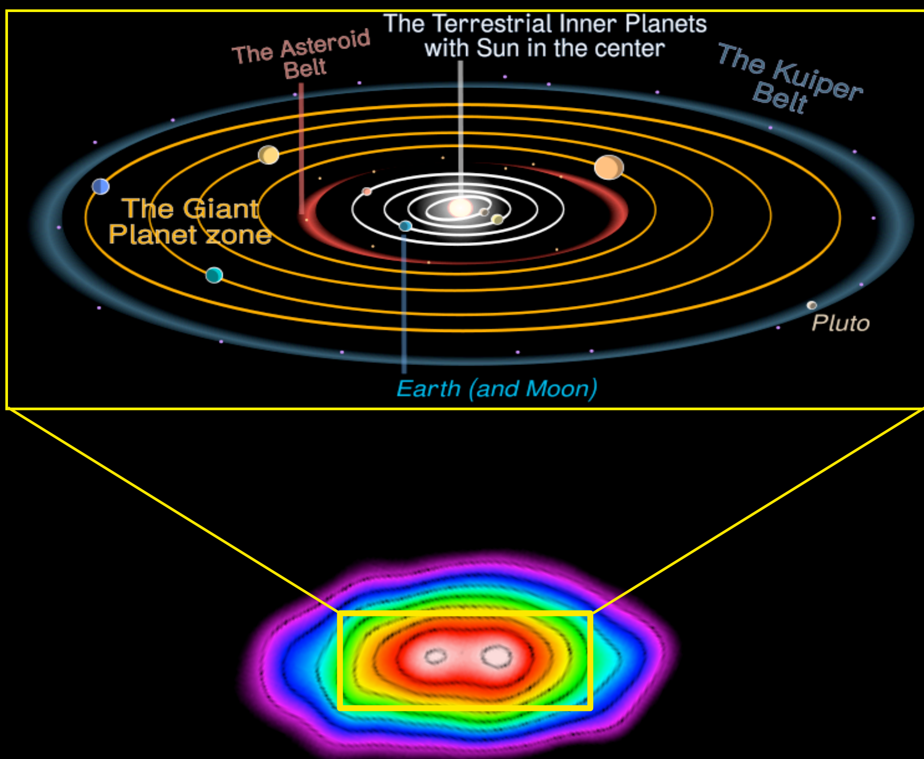
# High resolution observations of circumstellar disks




Andrea Isella
Michelson Postdoctoral Fellow 2007
Caltech

Collaborators:
John Carpenter
Anneila Sargent
Laura Perez

# Talk Outline

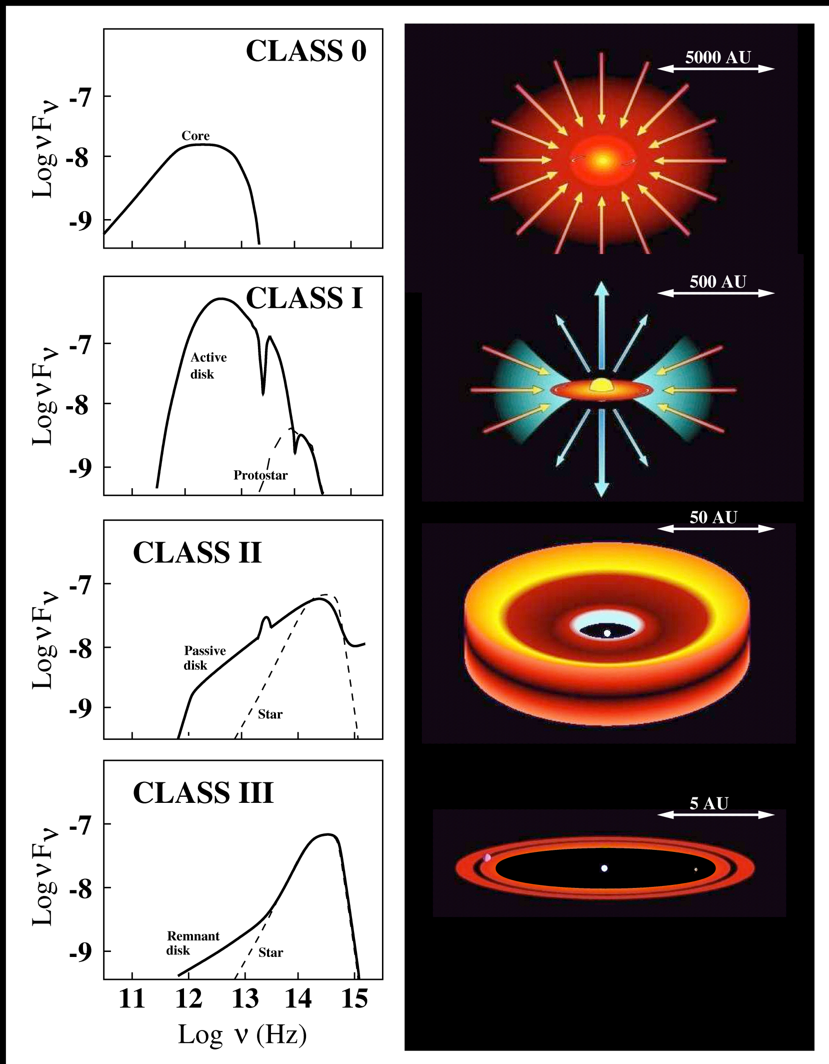
- Circumstellar disks observed at 0.5-0.7'' (80AU)
  Disk surface density and evolution

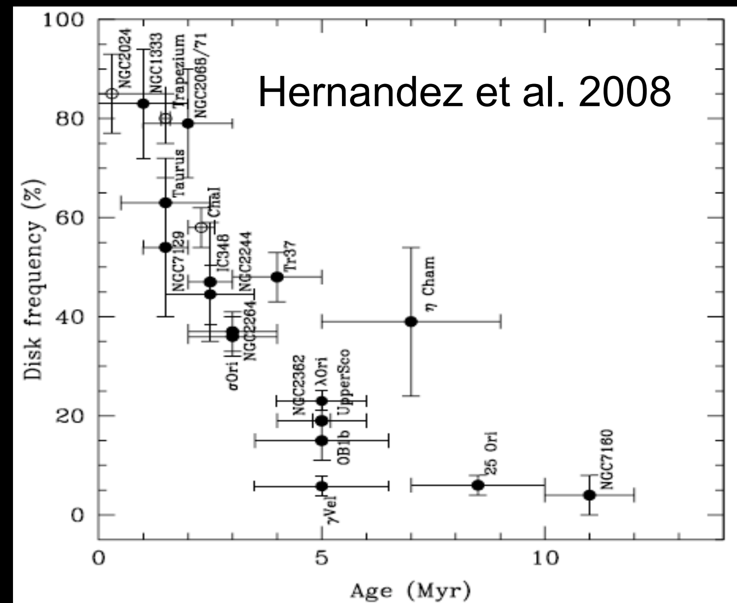
  (Isella A., Carpenter J., Sargent A., 2009, ApJ, 701, 260)

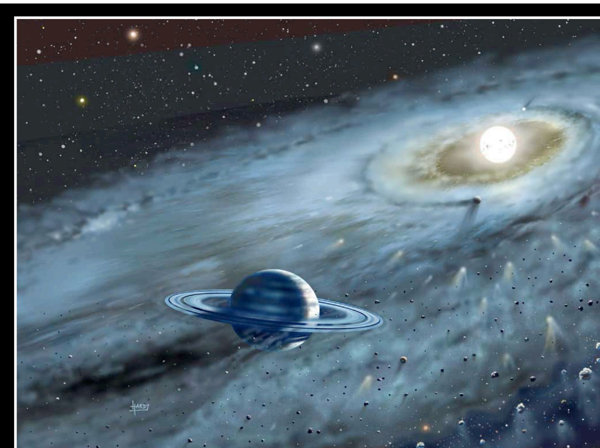
- Circumstellar disks observed at 0.15'' (20 AU)
  - presence of planets.
  - radial variation of the dust properties.

  (Isella A., Carpenter J., Sargent A., 2009, in prep)

# From molecular clouds to planets

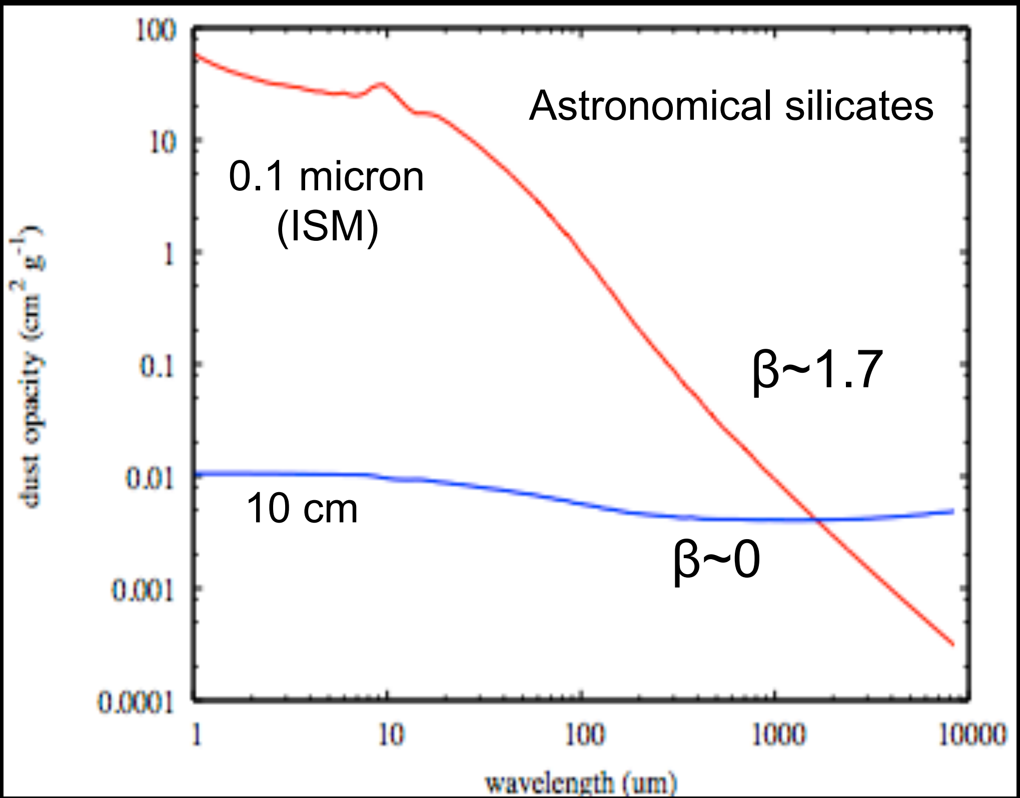


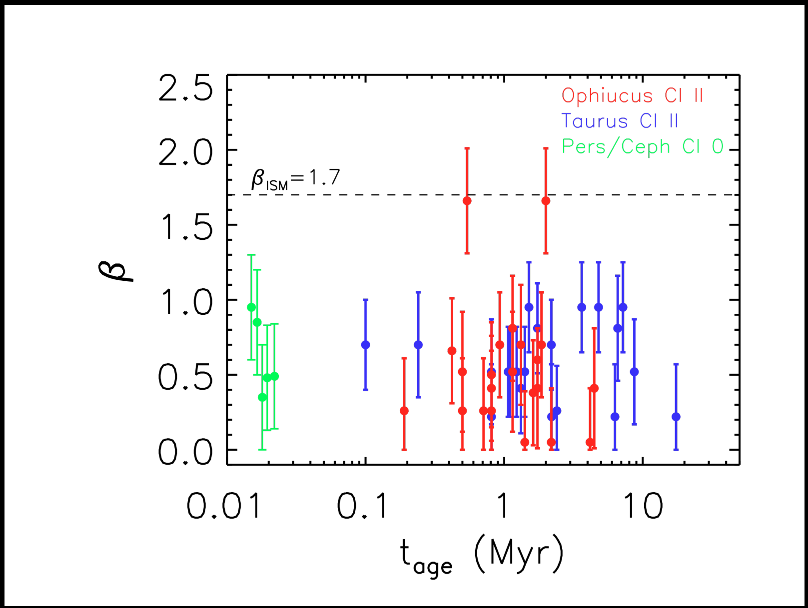



# Grain growth

$$k_\nu \propto \nu^\beta \rightarrow F_\nu \propto \nu^{2+\beta+\Delta\beta}$$



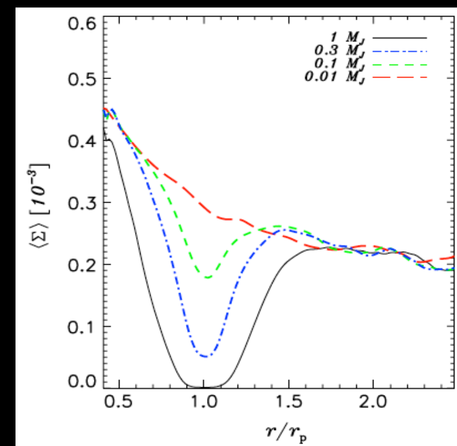



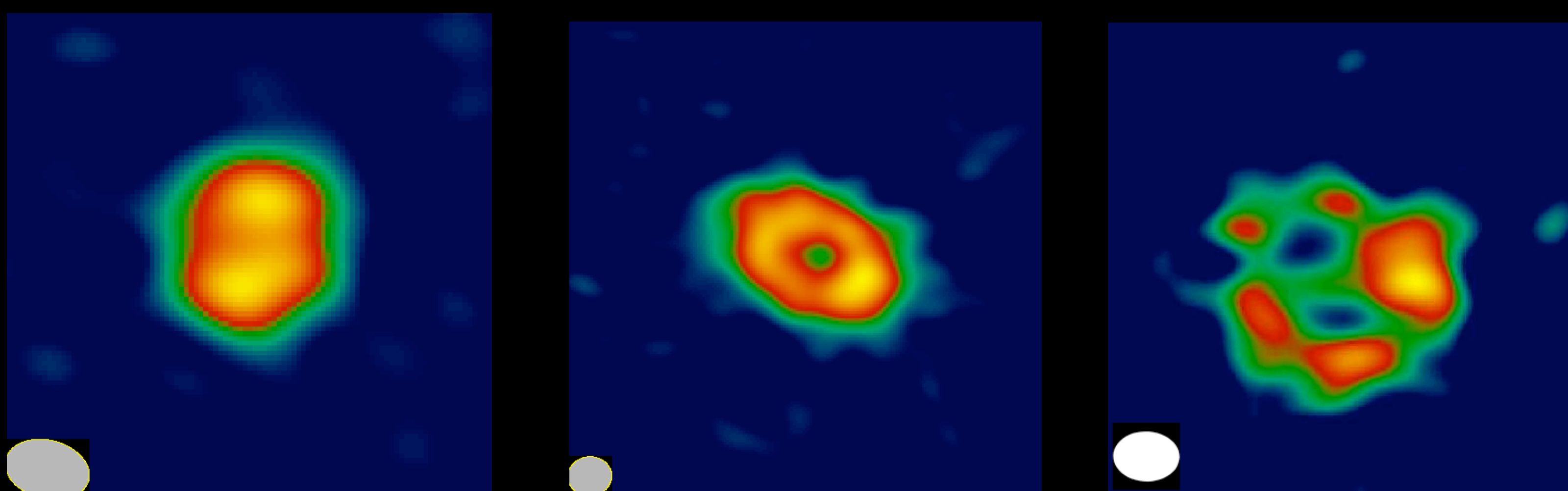

Ricci et al. (2009), A&A submitted

# Disk clearing and gap formation

Geoff Bryden

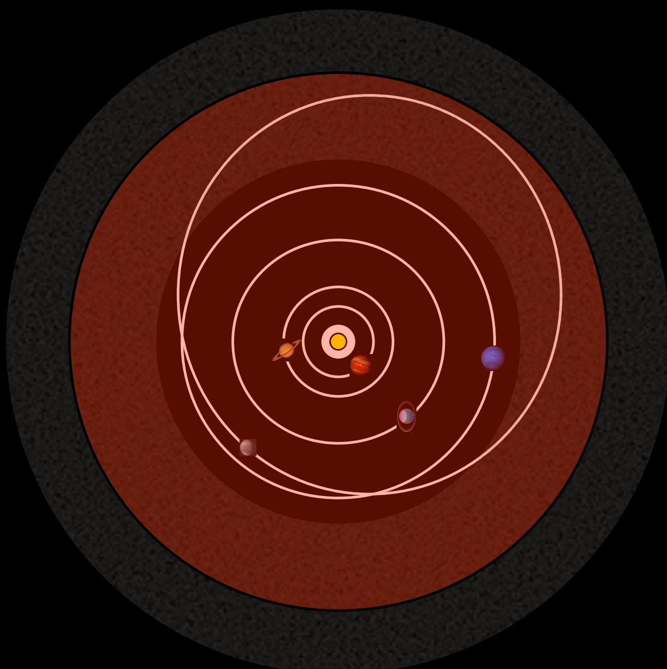
Wolf et al. (2007)

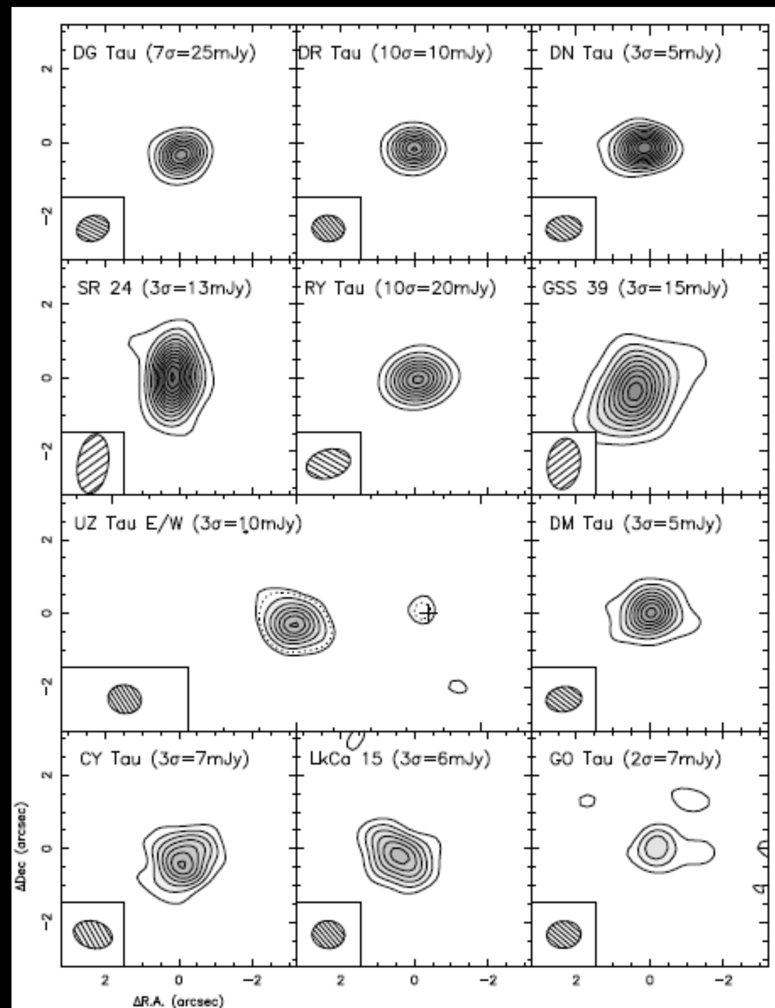


Perez, Carpenter, & Isella (in prep)

# Spatially resolved observations of the outer disk






Isella et al. (2009)

# Disk model

$$F_\nu(R) \propto \Sigma(R) \times k_\nu(R) \times T(R)$$

Lynden-Bell & Pringle 1974

Similarity solution for the disk surface density of a keplerian viscous disk

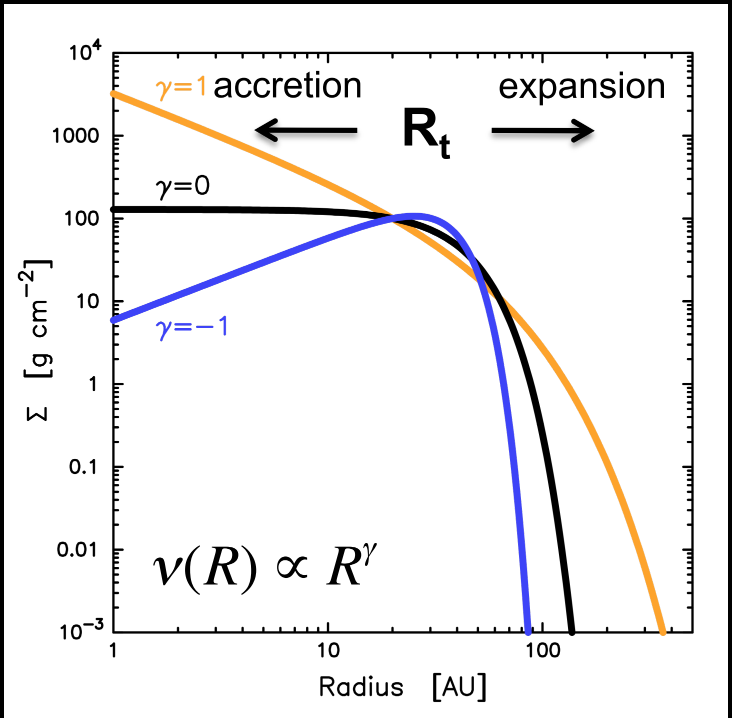
$$\Sigma(R,t) = \Sigma_t \left(\frac{R_t}{R}\right)^\gamma \times \exp\left\{-\frac{1}{2(2-\gamma)}\left[\left(\frac{R}{R_t}\right)^{(2-\gamma)} - 1\right]\right\}$$

$$R_{in} < \Sigma(R) < \infty$$

$$R_{90\%} \sim 4R_t$$

$$R_t(t) \propto (t/t_s)^{1/(2-\gamma)}$$

$$M_d(t) \propto (t/t_s)^{-1/(2(2-\gamma))}$$



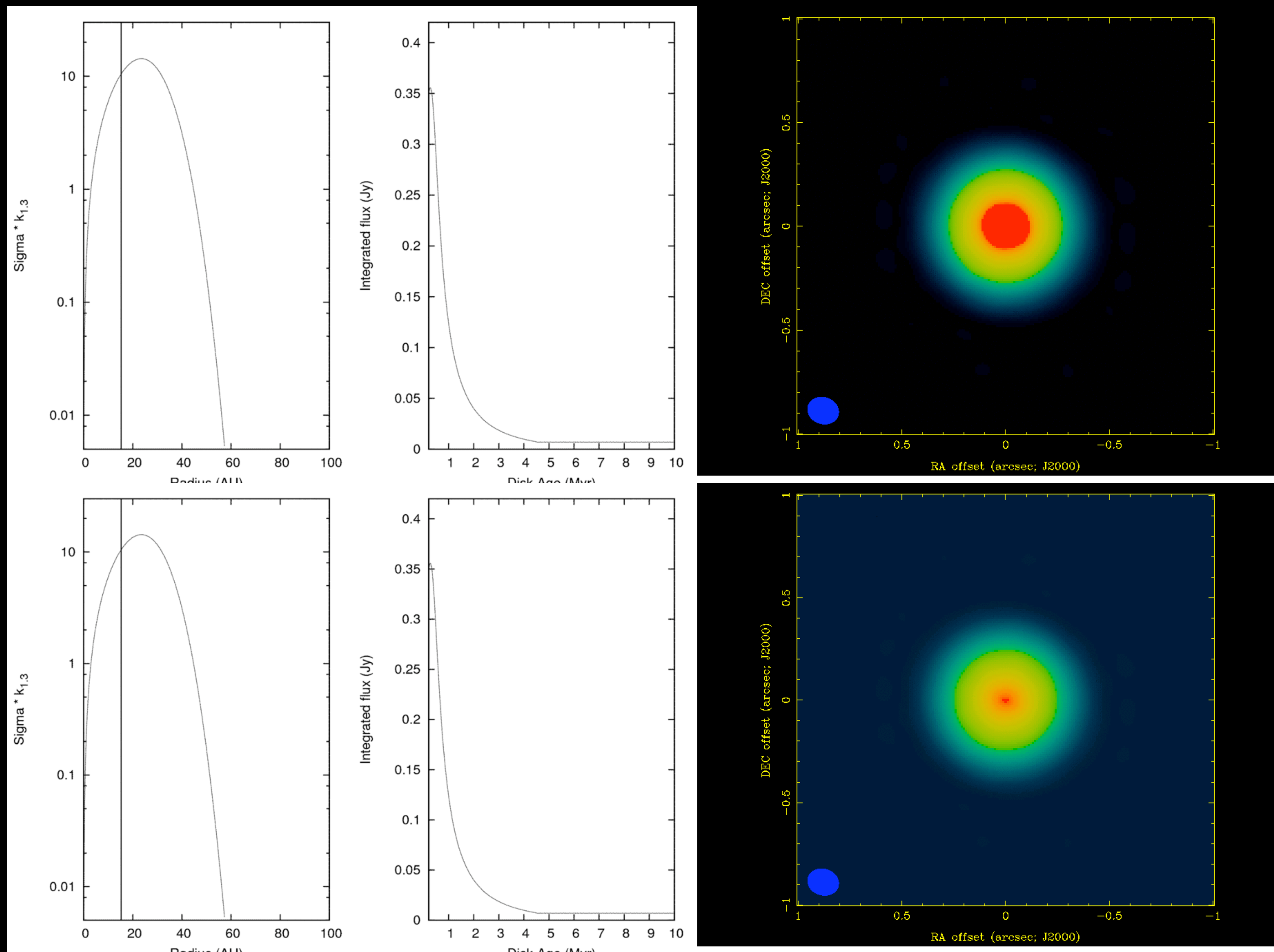

Isella et al. (2009)

# Viscous disk evolution

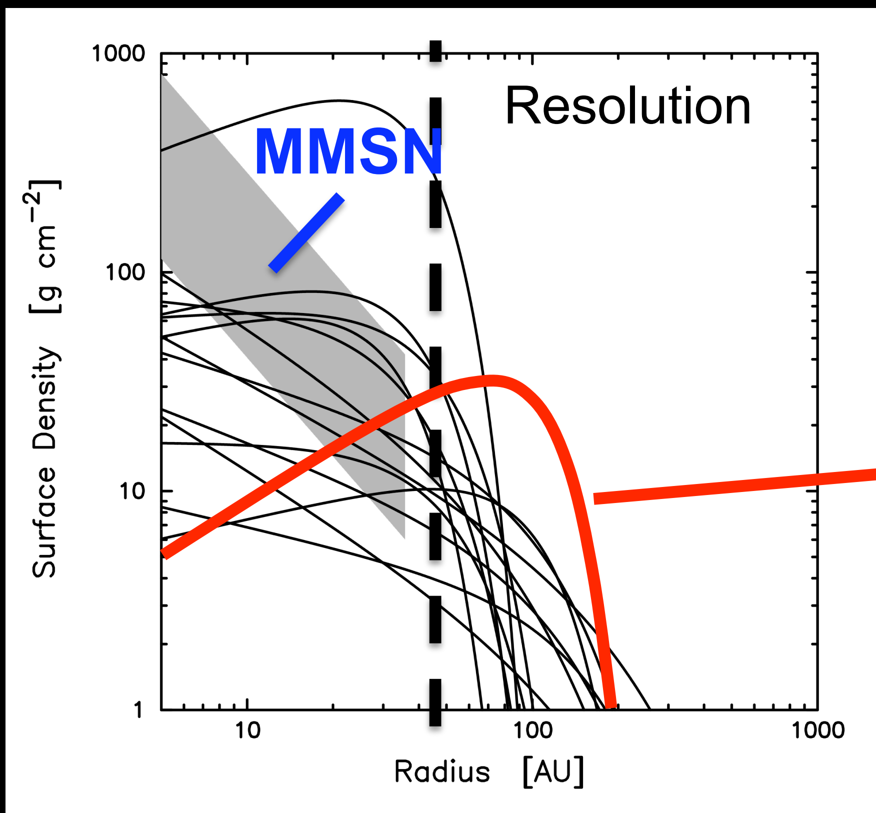
$\gamma = -1$

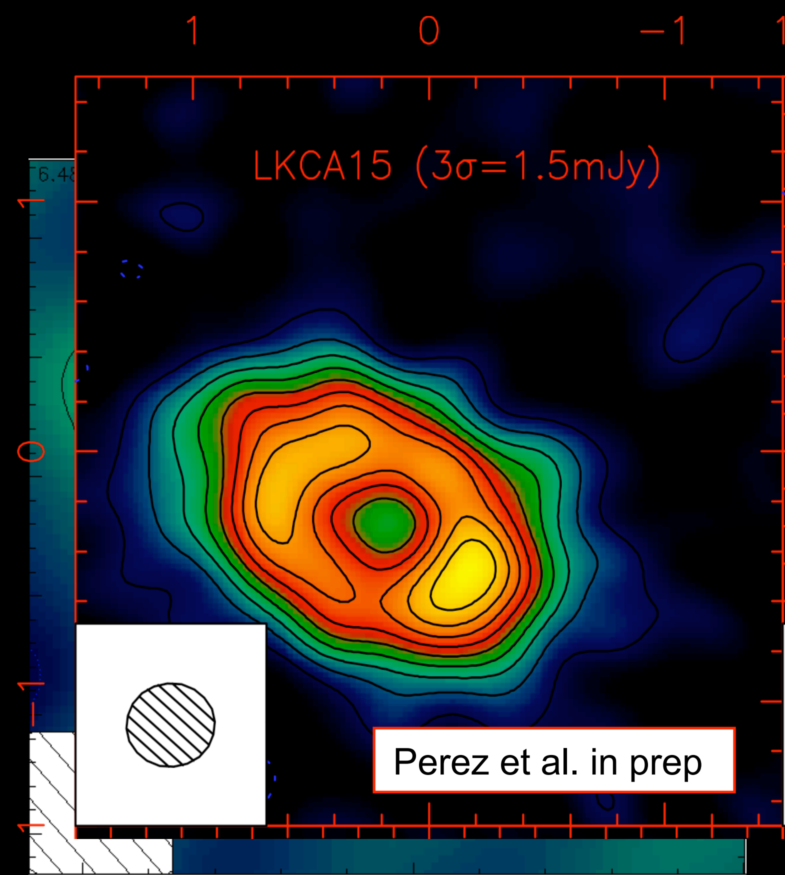
$R_1 = 30$ AU

$M_0 = 0.05\ M_{\odot}$



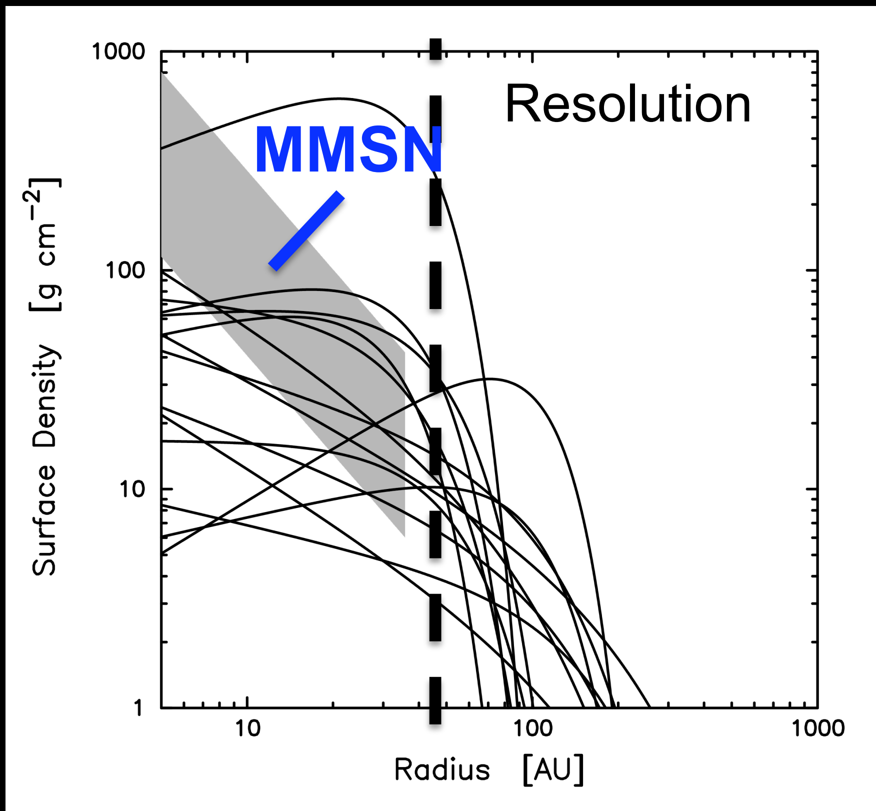
# Surface density



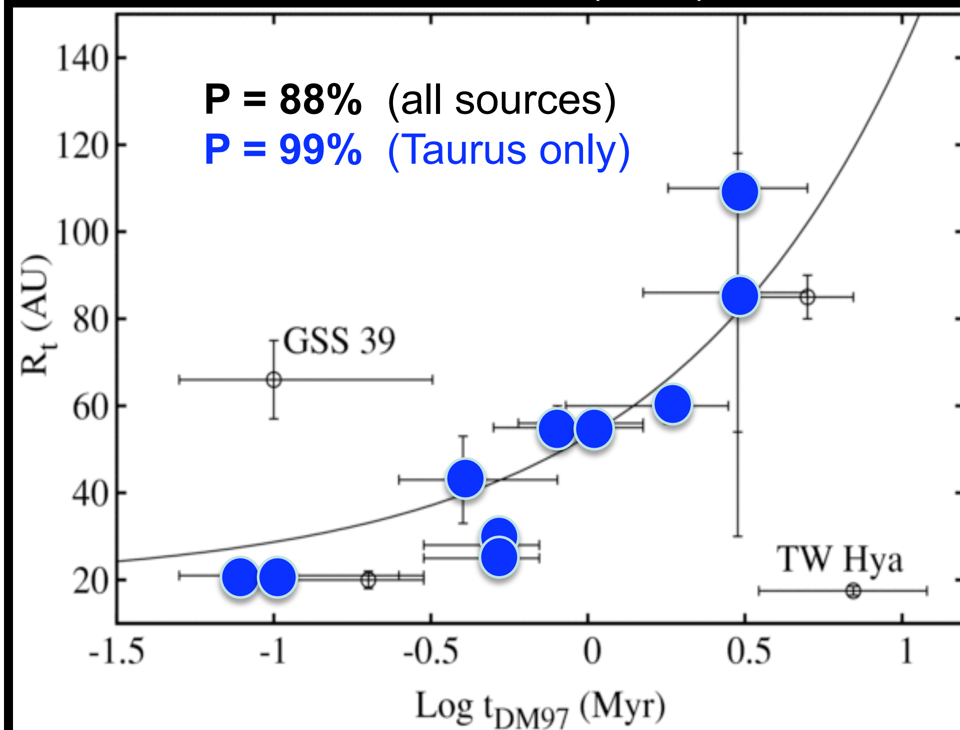




MMSN = Minimum Mass Solar Nebula

# Surface density



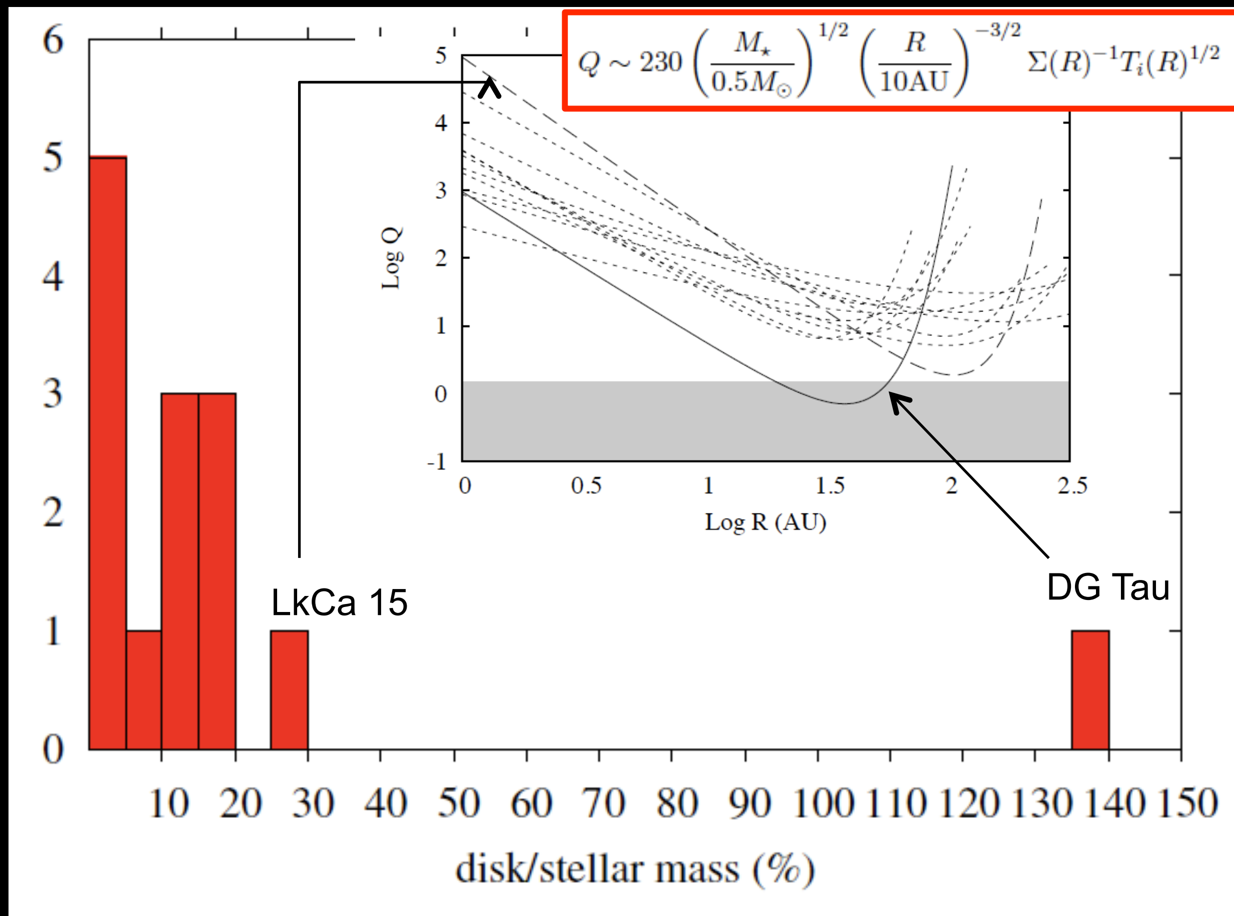

Isella et al. (2009)




$R_{90\%}(t=0) = 50 - 80$ AU
$t_s = 0.1\text{-}0.3$ Myr

MMSN = Minimum Mass Solar Nebula

# Disk stability

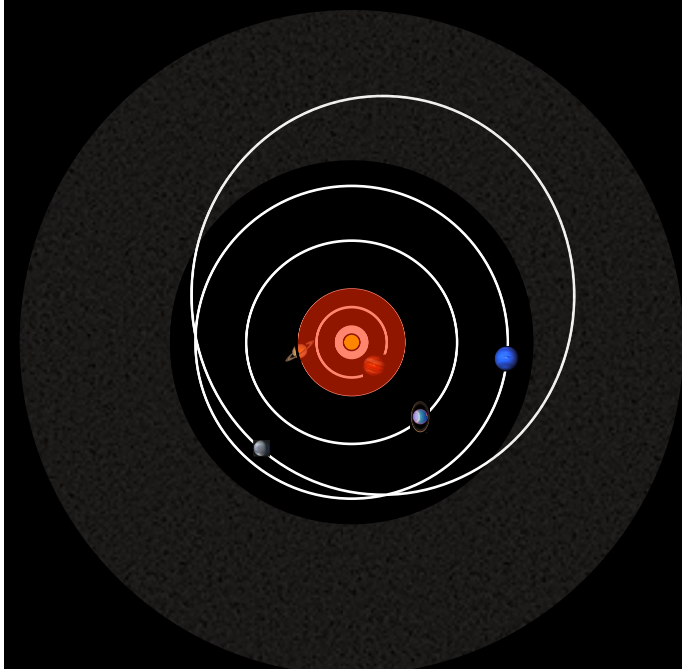


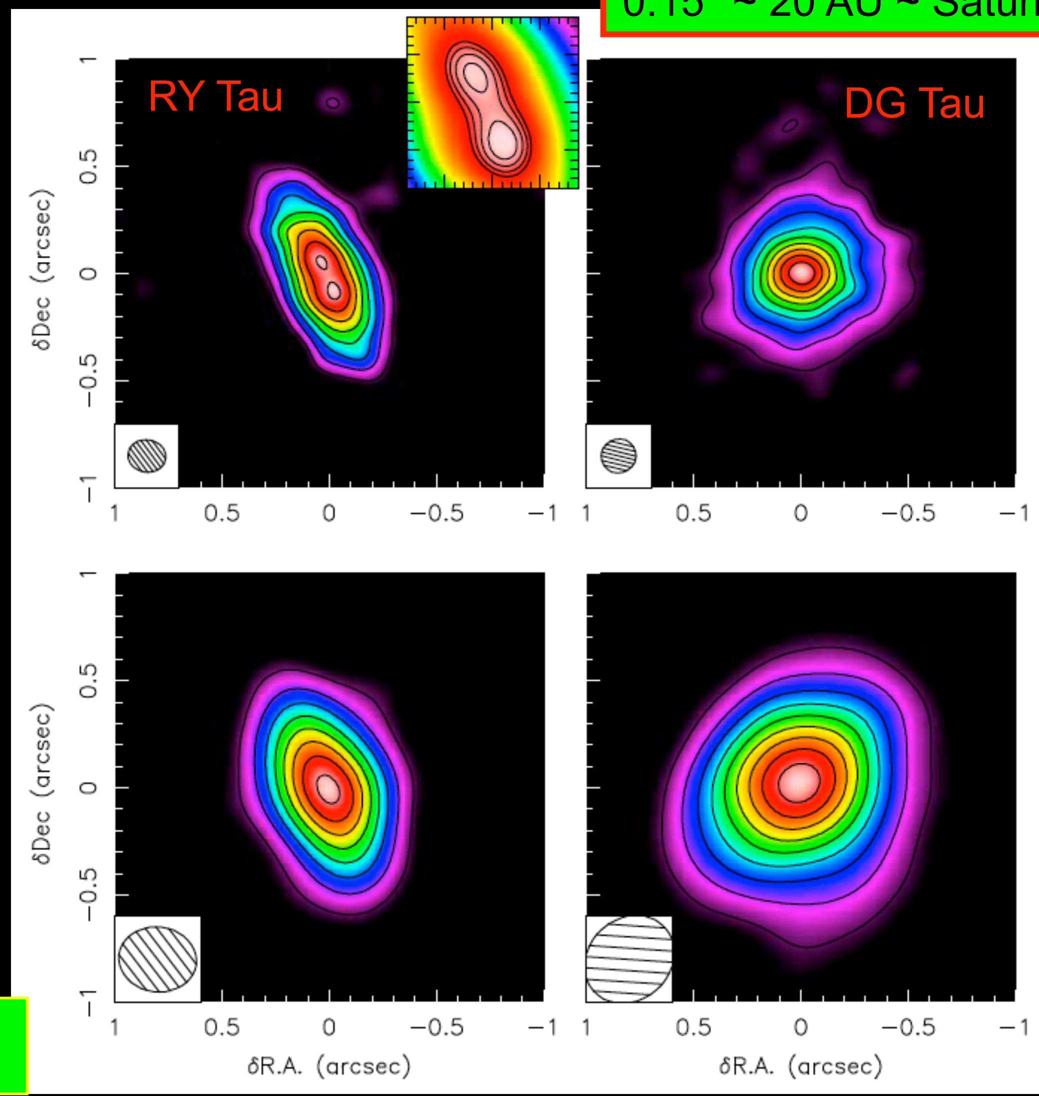

Caveats: dust opacity, stellar mass !

# Disks @ 0.15'' resolution

Isella, Carpenter & Sargent (in prep.)

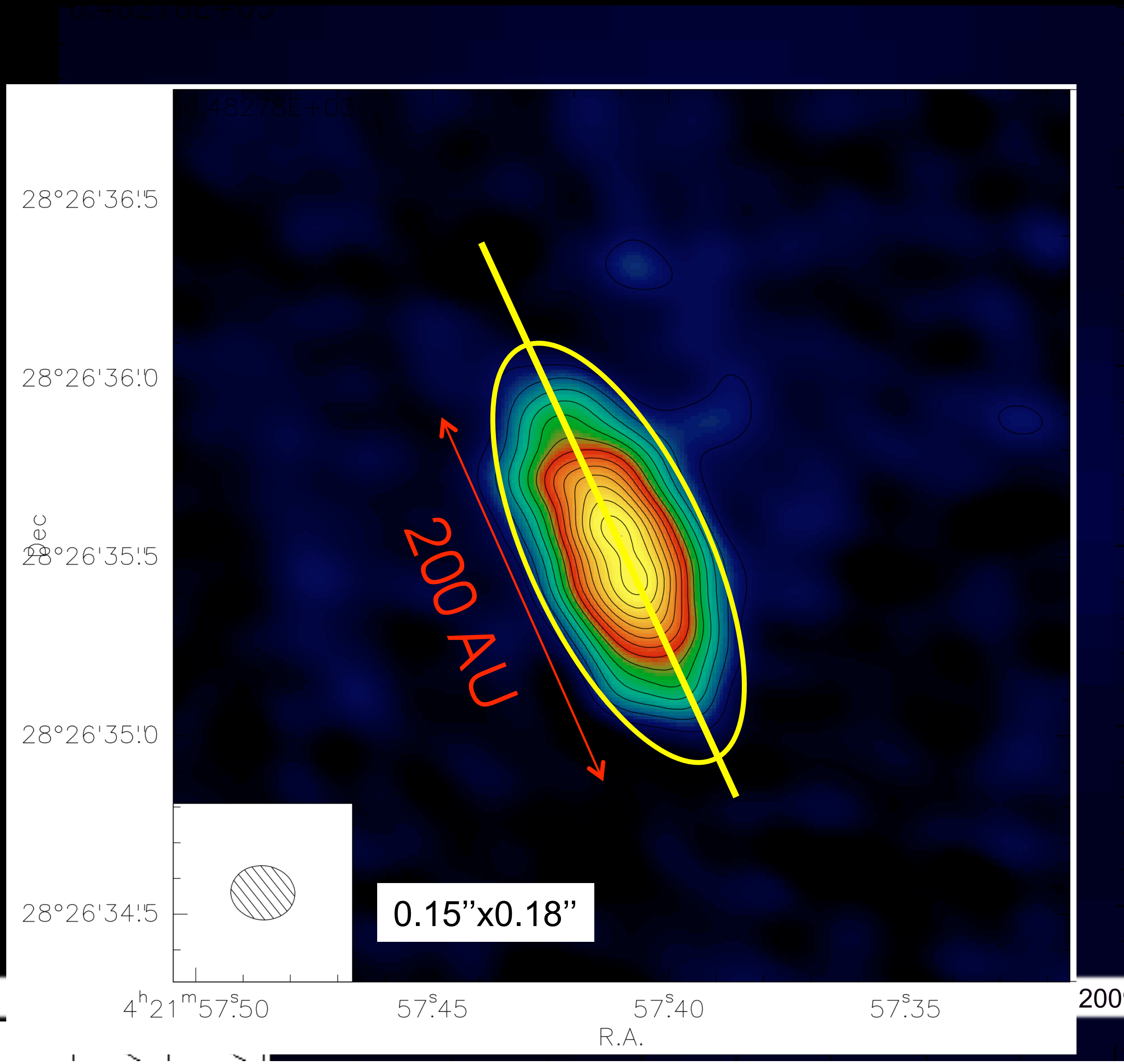
0.15'' ~ 20 AU ~ Saturn orbit





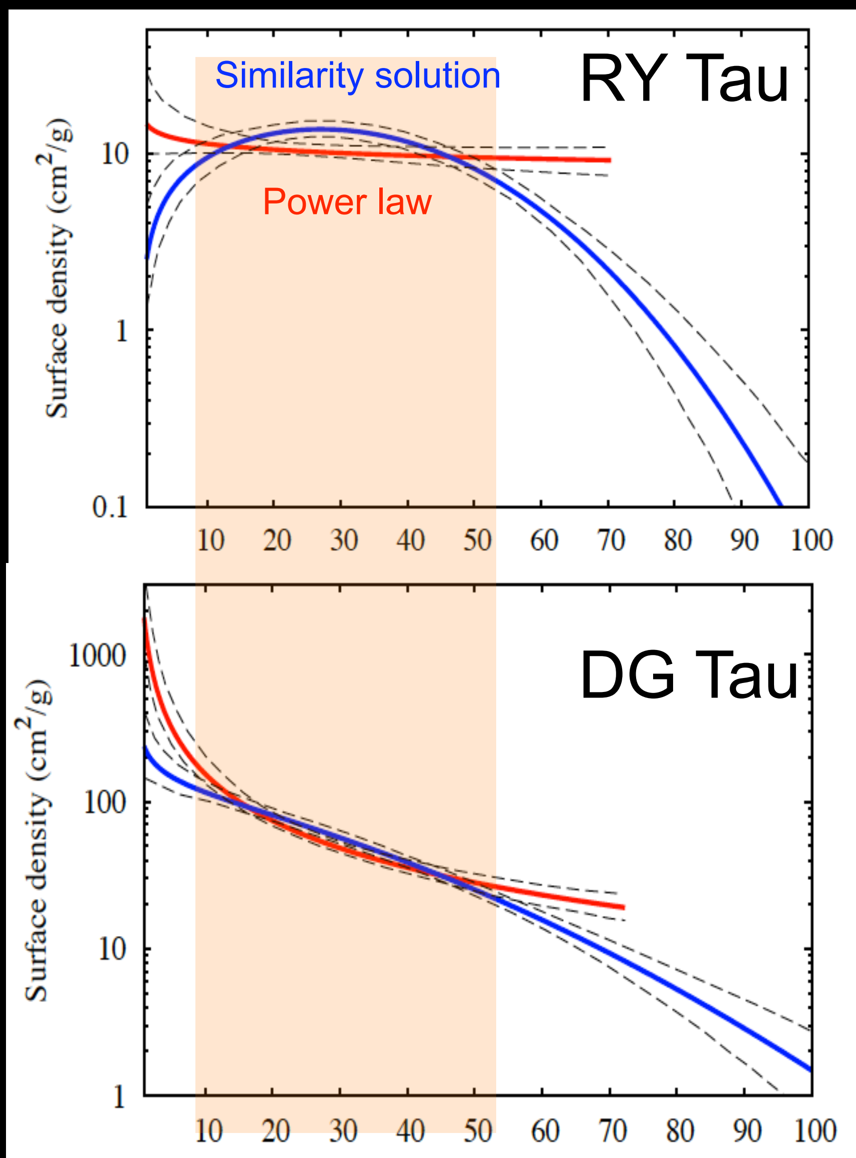

Age < 1Myr

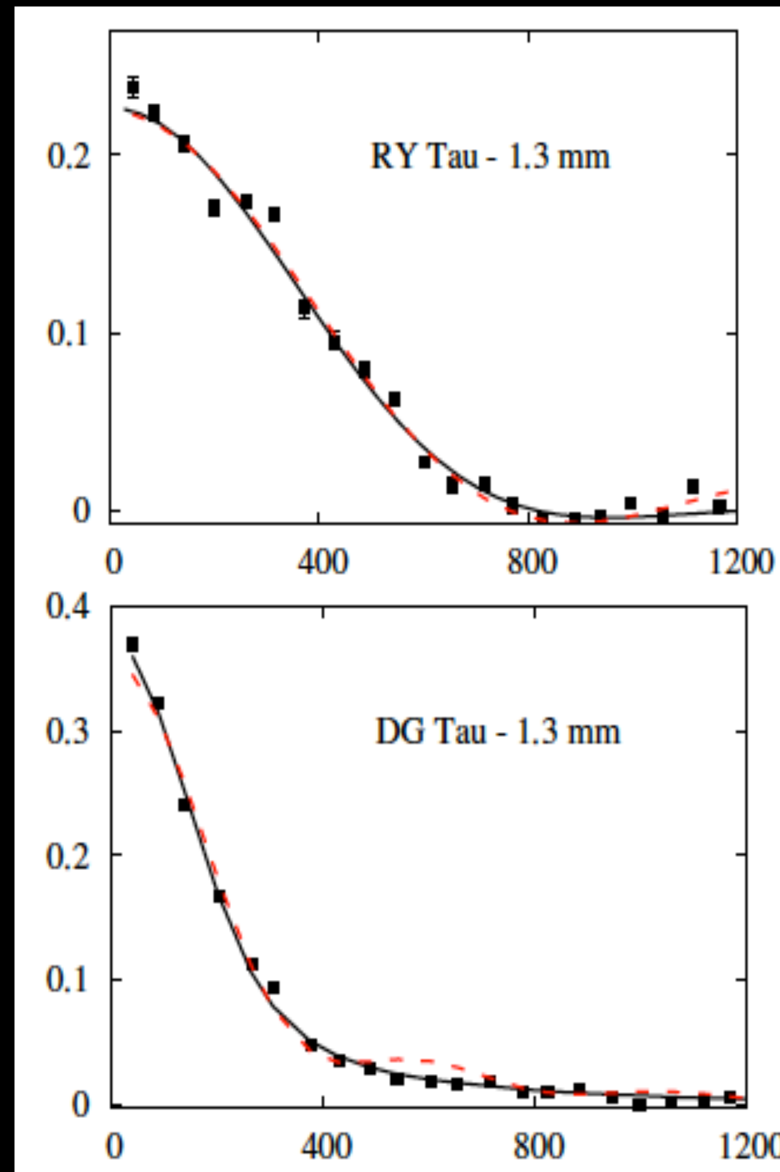
# Example: RY Tau



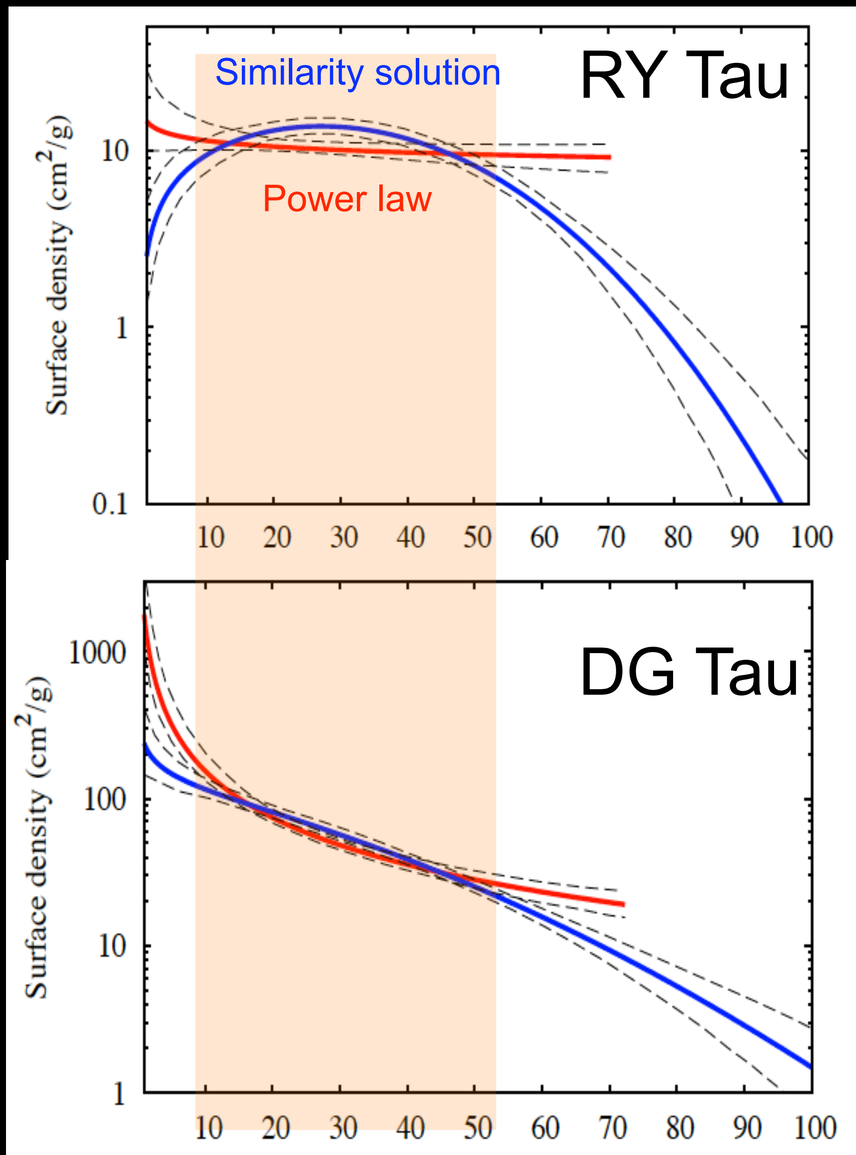

2009

# Disk surface density

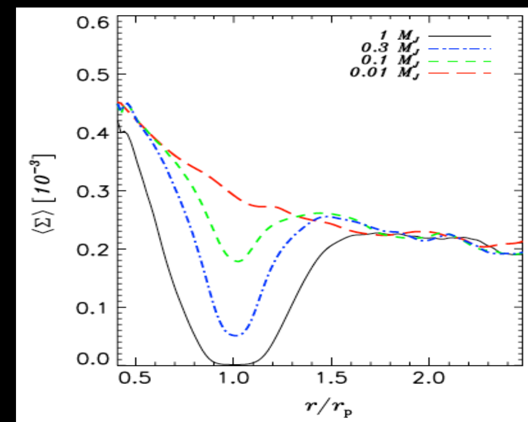


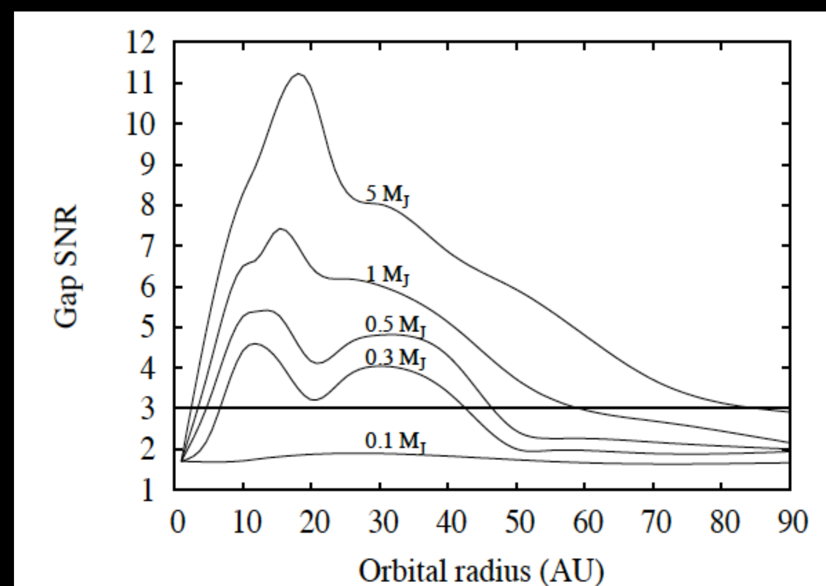



# Presence of planets

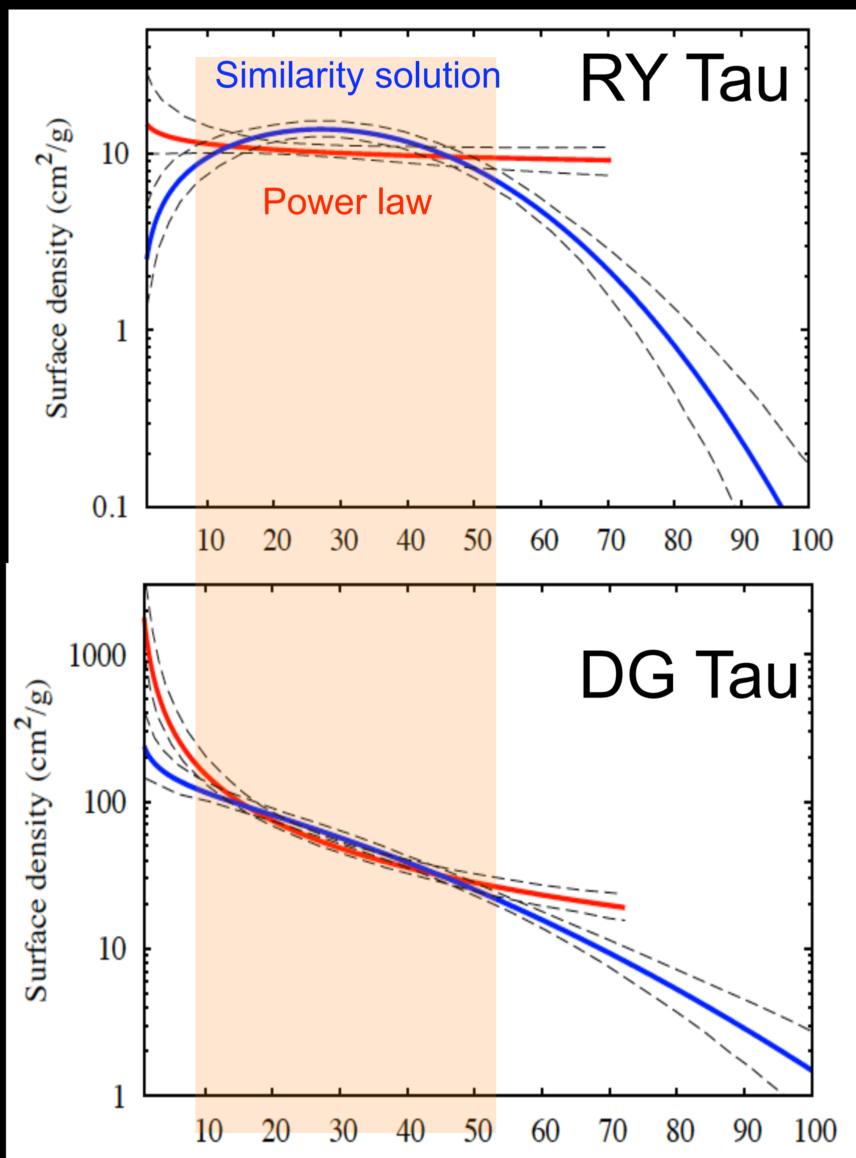


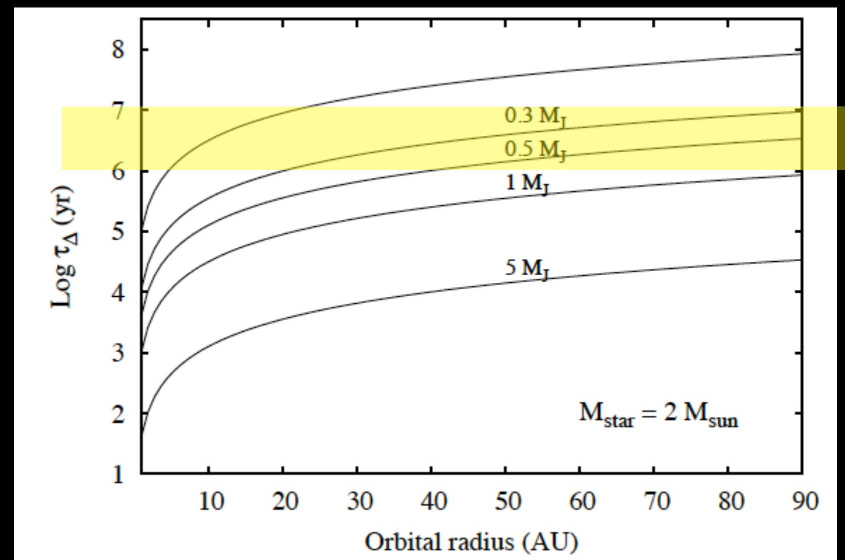

$$\Delta = 2R_p \sqrt[3]{M_P/(3M_\star)}$$

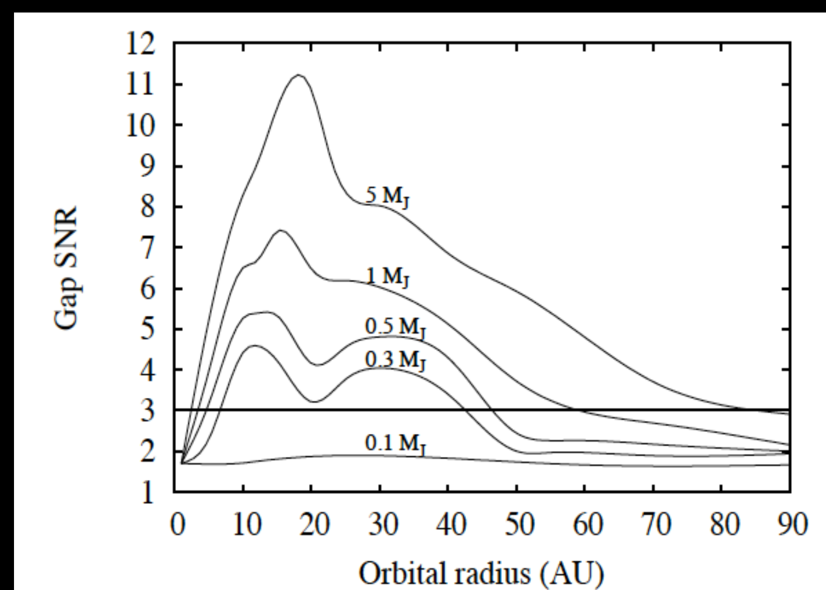


# Presence of planets



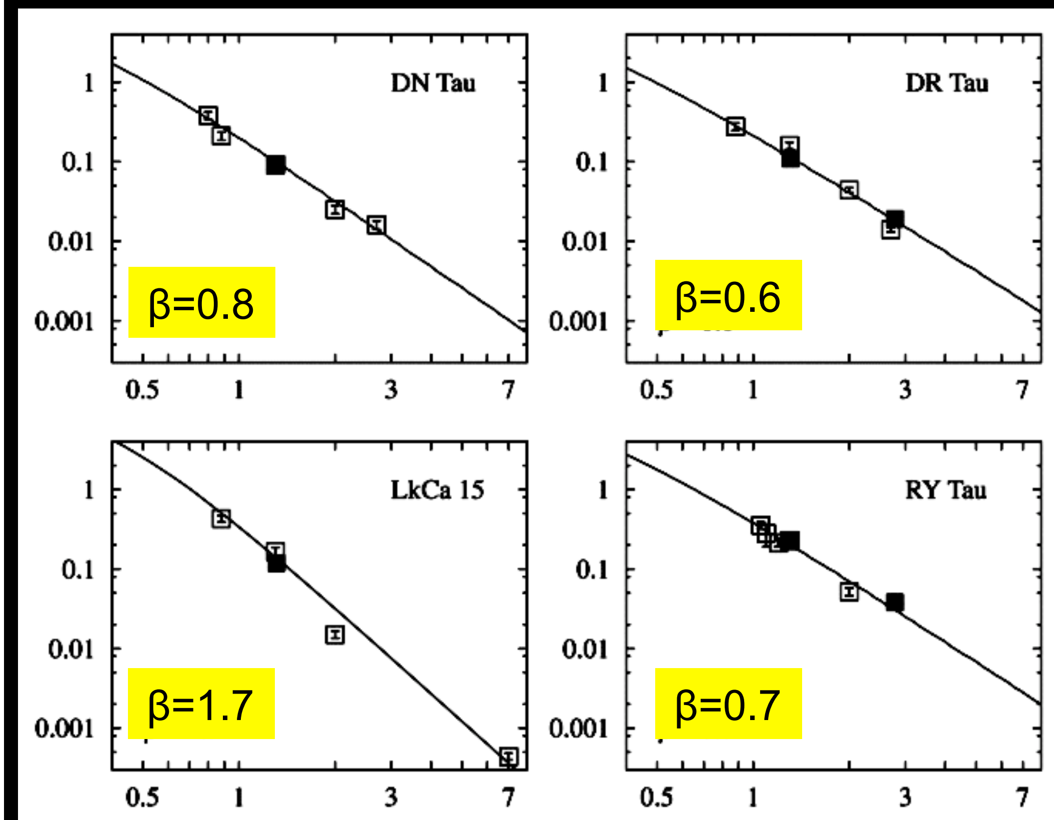



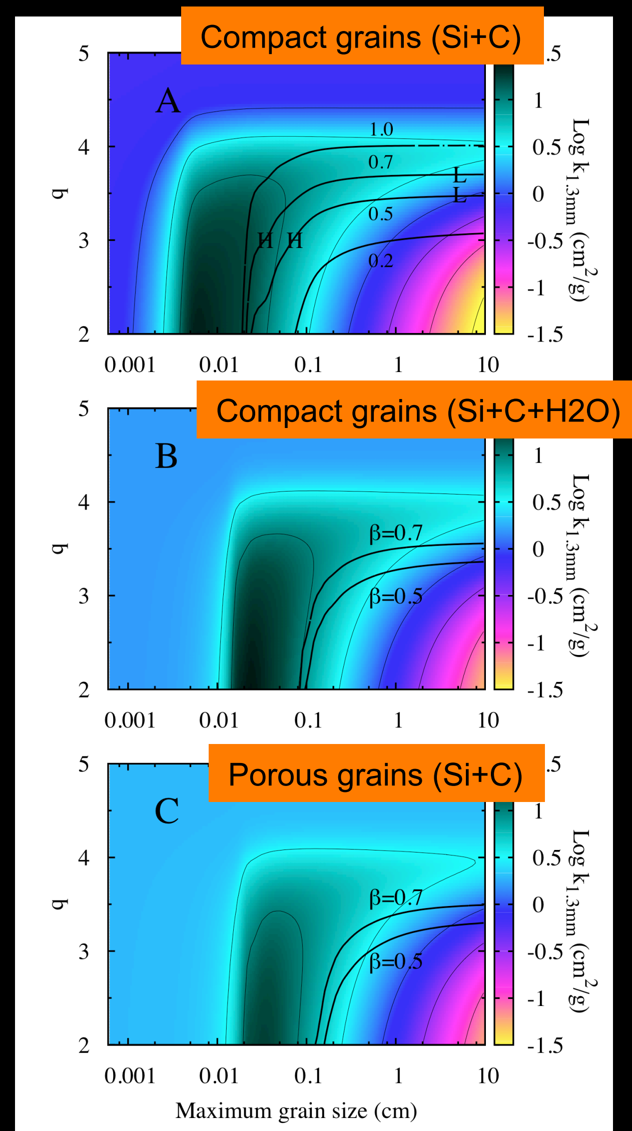
# Grain growth

See, Natta et al. (2007), PPV review

$$k_\nu \propto \nu^\beta \rightarrow F_\nu \propto \nu^{2+\beta+\Delta\beta}$$



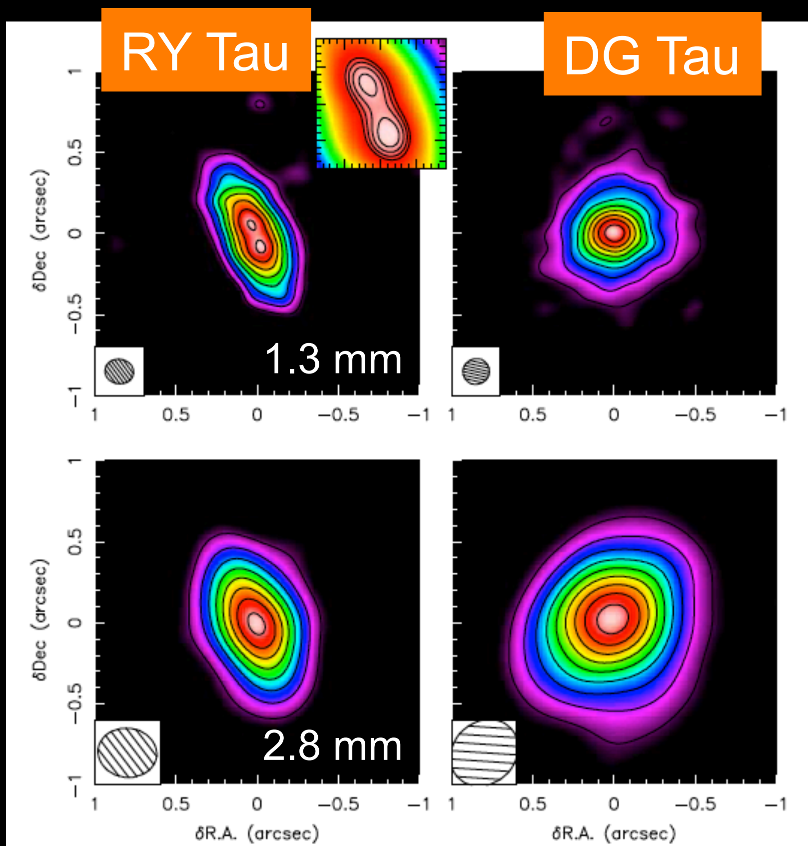

Wavelength (mm)




Isella et al. , in prep.

# Does the dust opacity vary with radius?

$$F_\nu(R) \propto B_\nu(T,R) \cdot \Sigma(R) \cdot k_\nu(R)$$

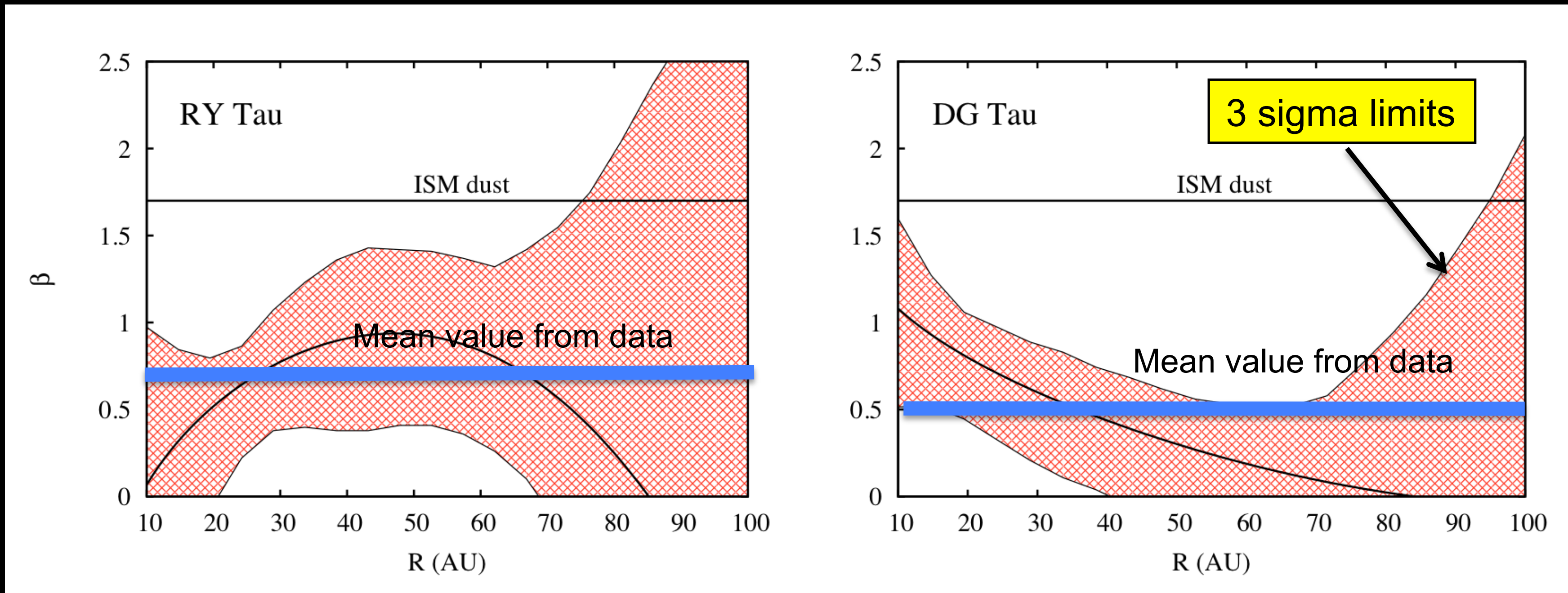



- particle growth (faster in inner disk)
- composition changes (ices in outer disk)

$$k_{1.3}(R) = k_{2.8}(R)\left(\frac{2.8}{1.3}\right)^{\beta}$$

$$\frac{F_{1.3}(R)}{F_{2.8}(R)} \propto \frac{k_{1.3}(R)}{k_{2.8}(R)} \propto \left(\frac{2.8}{1.3}\right)^{\beta(R)}$$

# Does particle opacity vary with radius?




Isella et al. , in prep.

- β is lower than found for the interstellar medium
- No evidence for radial gradient in β

# SUMMARY

• @ 0.7” resolution:

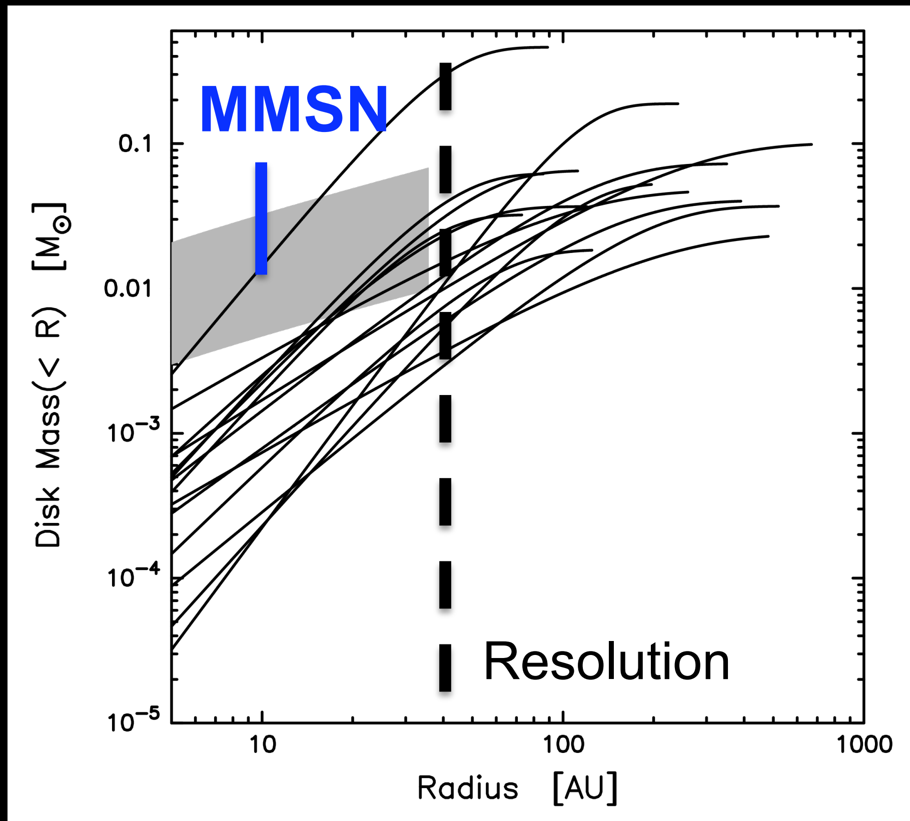
- different surface densities and masses
- the disk radius increases with time

• Angular resolution < 0.3’’ is required to resolve structures in the nearby circumstellar disks.

- A+B+C array observations of DG Tau and RY Tau exclude the presence of planets more massive than Jupiter between 10 and 50 AU.
- Dust in RY Tau and DG Tau has been reprocessed, β=0.5-0.7. This implies grain sizes larger than ~ 1mm. The radial dependence of β can be widely constrained.


Thank you

# Cumulative mass distribution




MMSN = Minimum Mass Solar Nebula

Caveat: dust opacity !