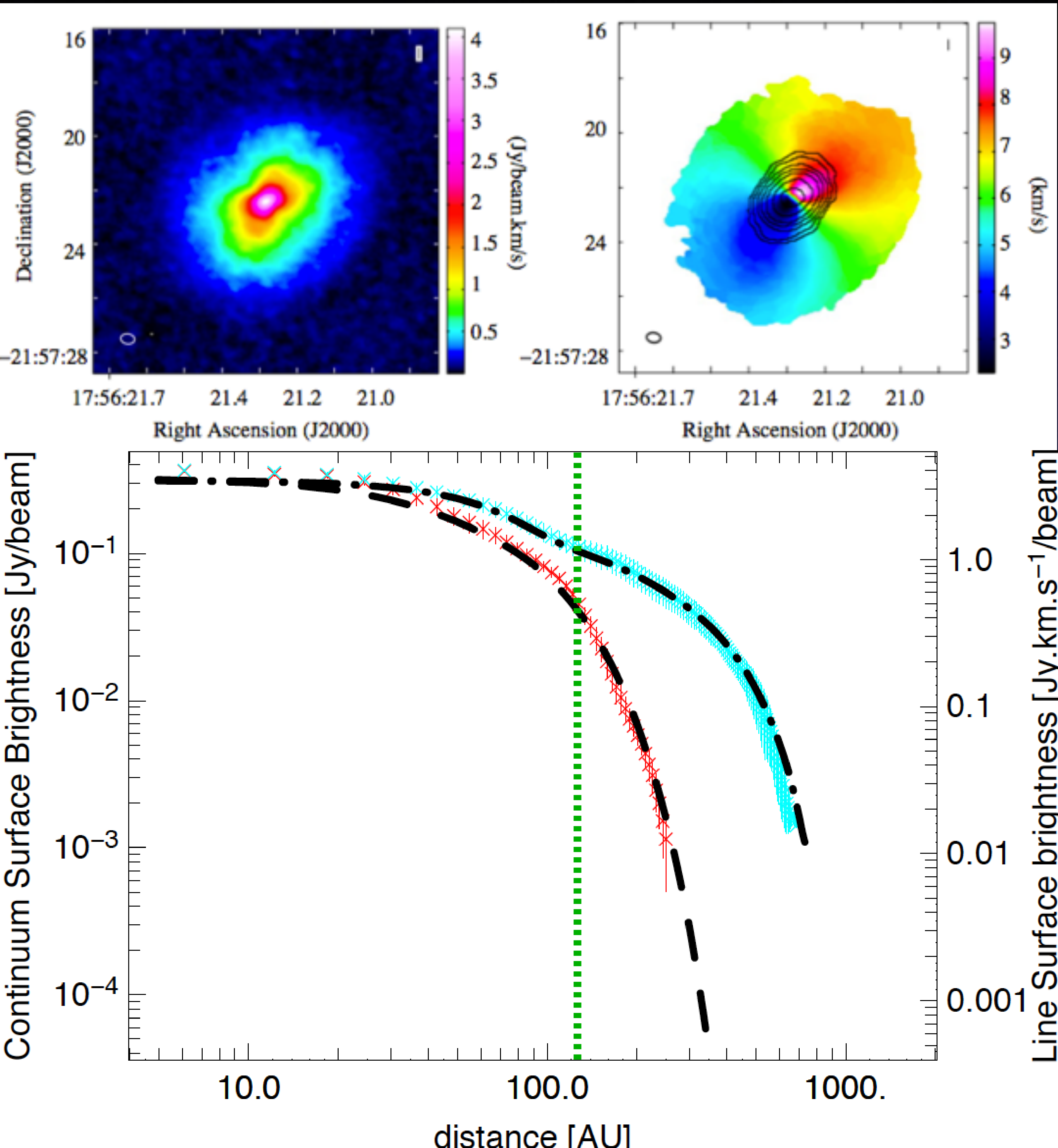




(Dipierro et al. 2015)

- Problem: short timescale

HD163296 as seen by ALMA

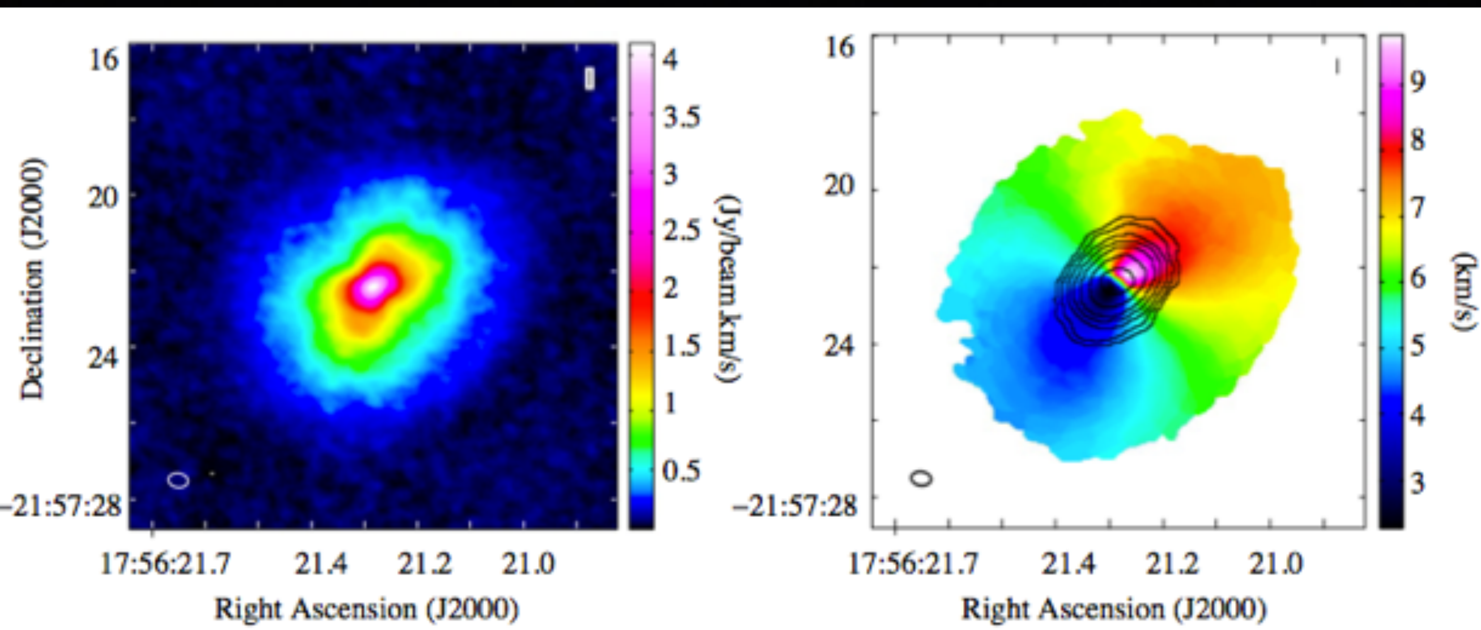


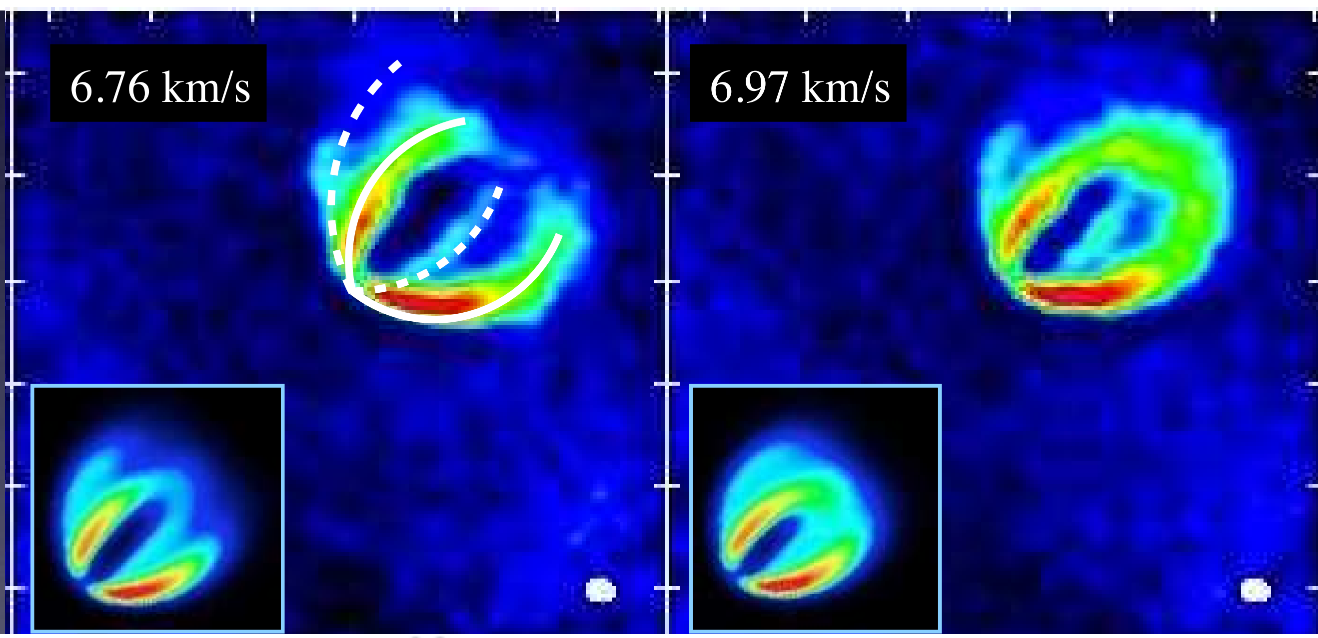
- Extent of the CO disk is much larger than that of the mm-grains disk
- Consistent with expectations from viscous spreading and migration of the larger grains

(deGregorio-Monsalvo+2013)

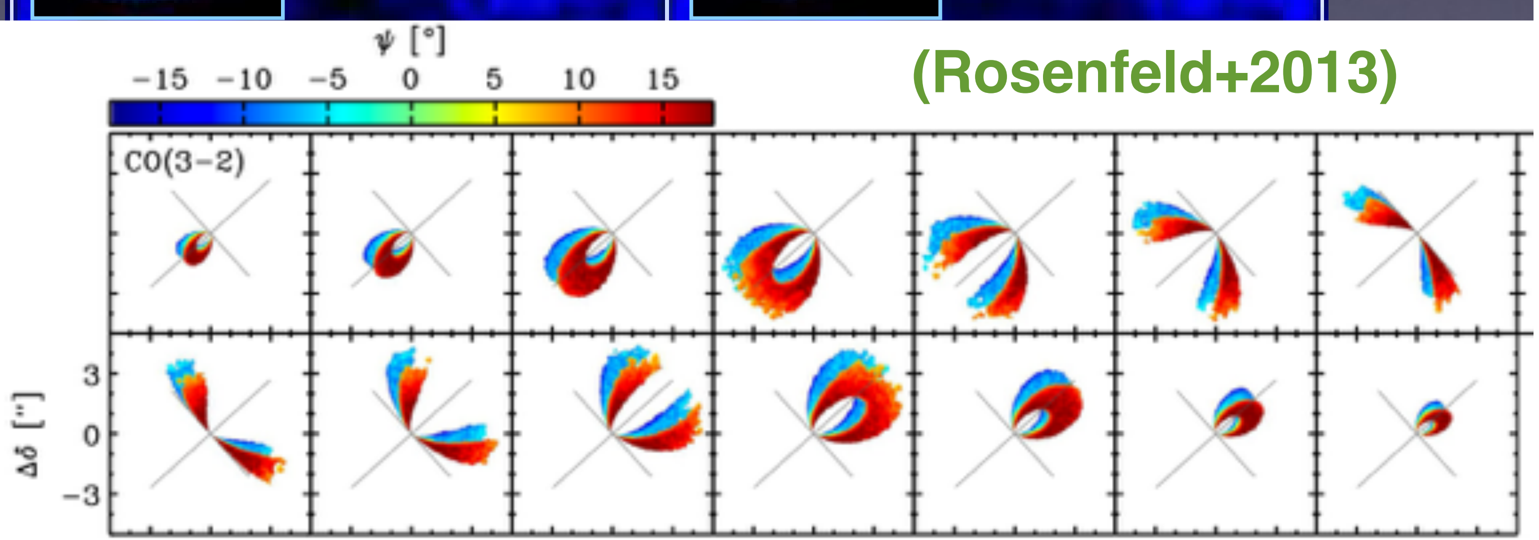
HD163296 as seen by ALMA

- Direct measurement of disk flaring and CO depletion on the mid plane

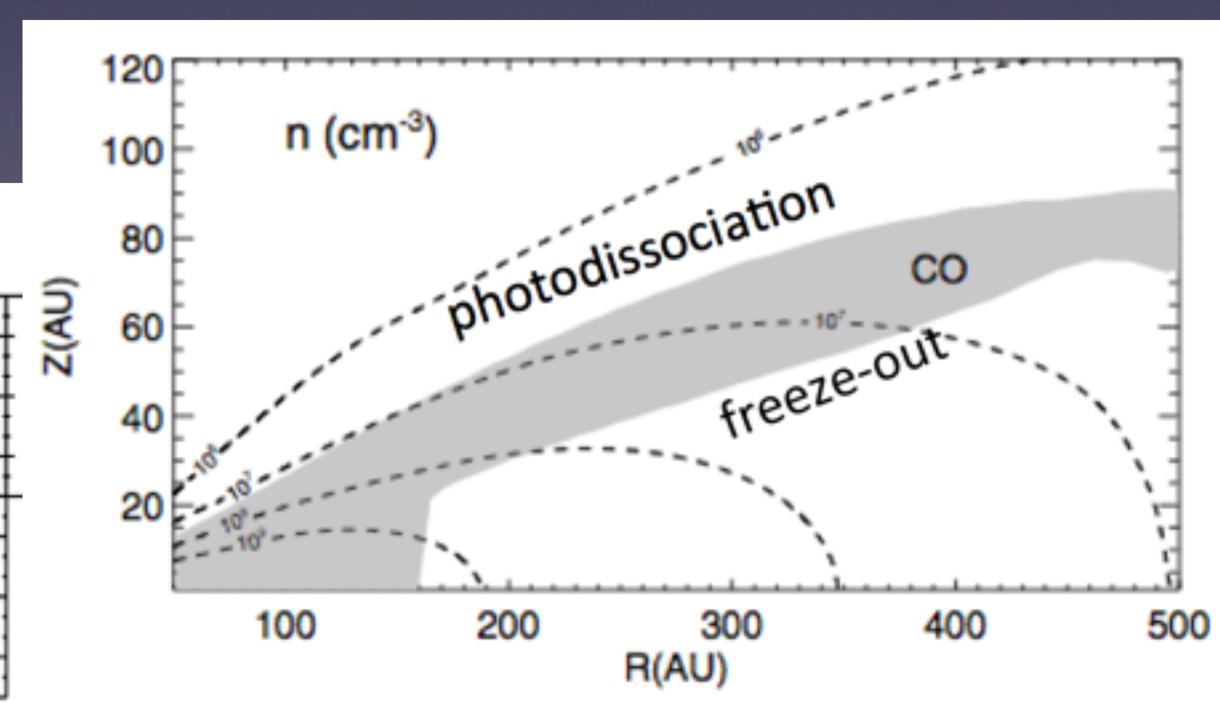




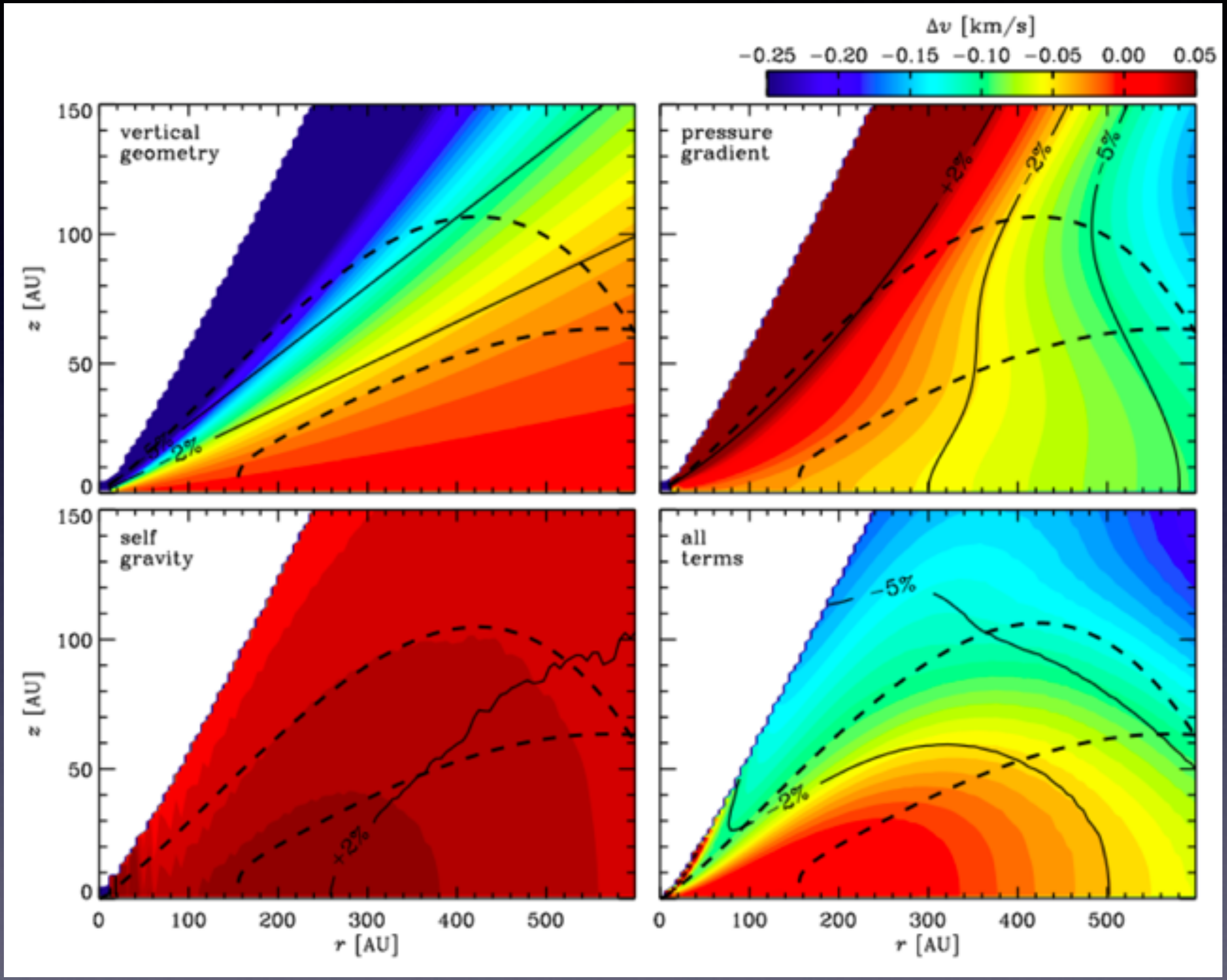
(deGregorio-Monsalvo+2013)



(Rosenfeld+2013)



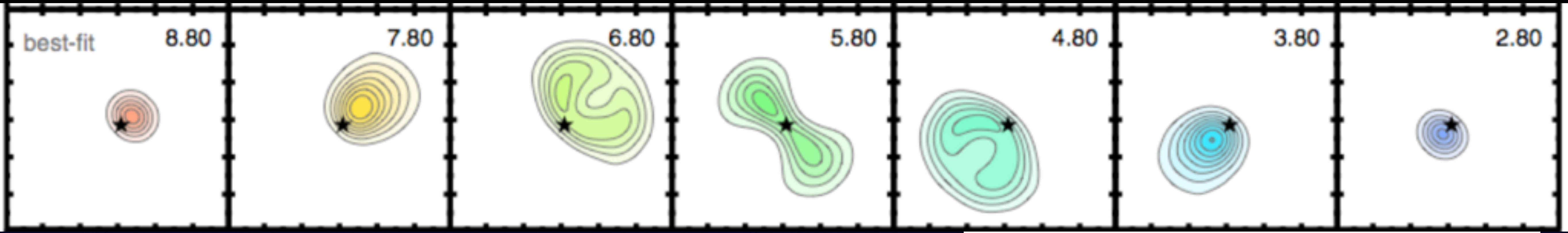
Gas kinematics

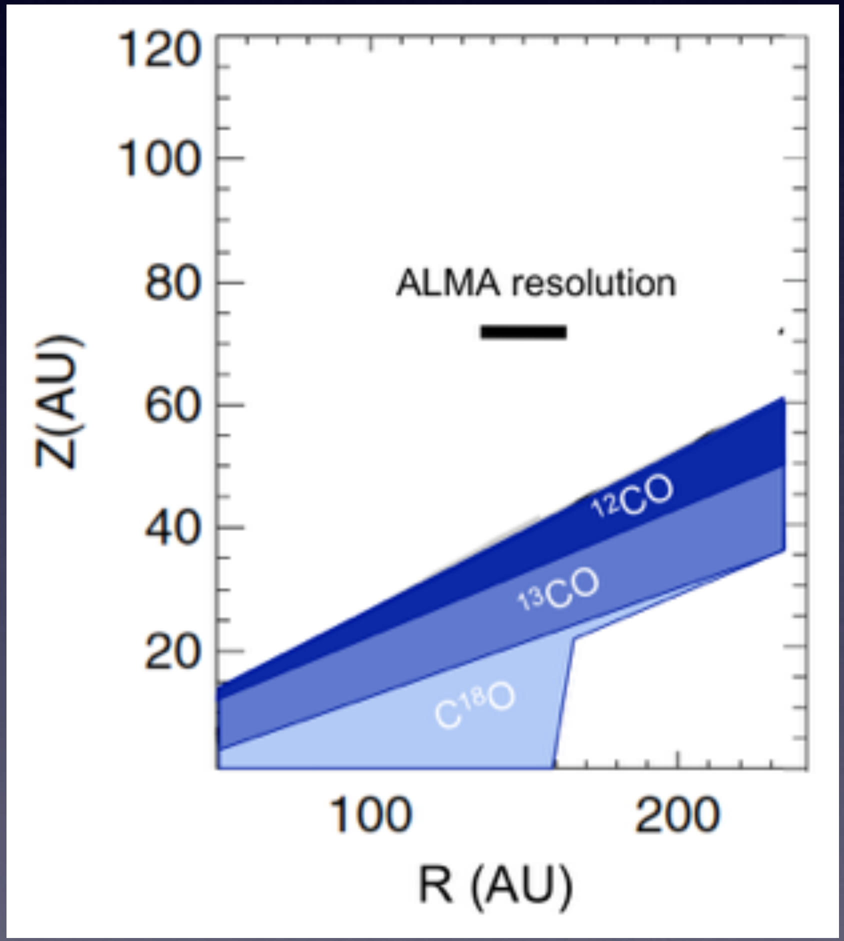


(Rosenfeld et al. 2013)

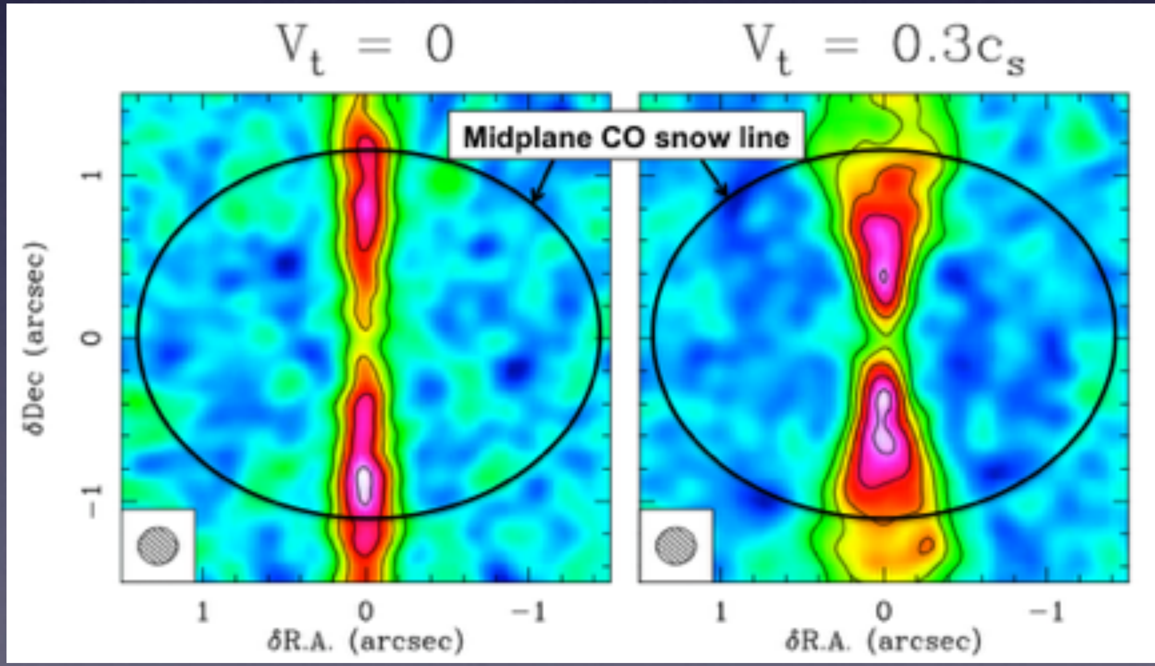
- Potentially a direct measurement of the disk self-gravity
- Not exactly Keplerian
- Largest effect is the pressure term 5%, self gravity 0.1-0.5%

Turbulence





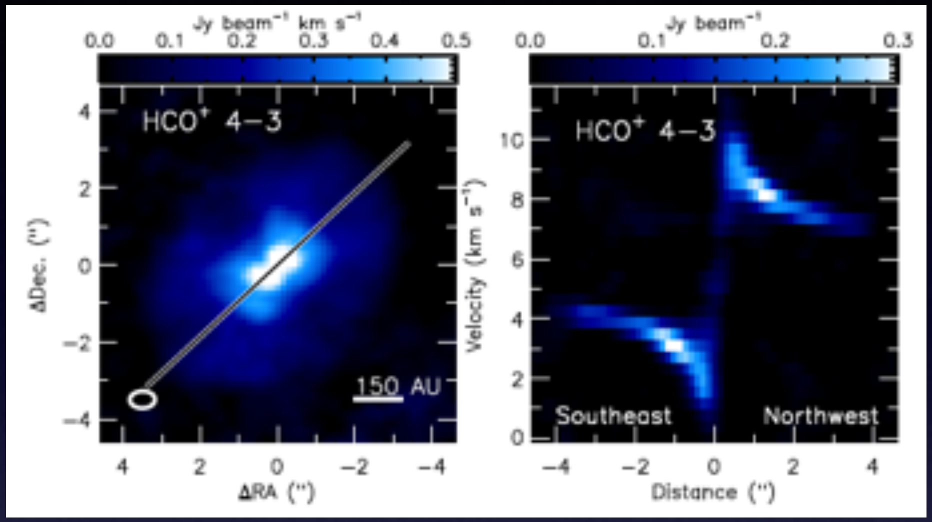
$$\Delta V(r) = \sqrt{\frac{2kT(r)}{\mu m_H} + \delta V_{tu}(r)^2}$$

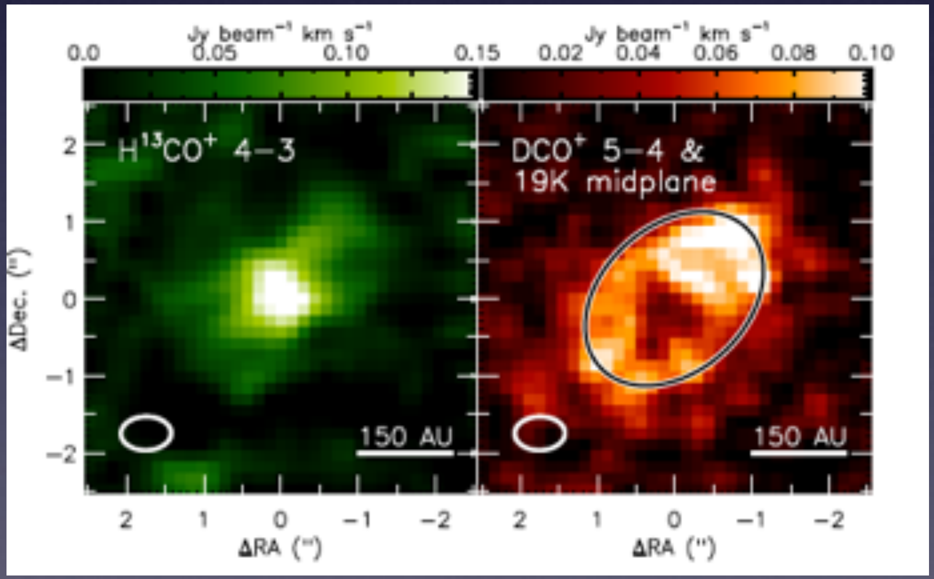


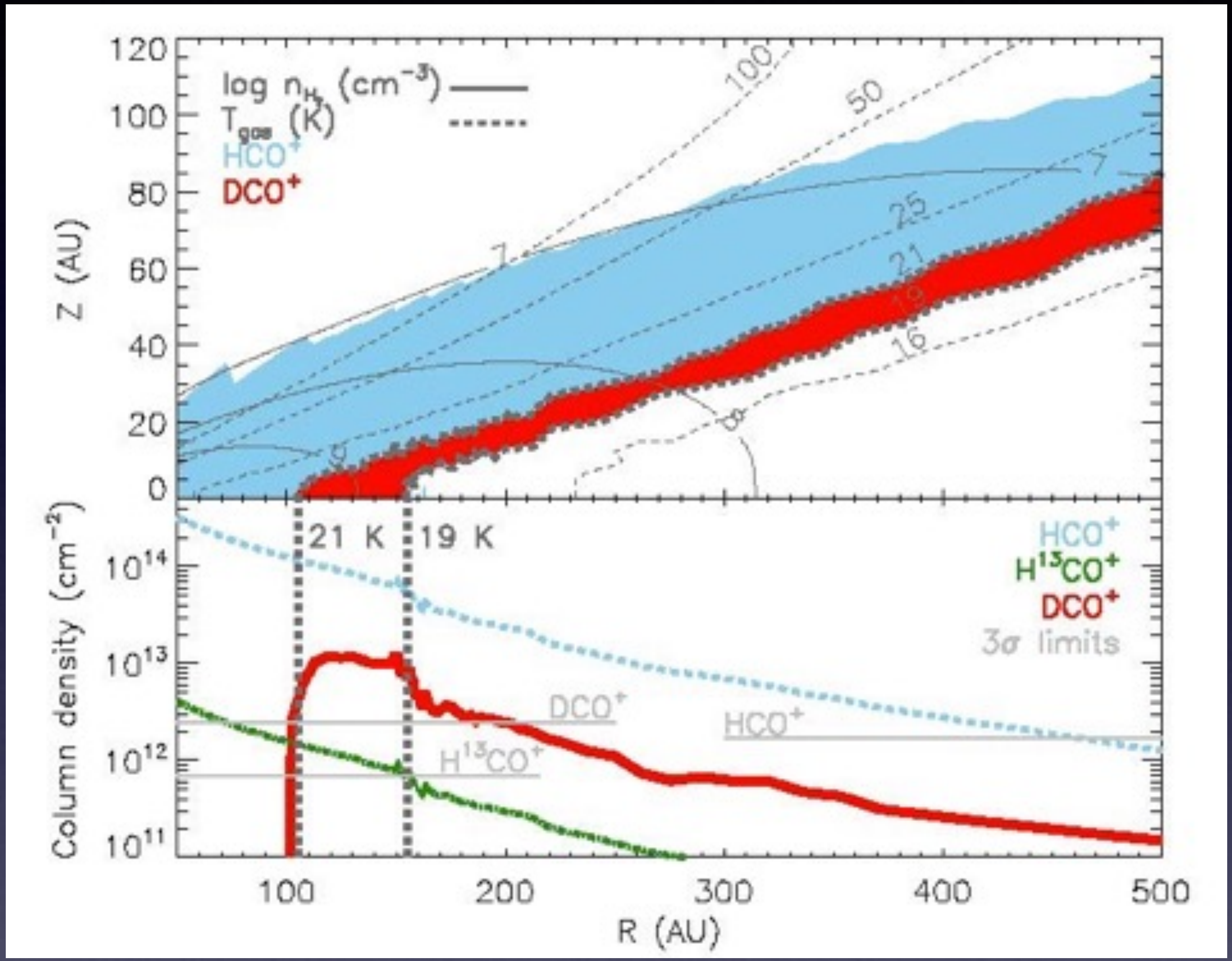
- Turbulence provide an additional line broadening term
- Measureable with ALMA: high S/N and resolution

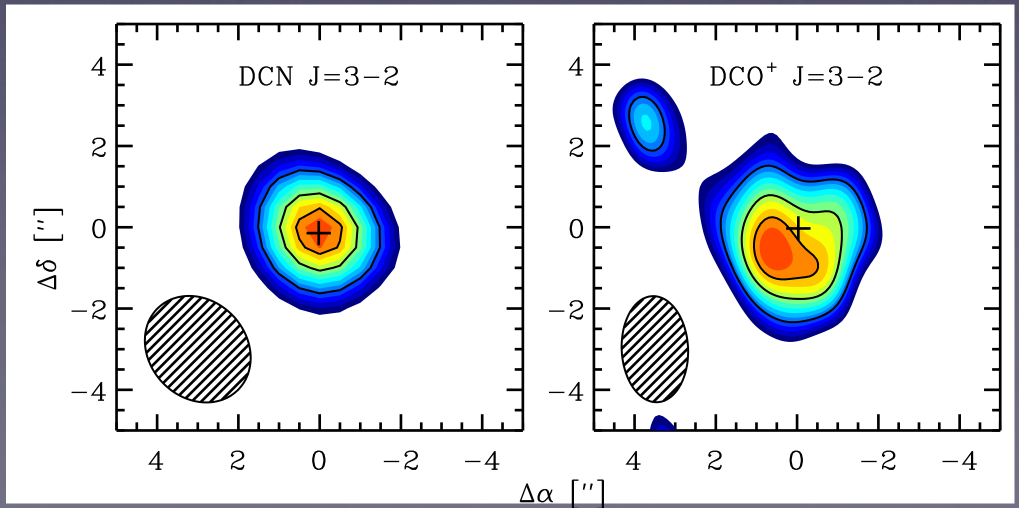
HD163296 as seen by ALMA

(Mathews et al. 2013)





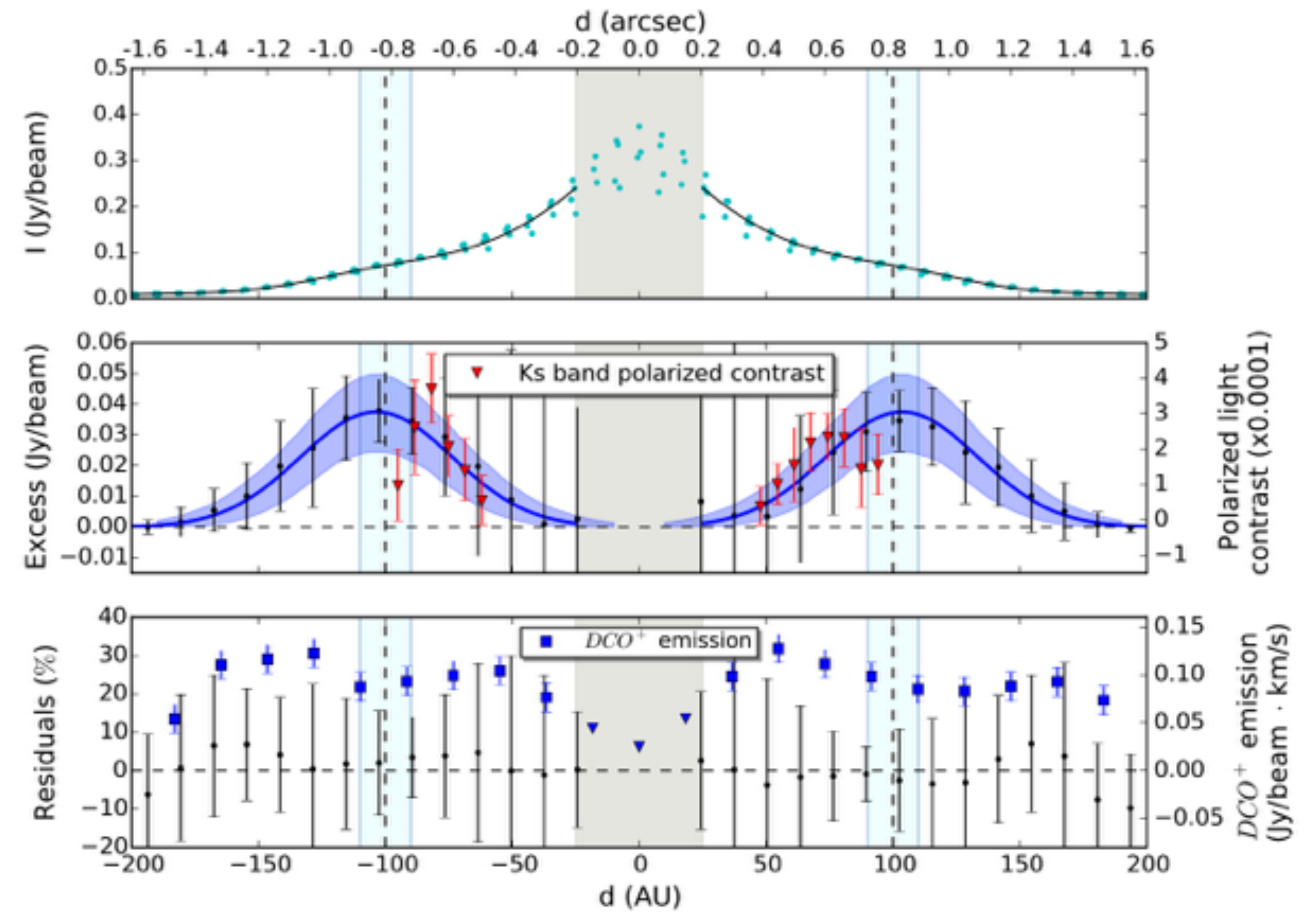


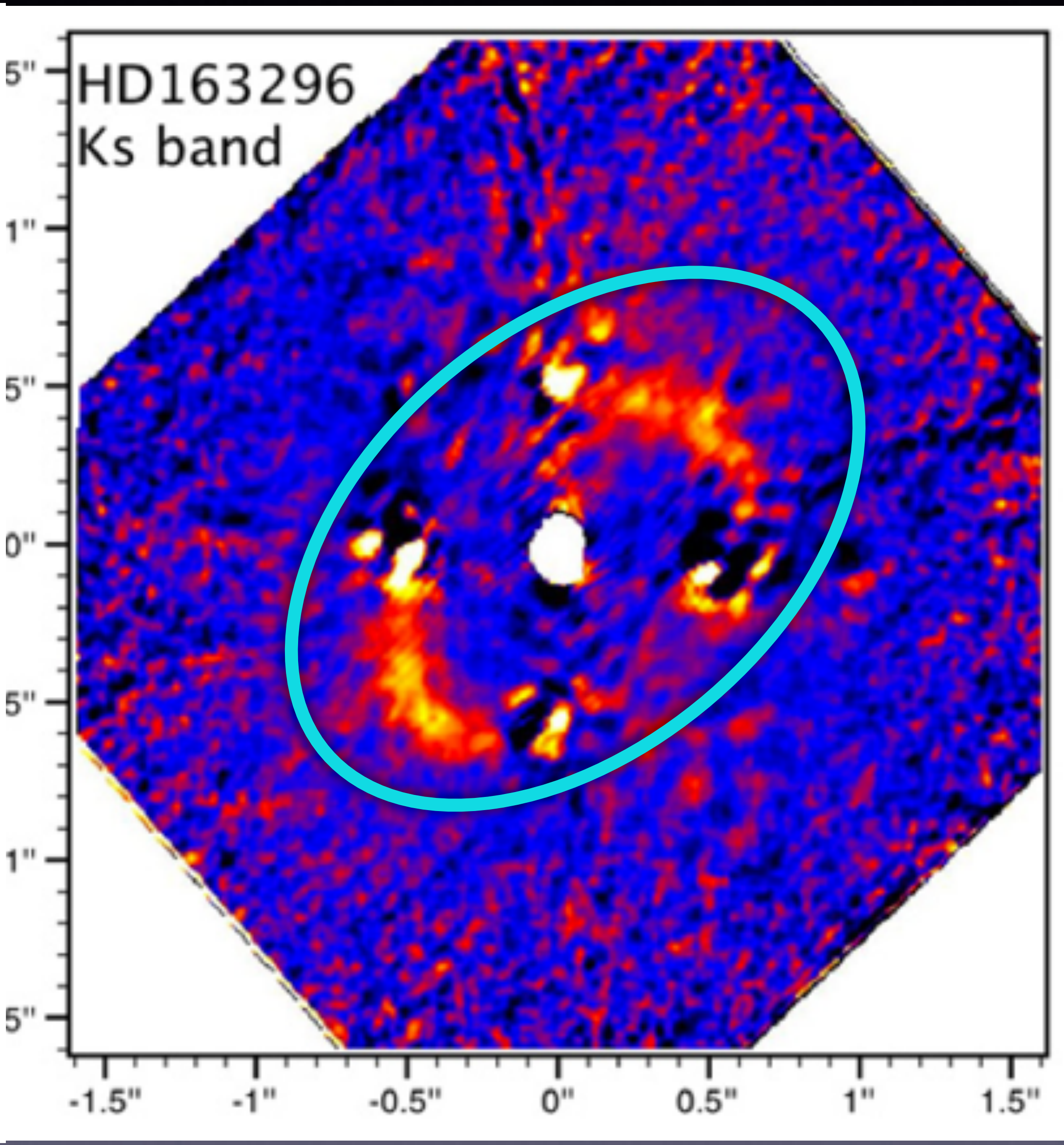


(Oeberg et al. 2012)

- Chemical measure of CO snowline

Grain growth and Snowline





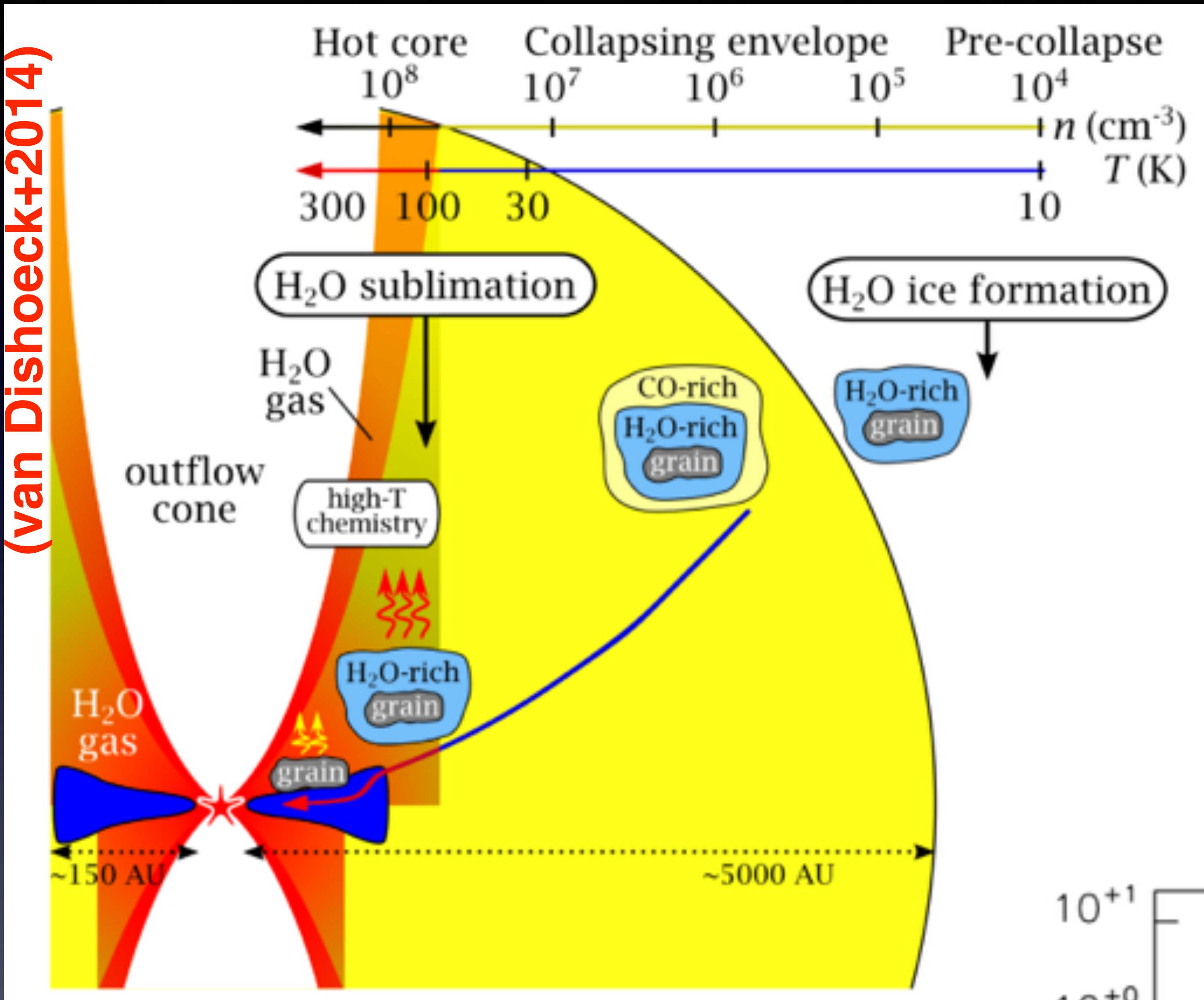
(Guidi+2015)

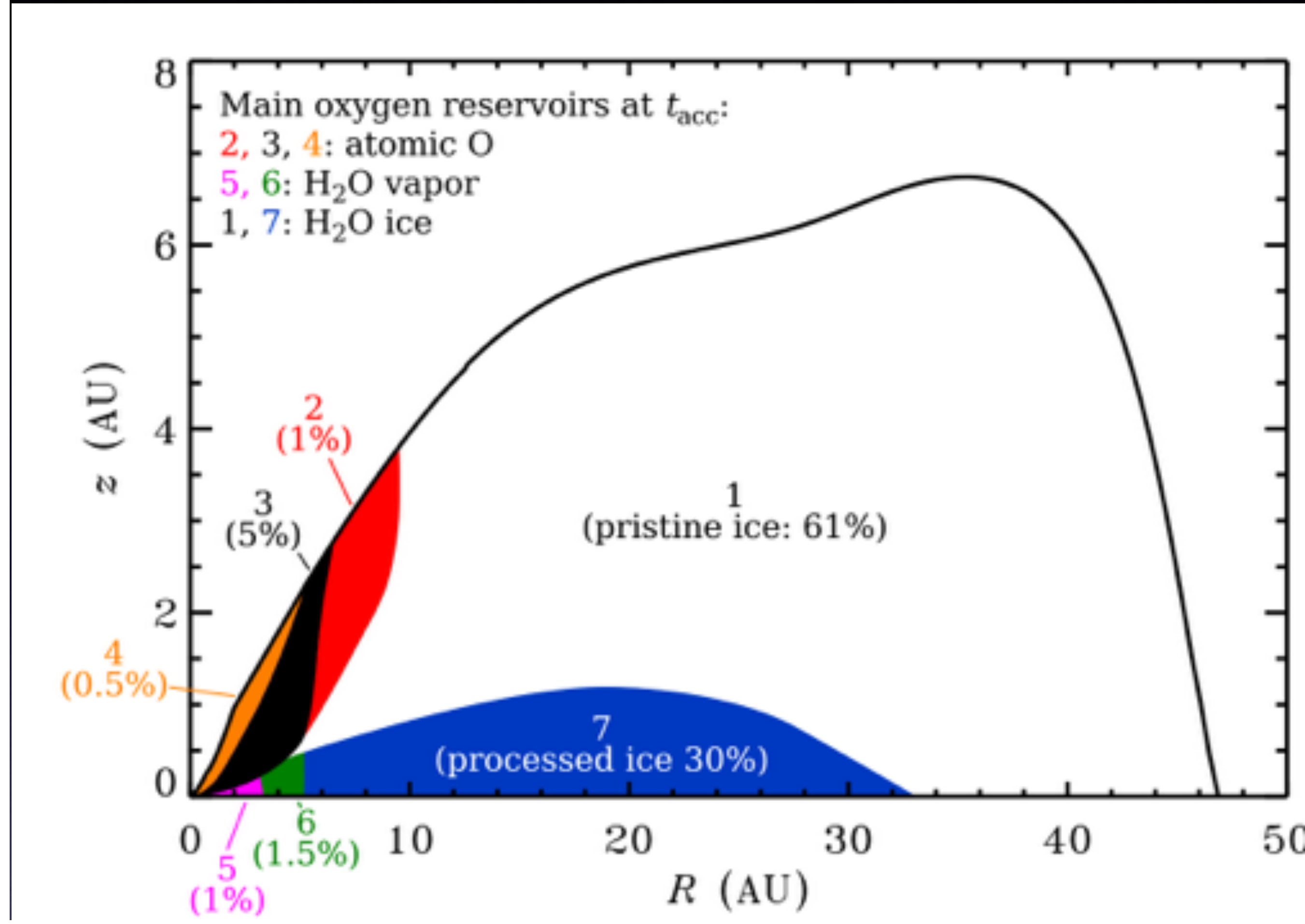
(Garufi+2014)

- Ices effect on grain distribution and growth
- ALMA will soon probe the effects at the water snowmen

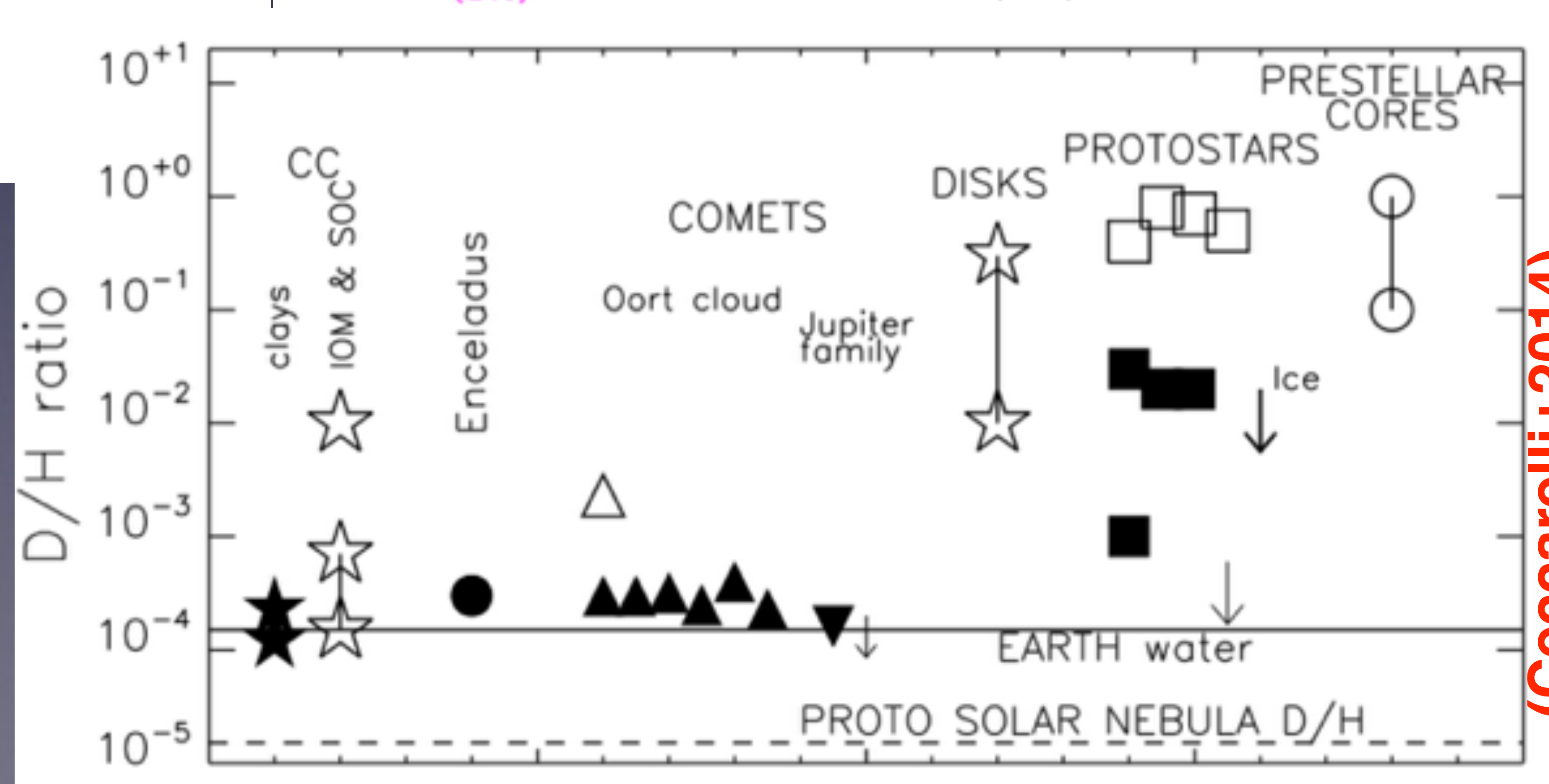
Deuteration and ices

(van Dishoeck+2014)



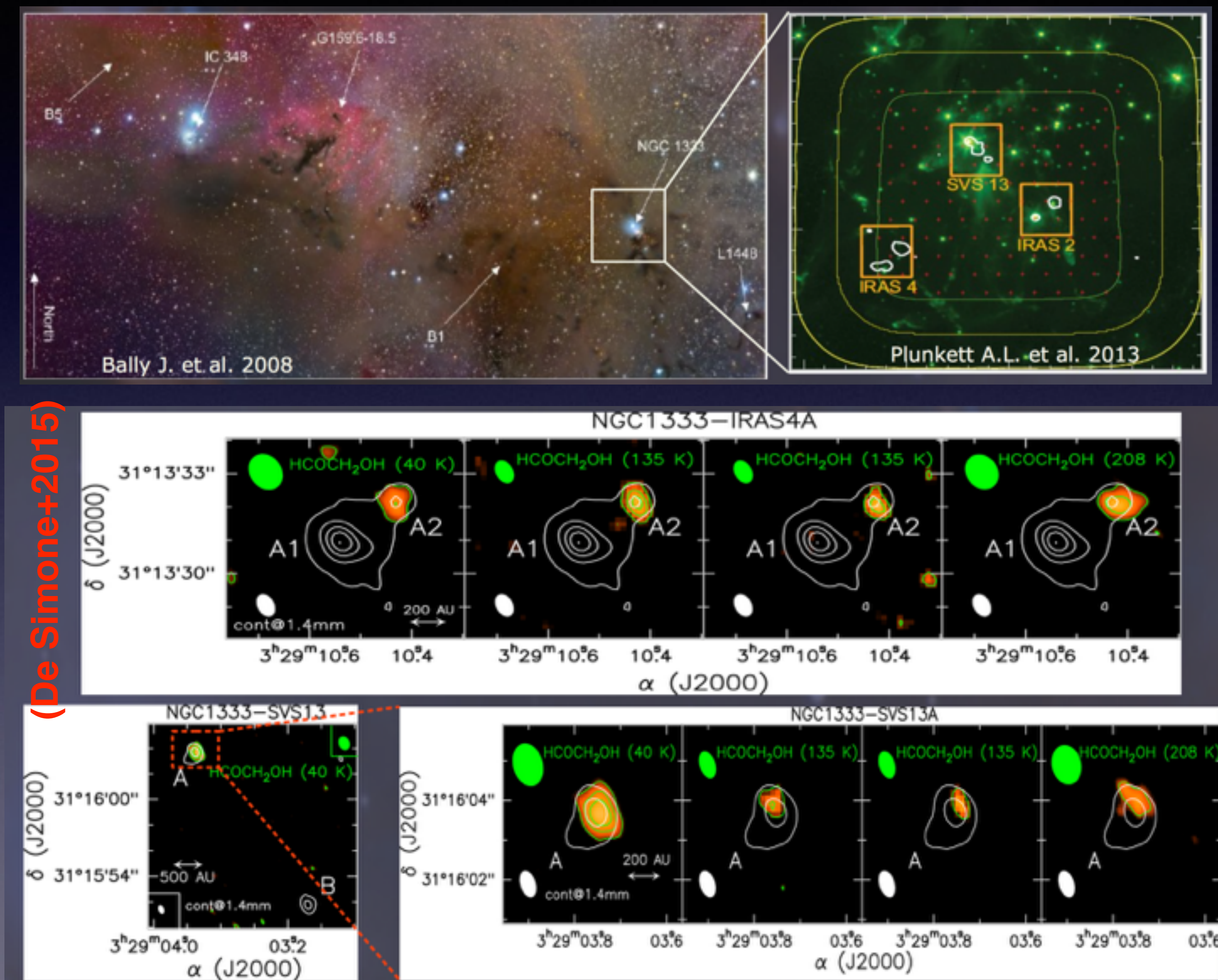


- Systematic difference between HD, HDO and other molecules
- Need resolved measurements



(Ceccarelli+2014)

Tracing COMs at disk formation times



- 33% of young protostars show the presence of Glycolaldehyde
- Emission is localised in a confined region with T~150K

- Glycolaldehyde in young protostars

Summary

- Disk properties and evolution are consistent with Solar System evidence
  - Caveats on limited population studies => mm surveys
- We are now within reach of a solution of the m-size barrier paradox
  - The nature and effectiveness of dust traps and their role in growing planetary cores are still under investigation
- We are starting to probe the disk chemistry and the pathways to deliver chemically processed material on the planets
  - ALMA is transforming this field