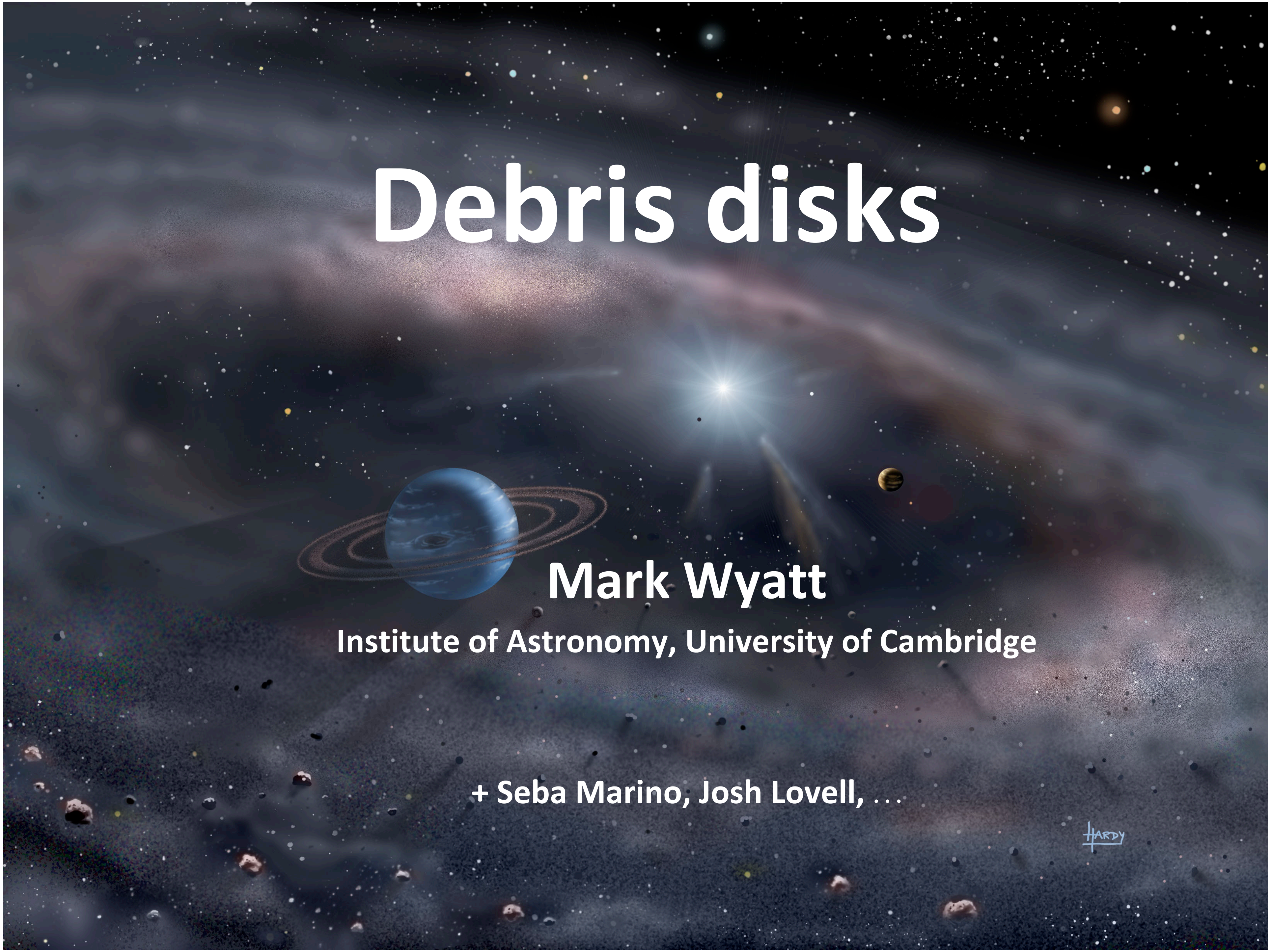


# Debris disks


**Mark Wyatt**

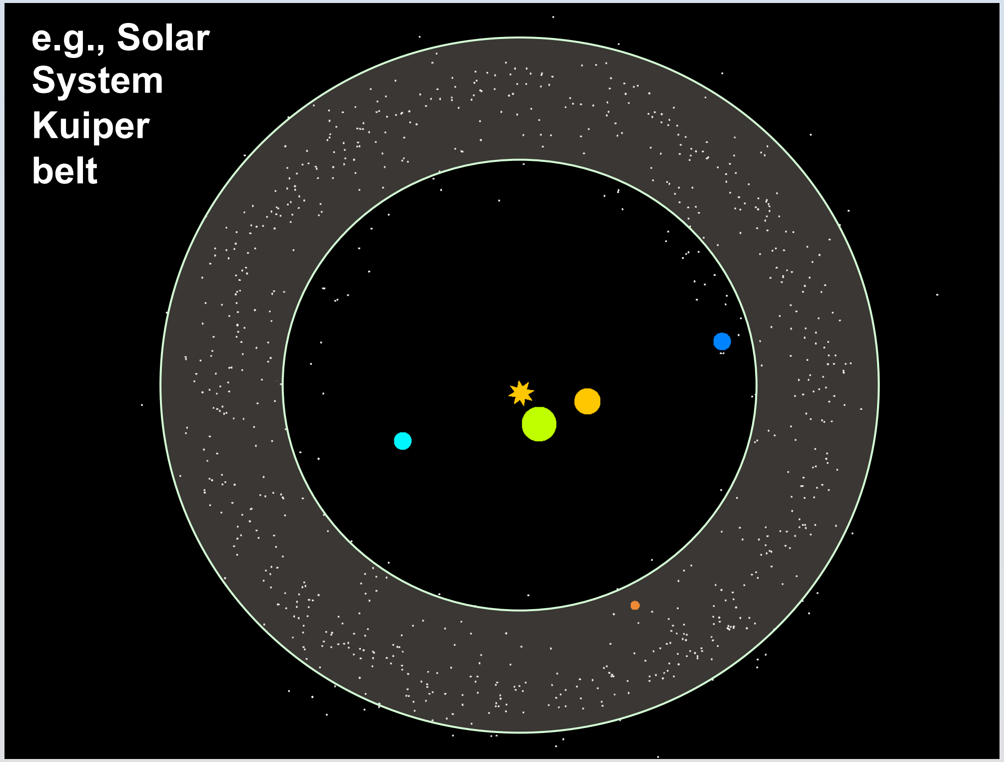
**Institute of Astronomy, University of Cambridge**

**+ Seba Marino, Josh Lovell, ...**

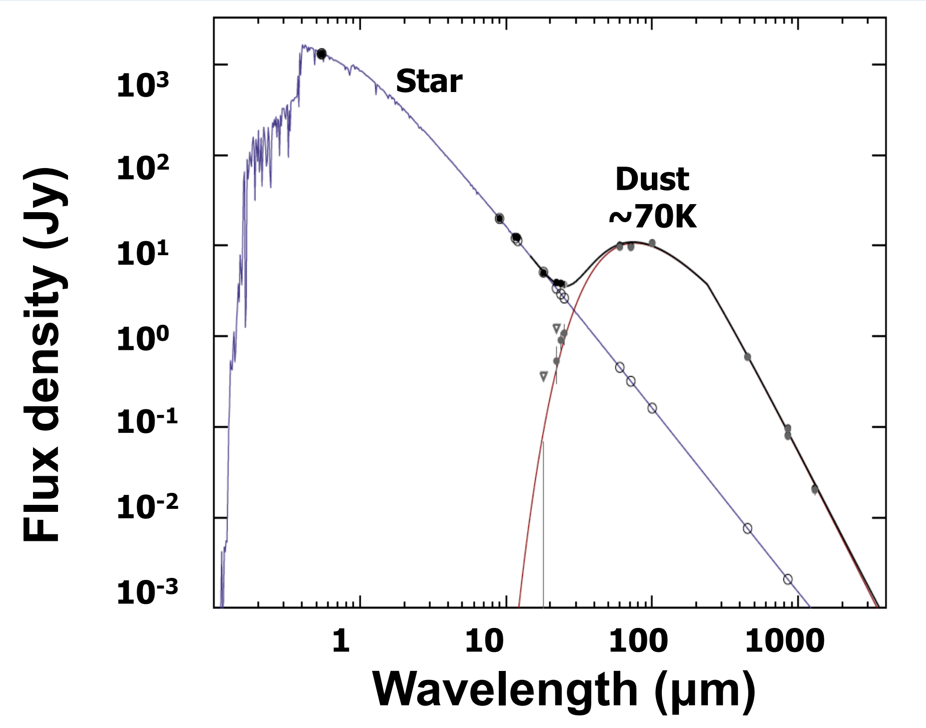
# What is a debris disk?

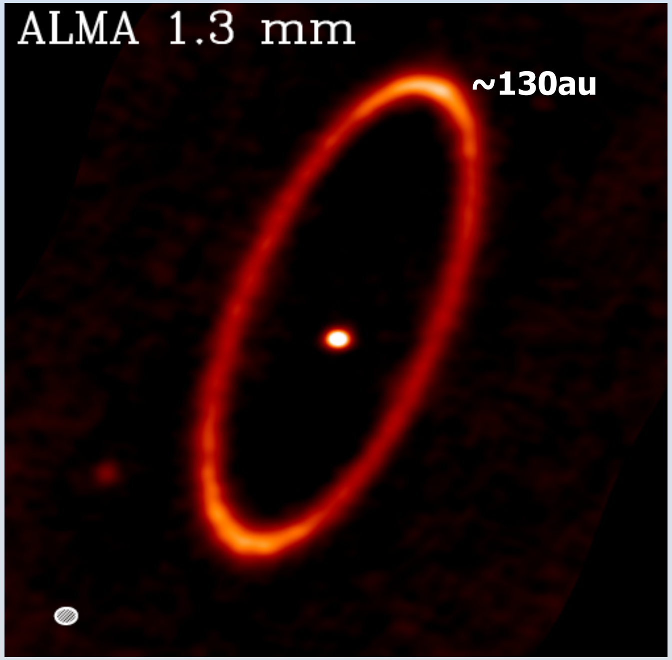
Non-planetary component of a planetary system

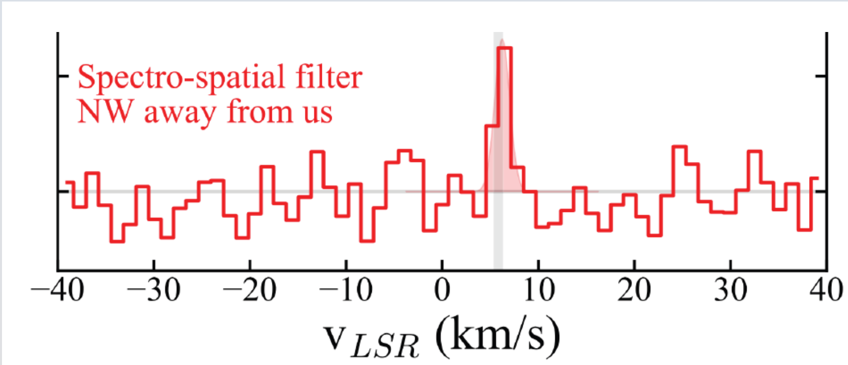
Descendant of a star's protoplanetary disk



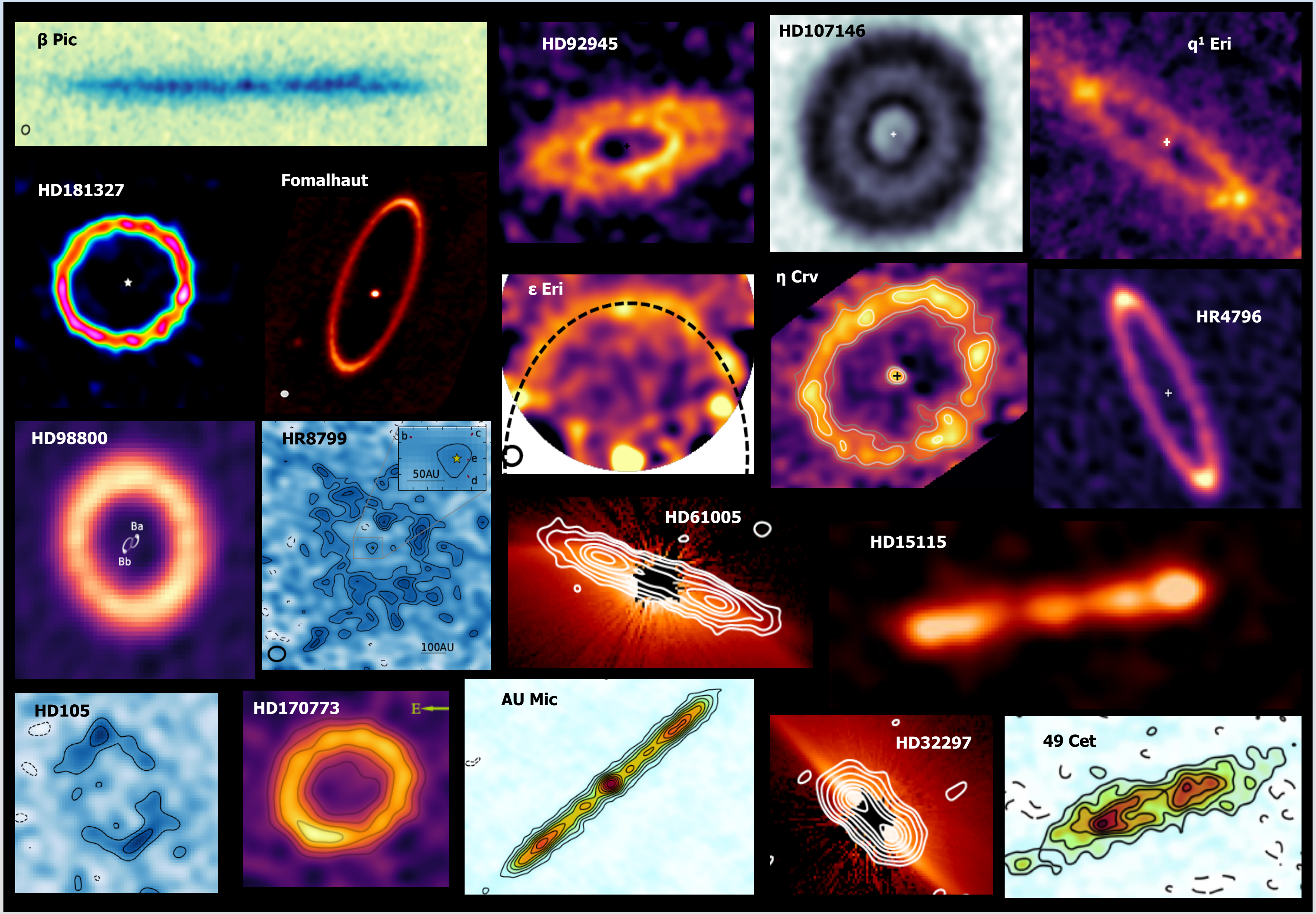

# How to detect a debris disk



# ALMA Gallery



# What we can learn from debris disks

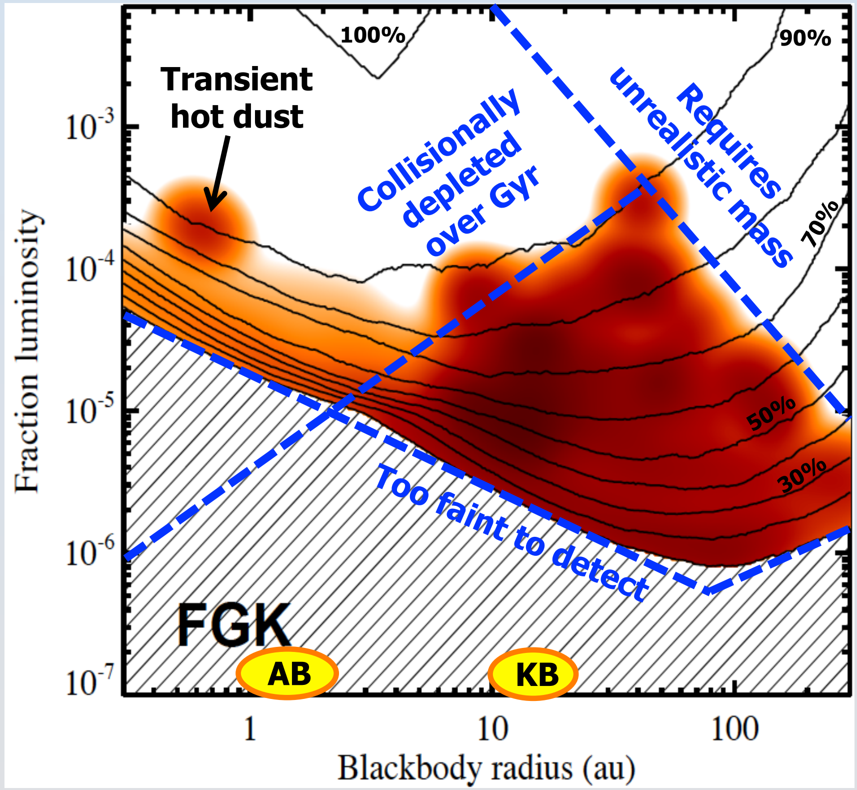
- Where do planetesimal belts form?
- How big are the planetesimals?
- What are the planetesimals made of?
- Does protoplanetary gas disk remain after disk dispersal?
- When did planetesimal belts form?

# Where do planetesimals form?

Far-IR photometric surveys find 20% of stars have detectable dust emission

Colour shows fraction of stars with excess emission in that region of parameter space

Distribution of known disks well understood

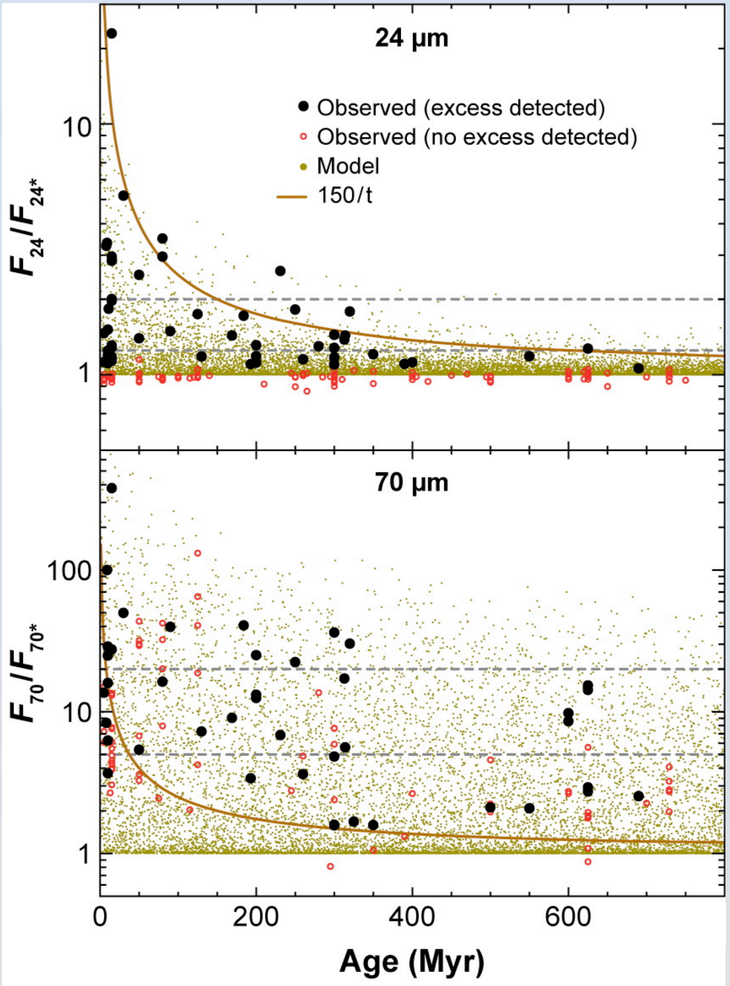



Wyatt et al. (2007); Sibthorpe et al. (2018)

# Where do planetesimals form?

Observations vs age explained by population model:

- all stars have a planetesimal belt that is ground down in collisions
- radii drawn from power law distribution 3-120au
- masses from log-normal distribution centred at $10M_{earth}$




Wyatt et al. (2007)

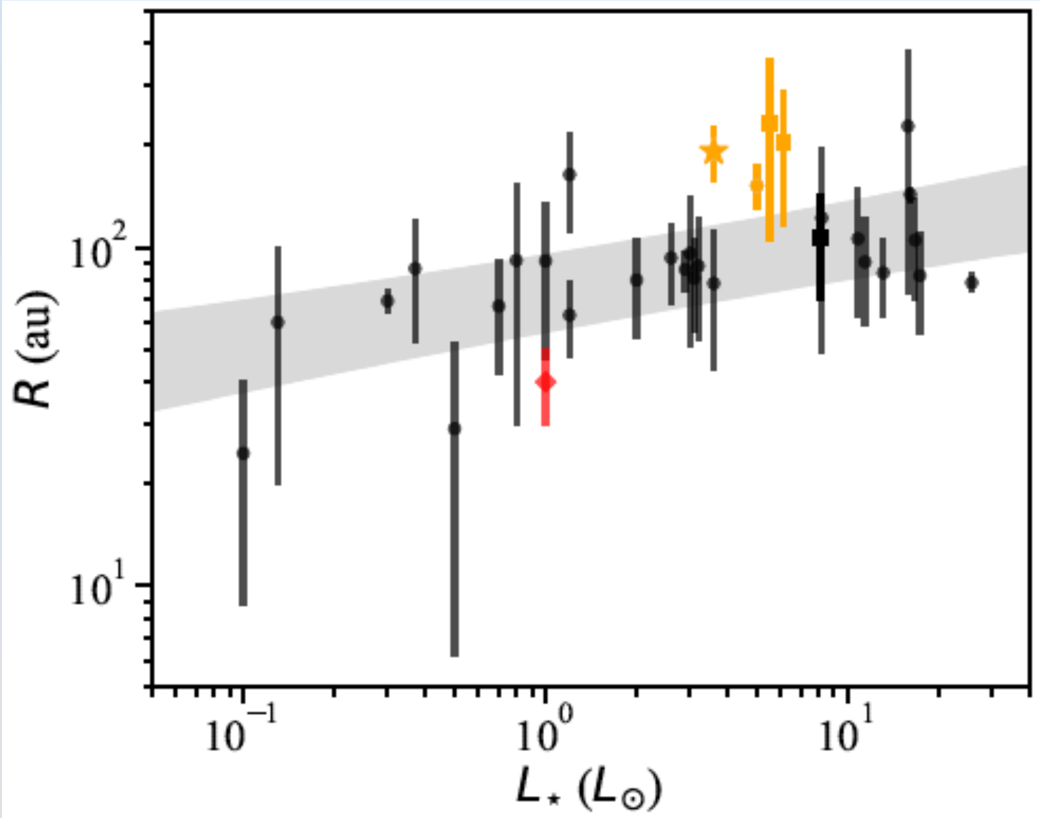
# Where do planetesimals form?

ALMA shows radii of planetesimal belts, often in narrow(ish) ring, but **see Marino talk**

Belt radius correlates with $L_*$

Is this linked to snow-lines in protoplanetary disks or orbits of massive planets?

Or to structures seen in protoplanetary disk images?

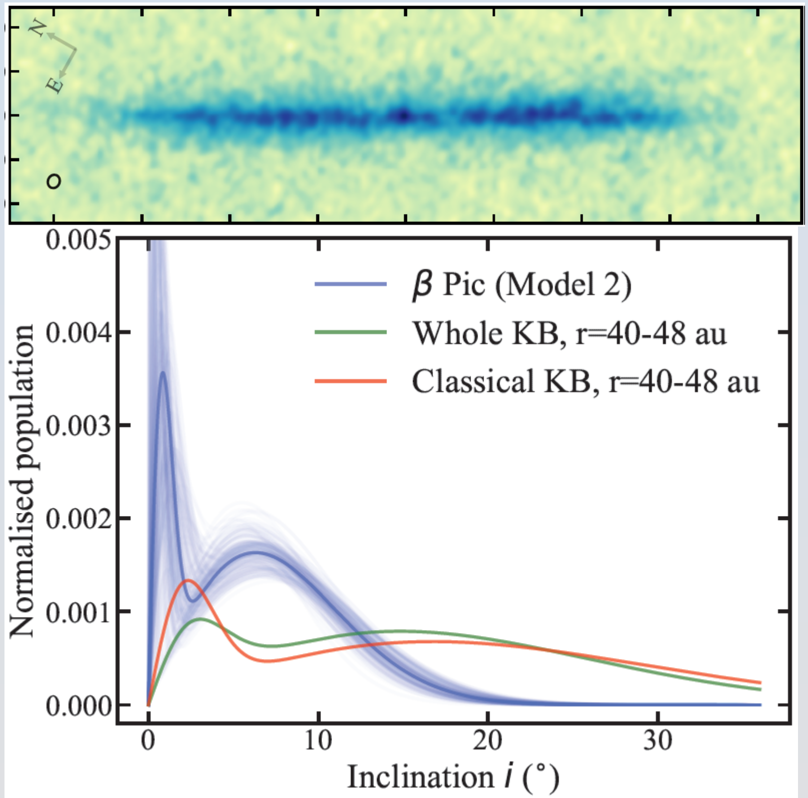



Matra et al. (2018); Sepulveda et al. (2019)

# How big are the planetesimals?

Collisional models imply >10km, but degenerate with strength and level of stirring

Disk vertical structure resolved by ALMA shows for β Pic a cold+hot inclination distribution (Matra et al. 2019)



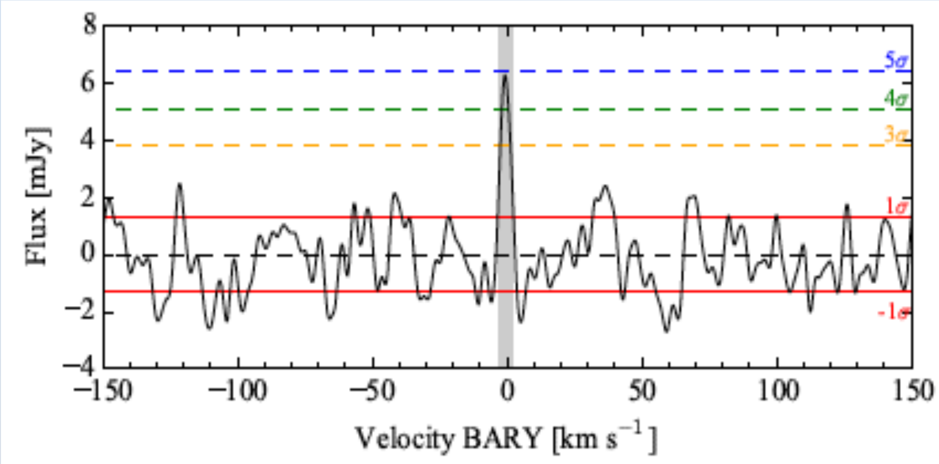

Other measurements of H/R are 0.03-0.08 for AU Mic, HR4796 and HD181327 (Marino et al. 2016; Kennedy et al. 2018; Daley et al. 2019), implying stirring by ~400km bodies (if not externally or born stirred)

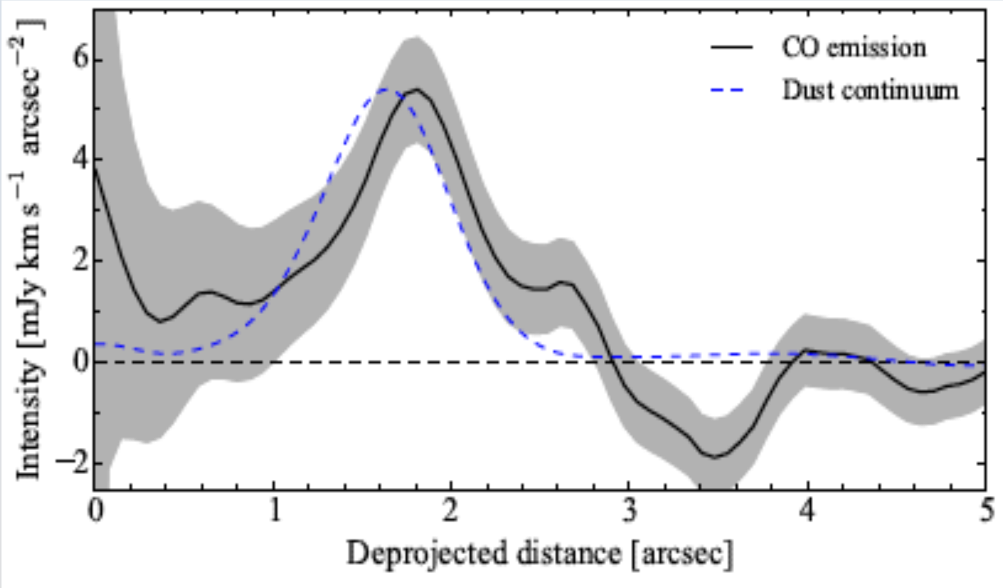
# What are planetesimals made of?

CO detected to HD181327 coincident with planetesimal belt

$M_{CO} = 2x10^{-6}M_{earth}$, but CO photodissociates in ~120 years, so must be continually replenished (i.e., it is secondary)

~20 debris disks now with CO detected (from all spectral types)

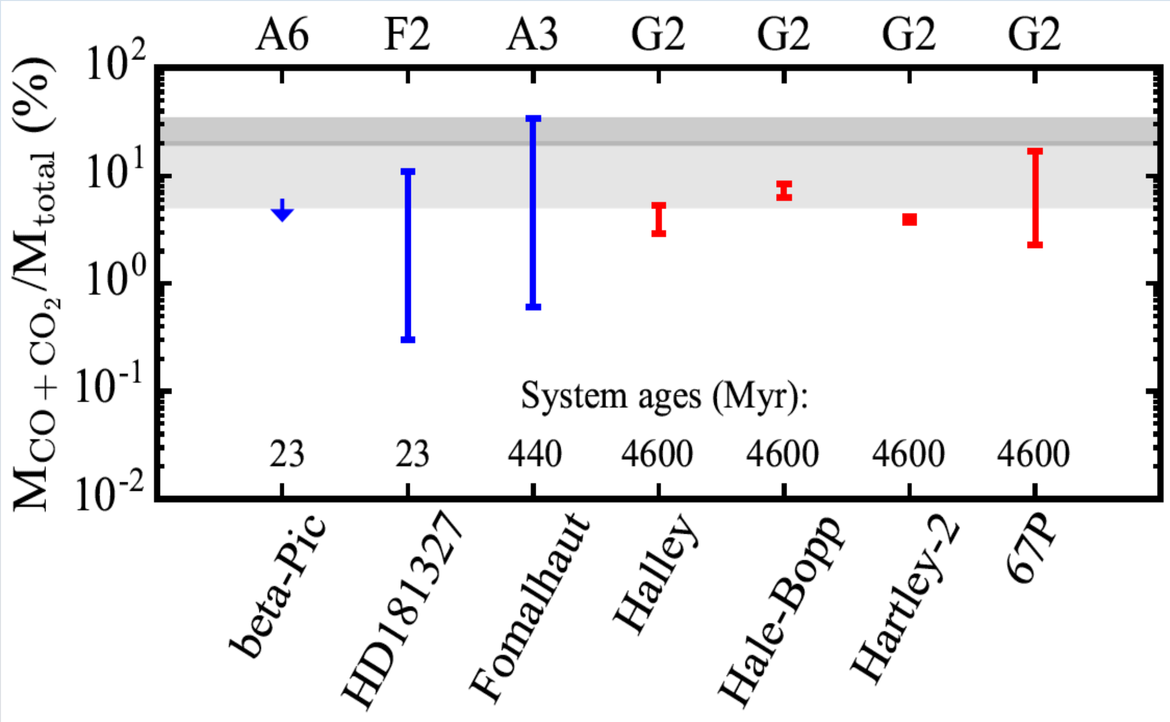



**Marino et al. (2016)**

# What are planetesimals made of?

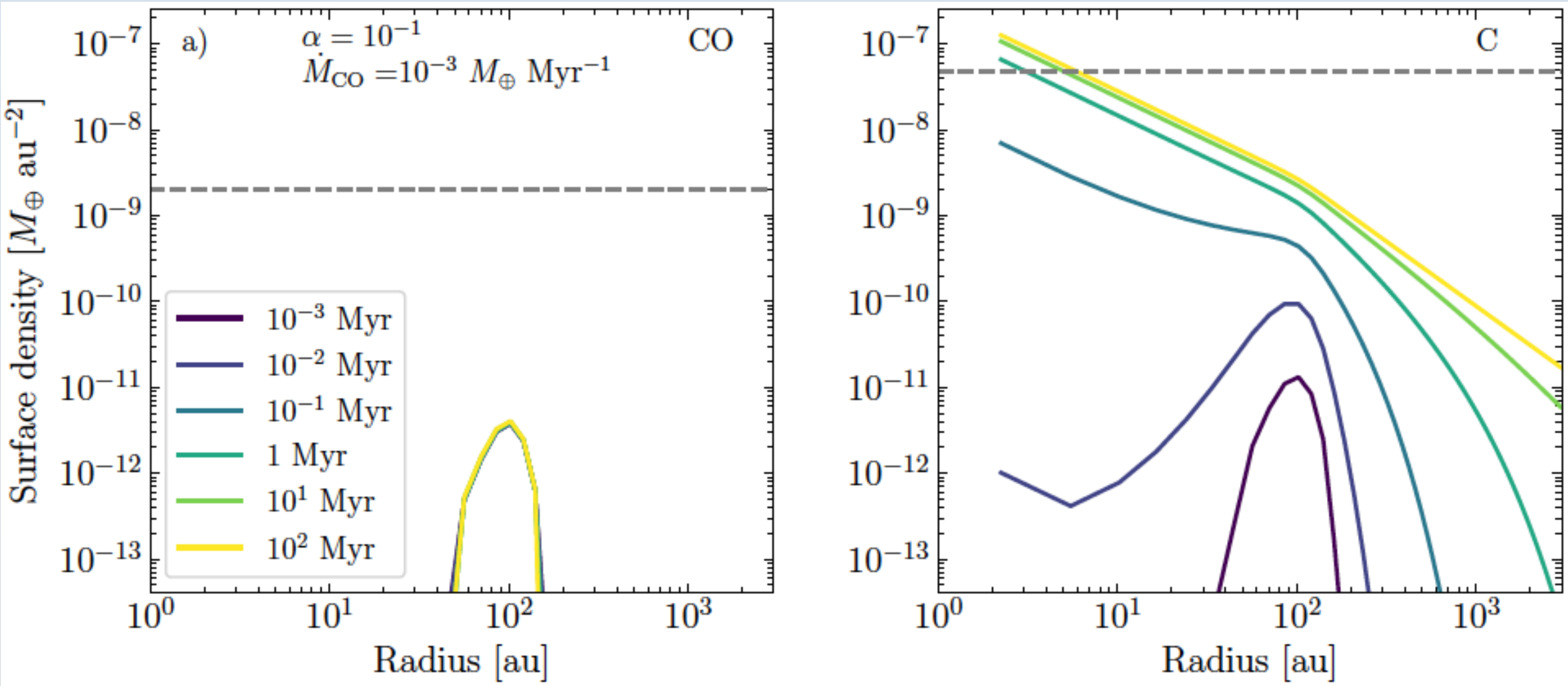
Assuming gas released in steady state, CO production and solid production rate (from dust) gives volatile fraction of planetesimals




Uncertain, but indications are Solar System comet-like composition, no other molecules yet (Matra et al. 2018; **see Ábrahám poster**)

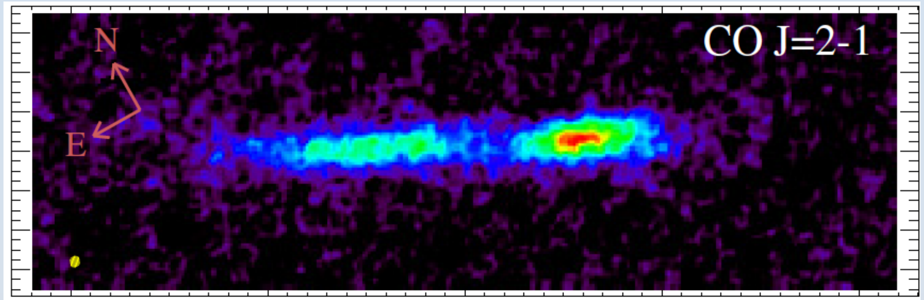
# Testing the secondary gas model

Steady state secondary gas model for origin of CO predicts accumulation of photodissociation products C and O that undergo viscous evolution (Kral et al. 2016; Marino et al. in prep.)

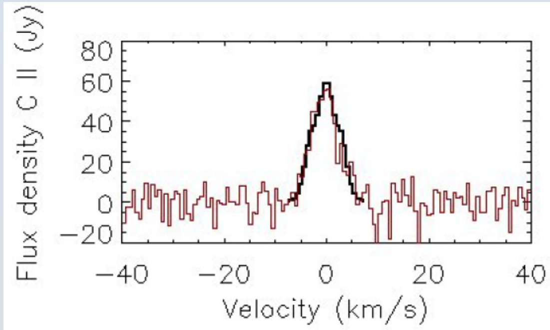


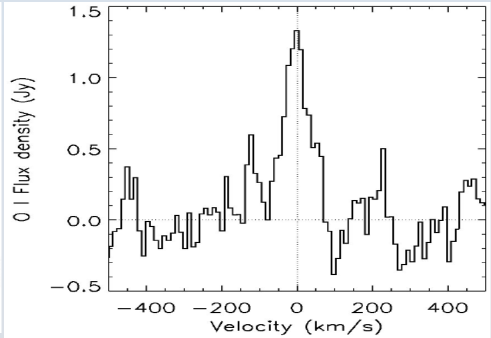
# Testing the secondary gas model

Application to the β Pic gas disk shows that the CO is co-located with the planetesimals

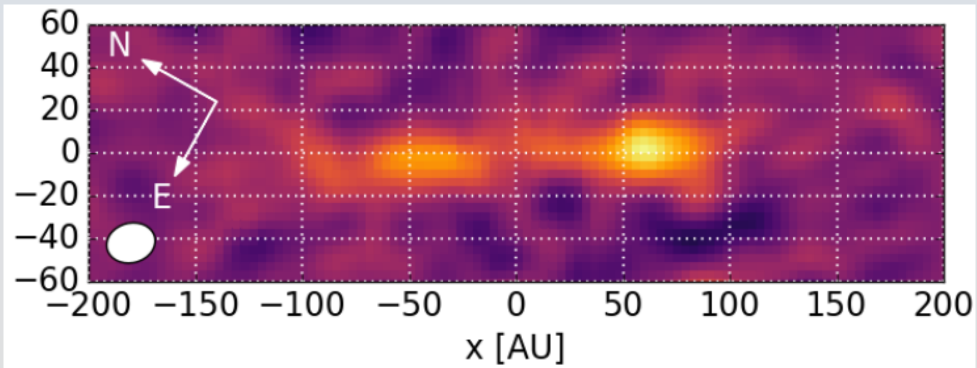



Model also explains CII and OI (though extra $H_2O$ composition, Kral et al. 2016)



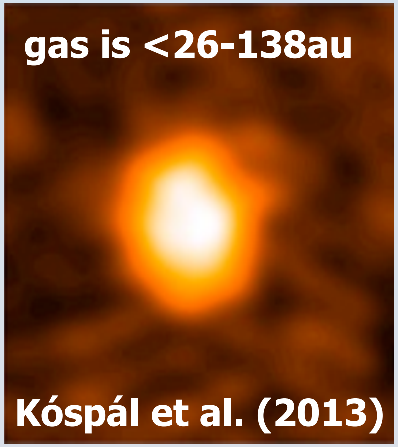



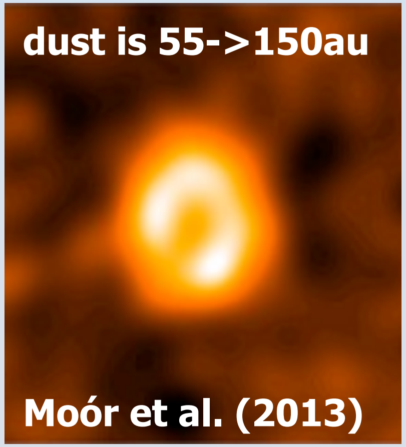

But CI distribution has a hole at centre – did gas production start recently? (Cataldi et al. 2018)



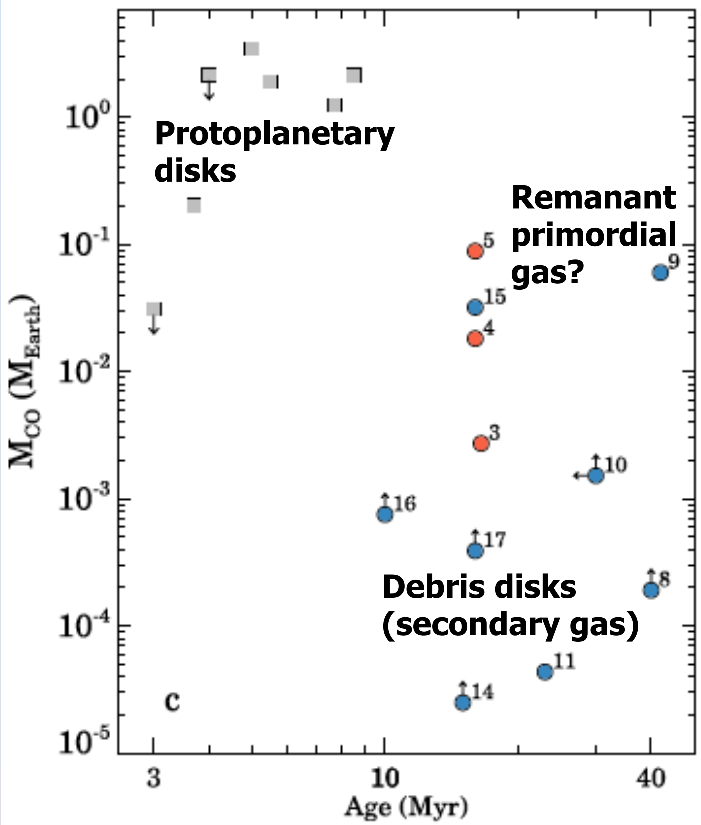
# Does protoplanetary gas remain after dispersal?

Problem disk of HD21997 (30Myr, A3V)



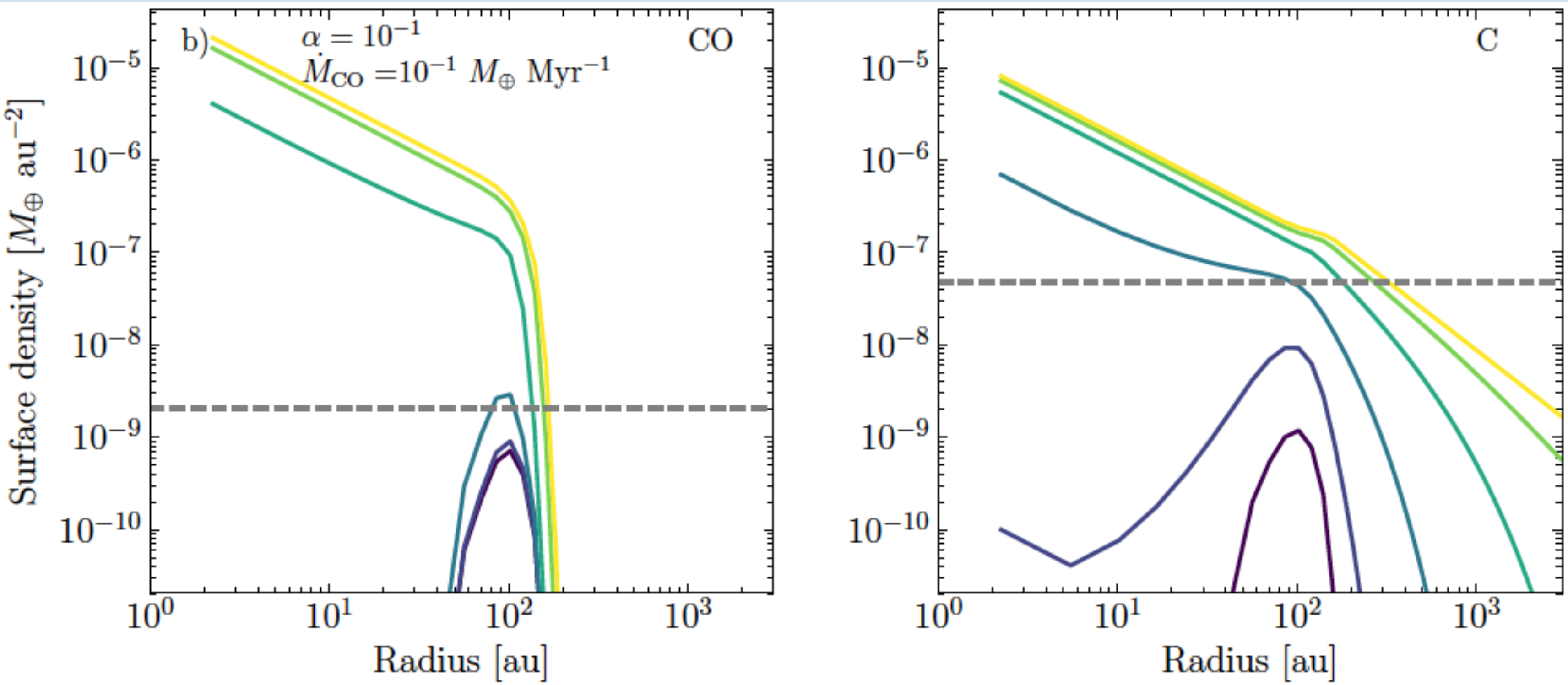

- Gas not co-located with dust, so not secondary, but primordial?
- CO must be shielded to stop photodissociation, but line ratios give $T_{ex}$=5.6K, and LTE if $H_2$-rich
- Also no CII or OI, whereas OI is common in PPD




Several other f>0.05% 10-40Myr A stars also show high CO levels (Moór et al. 2017)

# Shielded secondary gas disks

High CO production rate allows enough C to accumulate to shield CO which can then self-shield and spread viscously (Marino et al. in prep)

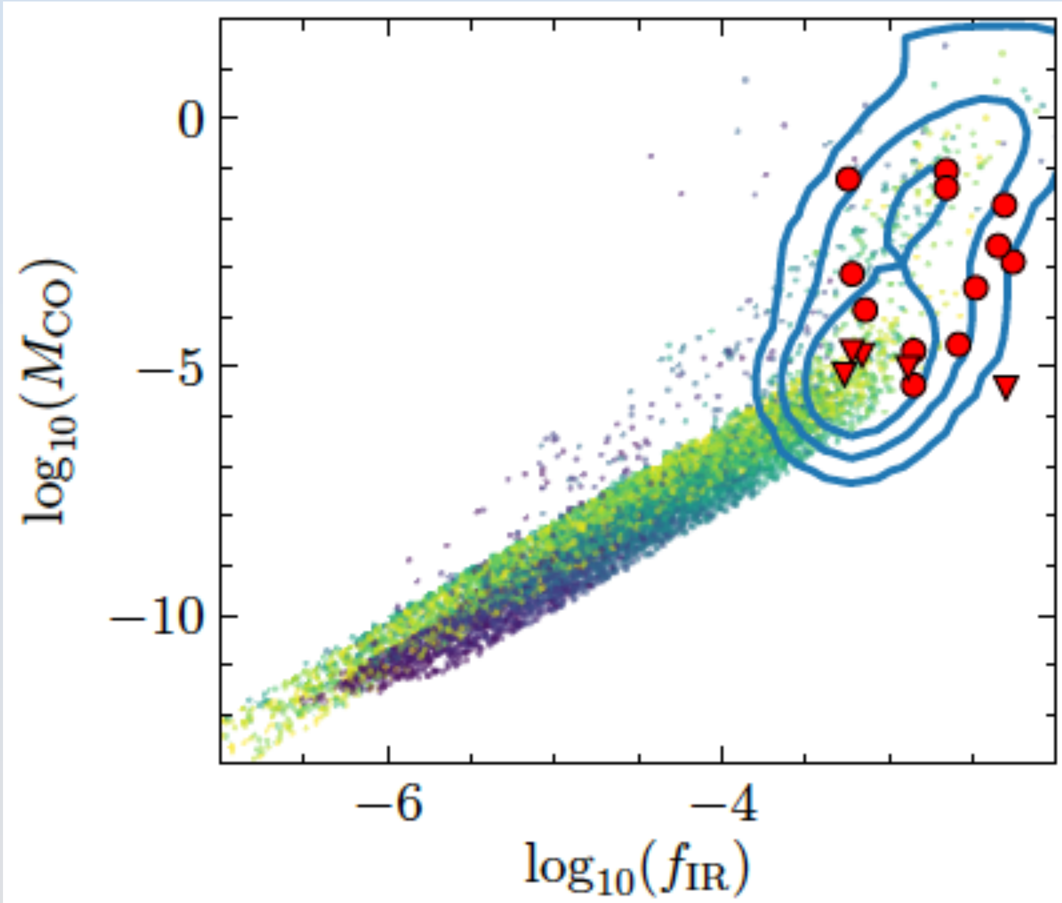



Observations of CI confirm that levels sufficient to shield CO in the disk of HD131835 (Kral et al. 2019)

# Shielded secondary gas disks

Applying the population model to A star debris disks and predicting their CO level, gives exactly this high CO population for 10-40Myr f>0.5% disks (the cut in Moór et al. 2017)

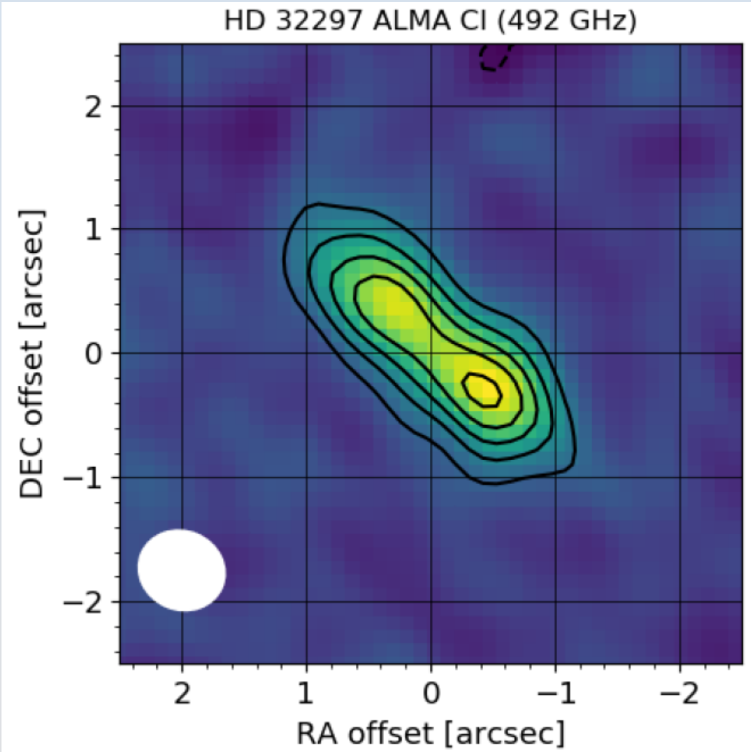
Applying the same model to FGK stars predicts no high CO population, as observed

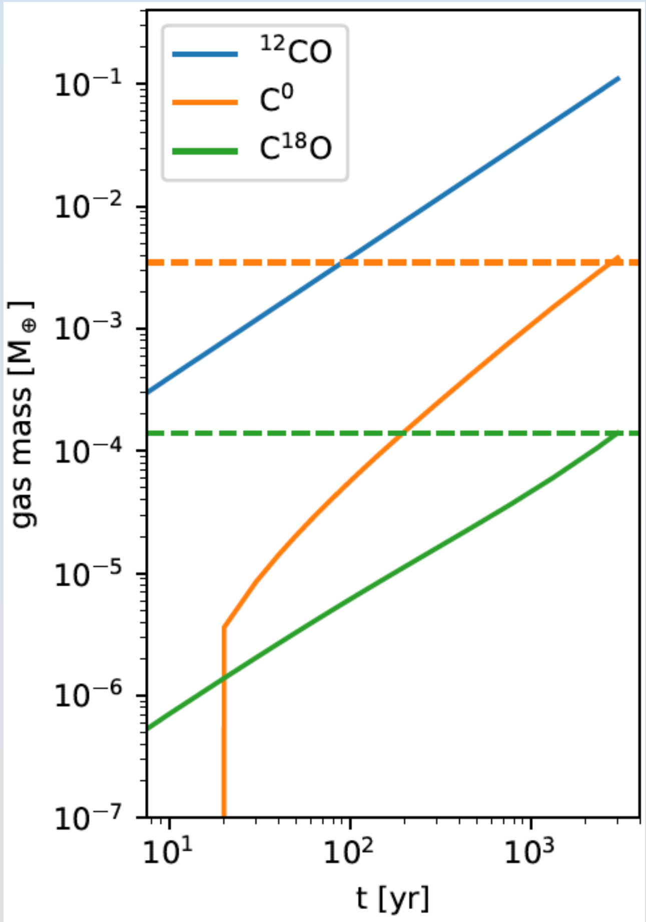



Marino et al. (in prep)

# But… stochasticity still possible

However, another high CO disk HD32297 is inferred to have a low CI mass and so require recent onset of high CO production (Cataldi et al. 2019)

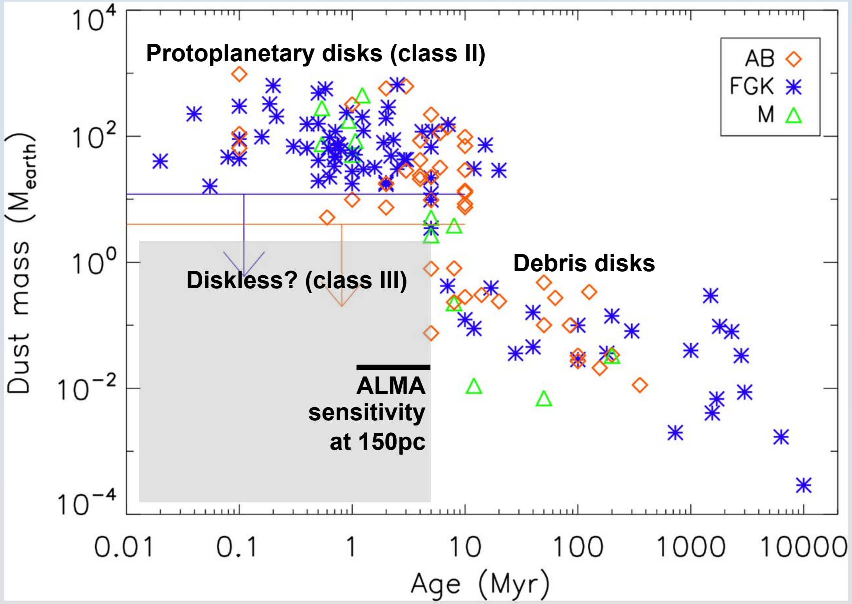


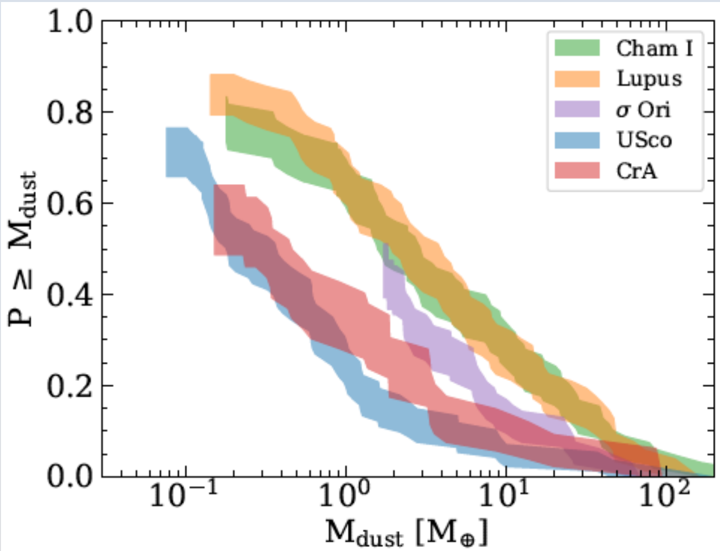



# When did planetesimal belts form?

Transition from protoplanetary to debris disks occurs <10Myr and is accompanied by orders of magnitude decrease in mm dust mass

Recent surveys have pushed down to lower dust masses (e.g., Cazzoletti et al. 2019, **Ansdell, Cieza, Herczeg talks**), but don't reach the ~0.1$M_{earth}$ of the most massive debris disks, and usually ignored class III stars



# When did planetesimal belts form?

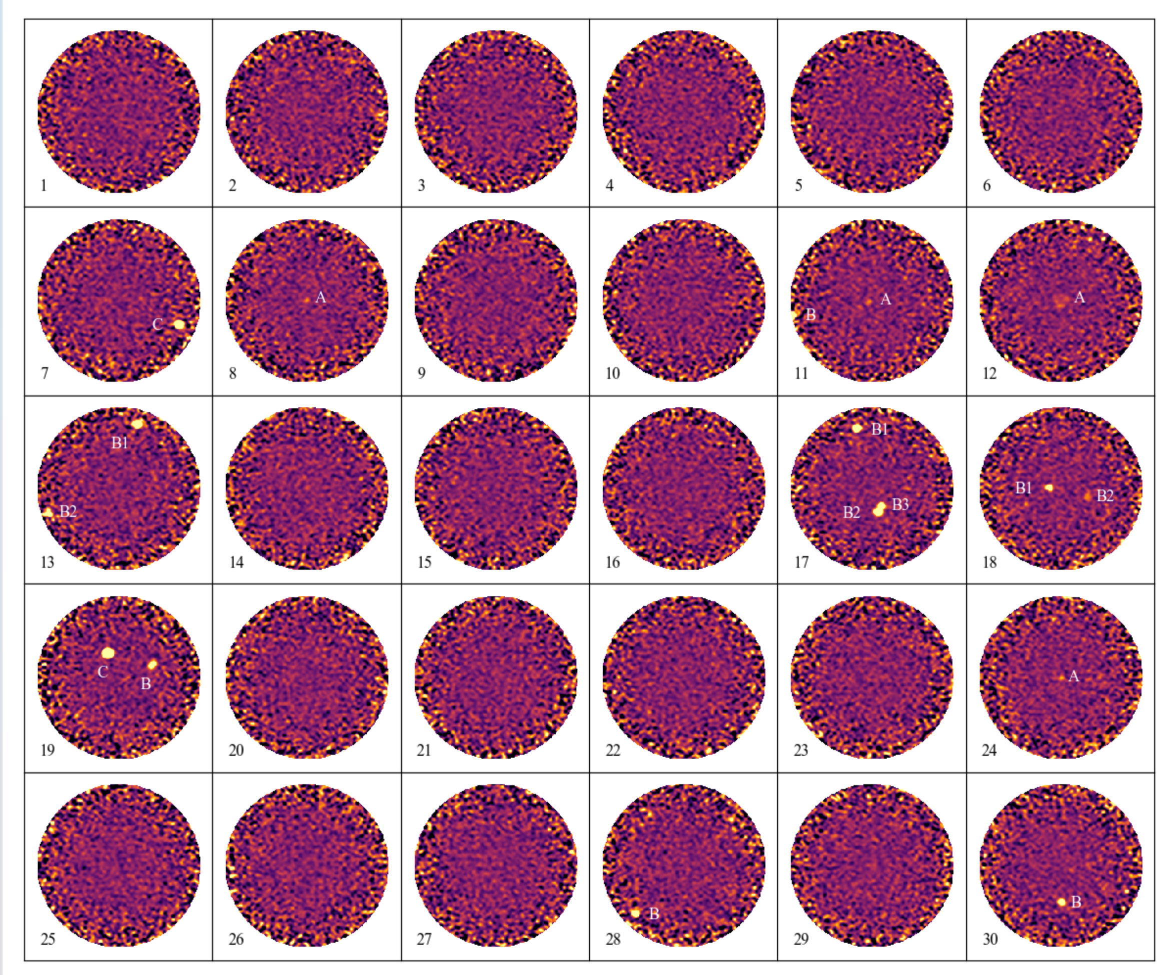
Survey of 30 class III's in 2Myr Lupus

4 detected at >0.02M$_{earth}$ cf 7% expected from older debris disks

Implies planetesimal belts in place by 2Myr?

Formation doesn't need long-lived PPD or delayed stirring

But some could be remnants of PPD (e.g., Owen & Kollmeier 2019)?




Lovell et al. (in prep)

# When did planetesimal belts form?

Did planetesimal belts form early on and so are present already at this stage?

And if so does their location bear any relation to the gaps and rings?

Or do they form in the process of disk dispersal, and so represent the ultimate fate of the mm-sized dust seen in PPD (e.g., Carrera et al. 2017)

# Conclusions

- Planetesimal belts form <2Myr (tentative)
- Planetesimals are volatile-rich, like Solar System comets
- Likely 100s km in size
- For most stars planetesimals are concentrated in a belt at a radius that correlates with stellar luminosity, but belts have a range of radii and masses
- Youngest most massive disks produce gas at high enough rate to self-shield so secondary gas reaches protoplanetary disk levels
- Dominant evolutionary process is steady state collisional erosion
- Interpretation of CI detections could indicate stochastic gas production