SKA and protoplanetary disks

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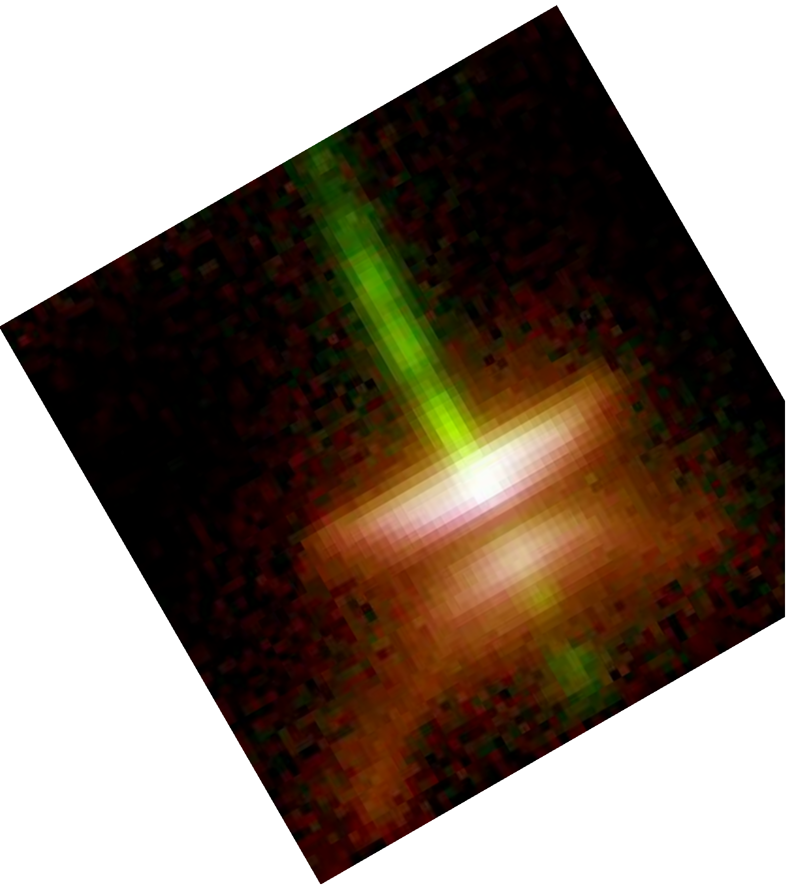
Protoplanetary Disks

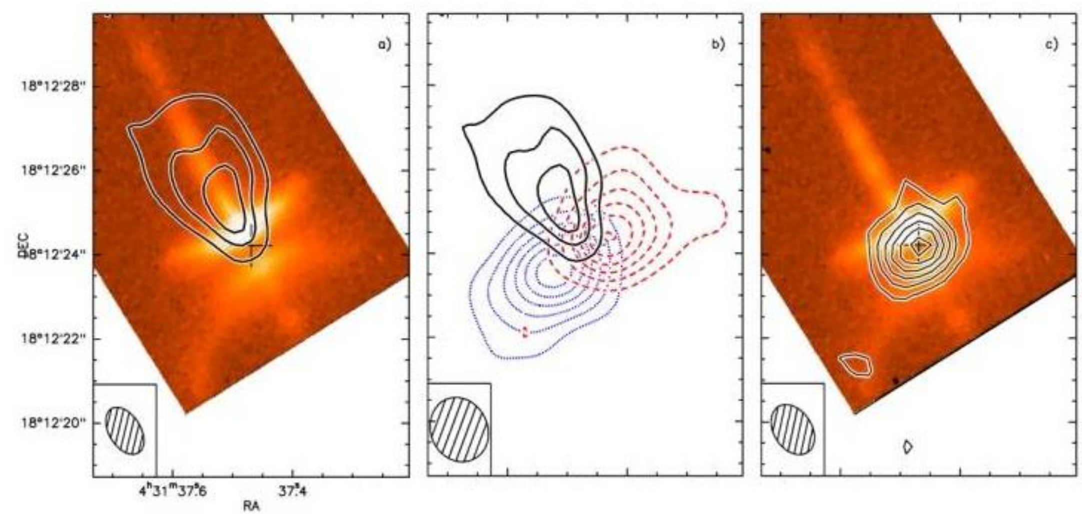
Optical Jet

Molecular Outflow

Keplerian Disks

Dusty Disks





Burrows et al 1996

Pety et al 2006

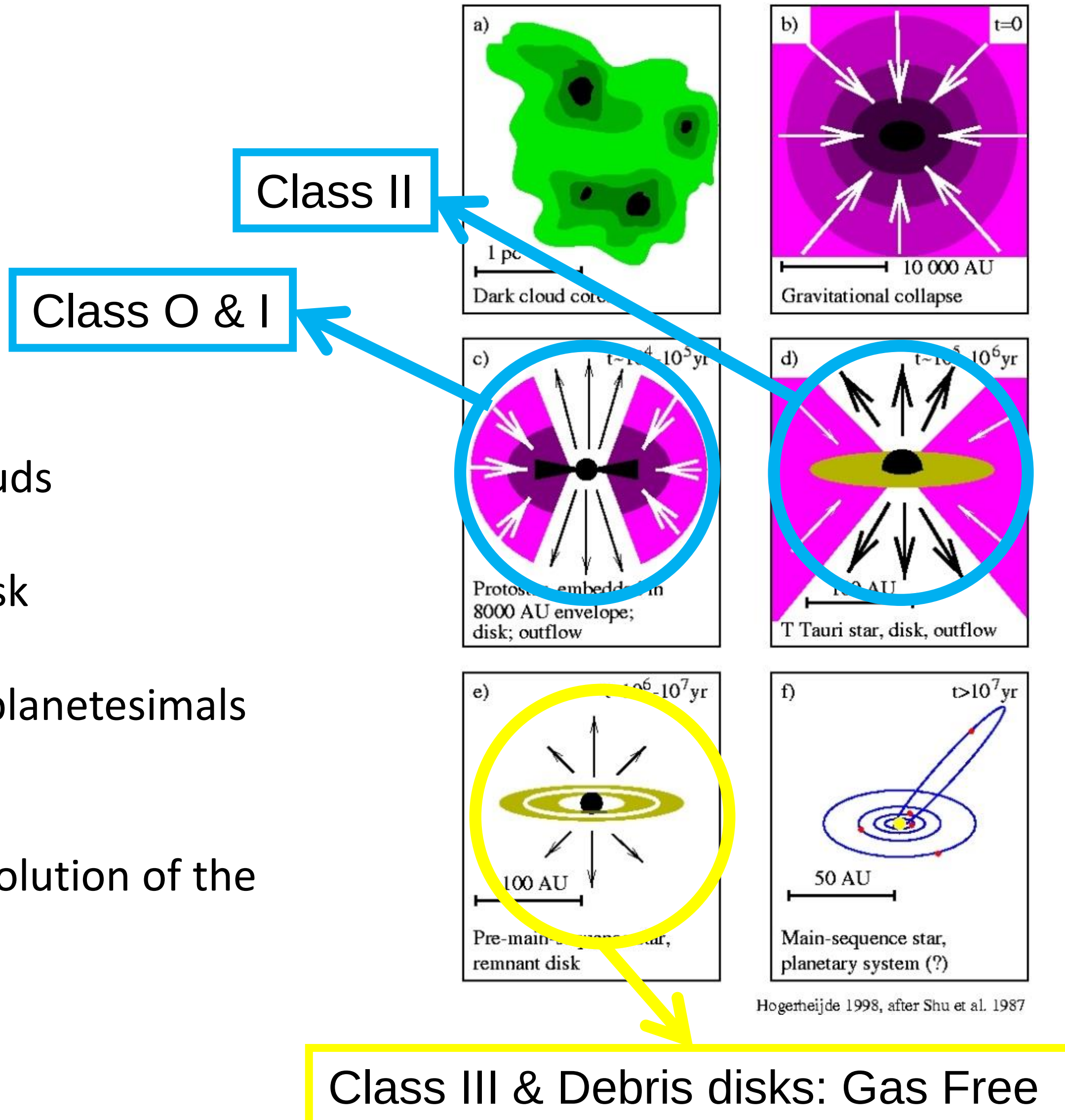
Protoplanetary Disks

Gravitational collapse of rotating clouds

Formation of a rotating, Keplerian disk

Growth of dust grains, formation of planetesimals and ultimately, planetary systems

Dissipation of residual gas, orbital evolution of the planetary systems



Hogerheijde 1998, after Shu et al. 1987

What we would like to know

- When does grain growth start ?
- What is the size distribution of dust grains ?
- How do disks disappear ?
  - Viscous spreading ?
  - Planetary formation ?
  - Accretion onto star ?
  - Photo-evaporation ?
  - Radiation pressure ?
  - Stellar winds (Gone with the wind) ?
- Where is angular momentum going ?
  - Disk winds ?
  - Magnetospheric stellar jets and winds ?
- Molecular Complexity
  - Up to what level ?
  - Before or during the disk phase ?
- Impact of magnetic field ?

What has been done at higher frequencies

- 0.4 - 1'' resolution images of disks in the nearest star forming regions (Taurus – rho Oph, i.e. 100 to 140 pc)
- Sensitivity limited
  - Only the brightest spectral lines: CO, ^{13}CO, and very rarely HCN, HCO^+, CN
  - Only simplest molecules detected. HC_3N is the most complex
  - Very limited studies at the VLA, only continuum emission
- Very limited samples
  - Size measurements of less than 200 objects in continuum, resolving may be 50 disks…
  - Of order 20 disks imaged in CO
  - Other molecules (decently) searched in less than 80 disks, found in less than 30 !..
  - Only half a dozen disks imaged in spectral lines other than CO !..

- ➔ High angular resolution (sub arcsec) + High sensitivity required (< 0.1 K) at 100 m/s spectral resolution for lines

High SKA (> 10 GHz)

- 1 km at 11 GHz ←→ 50 m at 220 GHz
- SKA at 11 GHz ←→ NOEMA at 220 GHz
- Same equivalent collecting area $(D/\lambda)^2$
- Better system noise for SKA (30 – 50 K)
- But lower aperture efficiency (*)
- And of course, loss in bandpass (Doppler width 20 times smaller for SKA than for NOEMA)
- → equivalent sensitivity for spectral line observations

SKA(11) = NOEMA(220)/3 = ALMA(220)/12

(*) noise factor 10 000 m^2/K

Low SKA (1.4 GHz)

- 1 km at 1.4 GHz ←→ 130 m at 11 GHz
- SKA at 1.4 GHz ←→ VLA at 11 GHz
- Same equivalent collecting area $(D/\lambda)^2$
- Poorer system noise for SKA
- Lower aperture efficiency
- And again, loss in bandpass (Doppler width 8 times smaller)
- → sensitivity

SKA(1.4) = VLA(11)/4

- Another comparison: with the 30-m at 90 GHz:
- 1 km at 1.4 GHz ←→ 15.5 m at 90 GHz x sqrt(64) for Doppler width

SKA(1.4) = 30-m(90)/32

SKA(11) = NOEMA(220)/3 = ALMA(220)/12
SKA(1.4) = VLA(11)/4= 30-m(90)/32

- « High » SKA
  - In spectral lines, may be able to use at best 1’’ spatial rsolution, if an efficient array configuration is available, with typical baseline lengths of 7 to 15 km.
  - Can do somewhat better for imaging of thermal emission from dust, perhaps down to 0.2 to 0.3’’, with an efficient configuration of 30 to 50 km.
  - With a few hours per source…
  - Some source multiplexing is possible thanks to field of view (but not always)

  - BUT… spectral lines between 10 and 25 GHz are much fainter than around 220 GHz !...(*)

  - ZERO to study molecular complexity (currently limited to HC_3N as the most complex detected molecule in disks so far…).
  - And extremely limited to study even the most « complex » detected molecules (C_3H_2, HC_3N)

- « Low » SKA
  - NOTHING in spectral lines (or almost…)

(*) As an example, NH_3 is detected in one disk by Herschel (3.6 m at 550 GHz), but still not with the VLA (130 m at 23 GHz)…

The real questions that SKA can address

- Photo-evaporation : search for HI
  - May require a thousand (may be only one hundred) hours per source, but provides a unique information
  - If SKA can integrate that long before being limited by systematics
  - Potentially interesting for medium mass stars (2-3 solar masses)

- Size of large dust grains
- Spatial segregation of dust with size
  - But cannot reach the ALMA resolution…
- Ionized jets and/or stellar winds (more or less collimated) ?
  - Configuration 100-300 km

Disentangle free-free emission from thermal dust emission

In the Spectral Energy Distribution

Rodmann et al 2006

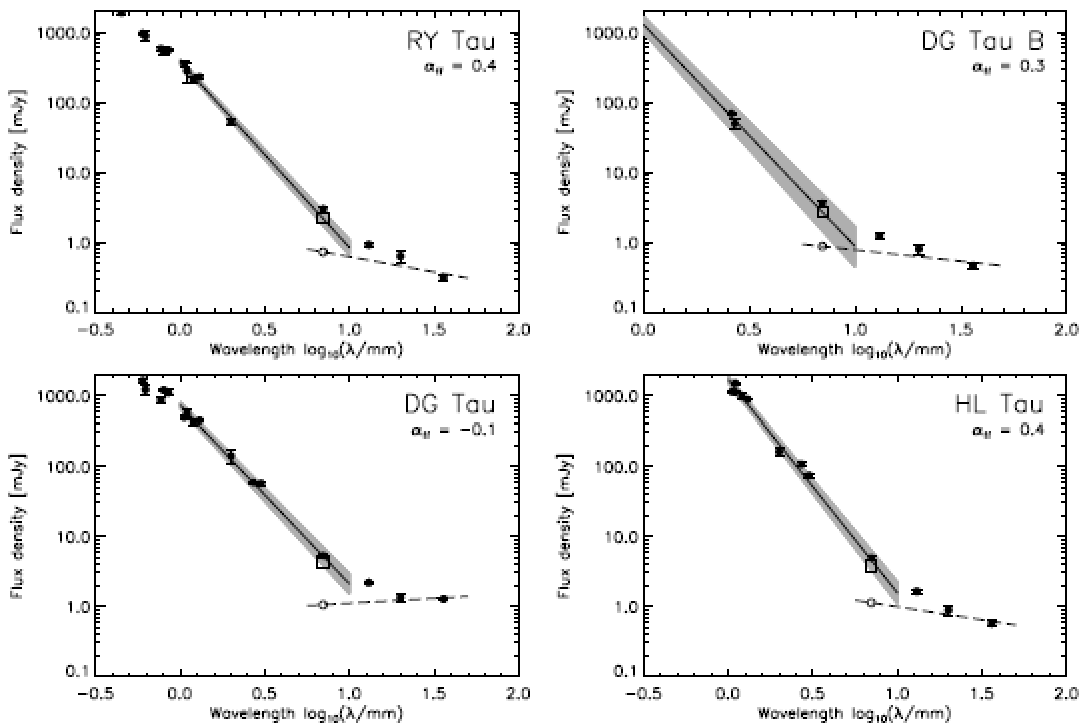


Fig. 3. Free-free emission contribution to 7-mm flux densities. The dashed line represents the fit to the centimetre fluxes, assuming that 50% of the 1.3-cm emission arises from free-free radiation. The square depicts the corrected 7-mm flux after subtraction of the estimated free-free contribution (shown as open circle). The thick line shows the power-law fit to the millimetre data; the shaded region indicates the uncertainty range for the 1–7 mm slope. Data points shortwards of λ = 7 mm were compiled from the literature (Table 5).

Disentangle free-free emission from thermal dust emission

But also spatially

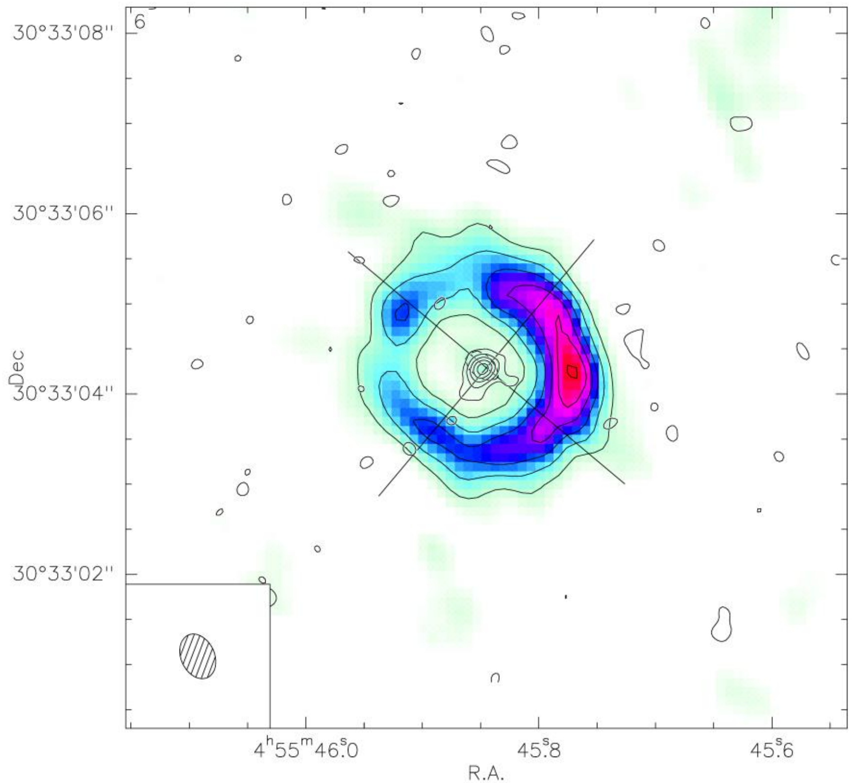
A dust ring seen at 220 GHz by the IRAM array

3.6 cm (VLA) emission perpendicular to the ring major axis (i.e. aligned with disk rotation axis derived from spectral lines)

Jet along disk axis?
Or Companion ?

See also HL Tau, Rodriguez et al 1994

AB Aur (Tang et al 2012, Pietu et al 2005)



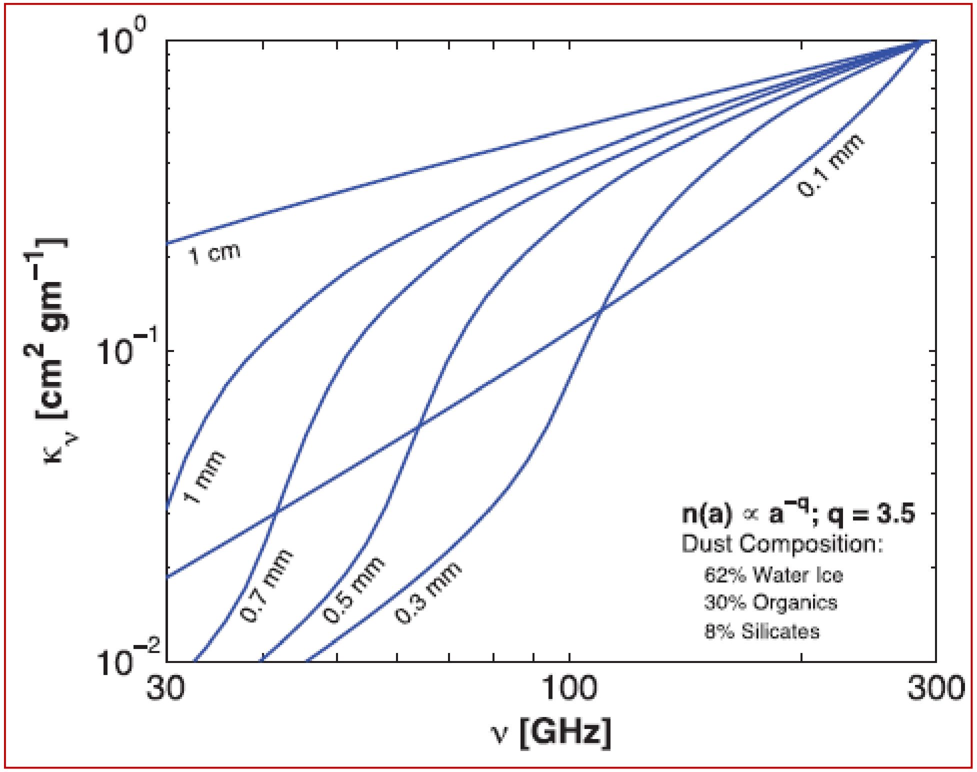
Grain Growth

The slope β is an indication of grain size (small grains have β about 1.5 2, large grains tend towards β = 0)

The frequency at which the slope changes quickly is an indication of maximum grain size

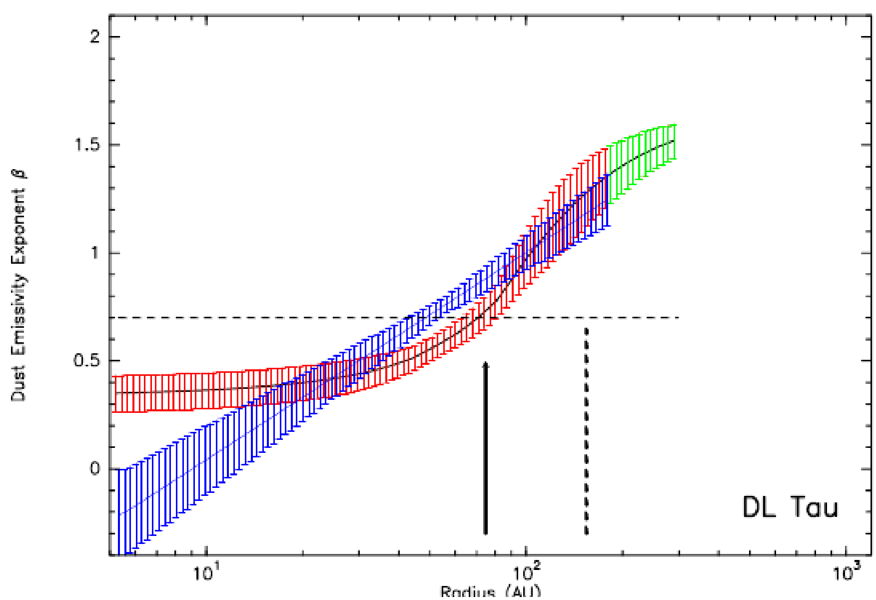
> 1 cm ➔ < 10 GHz

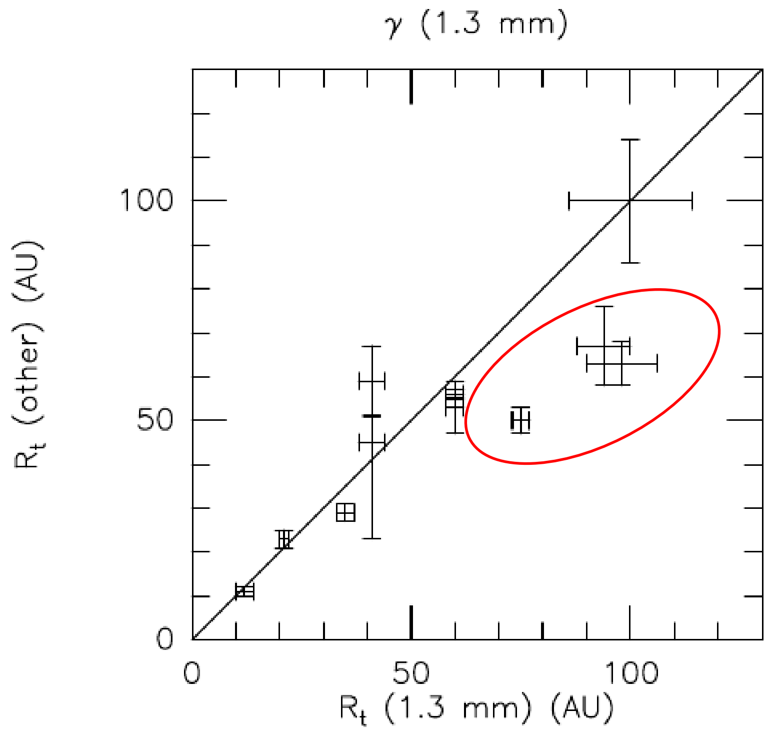
Beware of free-free contribution



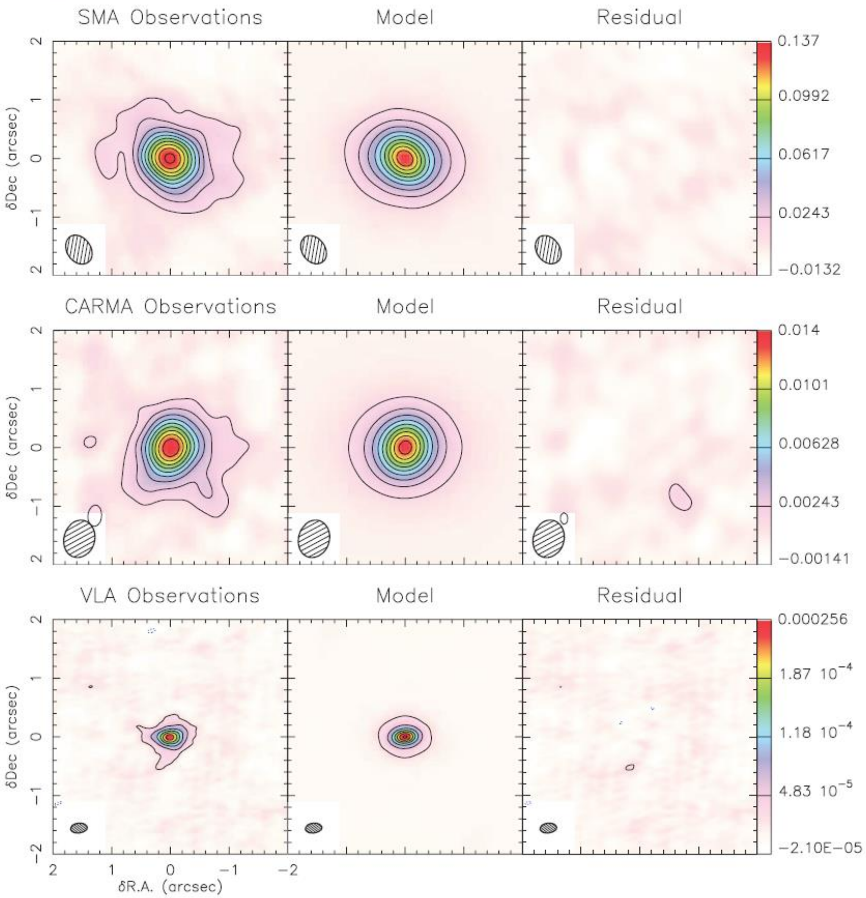
Radial dependency of Grain Growth

- Disks appear smaller at 3 mm than at 1.3 mm ➔ β(r) is variable
- β(r) ~ 0.5 for r < 30 AU,
  > 1 for r > 100 AU
- Down to what radius ?





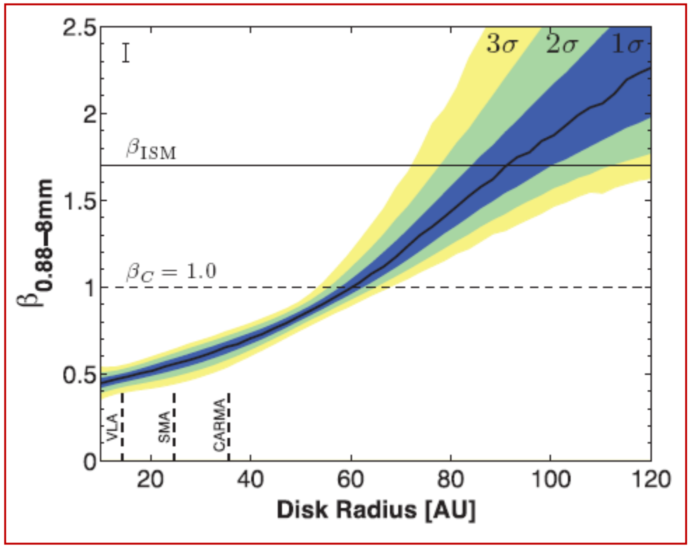
Guilloteau et al 2011
IRAM



AS 209

SMA, CARMA + VLA

Perez et al 2012



A (large) population of small disks

« faint » disks ➔ SMALL disks

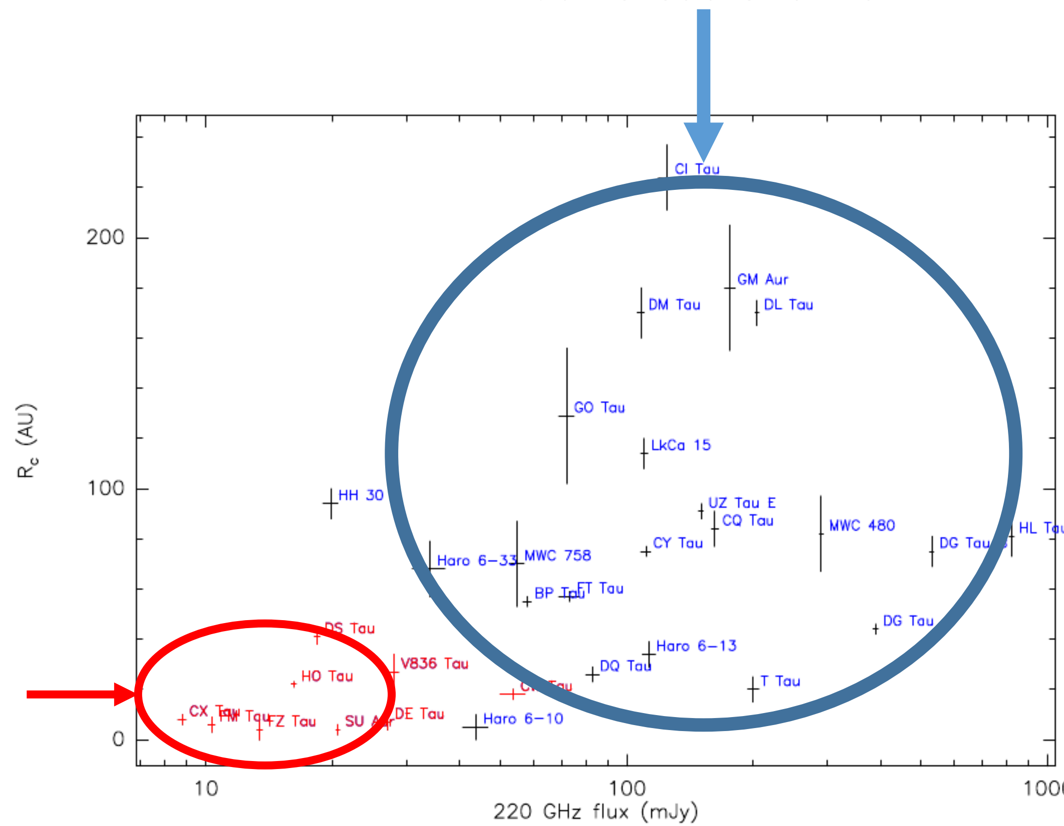
All with apparent β = 0

Very large grains ?

Or optically thick dense disks ?

25 % of the disk population…

« Usual monsters »
Guilloteau et al 2011



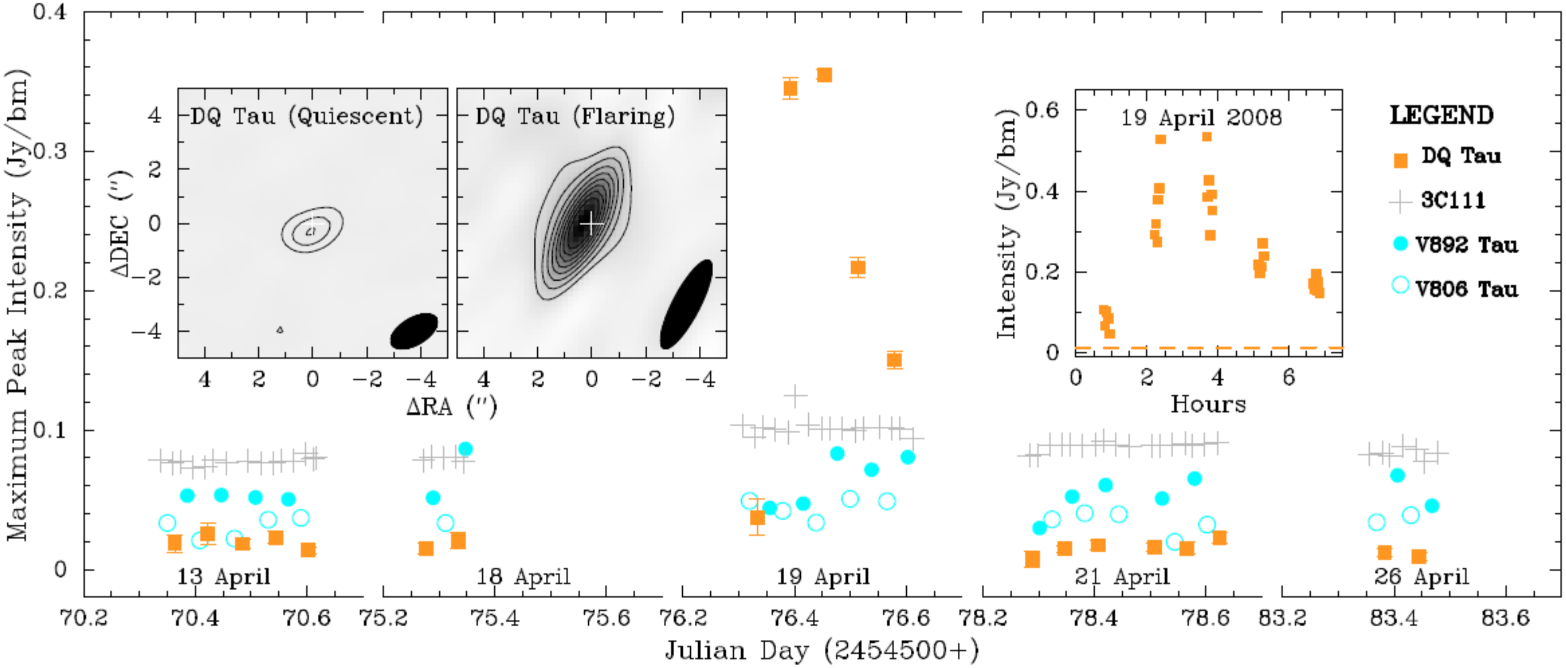
Small « normal » disks
Piétu et al 2014

Polarized dust emission

- Expected due to grain alignment with magnetic field
- Not yet detected in disks
- Frequency dependence ?
- A new field
- Within reach of SKA near 10 GHz, if free-free contribution can be adequately removed
- Even perhaps at longer wavelength (with same caveat)

Disk – star interaction

Salter et al 2008: DQ Tau mm burst



- Non-thermal emission
- Variability at all wavelengths
- Interaction between magnetospheres in young binary systems (DQ Tau, Salter et al 2008, V 773 Tau, Dutrey et al 1996)

- Correlation between optical activity and free-free emission ?

Conclusions

- Disentangle free-free from thermal emission from dust
  - If not already (partially) done with the EVLA
  - Or as a by-product of more general surveys (although high spatial resolution is required)
- Constrain dust grain size distribution
  - As above, but more difficult problem
  - Sensitivity depends on array configurations
- May be detect HI coming from photo-evaporation
  - No other instrument will do that
  - Very difficult, perhaps not feasible…

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Forget about the « craddle of life » …