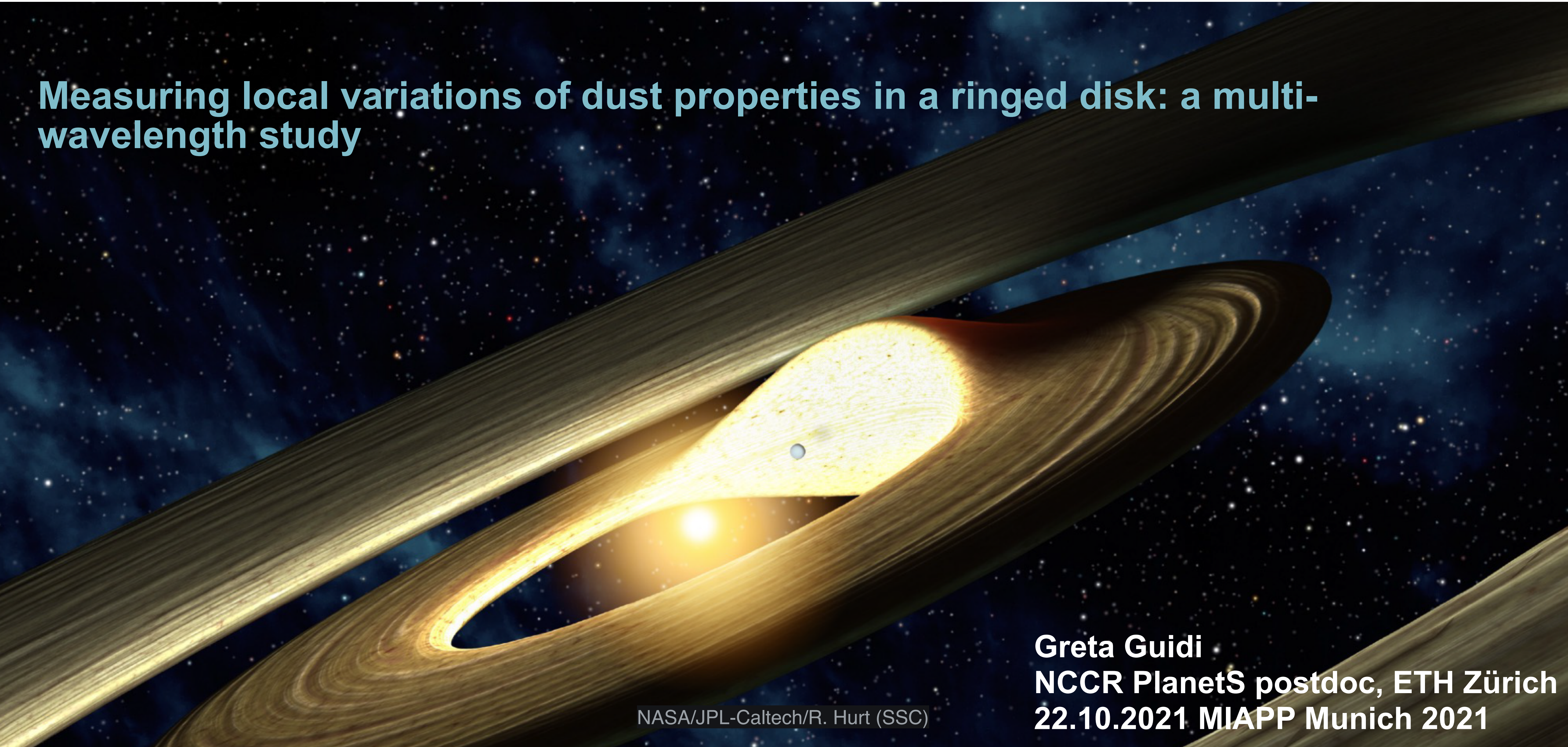
ETH zürich

PlanetS
National Centre of Competence in Research

IPA
Institute for Particle Physics and Astrophysics (IPA)
Exoplanets and Habitability Group

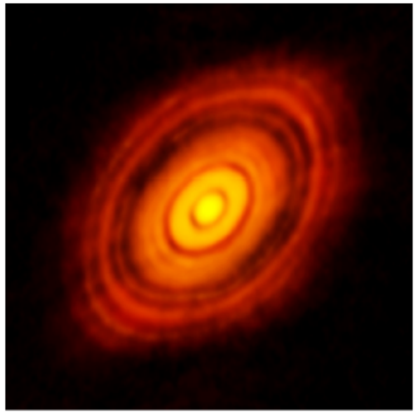
Measuring local variations of dust properties in a ringed disk: a multi-wavelength study


NASA/JPL-Caltech/R. Hurt (SSC)

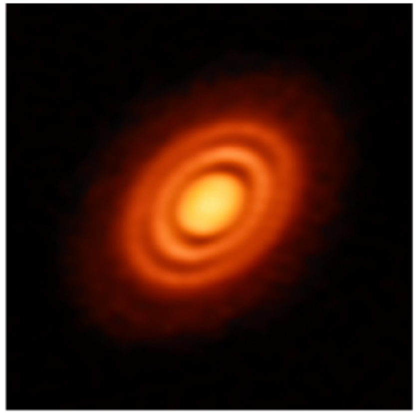
Greta Guidi
NCCR PlanetS postdoc, ETH Zürich

22.10.2021 MIAPP Munich 2021

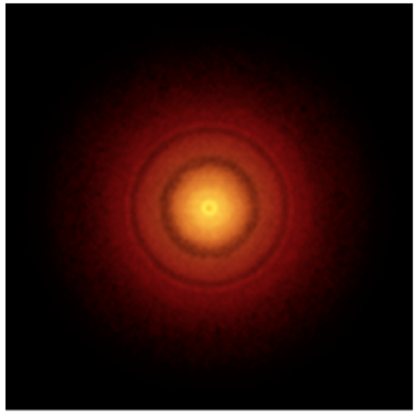
Context / motivation



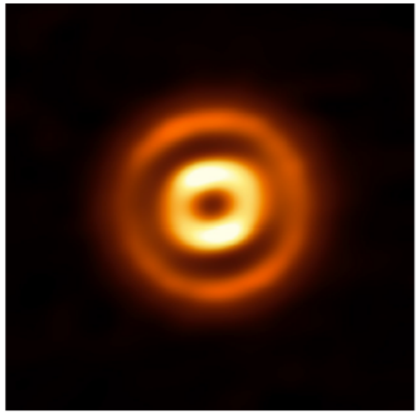
ALMA partnership et al 2015



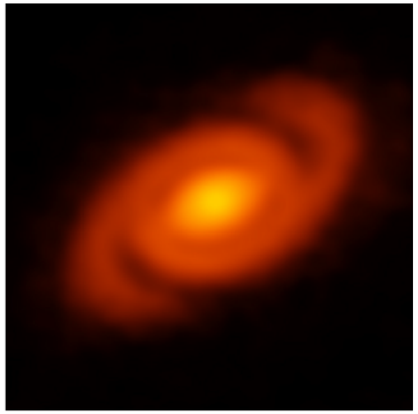
Isella et al. 2016



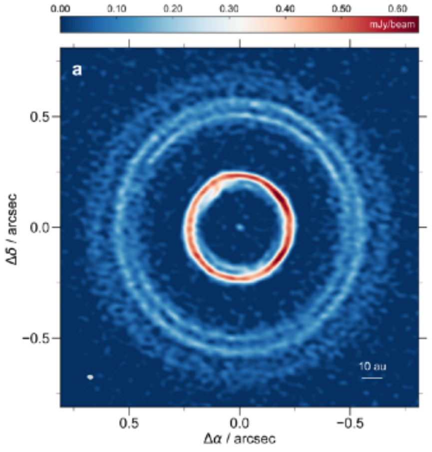
Andrews et al. 2016



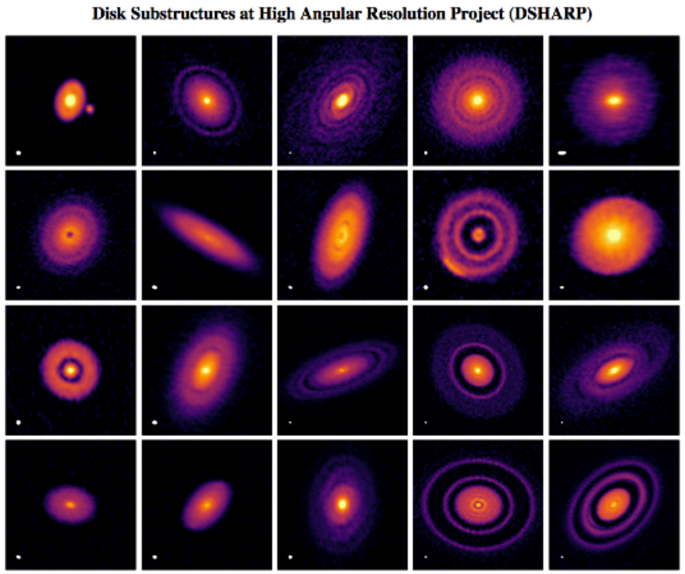
Fedele et al. 2017



Pérez et al. 2016



Pérez et al. 2019



Andrews et al. 2018

. What are the dust properties in these disks?

↓

. What are the mechanisms creating the sub-structures?

How large are dust grains in protoplanetary disks?

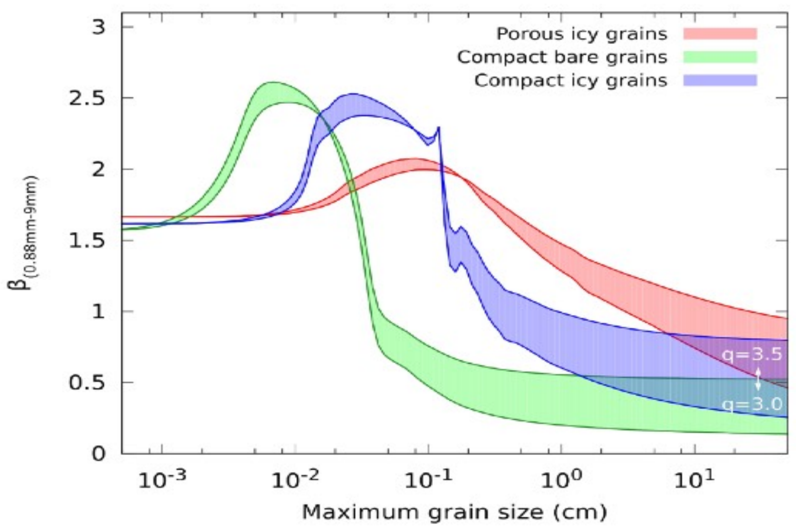
$\kappa_\nu \propto \nu^\beta$

- **Integrated spectral indices: α < 3**

amax ≳ mm

Beckwith et al. 1990, Natta et al. 2004 … Tazzari et al. 2021a, Miotello et al. 2014 (Class I)

(see M. Tazzari talk)

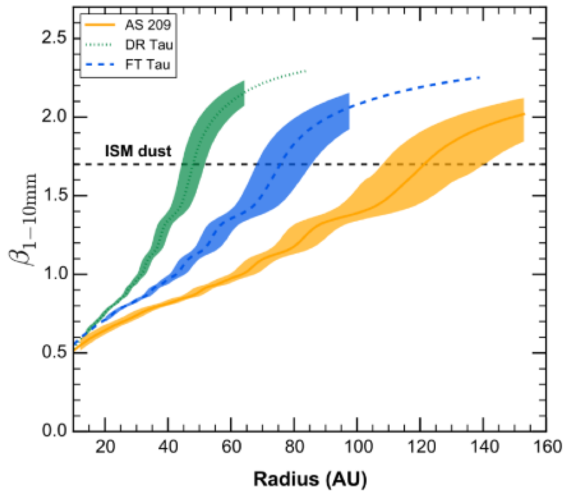


Testi et al. 2014

- **Resolved spectral indices (~30-40 au res): α monotonically increasing**

Perèz et al. 2012, 2015;
Guidi et al. 2016,…

Tazzari et al. 2016



amax ≳ mm

optical depth assumed/estimated <1

- **mm-polarization measurements: (see A. Kataoka's talk)**

  . amax ~ 150 um in HD142527 (Kataoka et al. 2016)
  . amax ~ 70 um in HL Tau (Kataoka et al. 2017)
  . amax ~ 300um in the inner regions of TWHya (Ueda et al 2020)
  . amax ~ 100 um in HD 163296 (Dent et al. 2019)
  …

amax ~ 100 um

- **High resolution (~5-10 au) multi-wavelength, single-source studies: non-monotonic spectral index varying across the sub-structures**

amax ???

Evidence of non-optically thin emission - >self-scattering (see Liu+2019, Zhu+2019) often included in the modelling

(see A. Sierra talk)

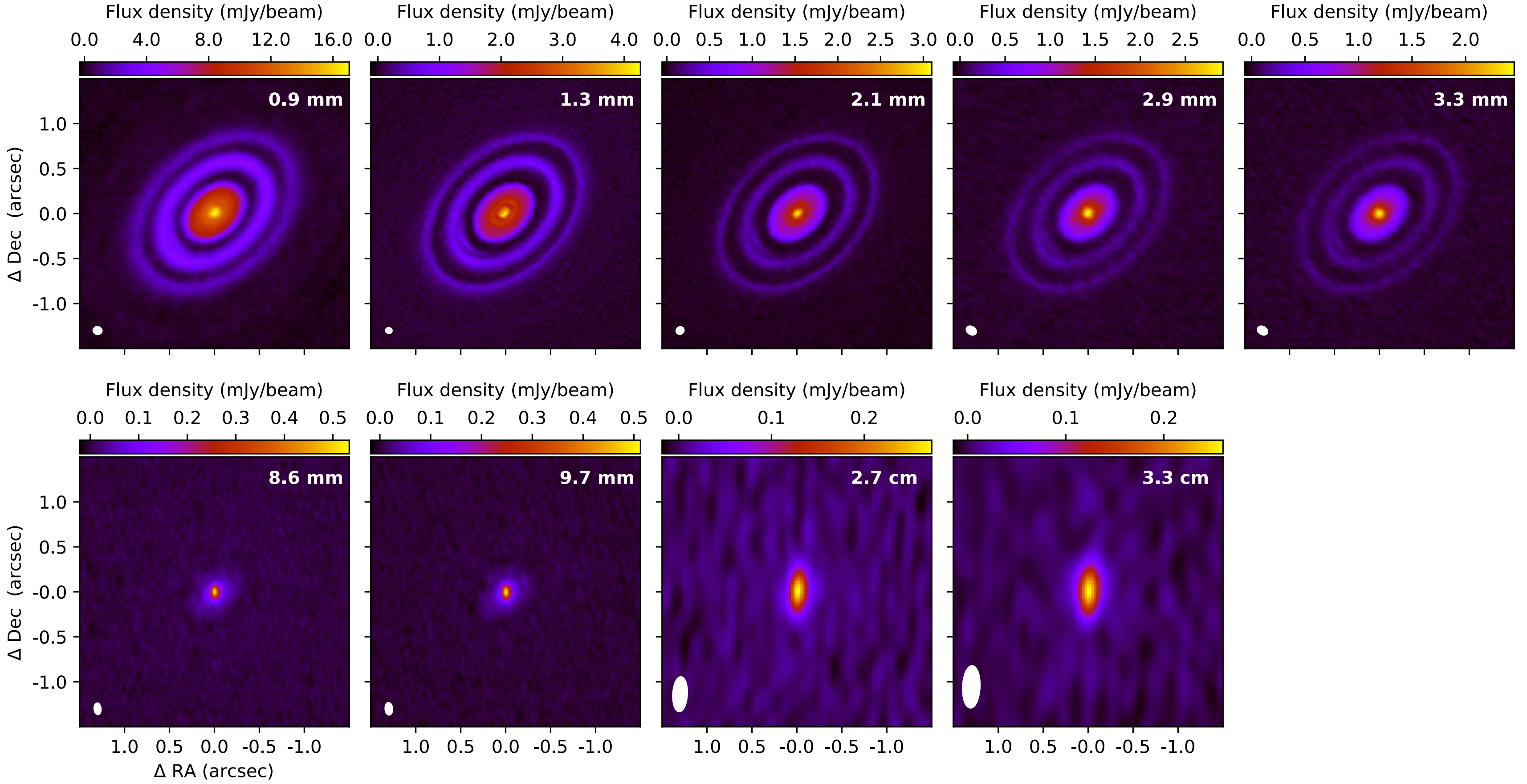
Zhang+2015, Huang+2018a, Dent+2019, Maciás+2019, Carrasco-Gonzalez+2019, Huang+2020, Long+2020, Maciás+2021, Sierra+2021, Liu+2021, …

. No clear picture of dust growth/evolution as function of radius/age

. Discrepancies between studies of the same sources

Distribution of solids in the rings of the HD 163296 disk: a multi-wavelength study

Guidi et al. 2021 subm.

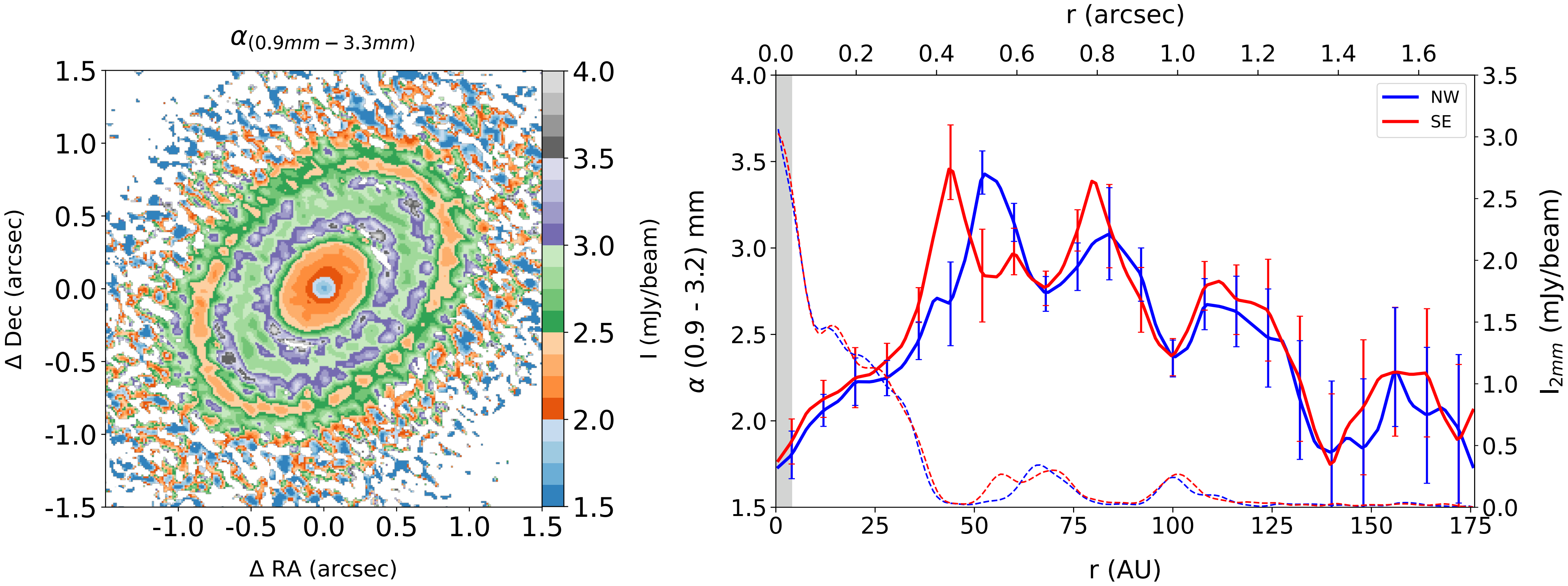


4 ALMA bands,
2 VLA bands

Resolution:
5 - 8 au up to 9mm
30 au at 3 cm

A. Isella, L. Testi, C. J. Chandler, H. B. Liu, H. M. Schmid, G. Rosotti, C. Meng, J. Jennings, J. P. Williams, J. M. Carpenter, I. de Gregorio-Monsalvo, H. Li, S.F. Liu, S. Ortolani, S. P. Quanz, L. Ricci, and M. Tazzari

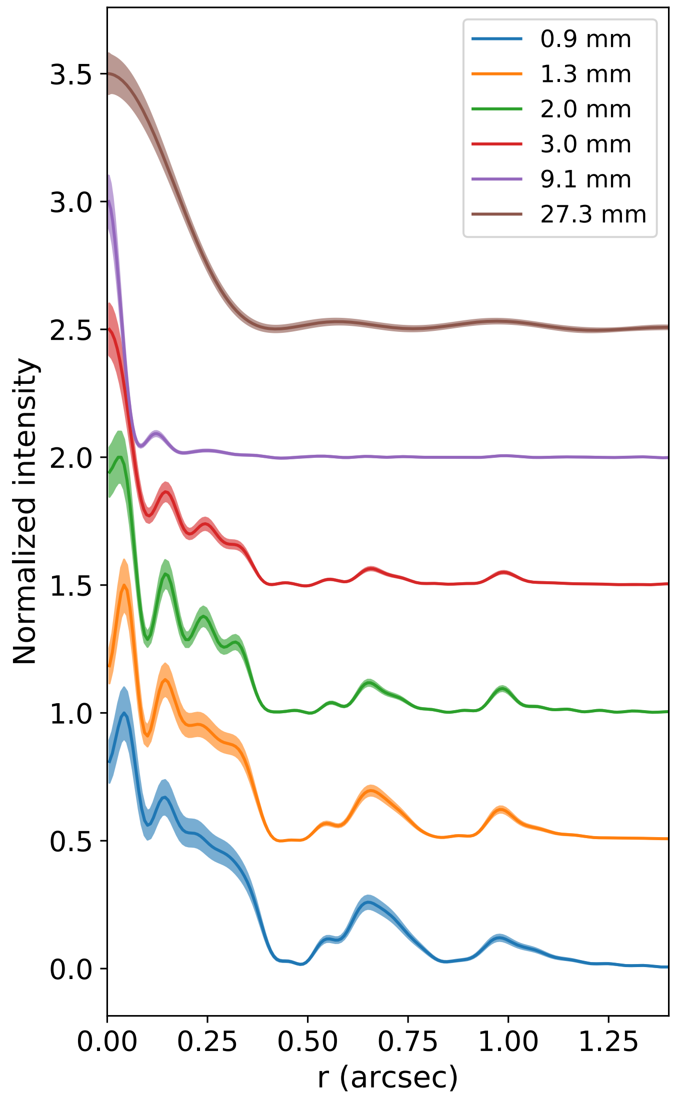
Flux spectral index

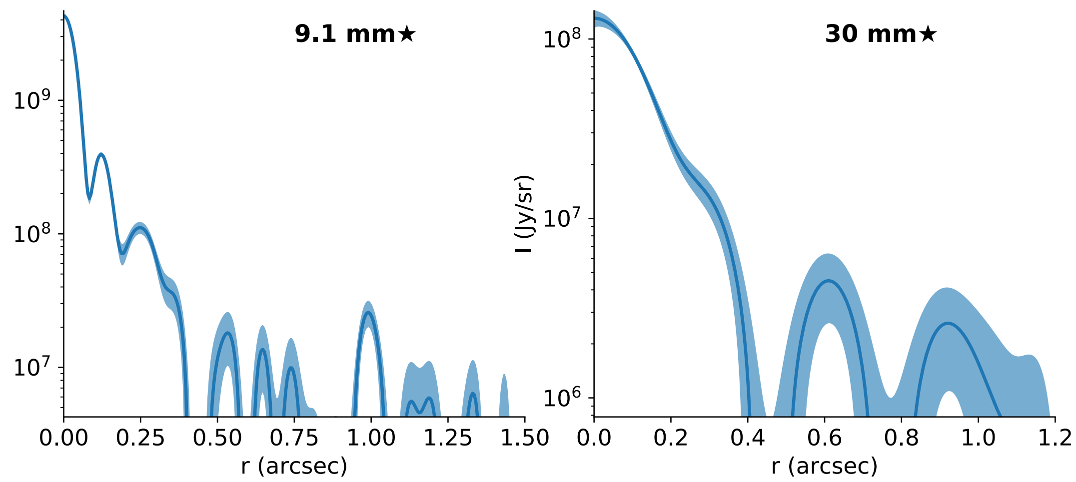


Lower alpha corresponds to larger grains?

Brightness profiles retrieval

obtained with “frankenstein” (Jennings et al. 2020)

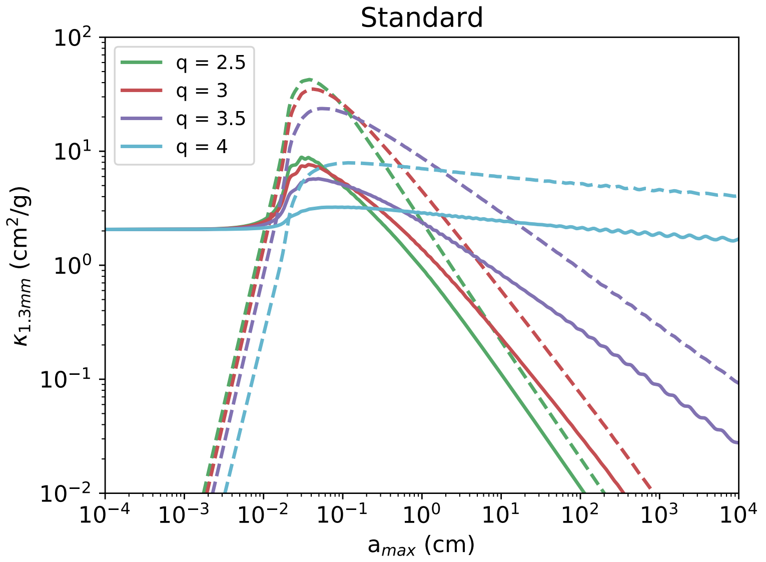


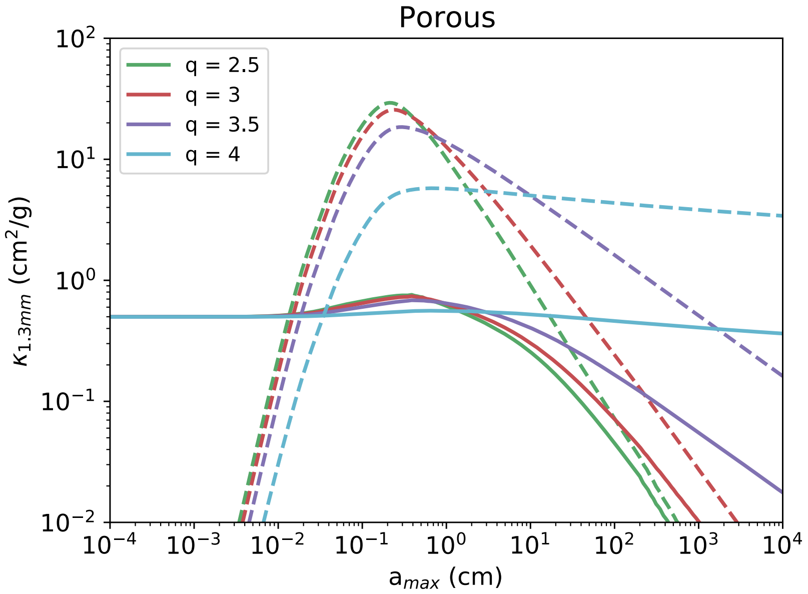


Substructures in the inner disk detected up to cm wavelengths.

At 3 cm we estimate ~40% of the flux due to free-free emission, 60% due to dust emission

SED modelling





8 dust models with varying size distribution index and composition

dust composition

DIANA standard opacities (Woitke et al. 2016)
volume ratios: 60% silicates, 15% amorphous carbon, and 25% porosity (standard)
16% silicates, 4% carbons, 80% porosity (porous)

size distribution $n(a)da \propto a^{-q}$ q = 2.5, 3, 3.5, 4

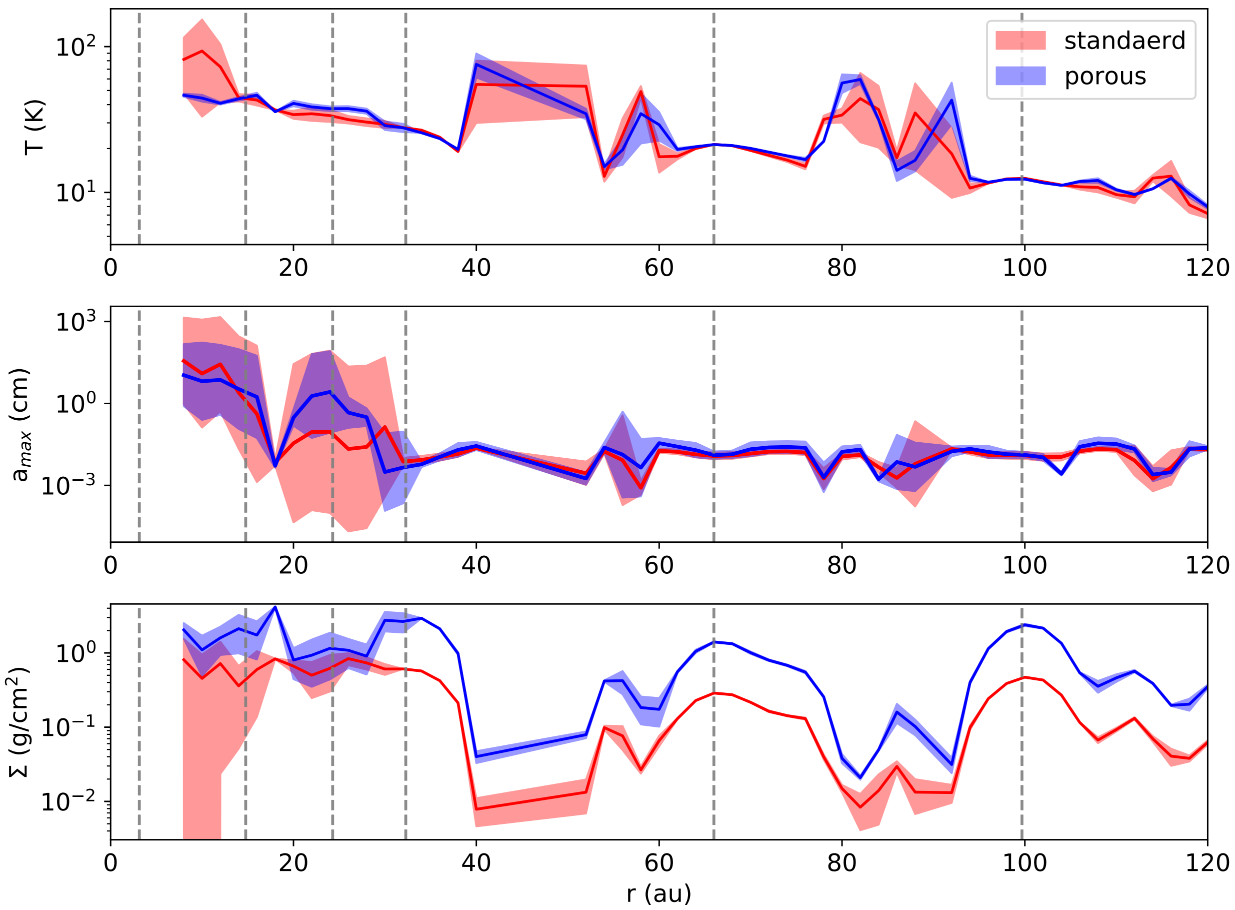
Analytical description of radiative transfer, with scattering from isothermal slab (e.g. Zhu + 2019)

$$I_\nu = B_\nu(T)(1 - e^{-\tau_\nu/\mu}) \cdot (1 - \omega_\nu F_\nu(\tau_\nu, \omega_\nu))$$

depends from T, a_{max}, Σ_d

SED modelling

Monte Carlo nested sampling (ultranest, Buchner+2021)



Best-fit parameters averaged across the size distributions, for standard and porous grain separately

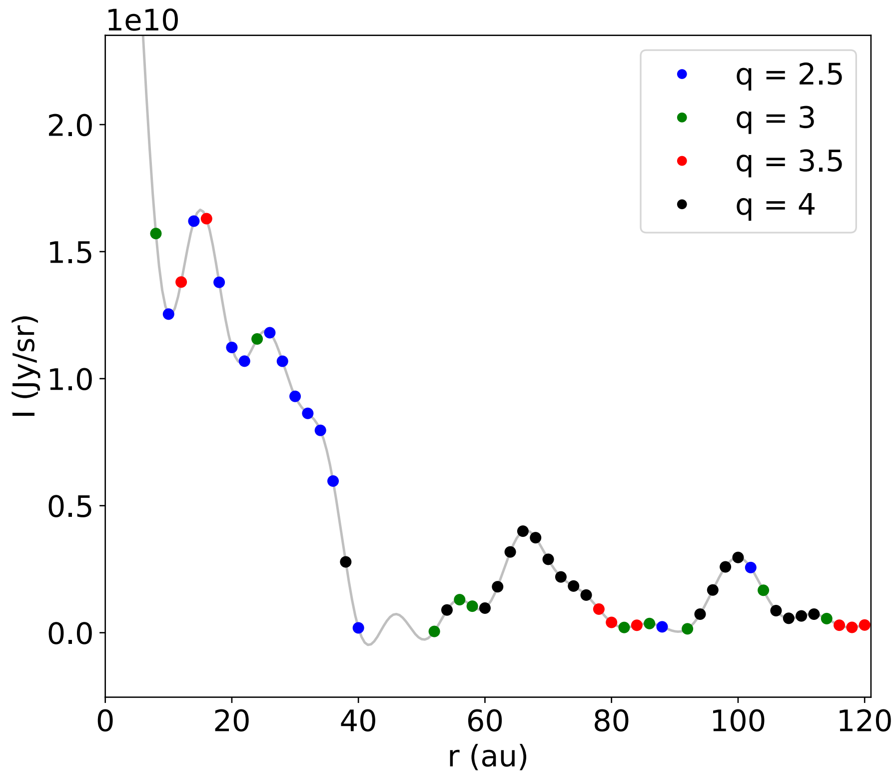
- ~agreement in T and amax
- Surface density assuming porous grains is 4x higher

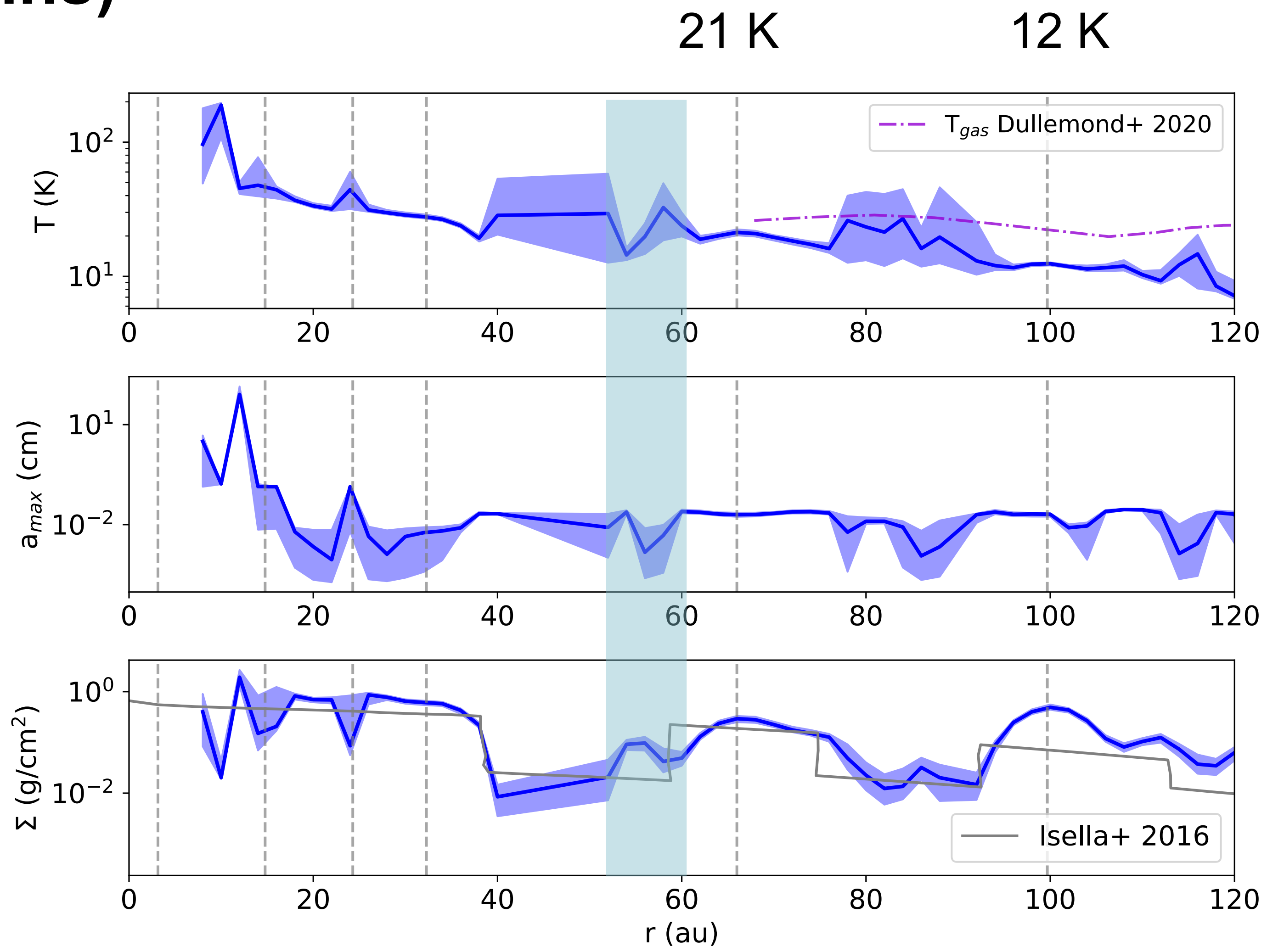
↓

Mdust is 4 x higher!

. Standard grains are a better solution at 80% of the radii

Best-fit model (standard grains)

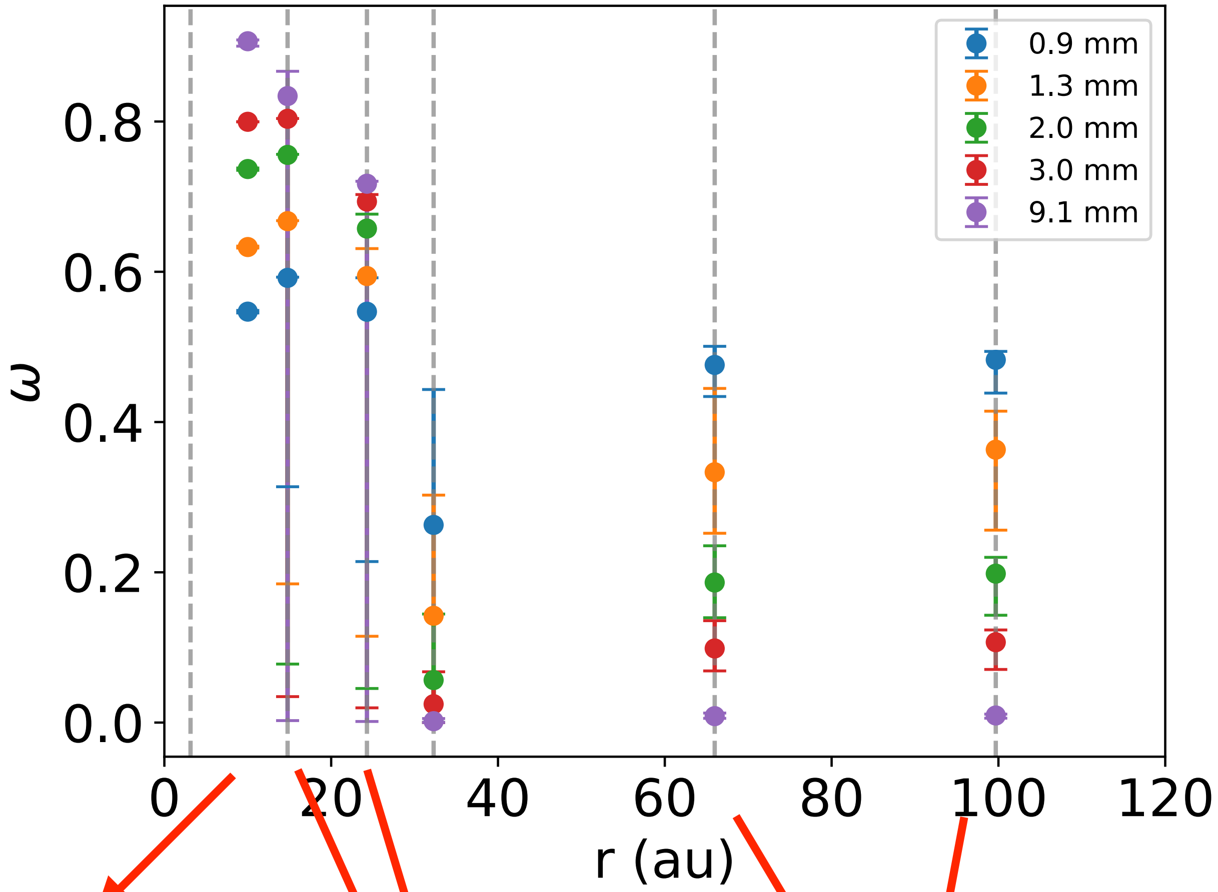




Mdust = 286 ± 50 $M_\oplus$ (8.6 10^{-4} Msun)

1/3 of the mass in the 100 au ring

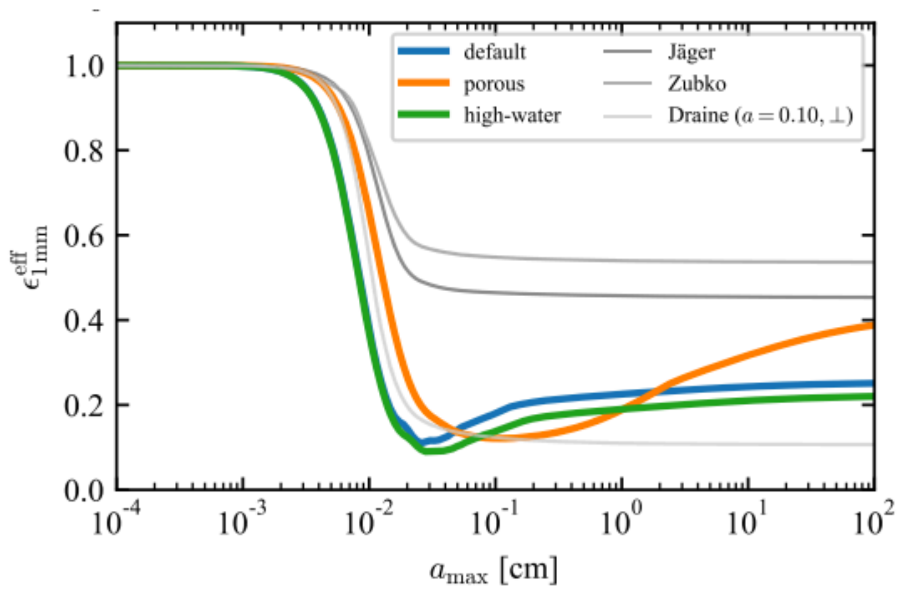
Best-fit model (standard grains)



amax = mm-dm in the inner disk (<15 au)

amax ~ mm

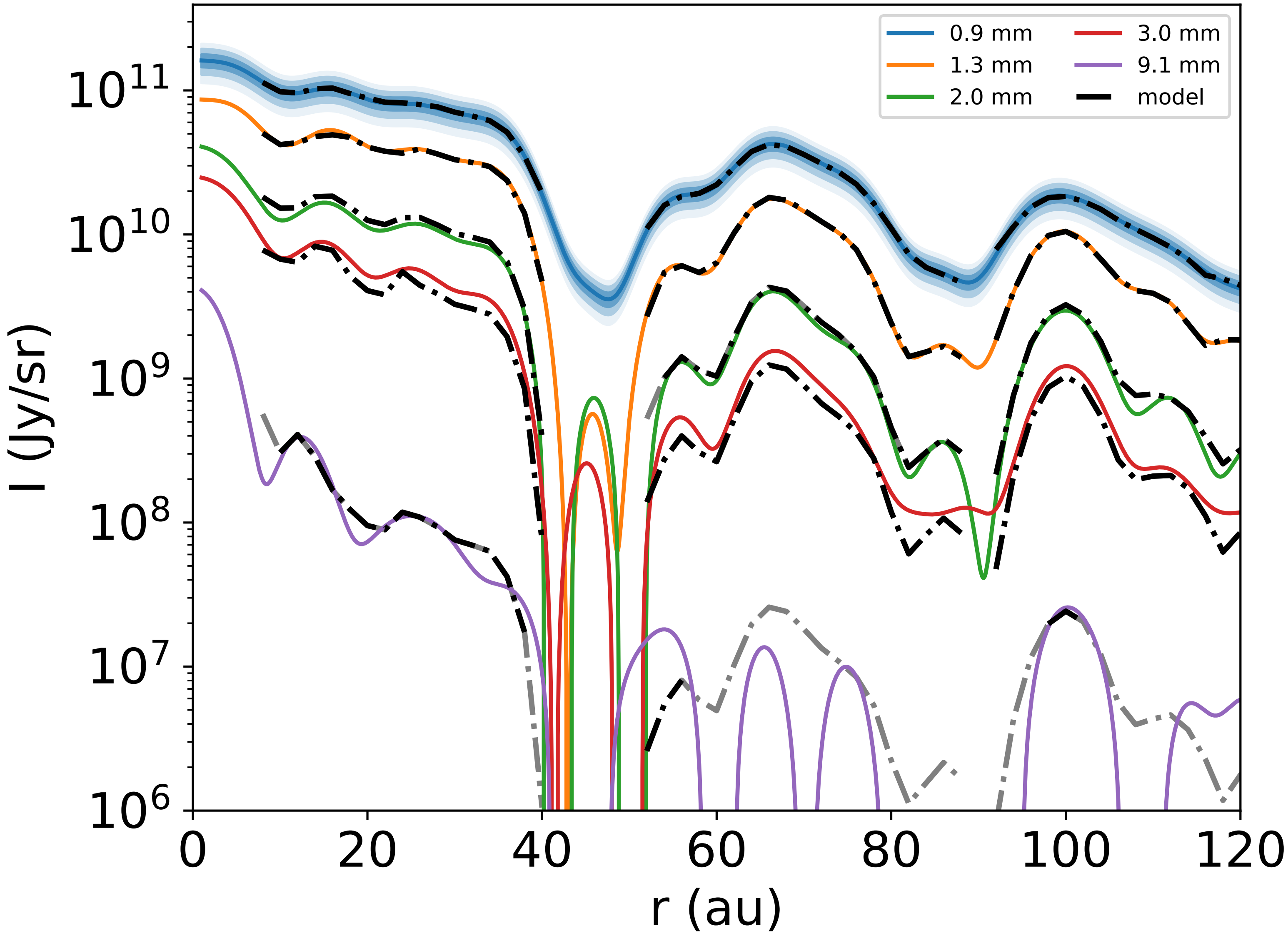
amax = 200 um in the outer rings (and gaps)



Birnstiel et al. 2018

Peak of the albedo is at ~ 2 π amax independently from the composition

Best-fit model (standard grains)

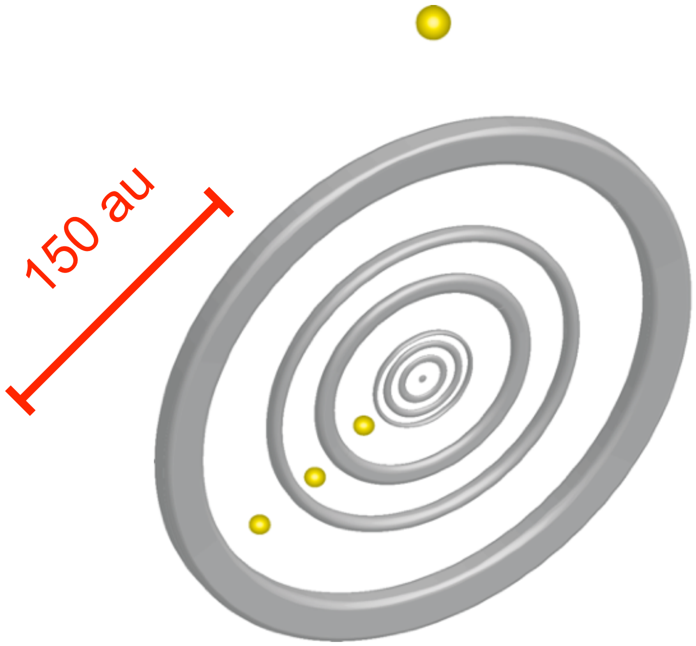


Flux calibration errors:
. B3, B6: 5%
. B7, B4, VLA Ka: 10%

9 mm flux not included at r<10 au because of uncertainties on the free-free contribution

Summary and conclusions

. Higher T in the dust gaps
. 200 um grains outside ~40 au. Consistent with polarization measurements (100-150 um grains from Dent et al. 2019; Lin et al. 2019; Ohashi & Kataoka 2019)
. Hints of a steeper size distribution (q~4) in the 67 and 100 au rings
. Significant mass fraction in the 100 au ring



What about the planets?

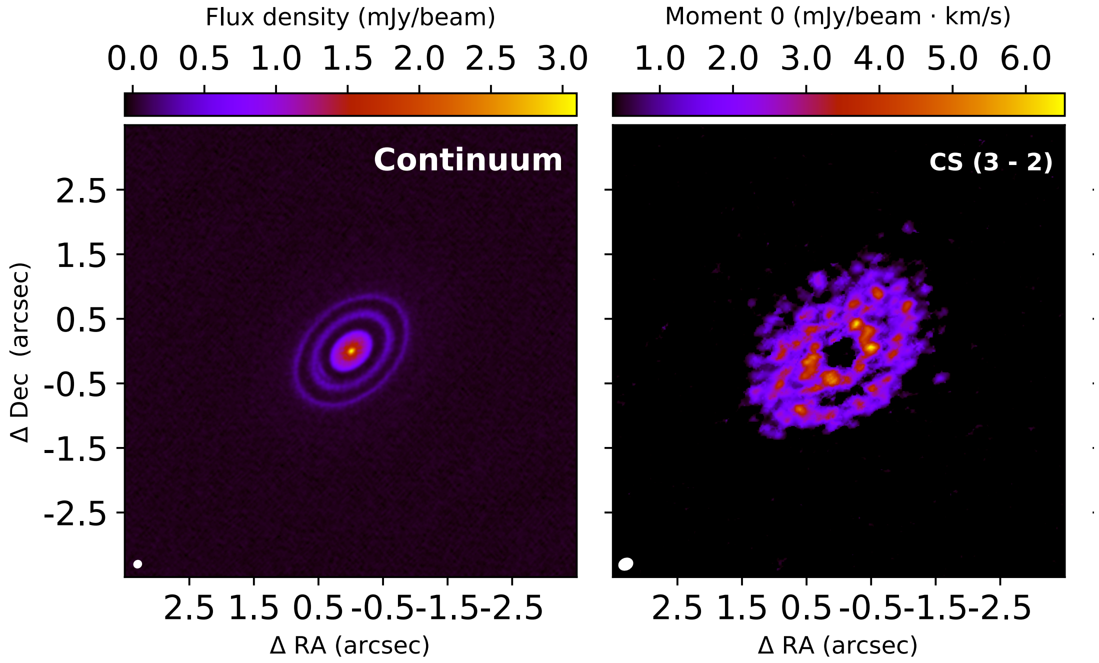
. Higher scale height in the 67 au ring (Doi&Kataoka 2020, Guidi et al. 2018) -> vertical stirring from planets
. Small grains from collisions in the highly collisional environment (see Turrini et al. 2019)
. No clear evidence of differential segregation (hints of segregation in the 100 au ring)

Caveats

. Unknown dust composition
. Size distribution - not a power law?
. Mass hidden in large bodies?

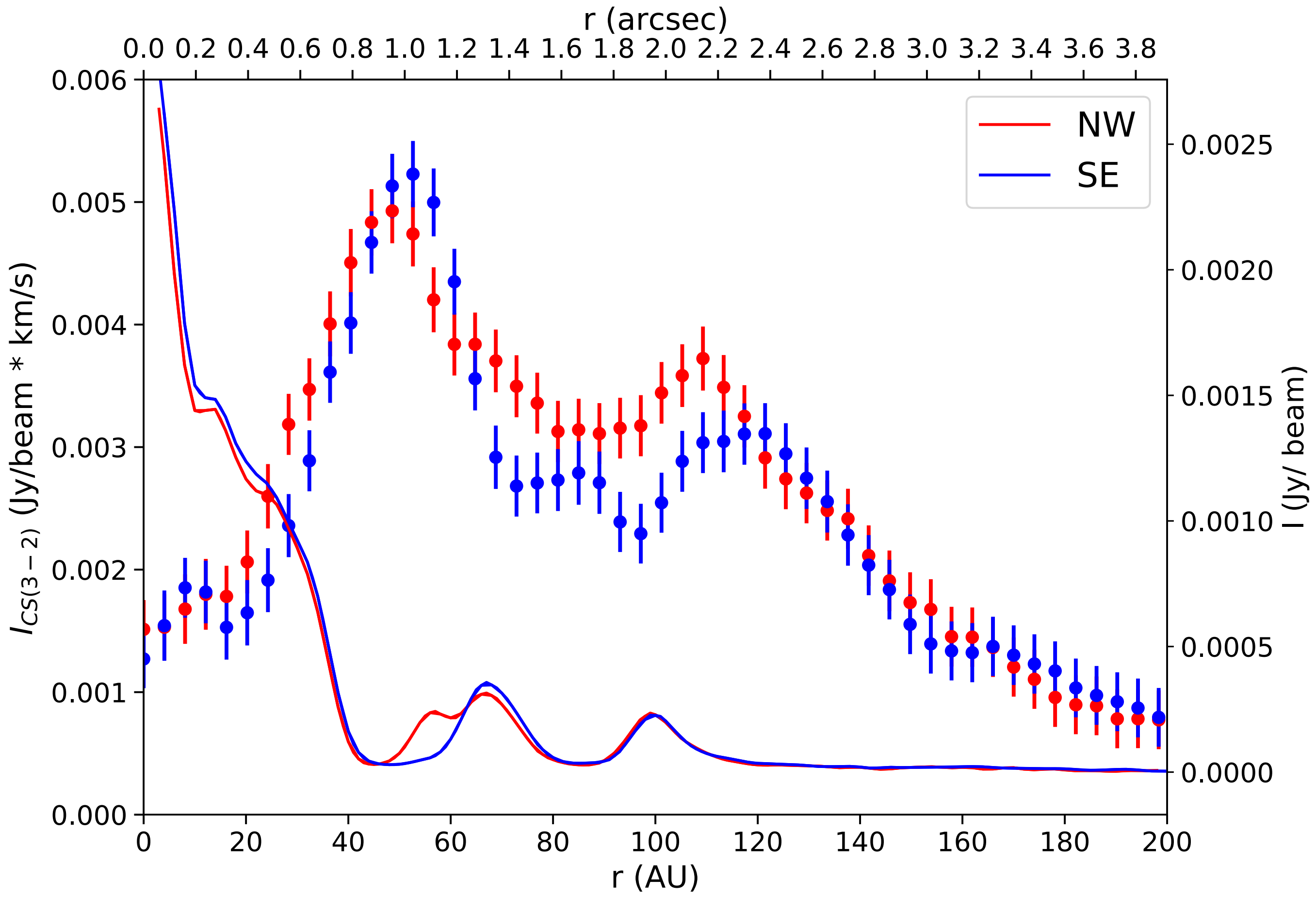
Results can heavily depend on the initial assumptions on the dust

Preliminary: CS emission in HD163296 at high resolution (~15au)

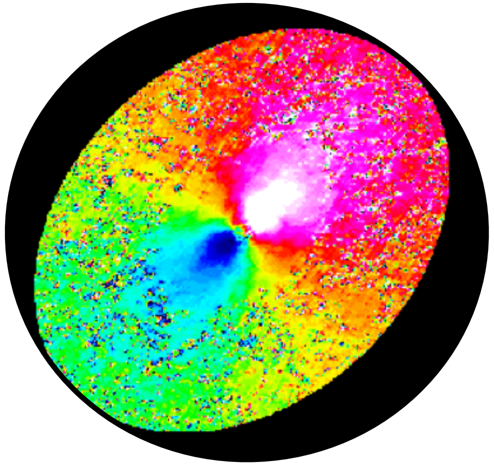


+ other serendipitous detections

Moment 0 radial profile of CS (3-2) emission



CS (3-2) Moment 1



Guidi et al. in prep.