

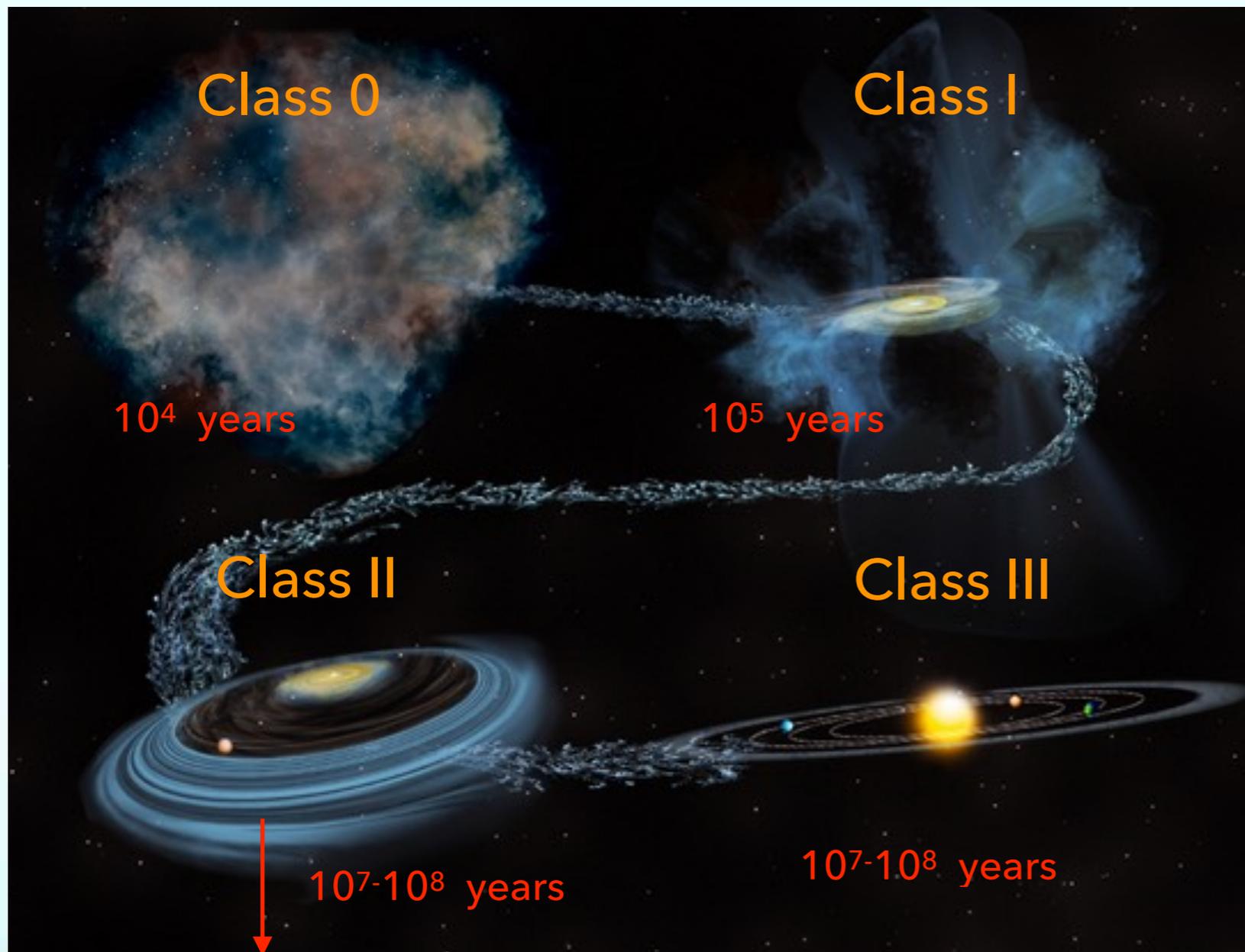
Dust evolution and planet formation in protoplanetary disks: the potential of ALMA Band 2

Unveiling ALMA Band 2
26 February 2026 (Bologna, Italy)



Greta Guidi, Institut de Planetologie et d'Astrophysique de Grenoble (FR)

Context: protoplanetary disks and Young Stellar Objects



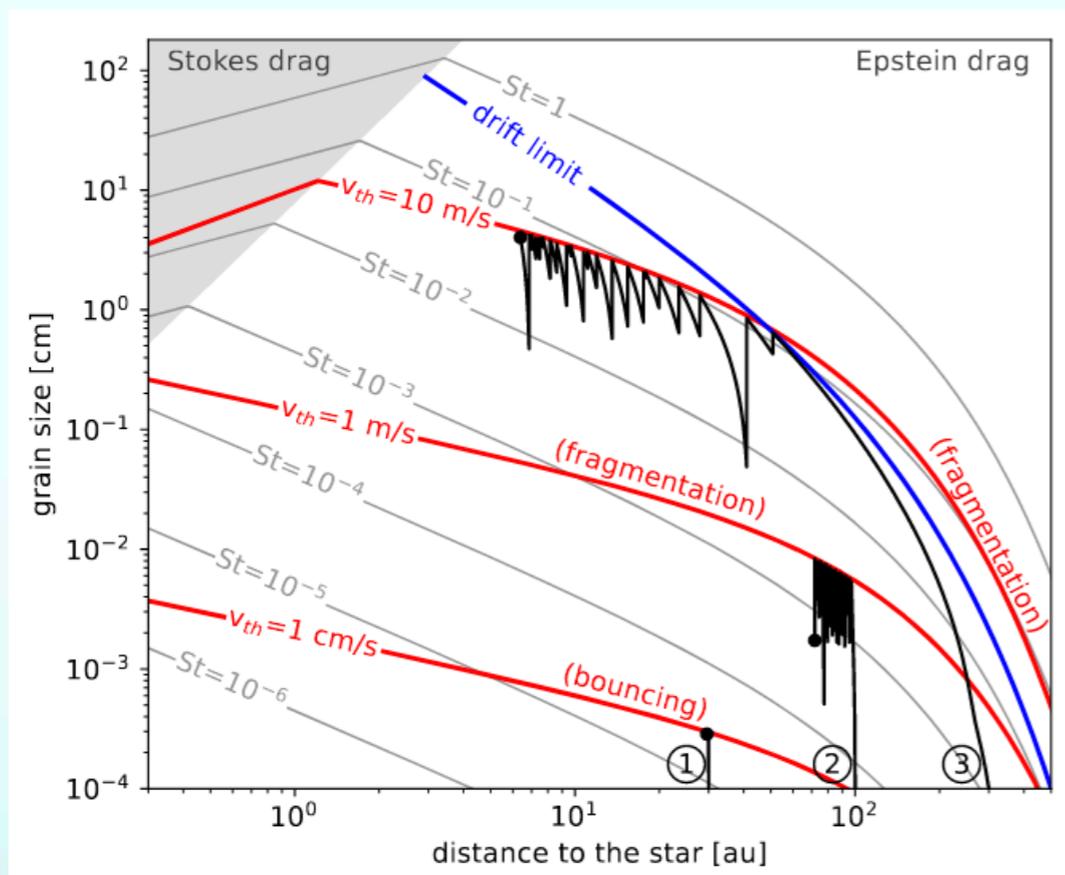
Protoplanetary
disks

Planet formation thought to occur during the Class II stage (or maybe earlier?! see also J.Pineda talk)

Grain size -> dust must grow to pebble-size in order to trigger the formation of planetary cores

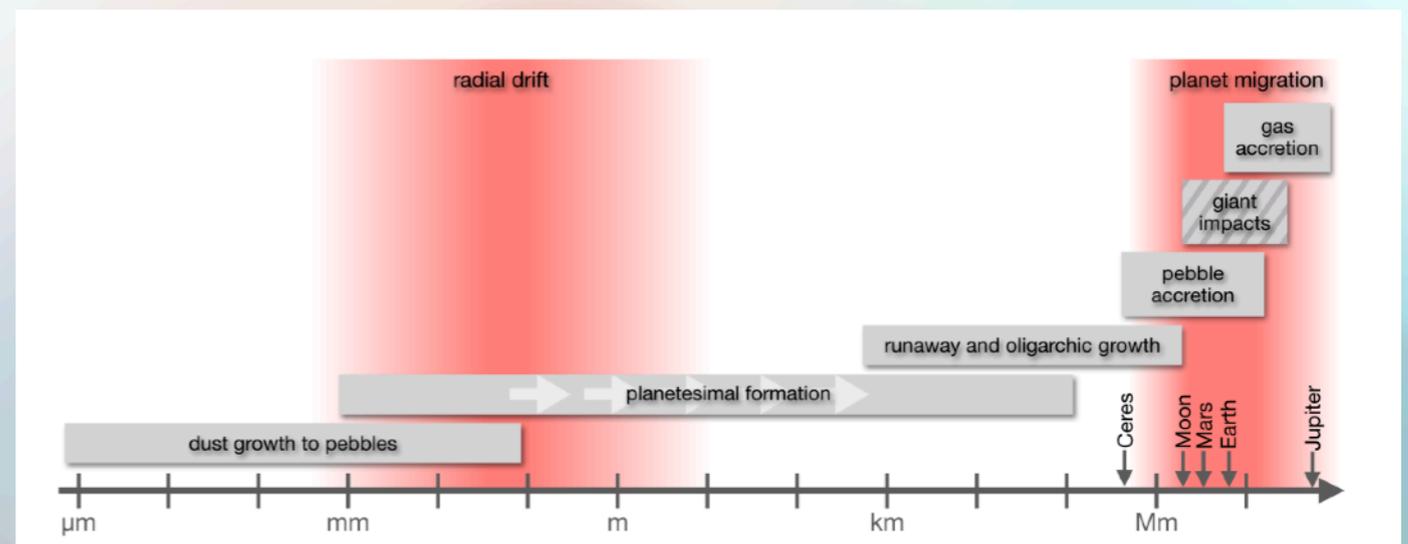
Current issues in planet formation: dust growth barriers

- . Radial drift (or meter-size) barrier (Weidenschilling et al. 1977)
- . Fragmentation/bouncing barriers



Drążkowska et al. 2023

→ Large grains should be rapidly removed by radial drift, unless dust pressure traps are slowing down this mechanism.

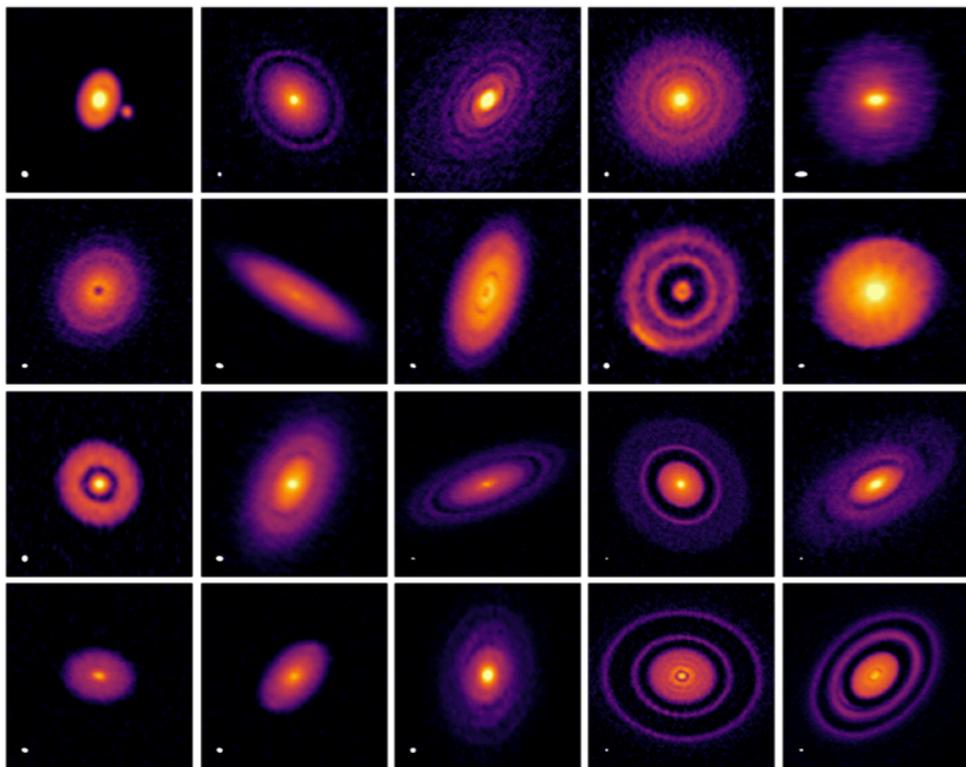


Current issues in planet formation: observational results

Substructures (rings, gaps, spirals) seem ubiquitous in disks we can spatially resolve.

Most disks are located in Star Forming Regions, the majority at distances of 100-200 pc.
Typical disk radius ~ 30 au \rightarrow less than $0.5''$ angular size

Disk Substructures at High Angular Resolution Project (DSHARP)



Andrews et al. 2019

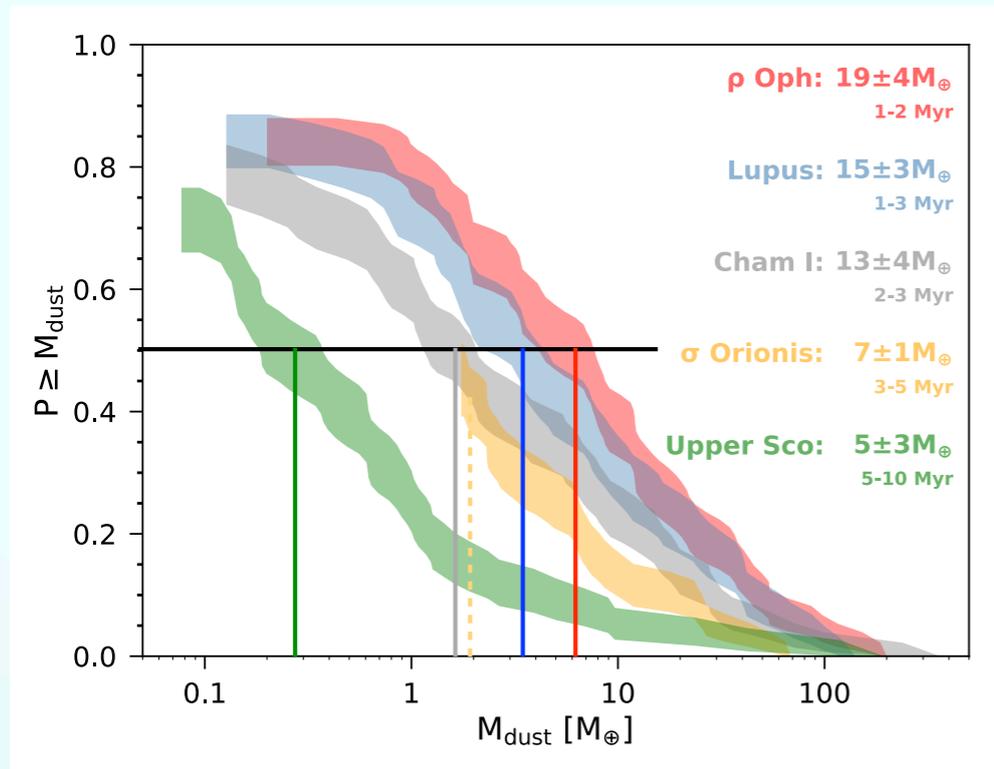
Proposed mechanisms for substructures:

- Protoplanets
- Photoevaporation
- Gravitational instabilities
- Streaming instabilities
- Chemical effects (volatiles condensation fronts)
- MHD winds
- ...

Current issues in planet formation: observational results

Low dust masses

Direct conversion from mm flux to dust mass



Adapt. from Ansdell et al. 2017, Cieza et al. 2018

- Planet formation already completed after 1 Myr?

- Caveats on mass estimates

- . Most mass in pebbles/planetesimals: not detectable by mm-telescope
- . Role of optical depth/dust self-scattering can be significant



Need for longer wavelength observations

Low gas masses

From CO isotopologues

$M_{\text{gas}} < 1 M_J$ in Lupus

Ansdell et al. 2016

Dust growth in disks

High resolution multi-wavelength studies (≥ 3 wle)

Zhang+2015, Guidi + 2016, Maciás+2019, Carrasco-Gonzalez+2019, Maciás+2021, Sierra+2021, Liu+2021, Guidi +2022, Guerra-Alvarado +2024

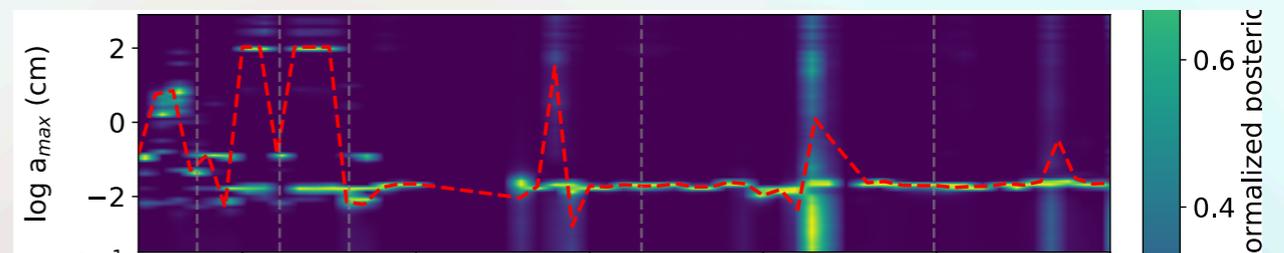
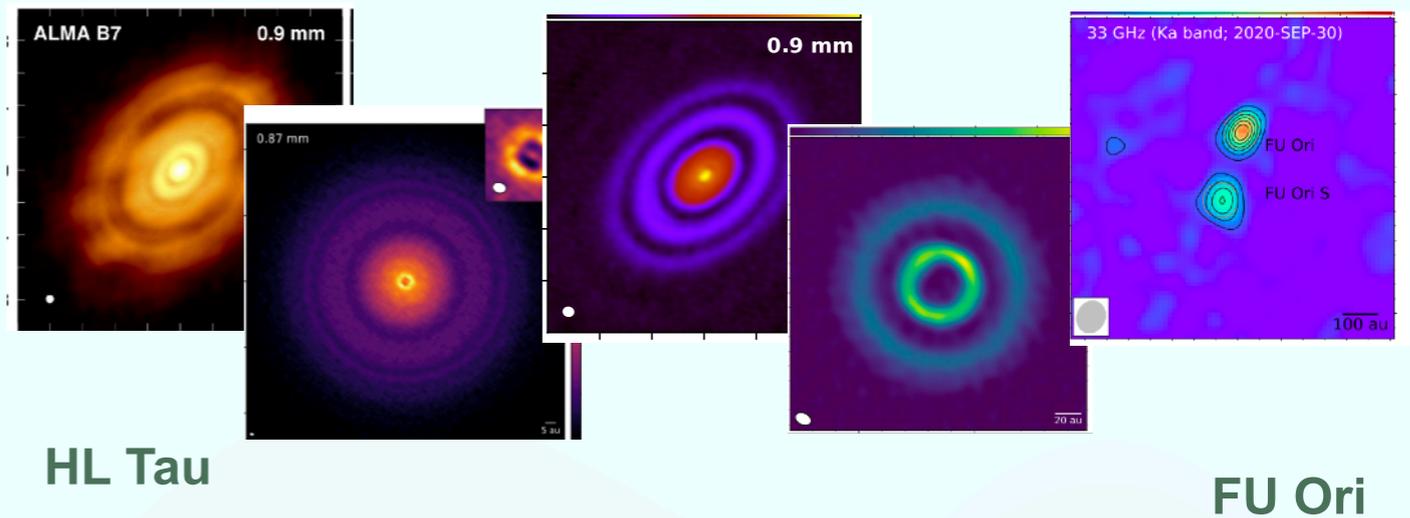
Radially decreasing grain sizes, a_{\max} 100 μm - 10s cm

Polarisation studies

$a_{\max} \sim 100\mu\text{m}$

Kataoka et al. 2016, Stephens + 2017, Kataoka et al. 2017, Dent et al. 2019, Ueda et al 2020, Lin et al 2023

However, we might be observing second generation dust, see e.g. Turrini et al. 2019, Testi et al. 2022



Guidi et al. 2022

$\sim 200\mu\text{m}$ grains

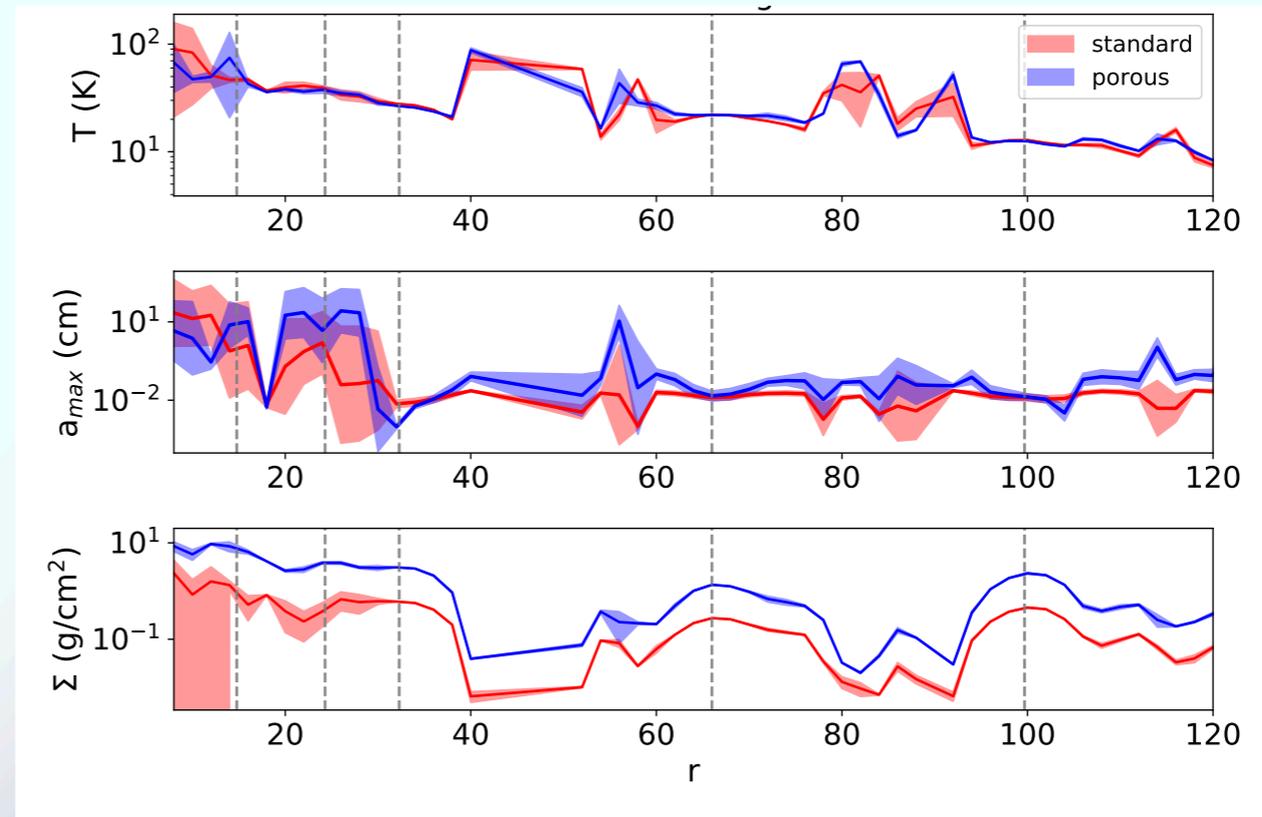
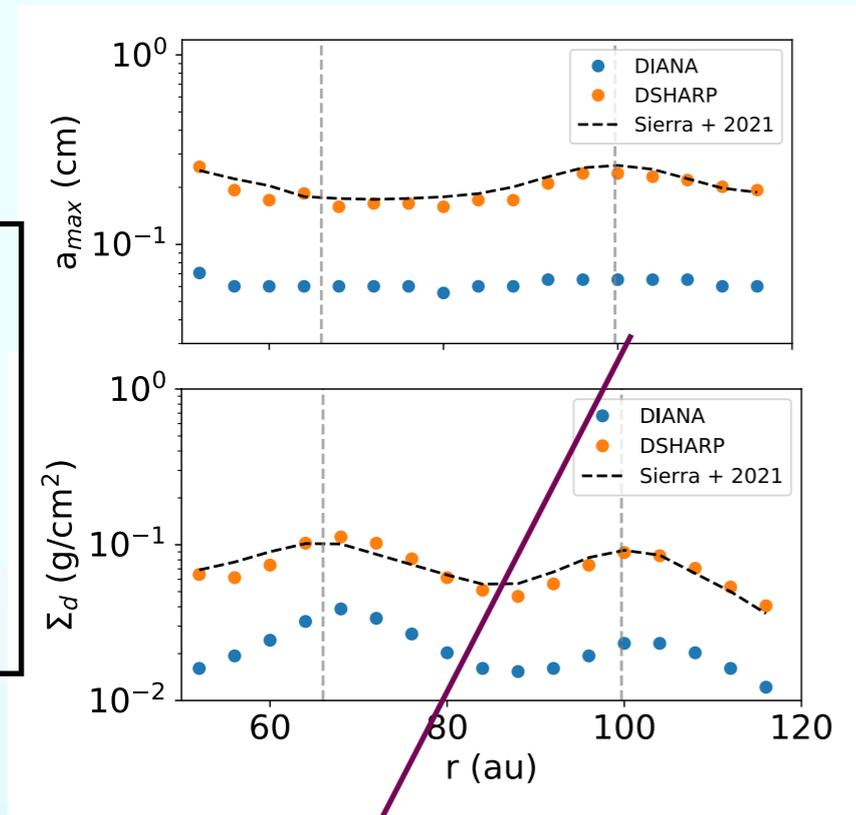
CAVEATS: unknown dust composition, shape, porosity

Grain size - effect of the assumptions on the dust composition

DIANA vs DSHARP opacities:

Compact (25 % porosity) vs porous (80 %) grains

Guidi et al. 2022



Grain size is 2-4 times larger

Surface density assuming porous grains is ~5 x higher

“dust trapping” not detected with DIANA opacities

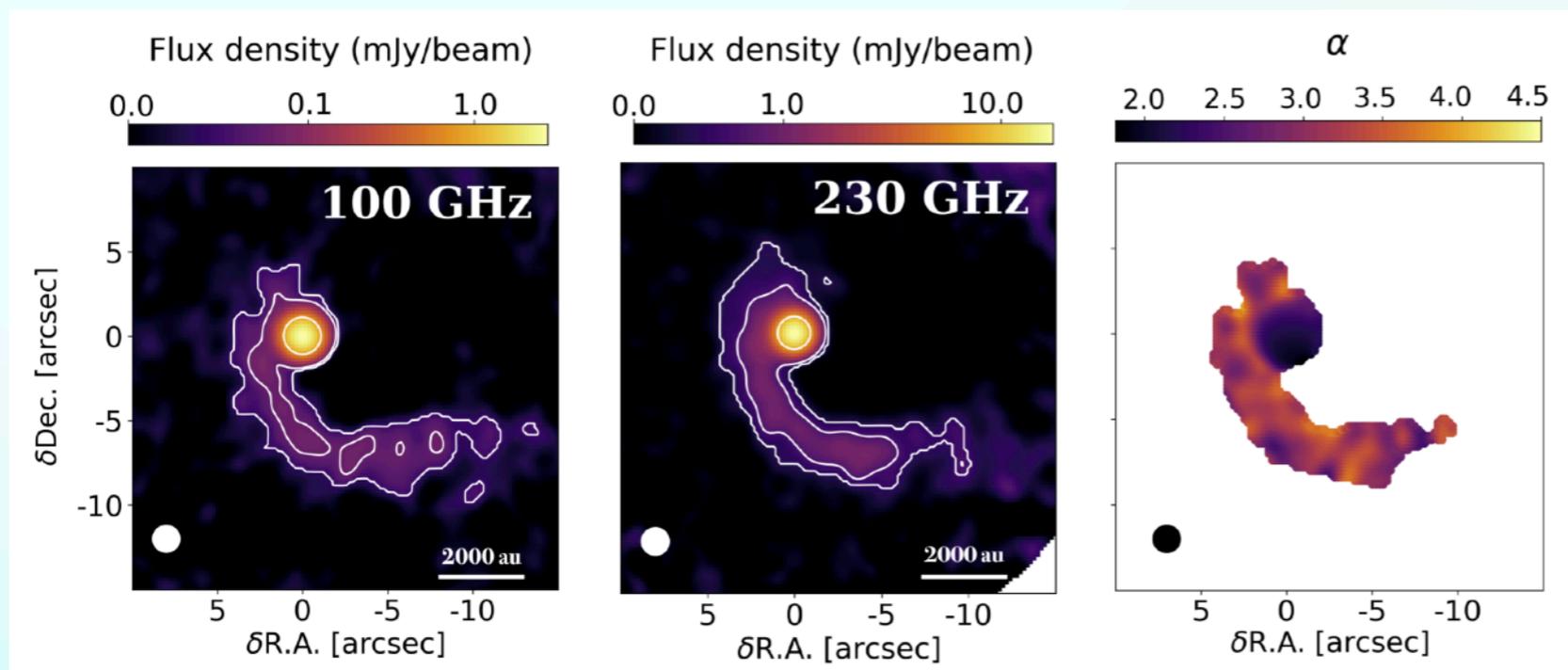
Choice of opacities significantly affects the derived mass and maximum grain size

See also Zhang et al. 2023 - HL Tau

Dust growth in disks

See talks by Columba, Cacciapuoti

Evidence of grain growth already in the envelope of class0/I systems (e.g. Miotello et al., 2014, Cacciapuoti et al. 2023), or even in streamers and outflows (Cacciapuoti et al. 2024, Sabatini et al. 2025)



Cacciapuoti et al. 2024.

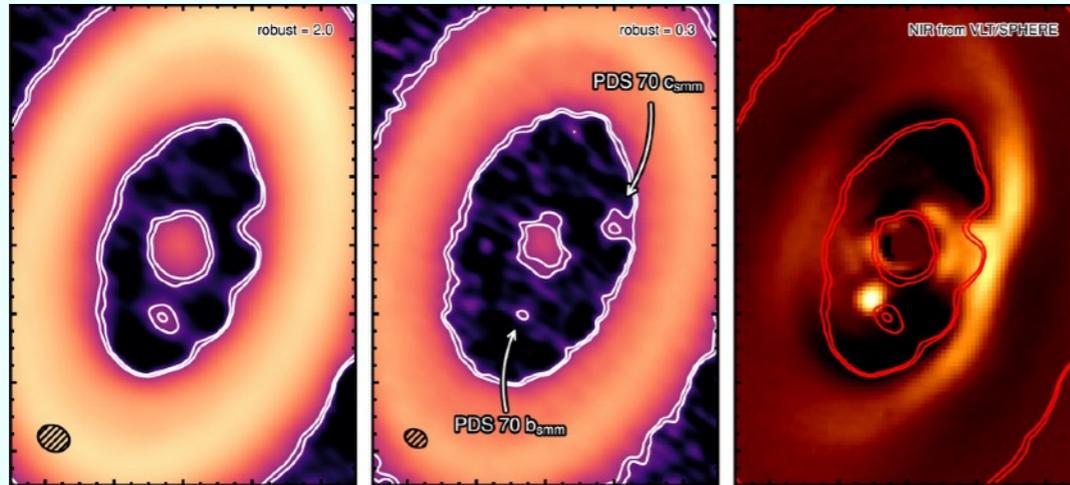
Do we see planets in disks?

Direct imaging

Protoplanets directly imaged in disks: only a handful of systems

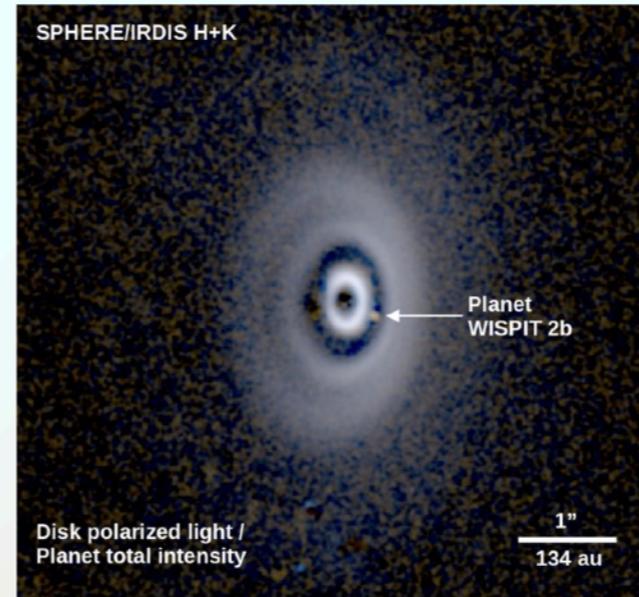
PDS 70b, 70c

Isella et al. 2019



(see also Keppler et al. 2018, Benisty et al. 2021)

WISPIT-2b



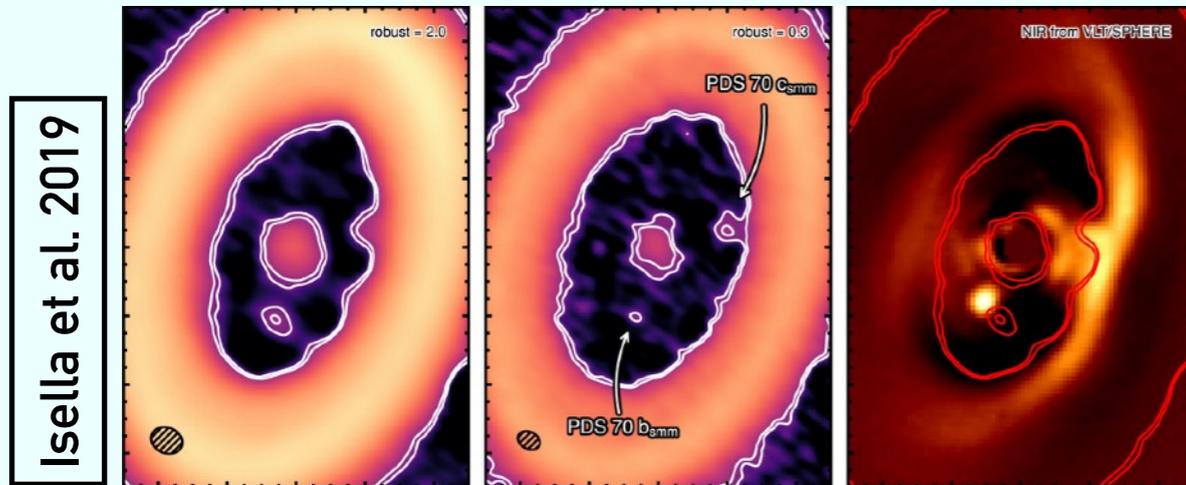
van Capelleveen et al. 2025

Do we see planets in disks?

Direct imaging

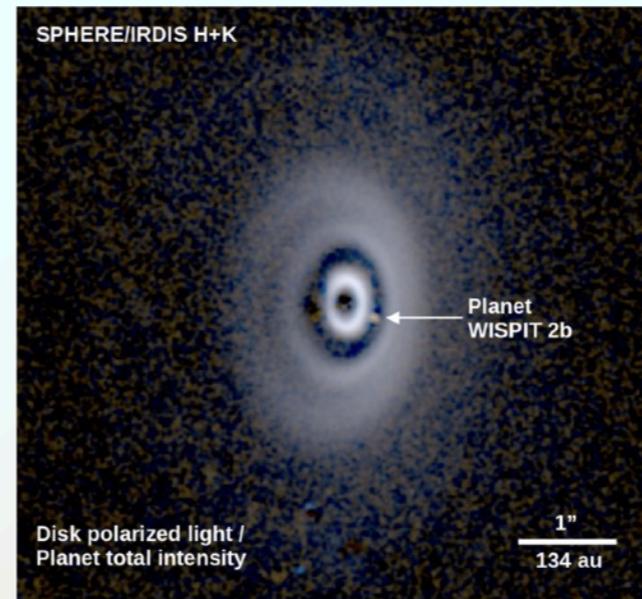
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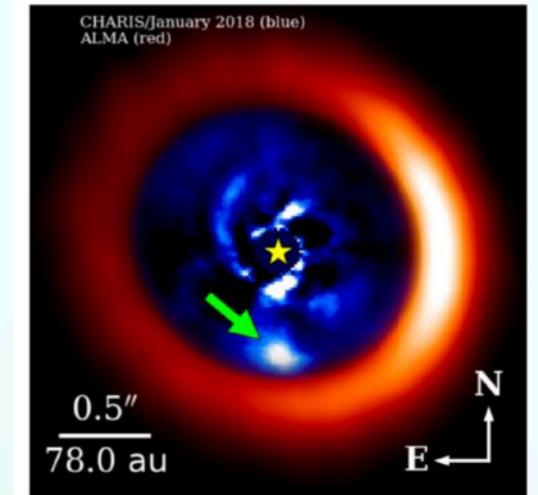
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WISPIT-2b



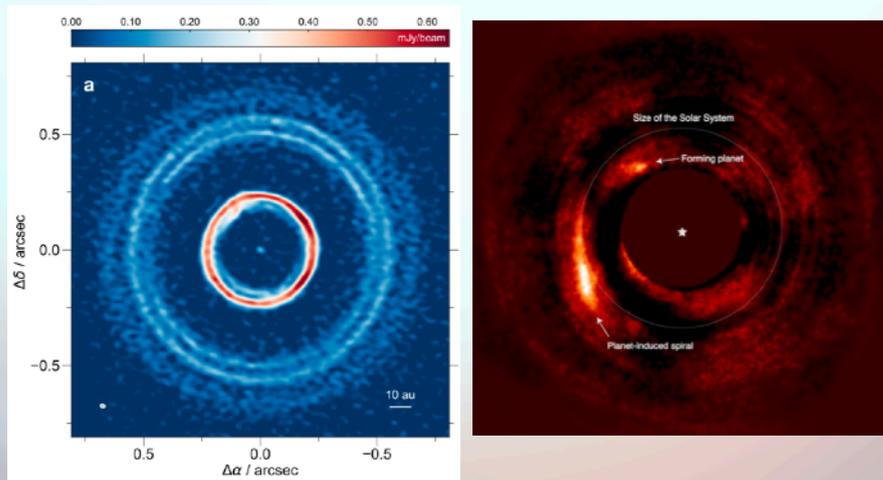
van Capelleveen et al. 2025

AB Aur b



Currie et al. 2022

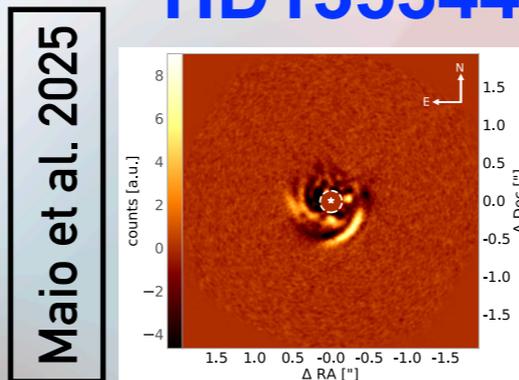
HD169142b



Pérez et al. 2019

Hammond et al. 2023

HD135344Bb



Maio et al. 2025

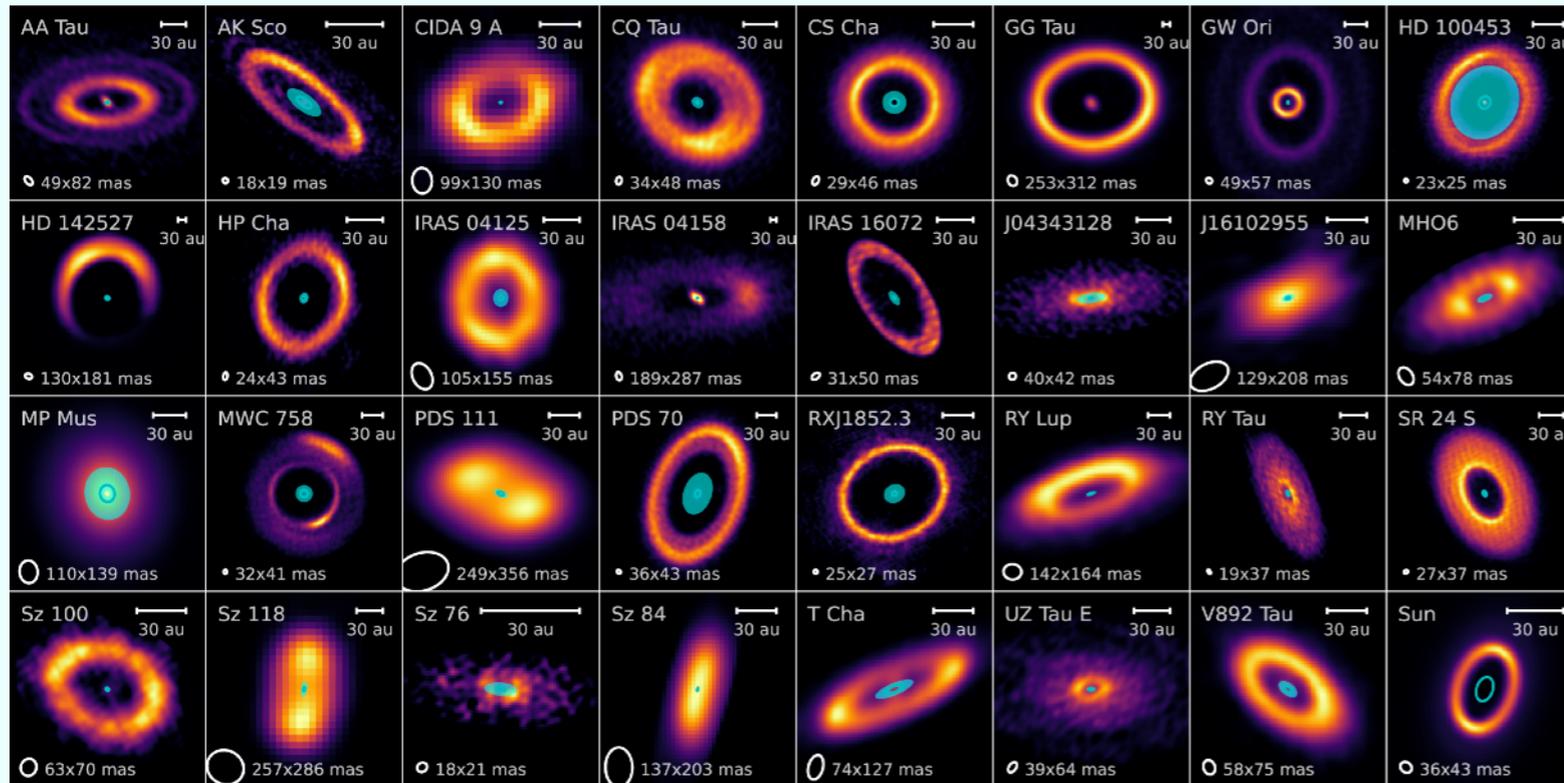
CI Tau b

Manick et al. 2024

Most searches for protoplanets in disks are unsuccessful: could be an optical depth issue

Do we see planets in disks?

Astrometry



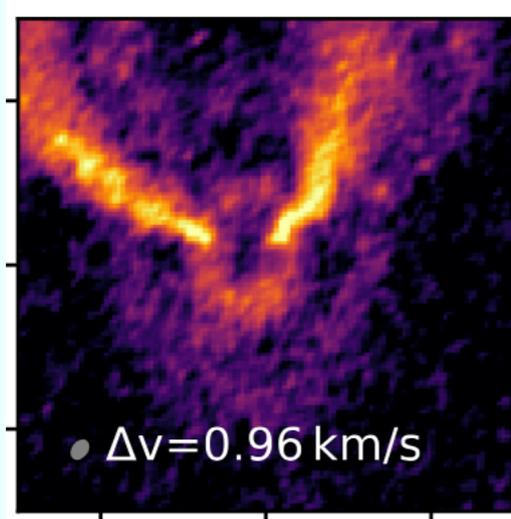
Search for proper motion anomalies in 98 transition disks with Gaia astrometry: found anomalies in 32% of the sample (most in the stellar mass regime).

About half not compatible with having carved the observed dust cavities.

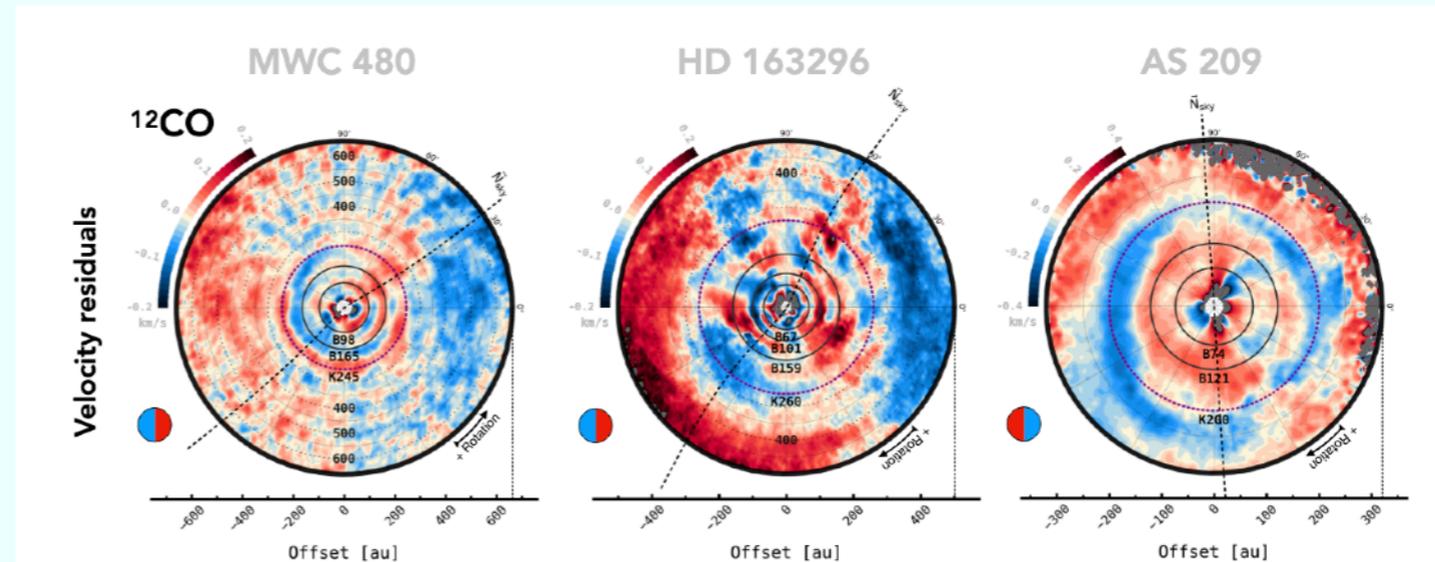
Vioque et al. 2026

Do we see planets in disks?

Gas kinematic



Pinte et al. 2019

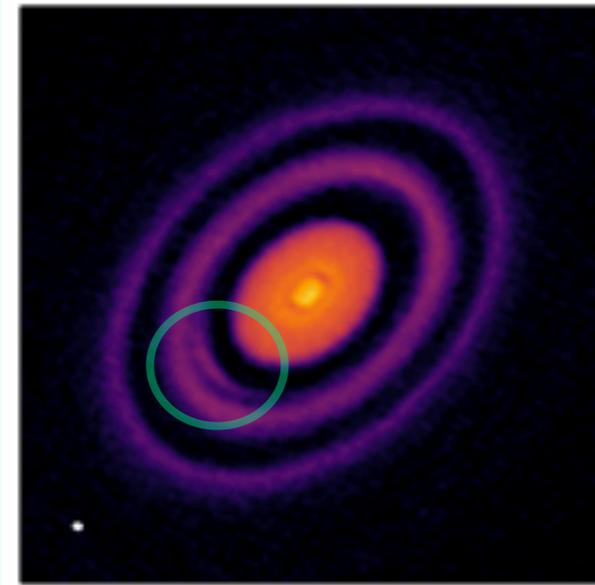


Izquierdo et al. 2023

Detection of velocity “kinks” in the gas distribution can point to the presence of planets

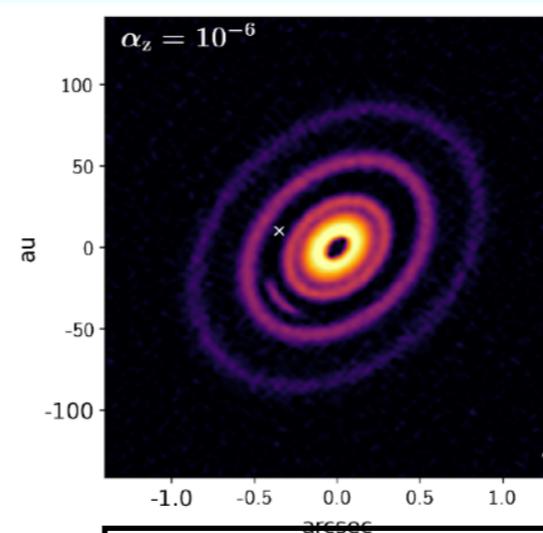
Asymmetric substructures

Proposed explanation for the crescent in HD 163296:
 . Dust trapping in the Lagrangian points of the planet-
 star system

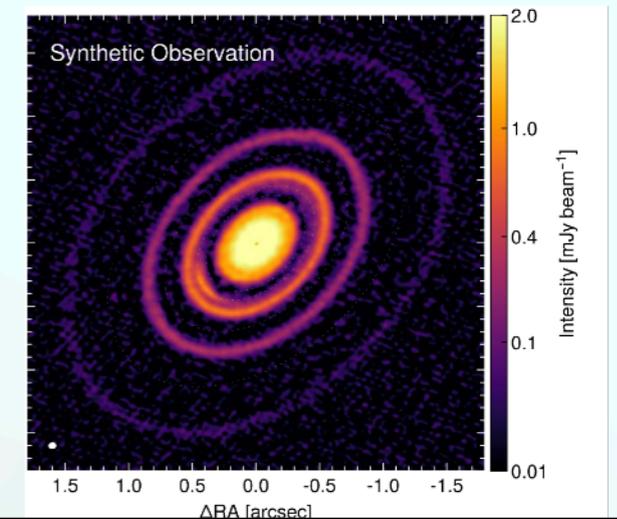


1 Mj planet:

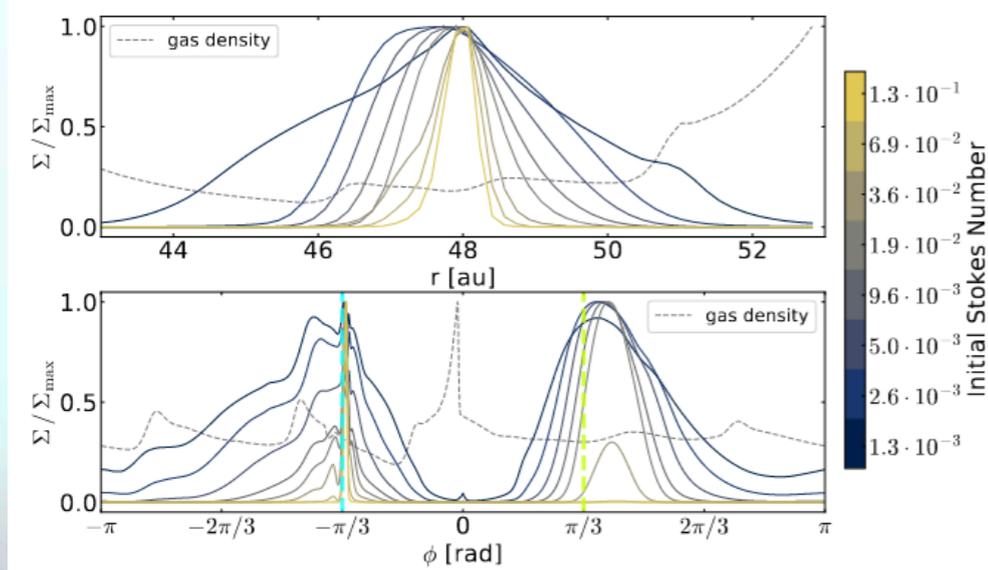
2 sub-saturn planets



Rodenkirch et al. 2021



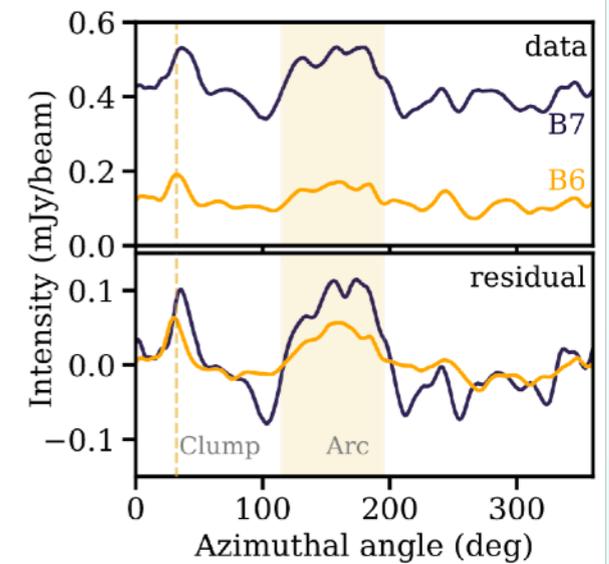
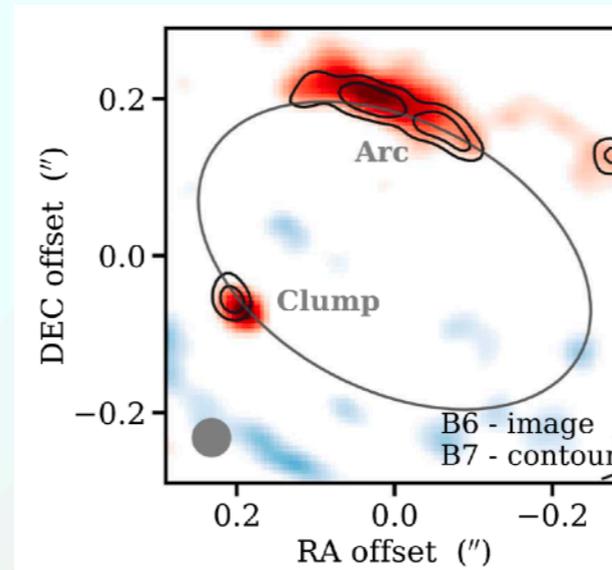
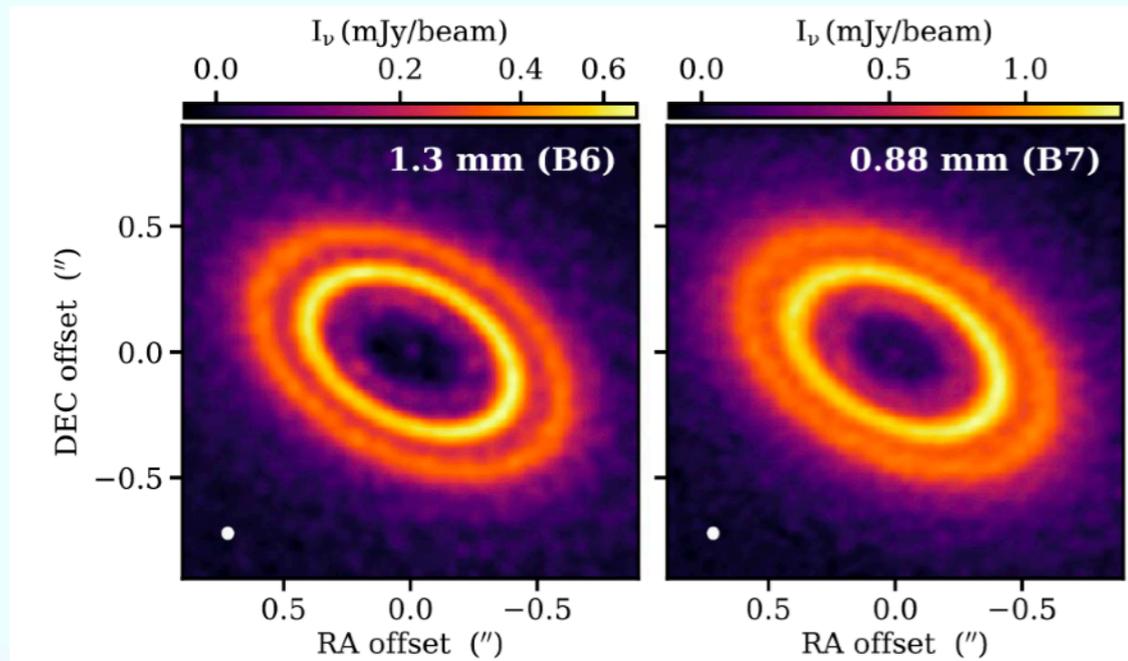
Garrido-Deutelmoser et al. 2023



Rodenkirch et al. 2021

Asymmetric substructures

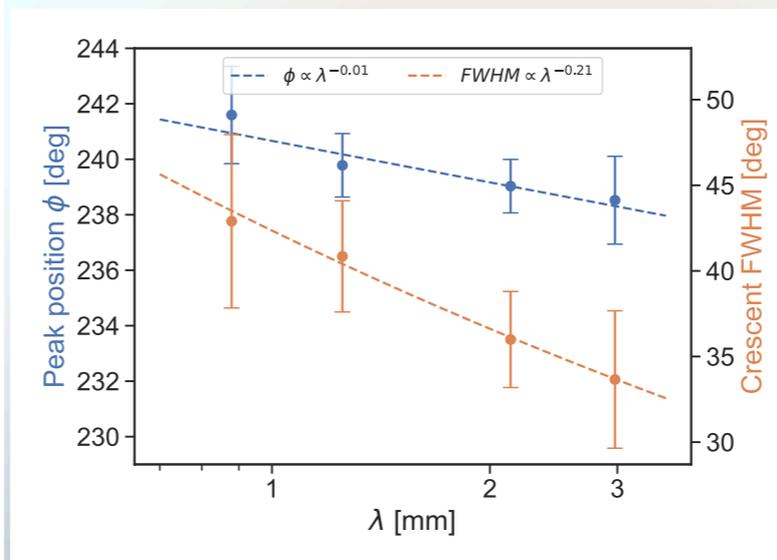
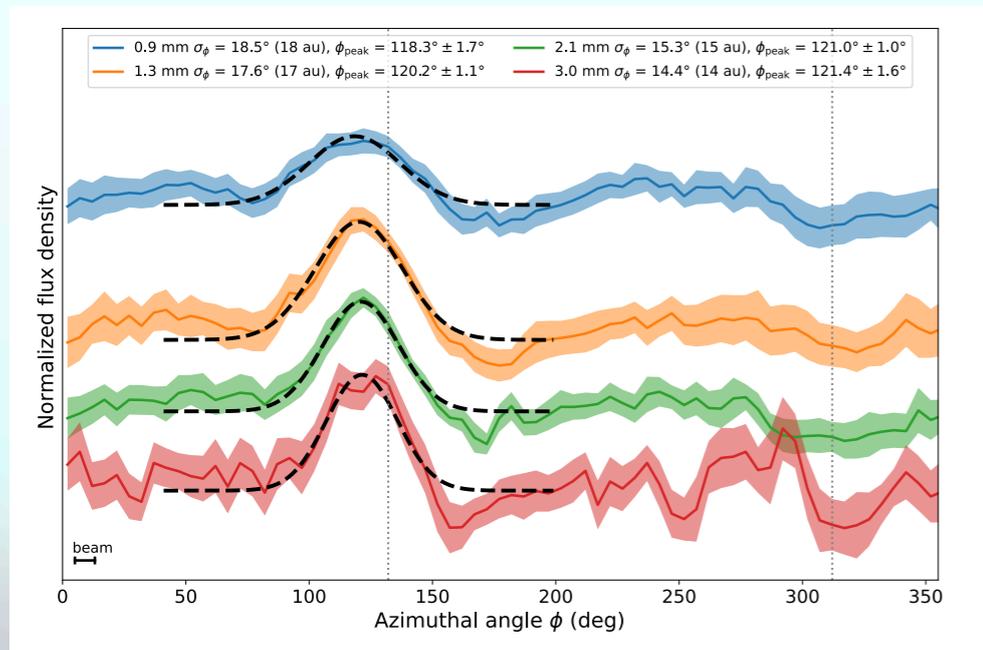
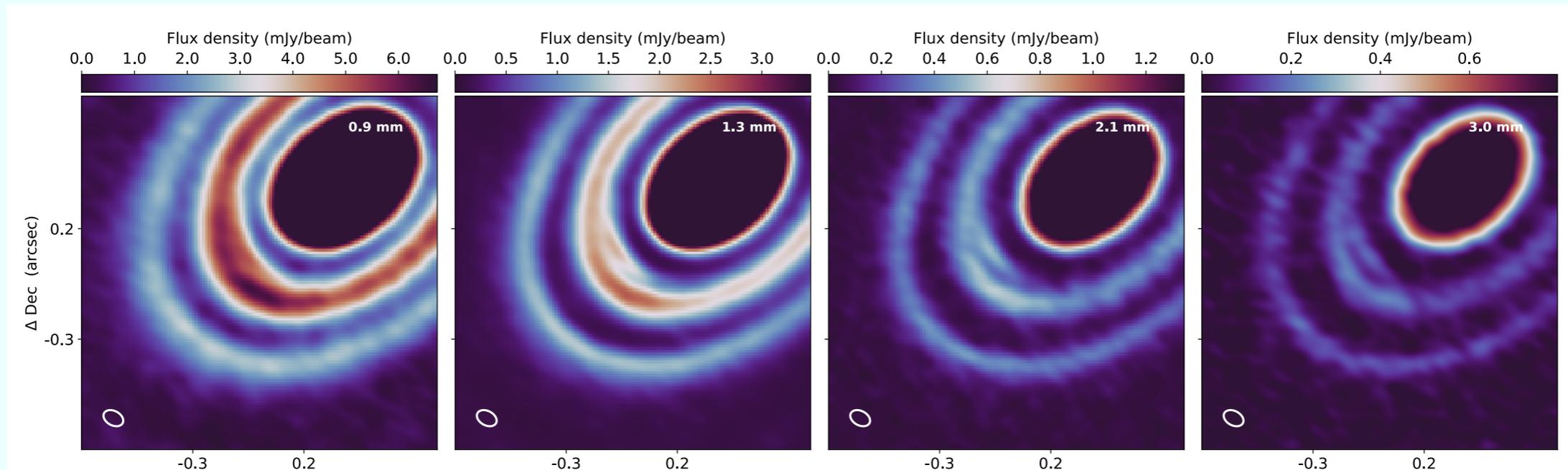
Dust trapping in Lagrangian points observed in LkCa 15



Long et al. 2022

The clump and the arc (separated by ~ 120 deg) trace dust trapping around L4 and L5, respectively.

Dust traps and gas kinematic signature in a crescent structure: HD 163296



. Crescent peak position slightly shifting counter-rotation wise with wavelength

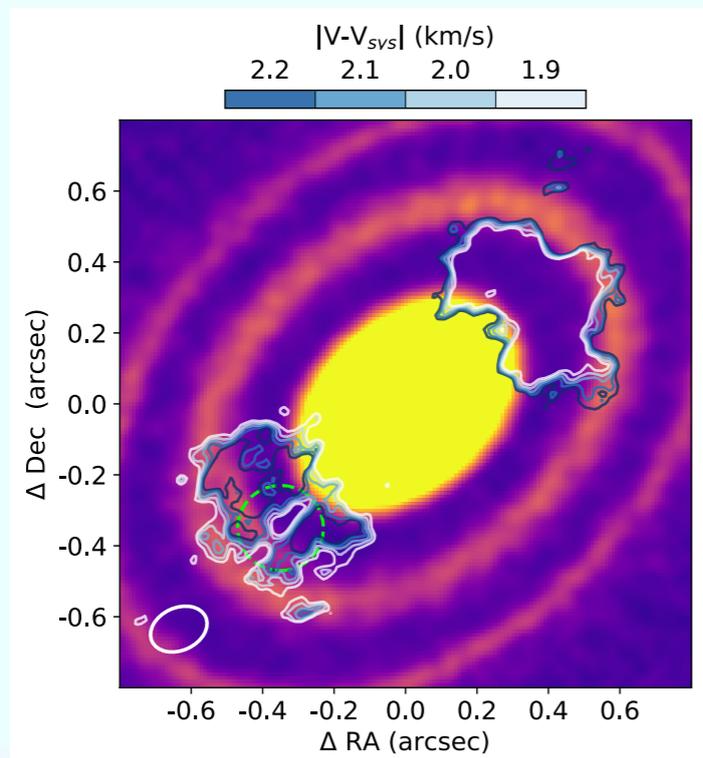
. Crescent width decreasing with wavelength

Guidi et al. 2026

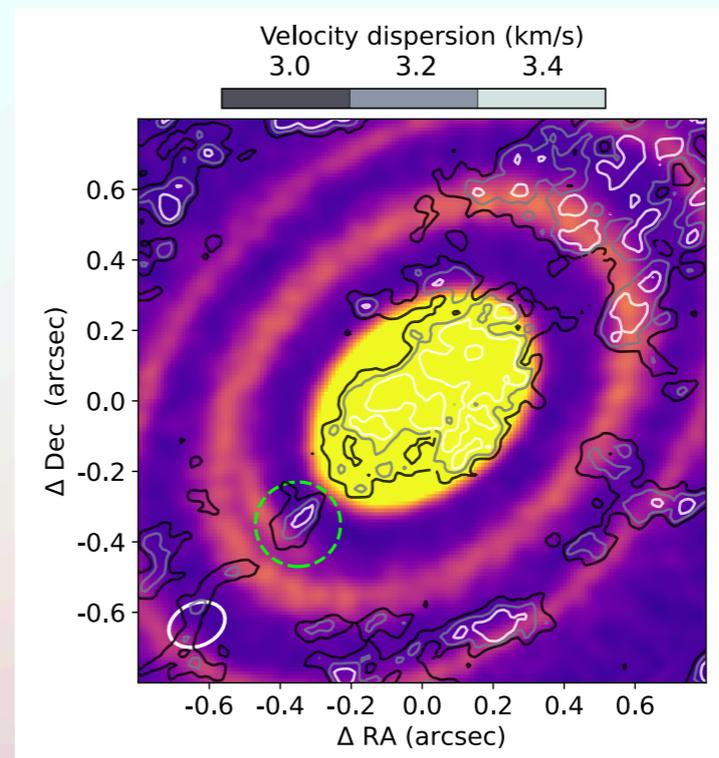
Dust traps and gas kinematic signature in a crescent structure: HD 163296

CS (3-2) shows kinematic anomalies near the location of the crescent

CS Moment 1 contours



CS Moment 2 contours

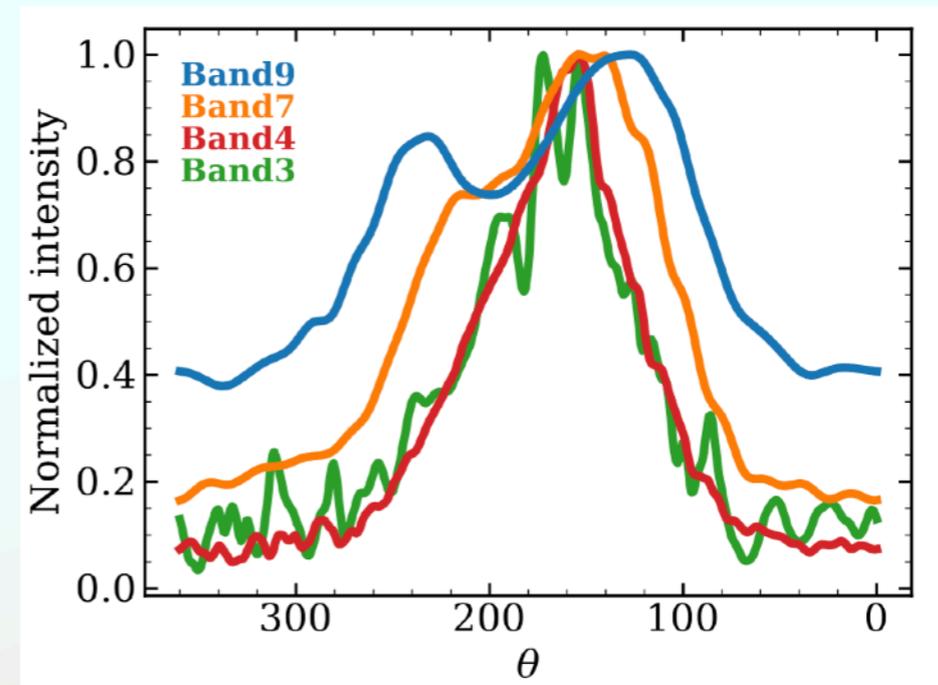
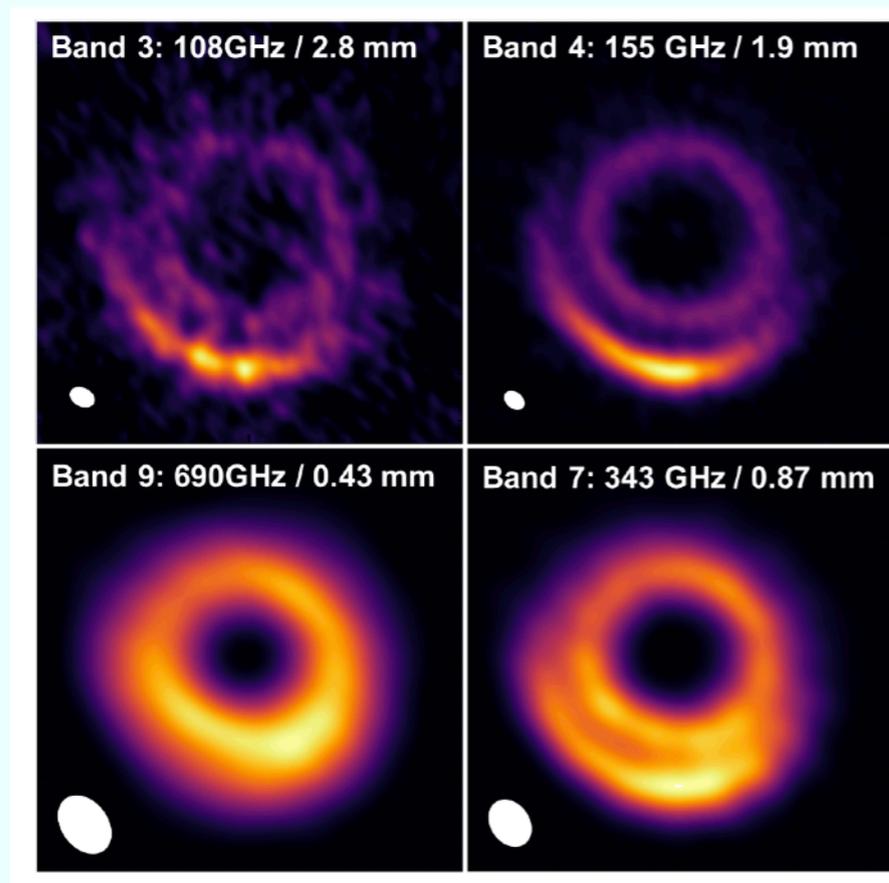


Guidi et al. 2026

Low SNR does not allow to fit the vertical structure of the CS emission (see also Law et al. 2024)

Current evidence does not point univocally to the crescent being produced by trapping in a Lagrangian point or trapping in a vortex

Asymmetric substructures



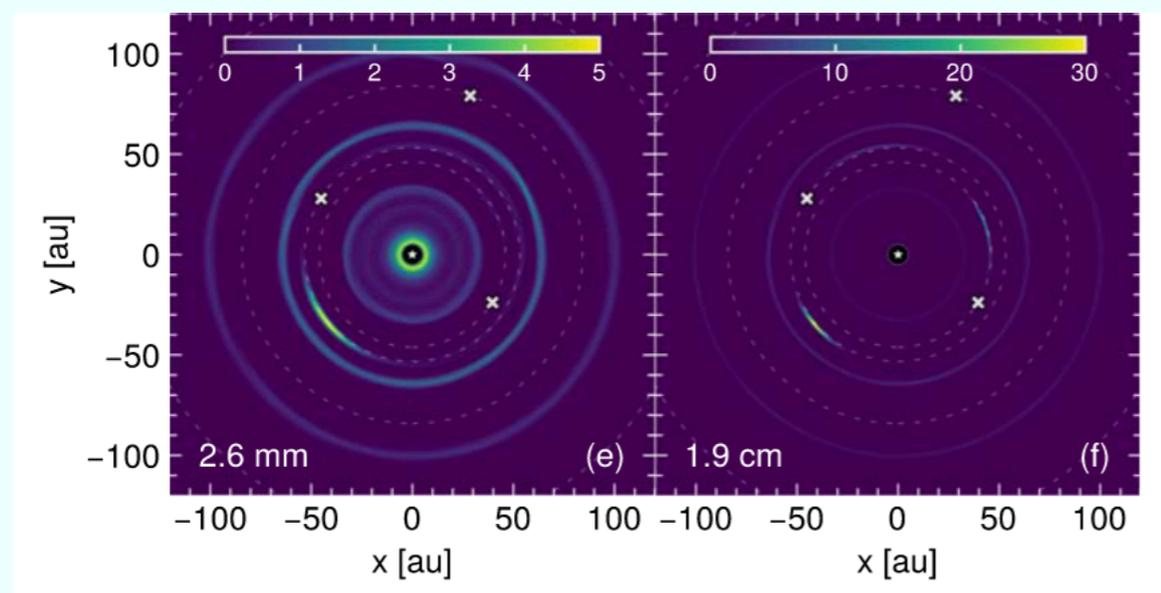
Cazzoletti et al. 2018

Similarities with HD 163296 study:

- Double peak “appearing” at 3 mm
- Peak shifting counter-rotation wise with w_{le} (opposite to what predicted for the effect of self-gravity in presence of a vortex (Baruteau and Zhu, 2016))

Asymmetric substructures

. Longer wavelength observations needed: larger Stokes I are more efficiently trapped

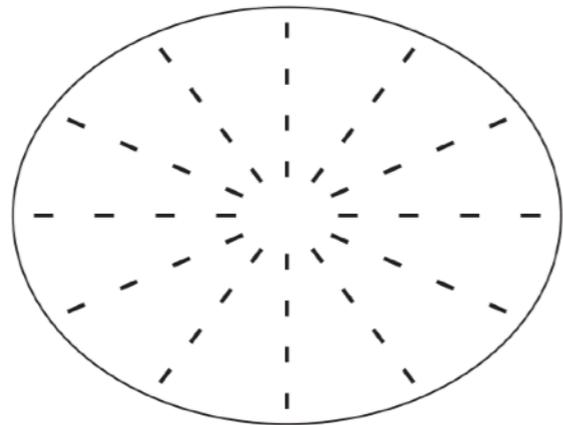


Garrido-Deutelmoser et al. 2023

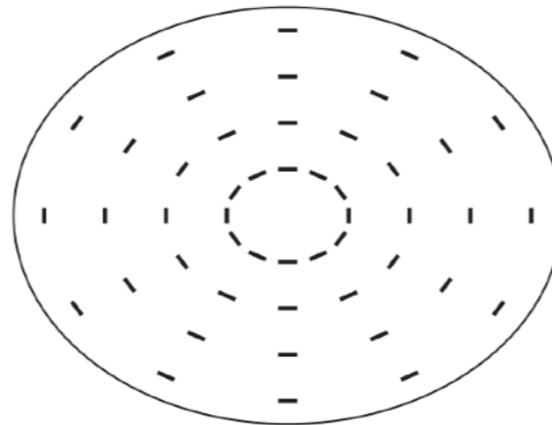
. Is this a transient structure? Multi-epoch observations needed

Polarisation in Class II disks

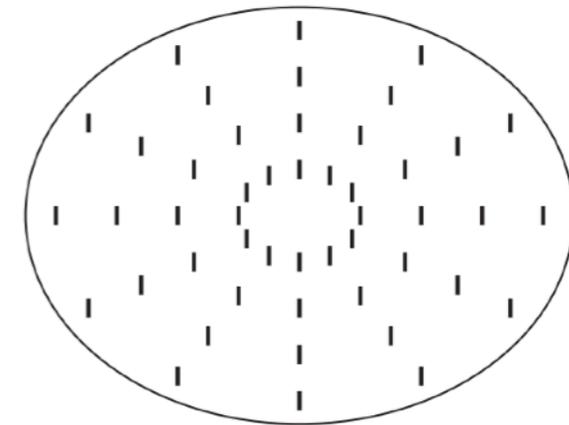
(a) alignment with toroidal magnetic fields



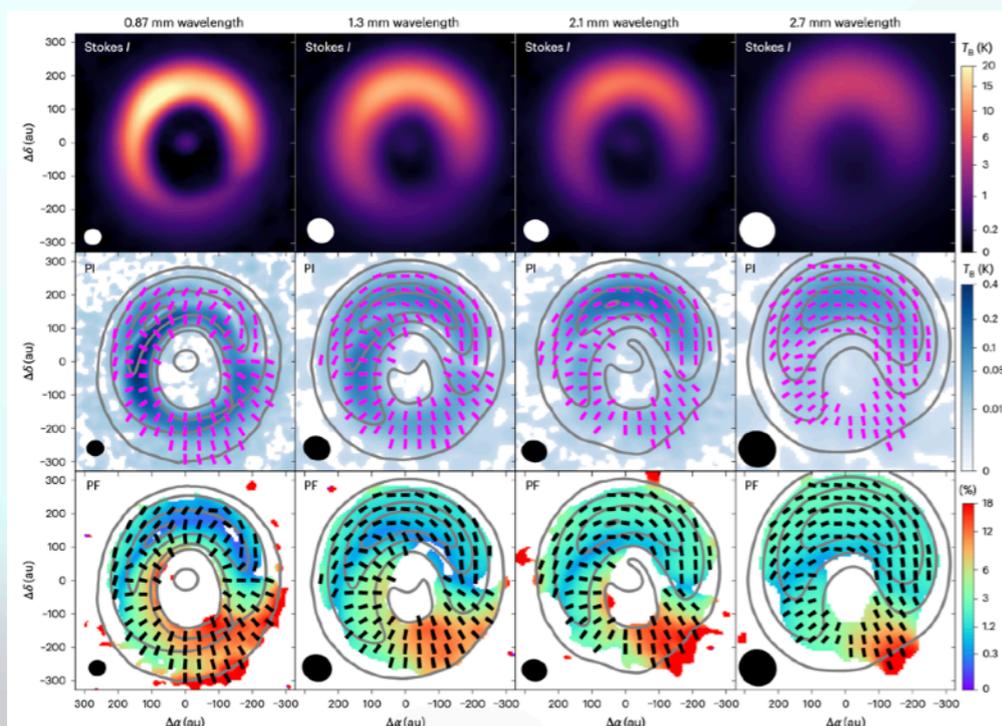
(b) alignment with radiation fields



(c) self-scattering



Kataoka et al. 2017

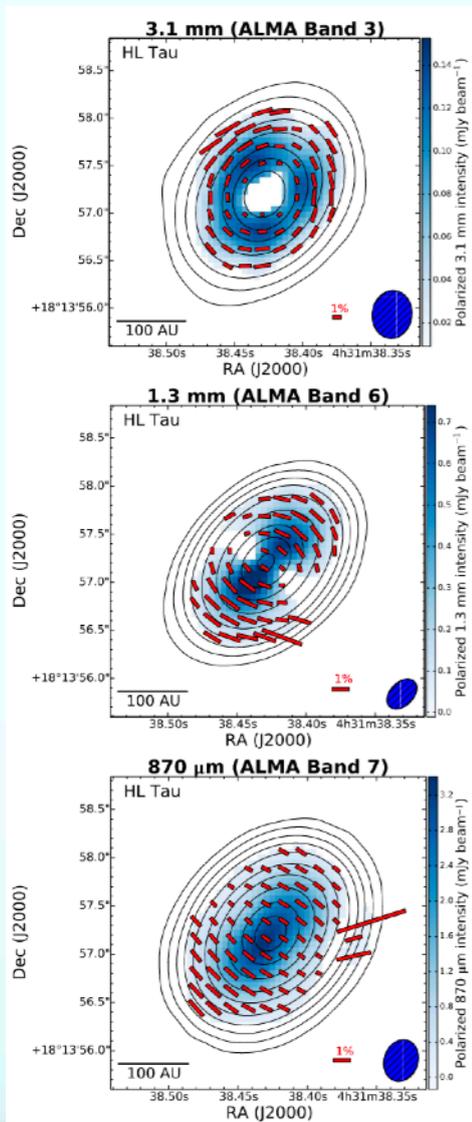


Multiple mechanisms generating polarisation in the same disk (self-scattering + alignment with magnetic field)

Ohashi et al. 2025

Polarisation in Class II disks

HL Tau, Class I/II



Stephens et al. 2017

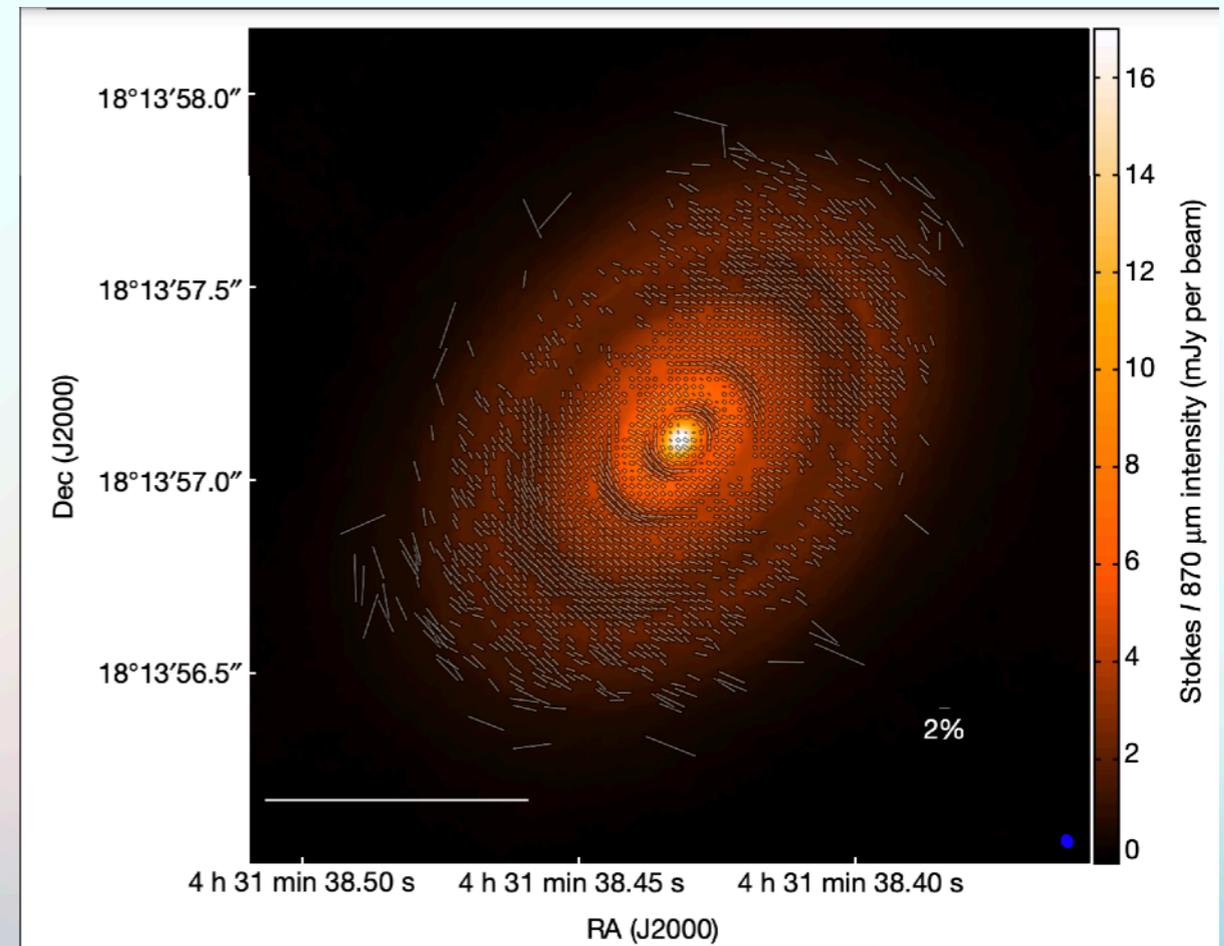
Grains aligned with radiation anisotropy

Dominant polarization mechanism varies with wavelength in the sub-millimeter range

Self-scattering

ALMA 0.87 mm at 0.033" (4.9 au)

Stephens et al. 2023



disk polarization is due to both scattering and emission from the aligned prolate grains

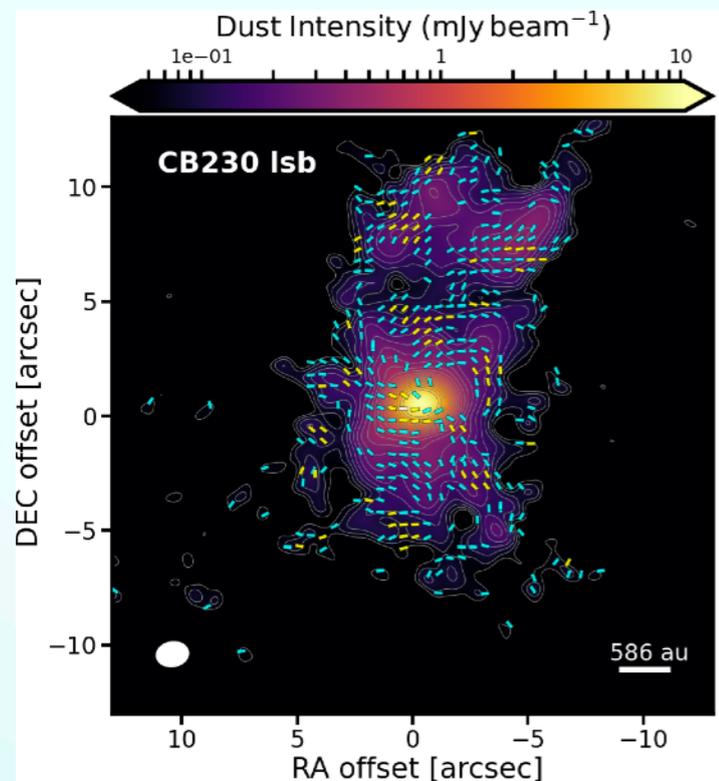
20

20

Polarisation at long wavelengths

In disks: typically low levels of linear polarisations ($\sim 1\%$) \rightarrow need for sensitivity!

See talks by Testi, Soave



credits A. Soave

ENYGMA large program

(PI Maury/Testi)

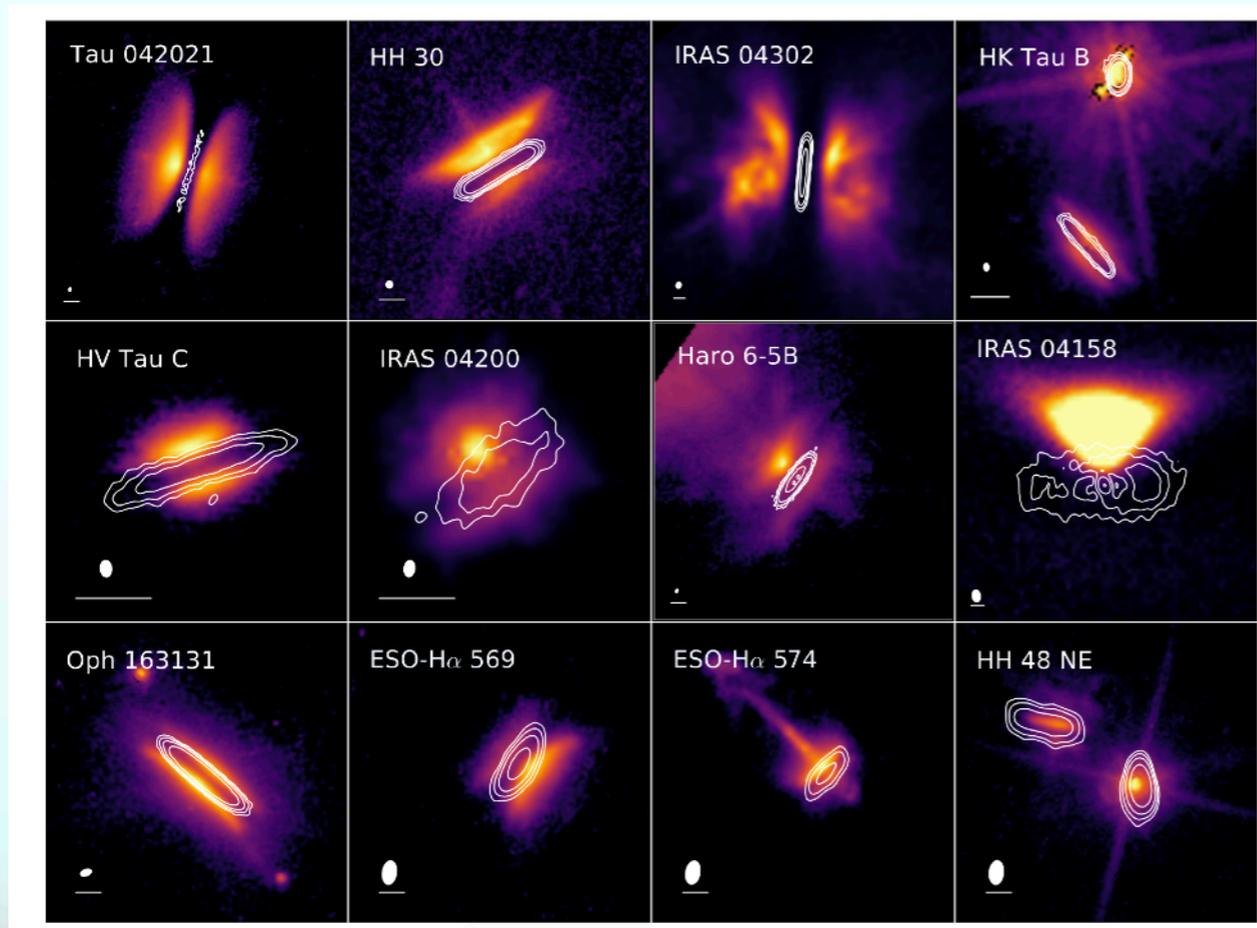
3mm polarisation with NOEMA

Study magnetic fields and dust properties in Class 0/I sources

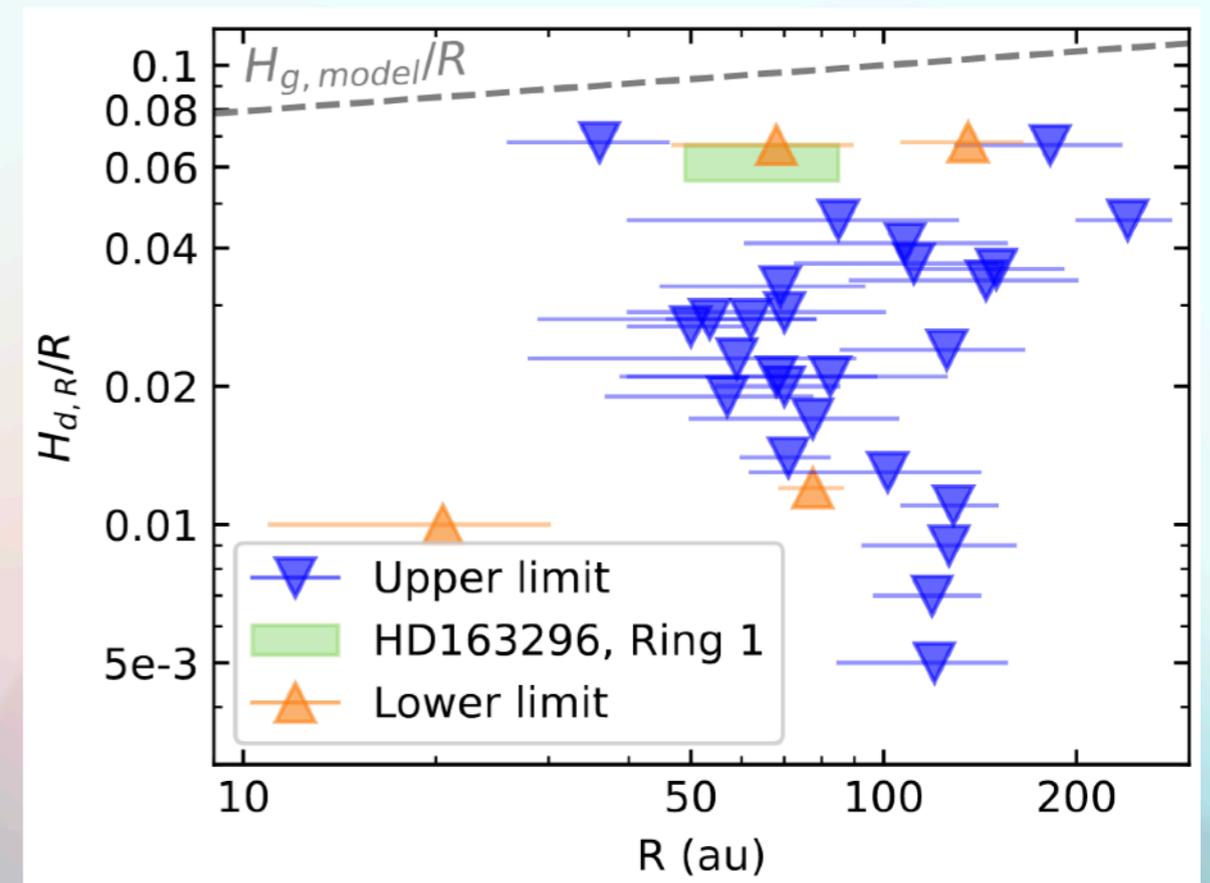
Dust settling in disks

Dust settling is important for planet formation efficiency

Nearly all Class II outer disks are settled in band 6-7



Villenave et al. 2020



Villenave et al. 2025

Dust settling in disks

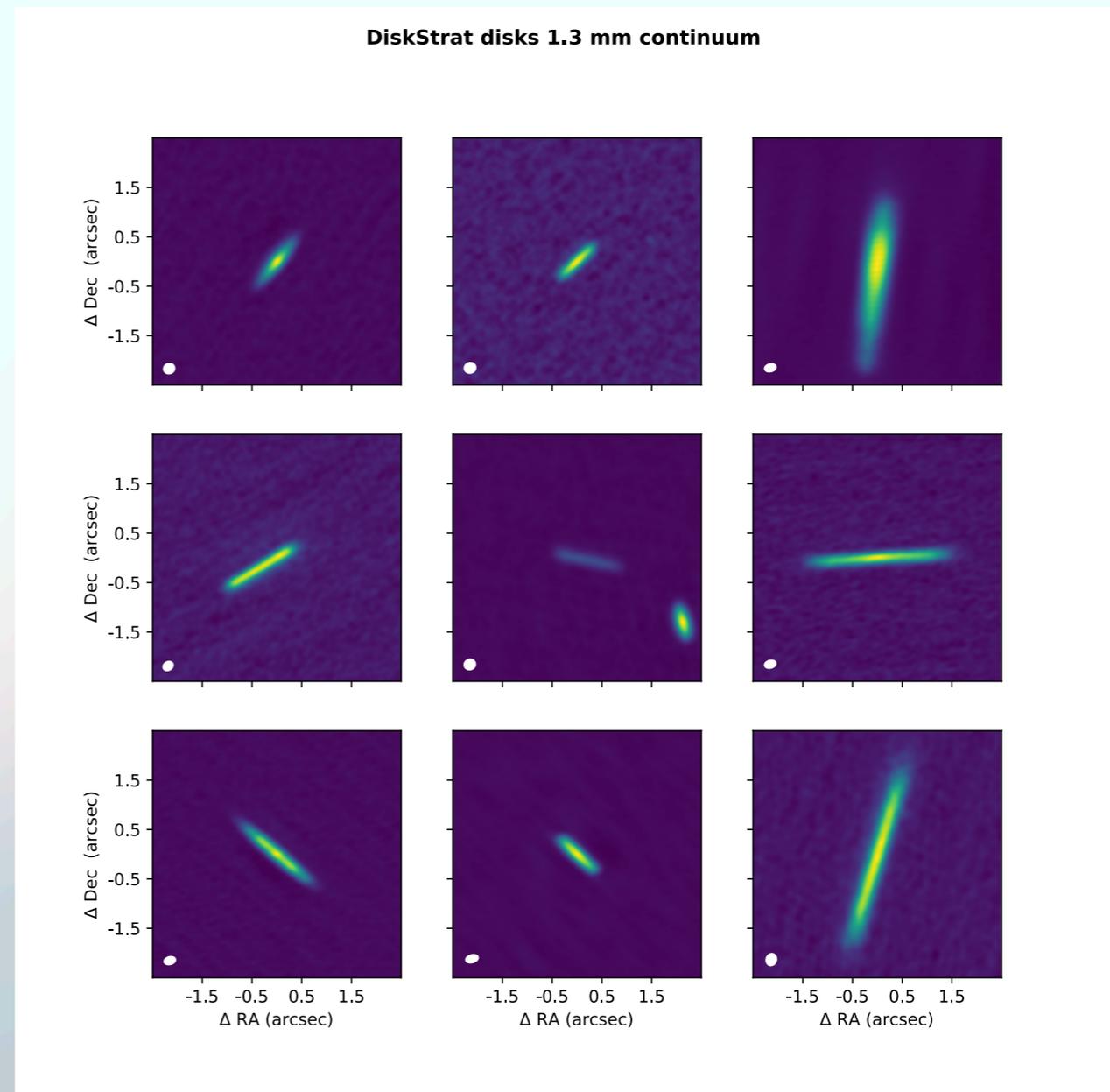
DiskStrat ALMA Large Program

PI R. Le Gal

co-PIs: Y. Aikawa, J. Bergner, C.
Espaillat, F. Menard

Map out the vertical structure/
chemical segregation;
Assess dust-chemistry relationships
in disks;
Characterize the physical and
kinematic properties of disk
atmospheres and winds.

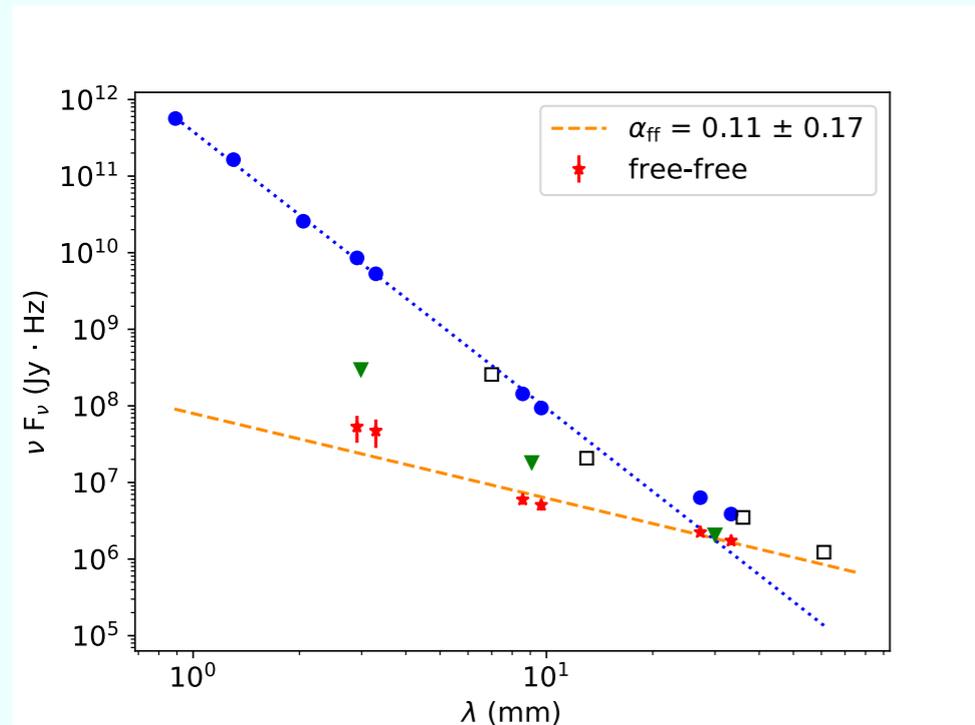
Resolution $\sim 0.15''$



Guidi et al. in prep

23

Non-thermal emission



HD 163296

λ [mm]	$F_{\text{free-free}}$ [mJy]	$\Delta F_{\text{free-free}}$ [mJy]	% total Flux
2.91	0.52	0.20	0.6
3.29	0.52	0.21	0.9
8.57	0.17	0.03	4.1
9.67	0.16	0.03	5.2
27.3	0.20	0.02	35
33.3	0.19	0.02	44

Guidi et al. 2022

Spectrum of 0.11 consistent with opt. thin free-free emission from disk/stellar wind

Estimates of non-dust emission:

7 mm 20% (Rodmann+2016)

1 cm 35% with large scatter (Garufi+2025)

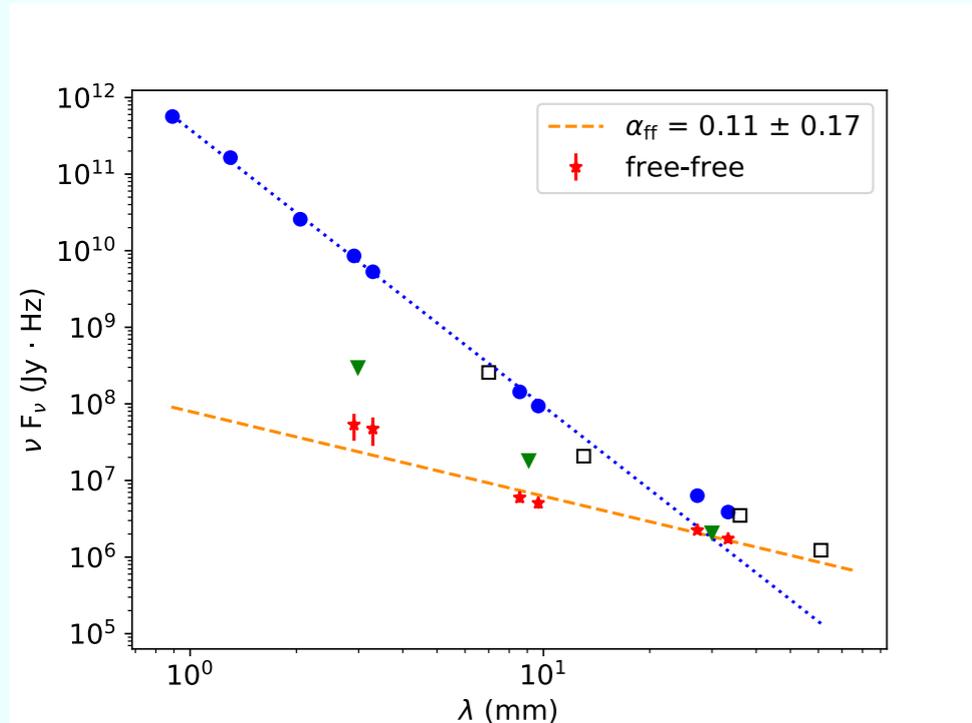
2 cm 65% (Garufi+2025)

3 cm 70% (Coutens+2019)

Surveys of SFRs indicate variability in the flux of the non-dust component

(e.g. Ubach+2017)

Non-thermal emission



HD 163296

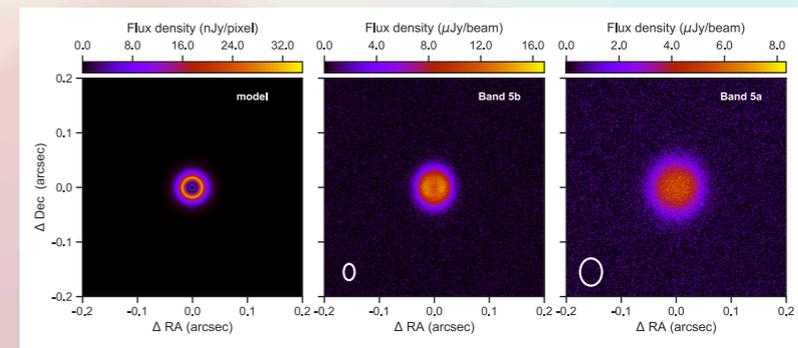
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Guidi et al. 2022

Spectrum of 0.11 consistent with opt. thin free-free emission from disk/stellar wind

Combination with longer wavelength observations + comparison with wind models

- Estimates of non-dust emission:
- 7 mm 20% (Rodmann+2016)
- 1 cm 35% with large scatter (Garufi+2025)
- 2 cm 65% (Garufi+2025)
- 3 cm 70% (Coutens+2019)



See Guidi et al.; Garufi et al. SKA AAll, under review

Surveys of SFRs indicate variability in the flux of the non-dust component

(e.g. Ubach+2017)

Exciting science with ALMA Band 2 for disk evolution studies

- * High sensitivity for continuum detection: lower dust optical depth, multi-wle studies, intra-band spectral index
- * Dust substructures characterization for multi-wle studies
- * Linear polarisation from dust: crucial to complement full intensity studies of dust properties
- * Lower J lines transitions: molecules closer to the midplane, dust less optically thick.
- * Edge-on disks: investigating dust settling
- * Deep observations for non-thermal emission estimates at long wavelengths - synergies with cm facilities

NOEMA @ Plateau de Bure



Thank you!