Protoplanetary disks and the onset of planet formation with the SKAO

3rd Sweden SKA Days
February 5th, 2026

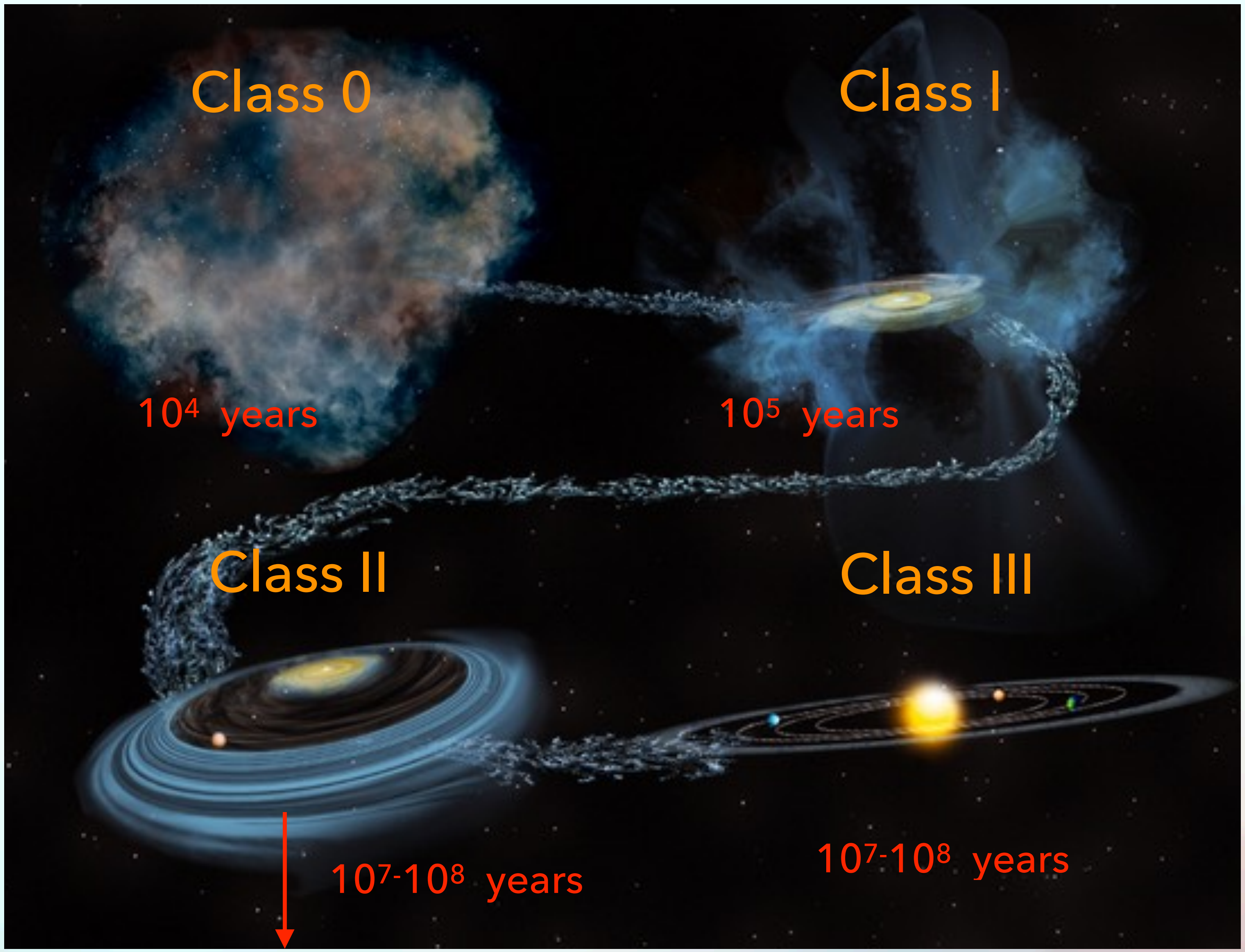
Greta Guidi, Institut de Planetologie et d'Astrophysique de Grenoble (FR)

Outline

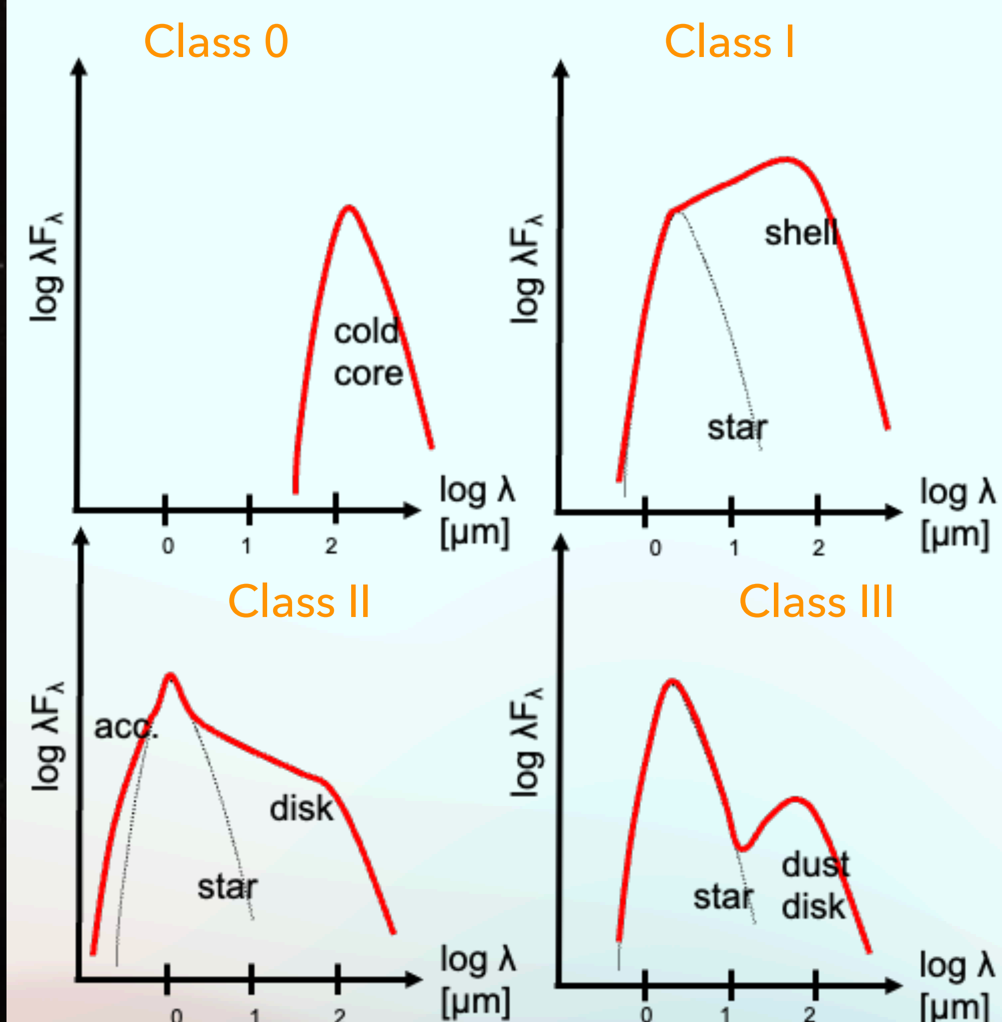
- Context: protoplanetary disks and Young Stellar Objects
- Planet formation and disk evolution: current issues and observational results
- Disks at cm wavelengths with the SKAO
    - Dust demographics and substructures
    - Ionized gas
    - Chemistry
- Synergies with other facilities

Context: protoplanetary disks and Young Stellar Objects

YSOs first classified by Lada (1987) based on IR spectral index



Protoplanetary disks



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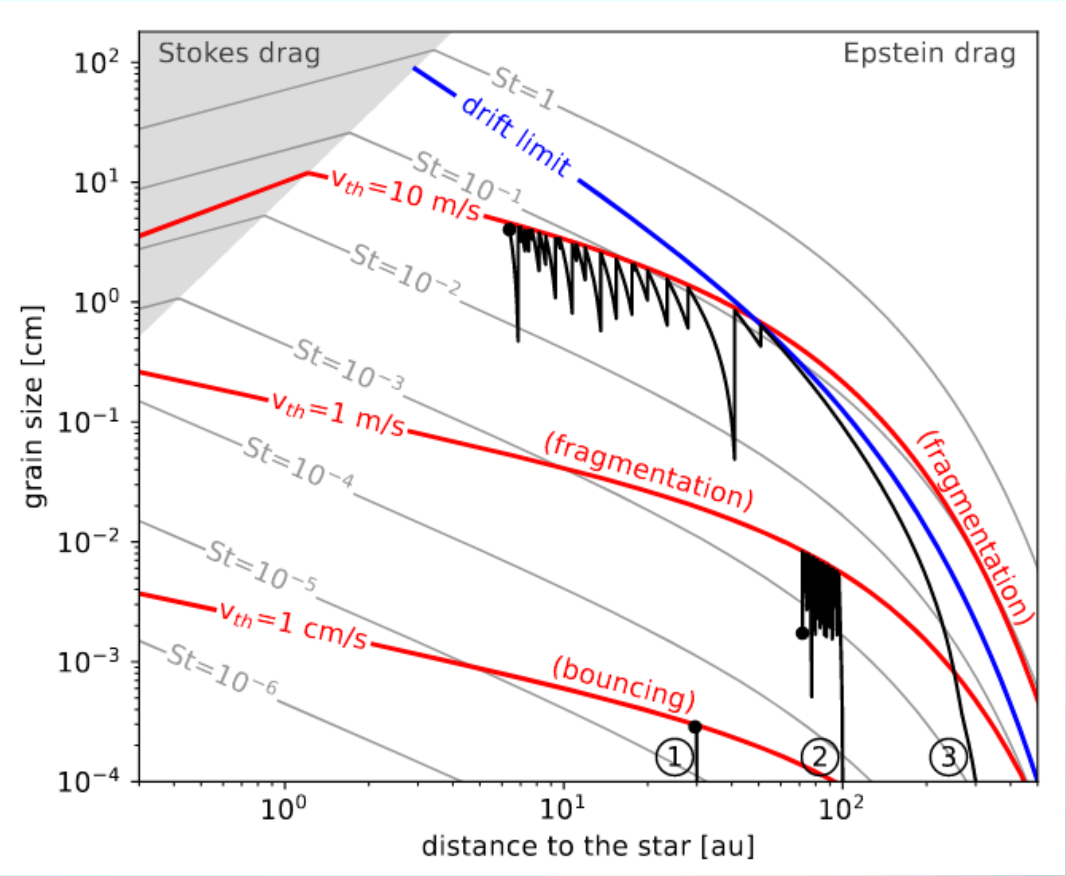
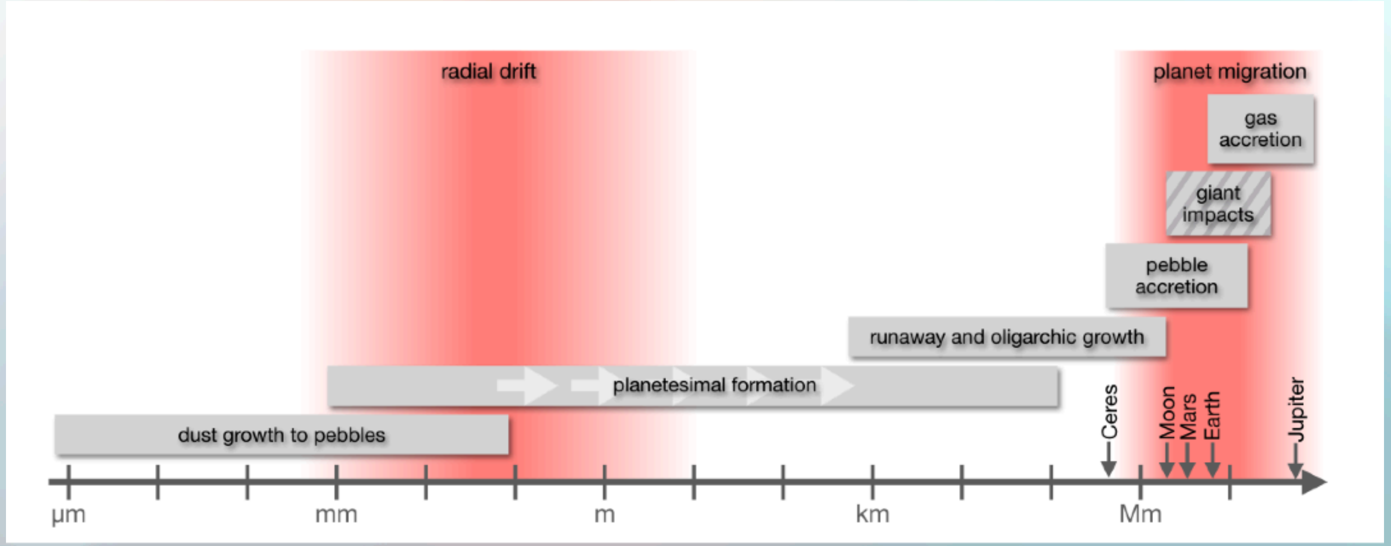
Current issues in planet formation: dust growth barriers

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



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

Drążkowska et al. 2023



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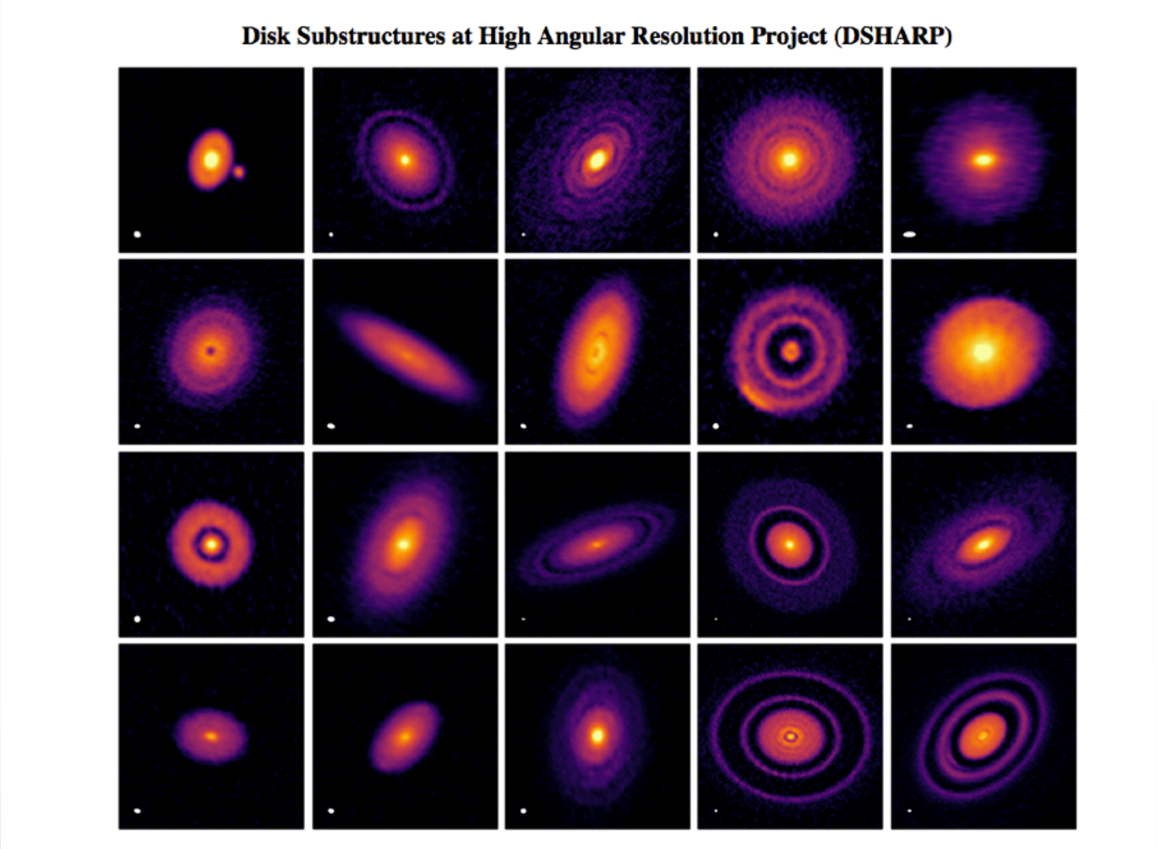
Current issues in planet formation: observational results

Most disks are located in Star Forming Regions, the majority at distances of 100-200 pc.
Typical disk radius ~ 30 au → less that 0.5” angular size

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



Andrews et al. 2019

Proposed mechanisms for substructures:

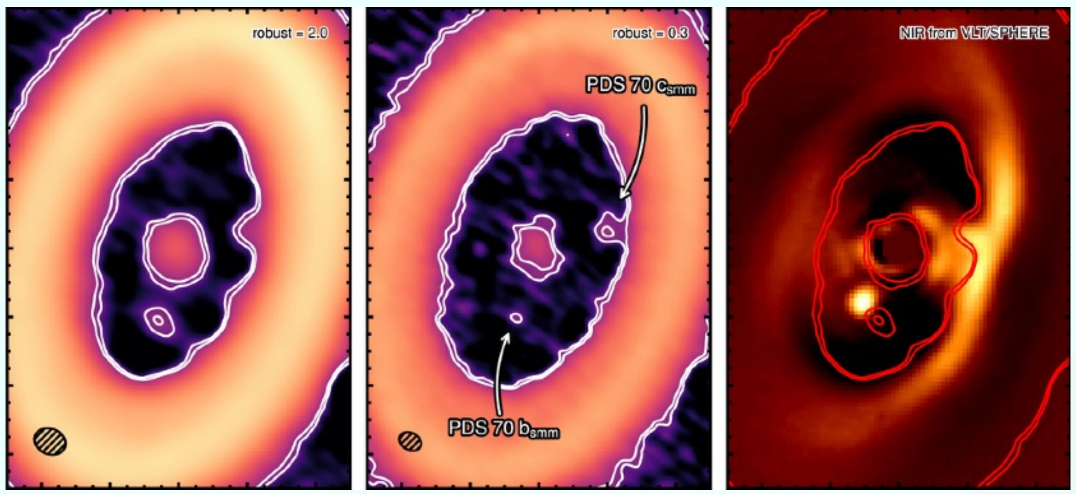
- Protoplanets
- Photoevaporation
- Gravitational instabilities
- Streaming instabilities
- Chemical effects (volatiles condensation fronts)
- MHD winds
- …

Do we see planets in disks?

Protoplanets directly imaged in disks: only a handful of systems

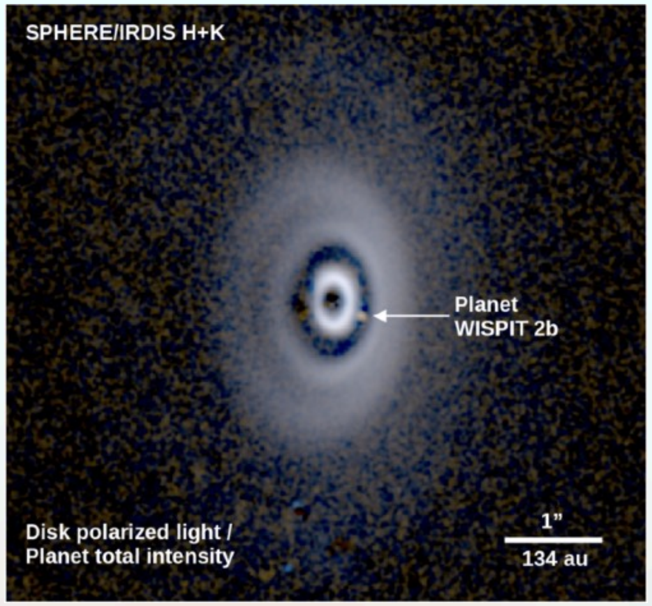
PDS 70b, 70c

Isella et al. 2019



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

WISPIT-2b



van Capelleveen et al. 2025

6

Do we see planets in disks?

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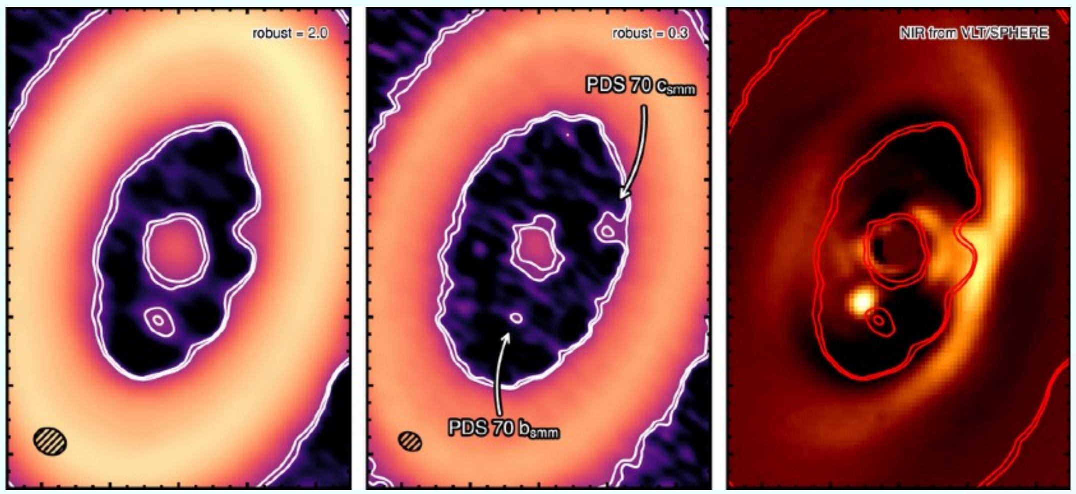

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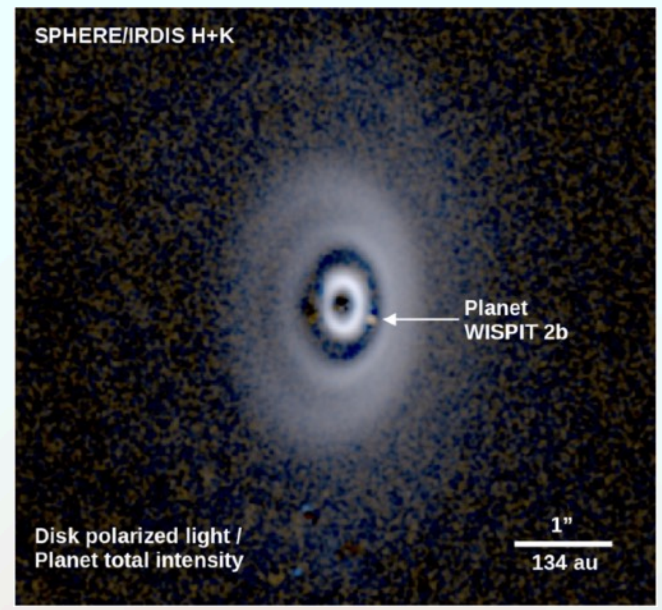
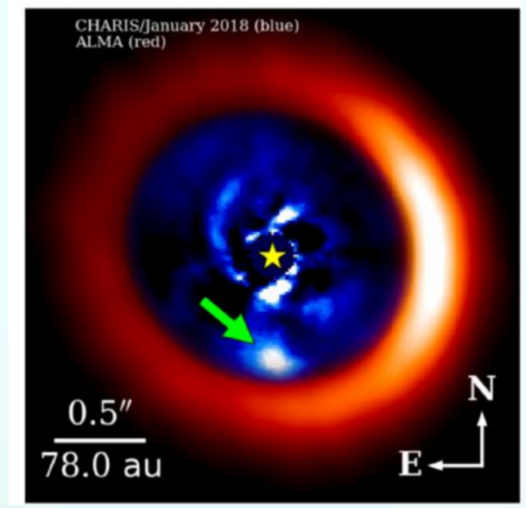


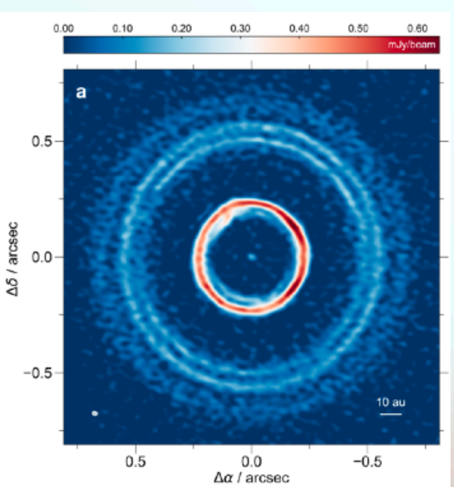
van Capelleveen et al. 2025

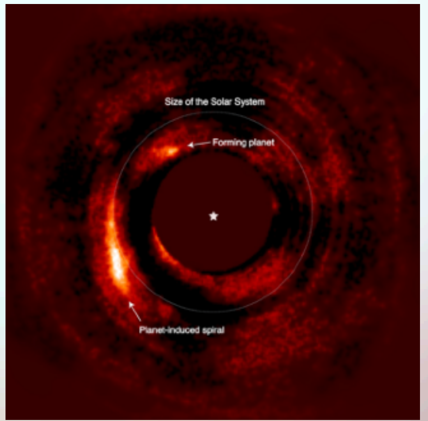
AB Aur b



Currie et al. 2022

HD169142b



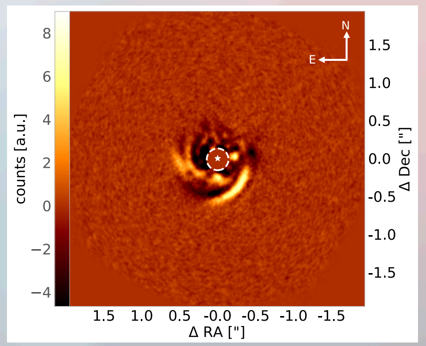


Pérez et al. 2019

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

7

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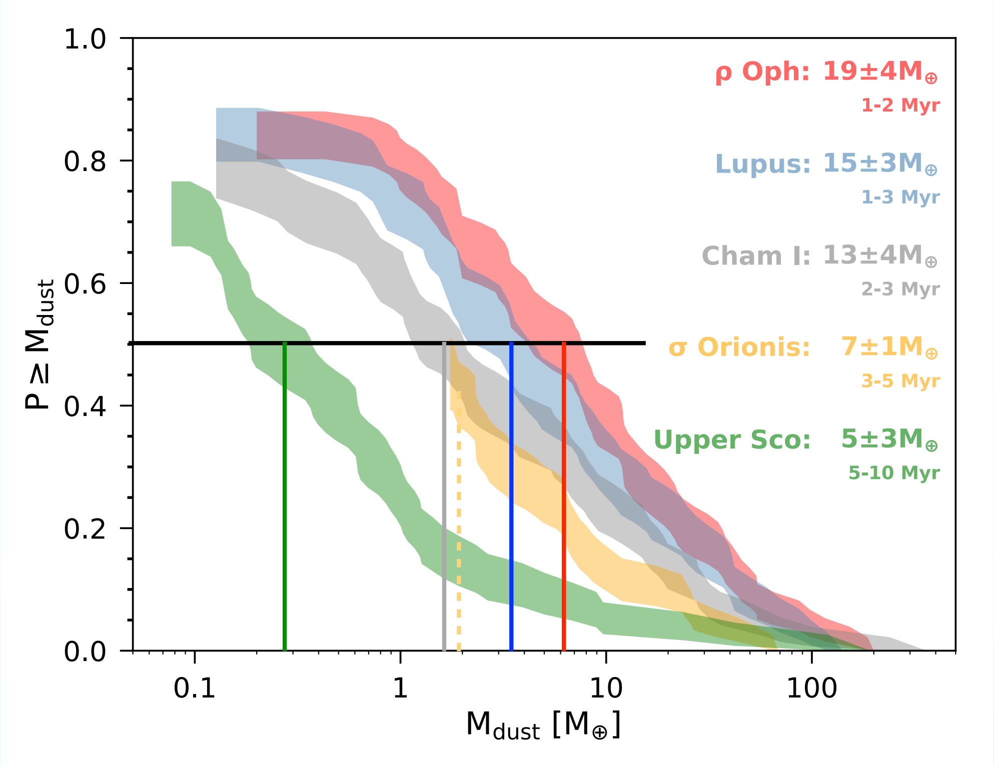
Current issues in planet formation: observational results

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 My?
- 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

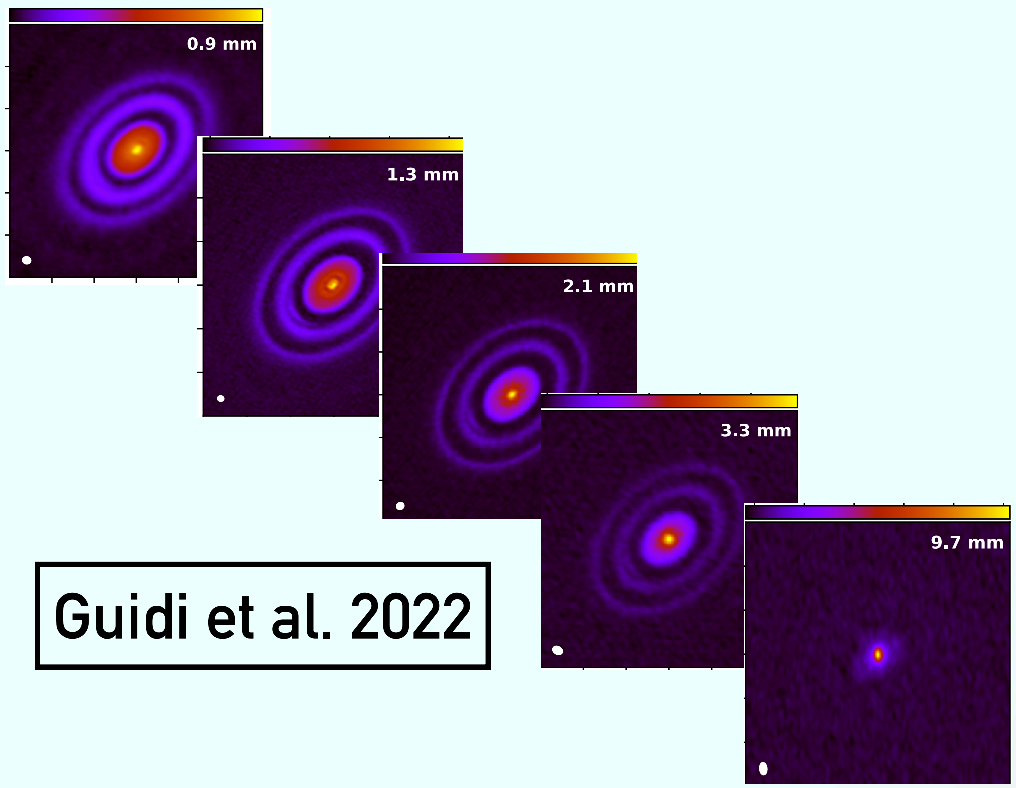
From CO isotopologues

Mgas< 1MJ in Lupus

Ansdell et al. 2016

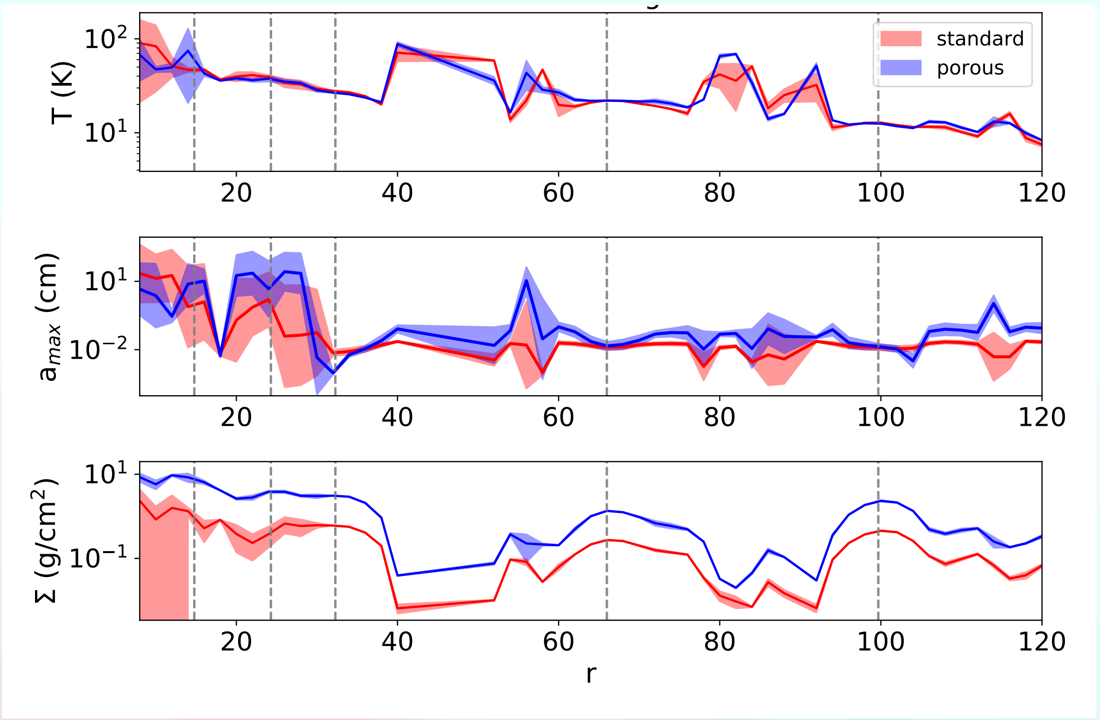
Disk multi-wavelength studies

HD 163296



Guidi et al. 2022

Comparison between dust models with different porosity: standard (25%) and porous (80%)



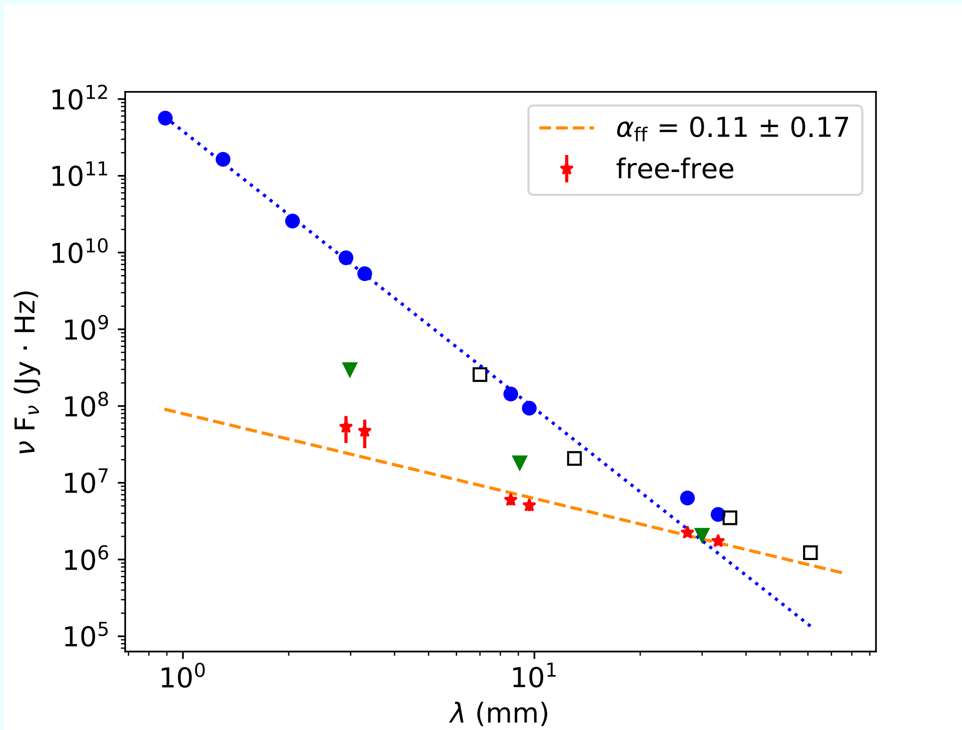
$M_\star$ ~2 Msun, age 6-10 Myr

a_{max} > mm/cm — 200 um

- Surface density assuming porous grains is ~5 x higher
- Grain size is 2-4 times larger

9

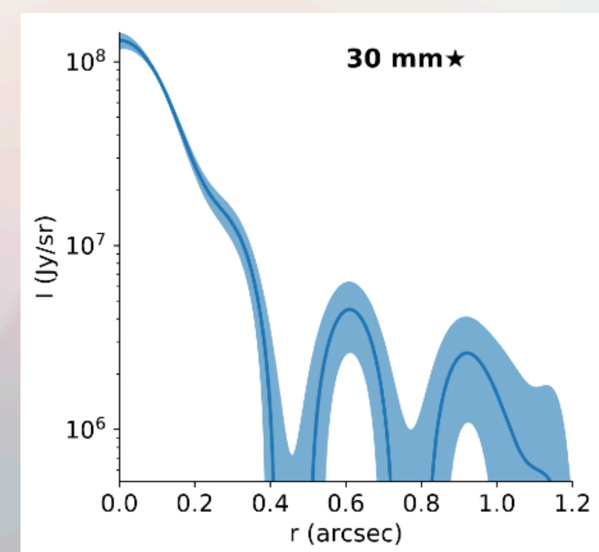
Disk multi-wavelength studies: non-dust contamination in HD 163296



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

Possible sources of contamination:
. Emission from free electron in the star surrounding
. Gyrosynchrotron emission from flares in the corona of magnetically active stars

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

Disk substructures detected at 3 cm!

Surveys of SFRs indicate variability in the flux of the non-dust component:
7 mm 20% (Rodmann+2016)
1 cm 35% with large scatter (Garufi+2025)
2 cm 65% (Garufi+2025)
3 cm 70% (Coutens+2019)

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SKA Advancing Astrophysics II

Cradle of Life WG chapters:

1) Searching for Extraterrestrial Intelligence with the SKA, C. D. Tremblay
2) Demographic/population studies of protoplanetary disks with the SKA, A. Garufi,
3) Understanding substructure and planet-disk interactions with the SKA, J. Speedie; Y. Wu
4) Probing ionised gas emission from disks with the SKA, G. Guidi
5) Disk Chemistry with SKA, L. Podio
6) Jets and outflows in young stellar objects with the SKA, G. Sabatini
7) Chemical complexity in the early stages of star formation in the SKAO era, E. Bianchi
8) Trans Neptunian Objects, Pablo Santos Sanz
9) SKA-ALMA synergies, J. Forbrich
10) Radio emission from Exoplanets and Brown dwarfs, R. Kavanagh
11) Star-planet interactions, H. Vedantham

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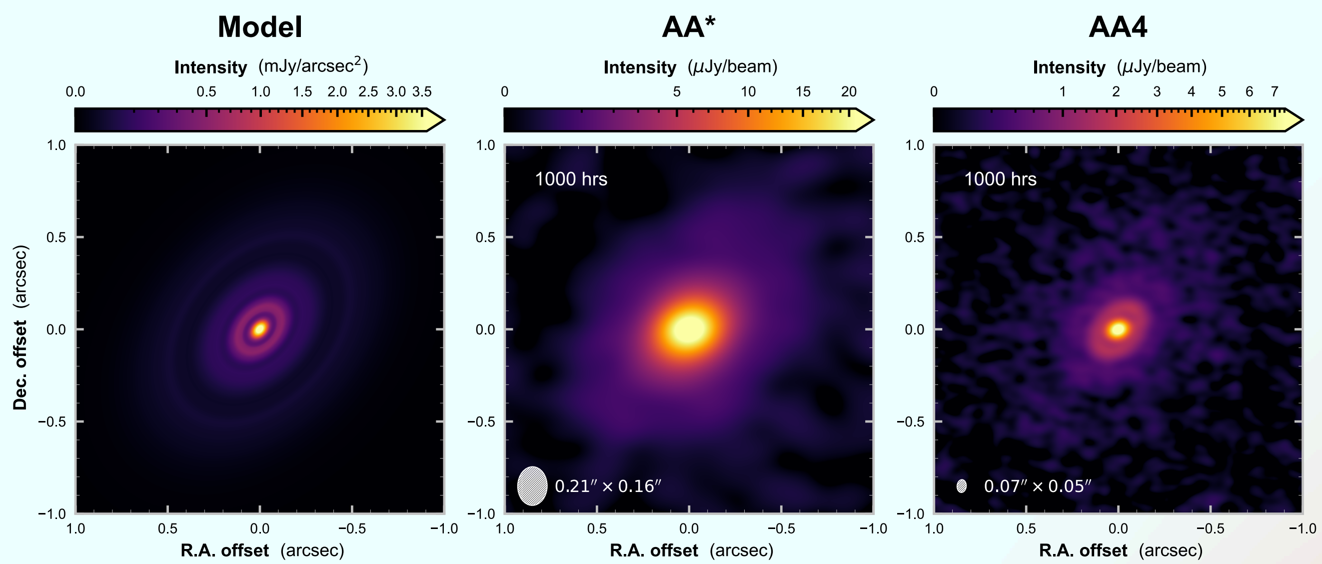
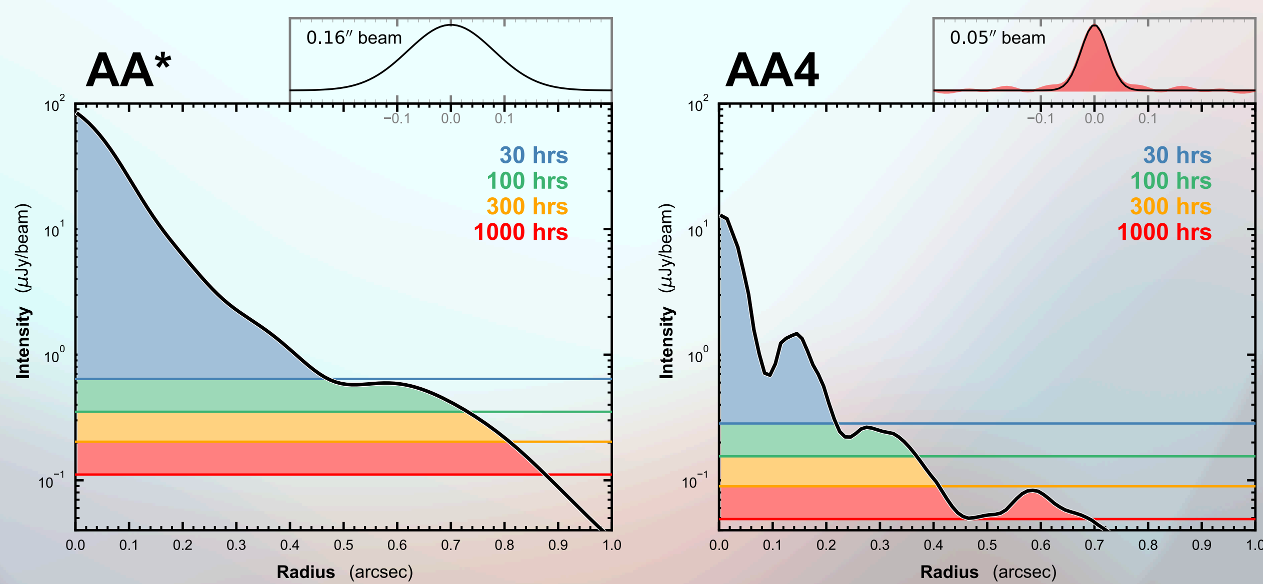
Dust in disks with the SKA-Mid

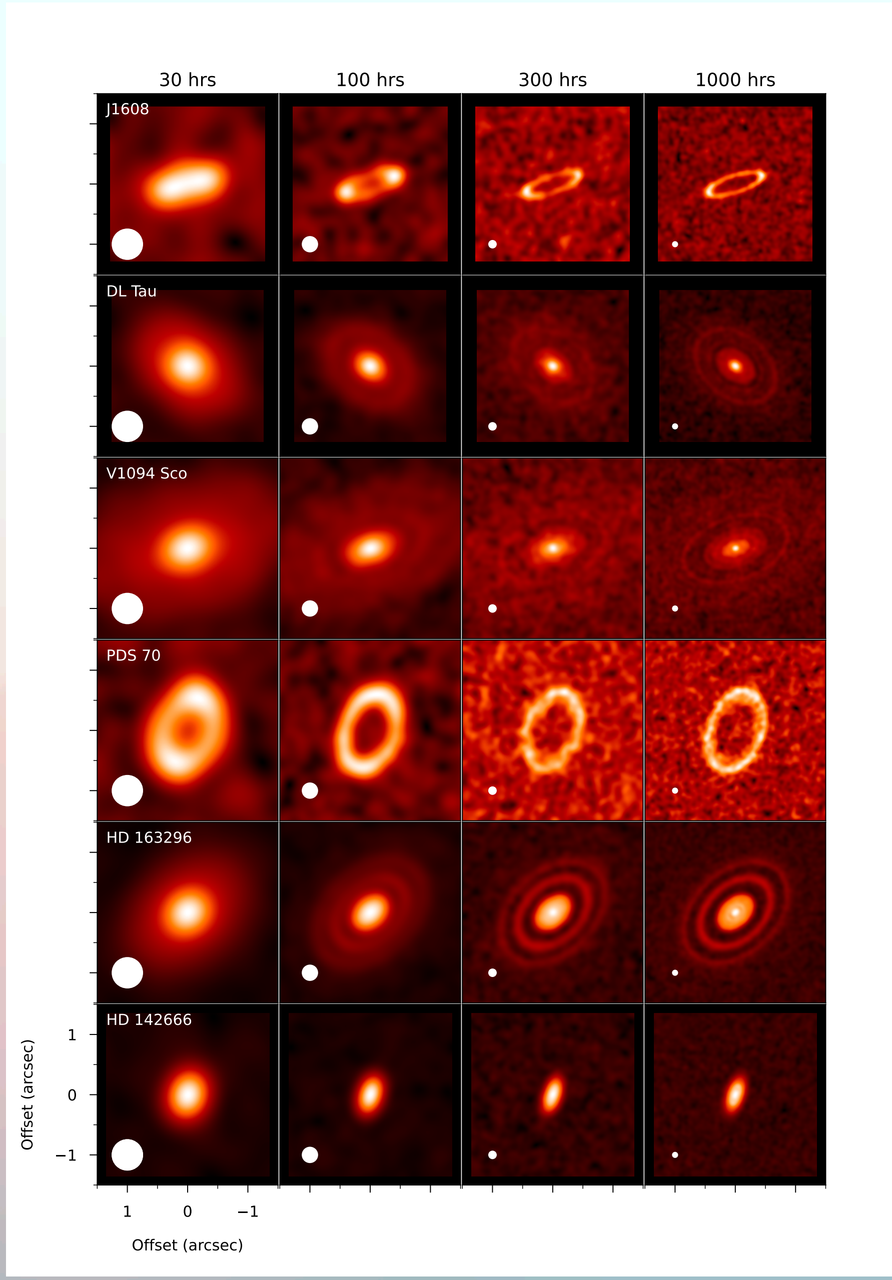
Wu&Speedie et al., SKA AAII

"Substructures in Planet-Forming Disks with the SKAO"

Simulations of HL Tau observations with SKA-Mid at Band 5b







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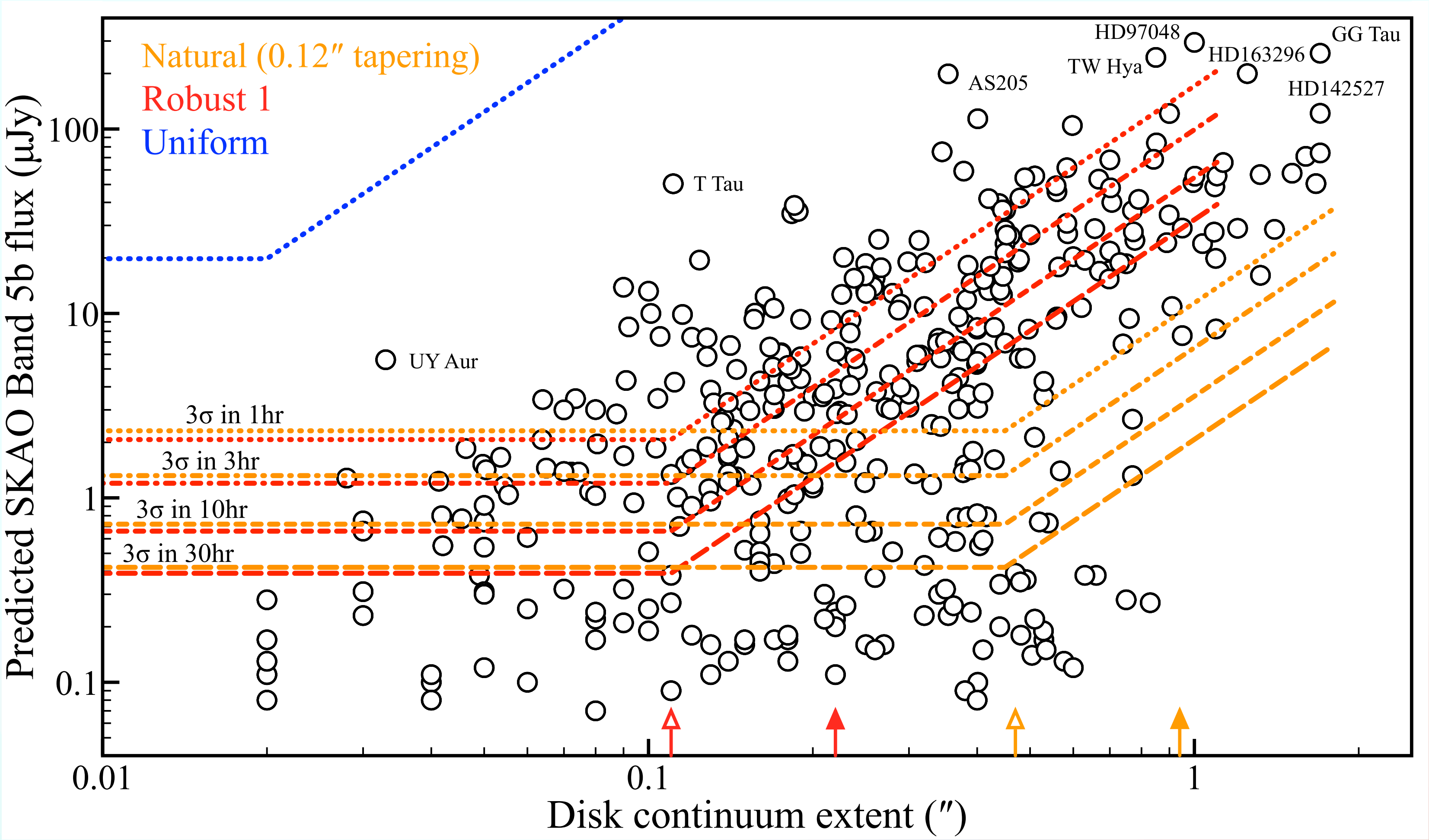
Dust in disks with the SKA-Mid

"Demographics of planet-forming disks with the SKAO"

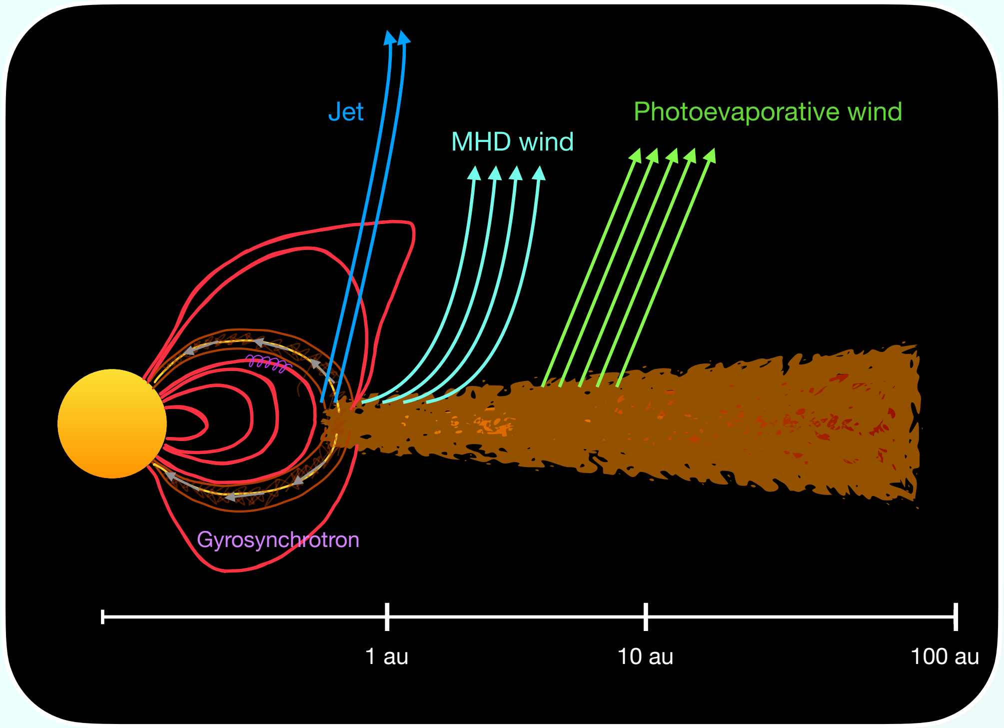


Fluxes estimated using a 2.8 dust spectral index between 1.3 and 3mm, radius from ALMA observations (upper limit)

Garufi et al., SKA AAII

Ionized gas emission in disks

"Ionized gas emission in protoplanetary disks with the SKAO"



Guidi et al., SKA AAII

In the cm range, continuum emission from electrons in the ionized winds dominates over the dust continuum.
RRLs such as the Hydrogen alpha transitions: often considered a key diagnostic to probe the presence of disk winds.

We use existing simulations from various disk wind models, including pure photo-evaporative (PE), magneto-thermal (MT), and isothermal magneto-hydro-dynamics wind models (MHD, semi-analytic). These models are used to produce synthetic observables for the free–free emission and for the Hydrogen recombination lines (Hα).

Models consider a Solar-type star at 140 pc.

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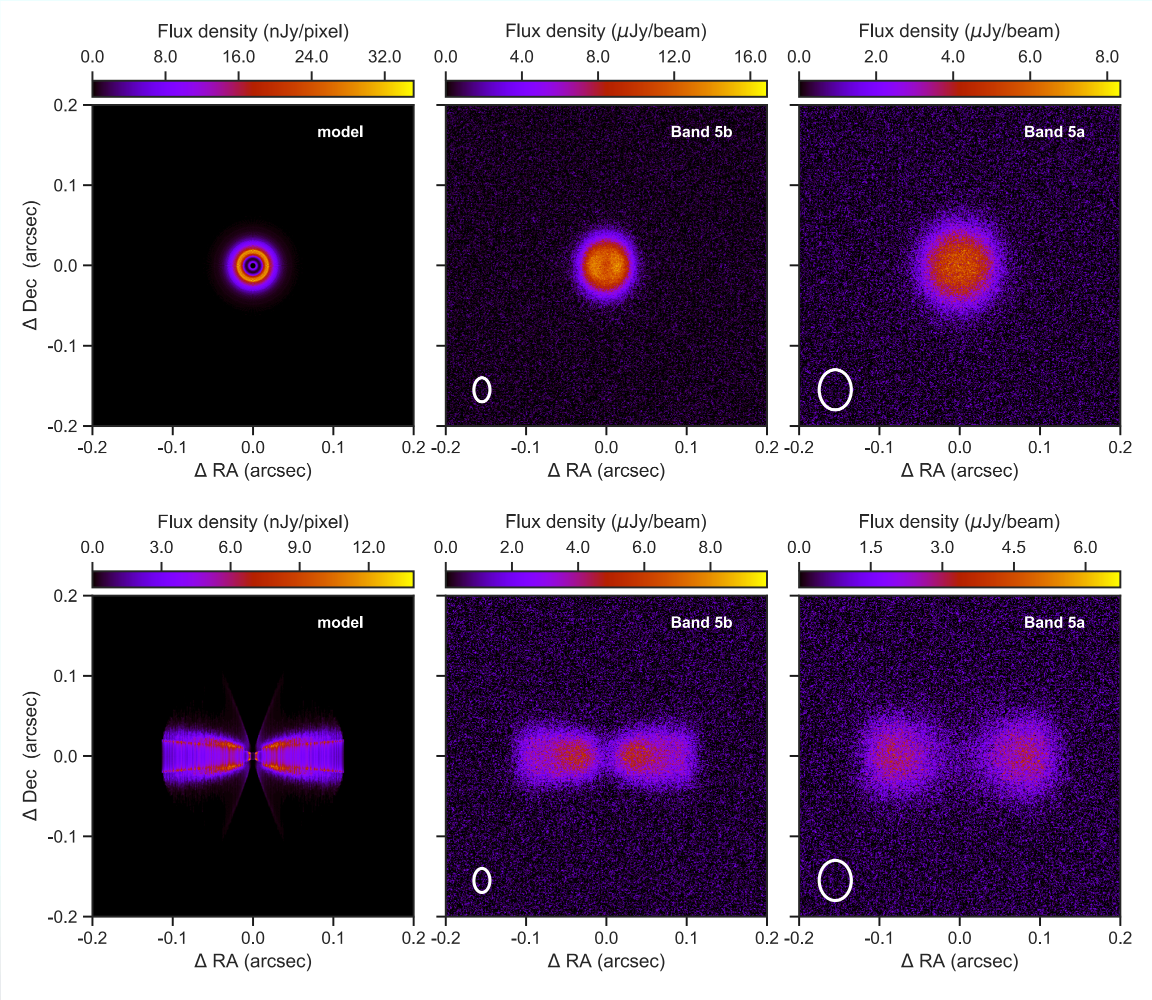
Ionized gas emission in disks

Free-free emission with magneto-thermal model in 10h of SKA-Mid AA4 at Band 5a and 5b, using briggs weighting with robust = -2.



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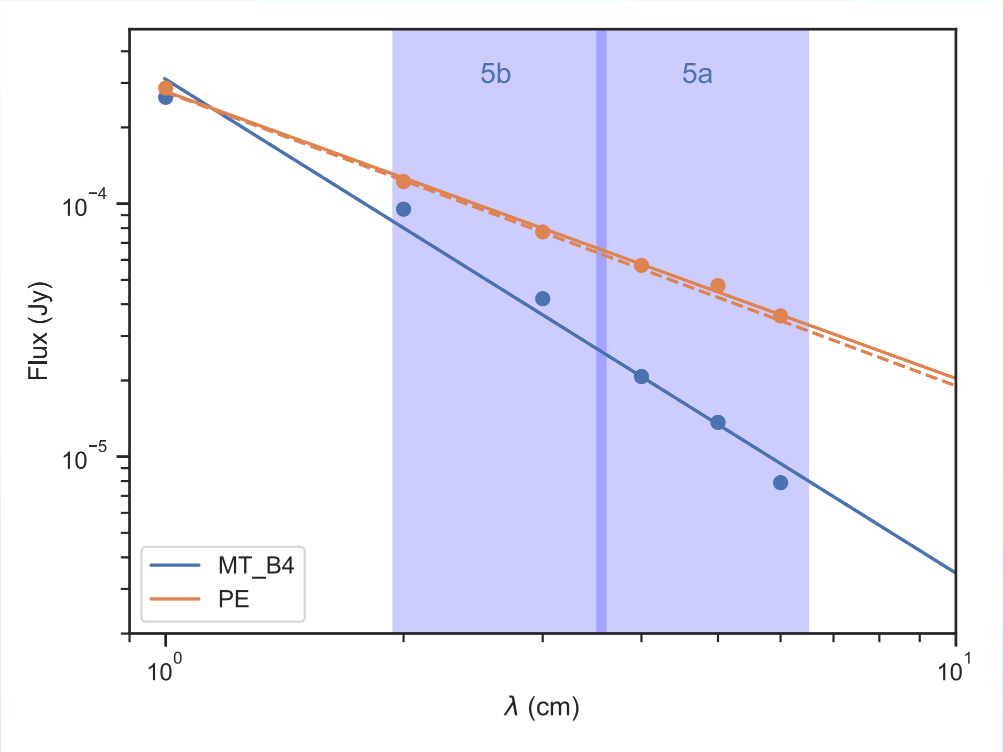

Guidi et al., SKA AAII

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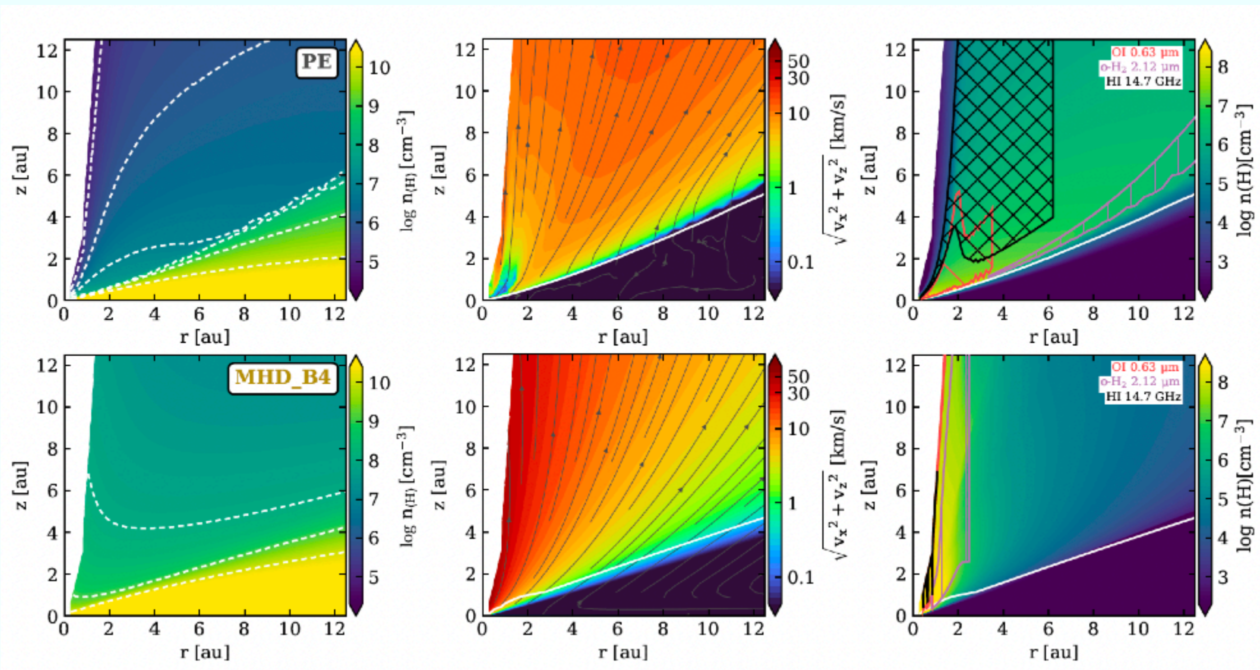
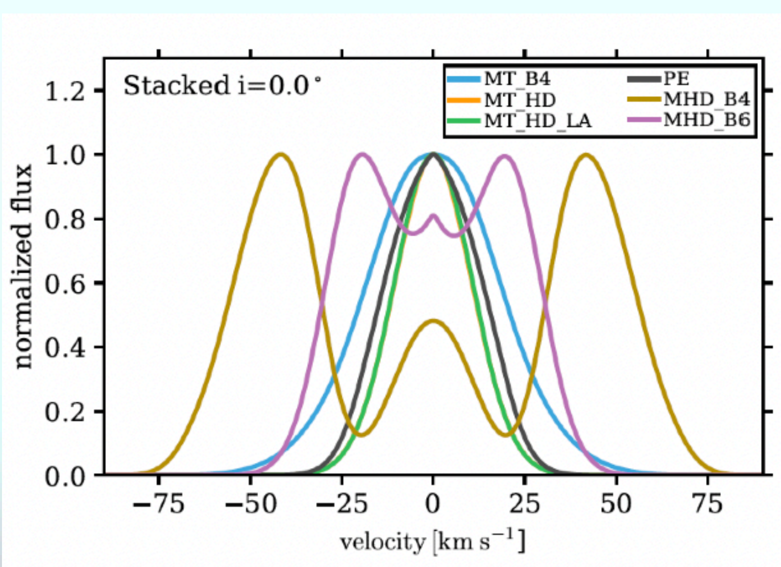
Ionized gas emission in disks

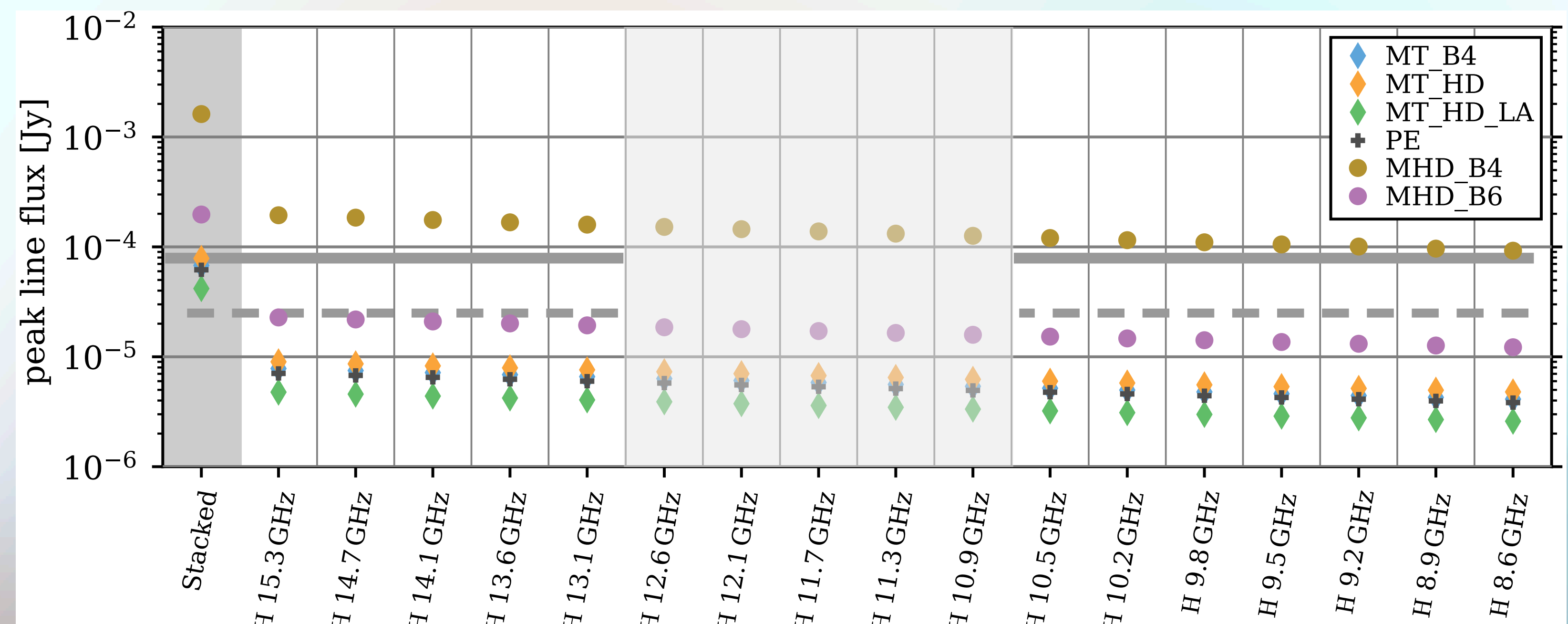


Two-dimensional density structure (total hydrogen number density), wind velocity field, and main line emitting regions (boxes), for the PE (top row) and the MHD_B4 model.

Guidi et al., SKA AAII

Detectability of H recombination lines with SKA-MId Band 5b, for the different models





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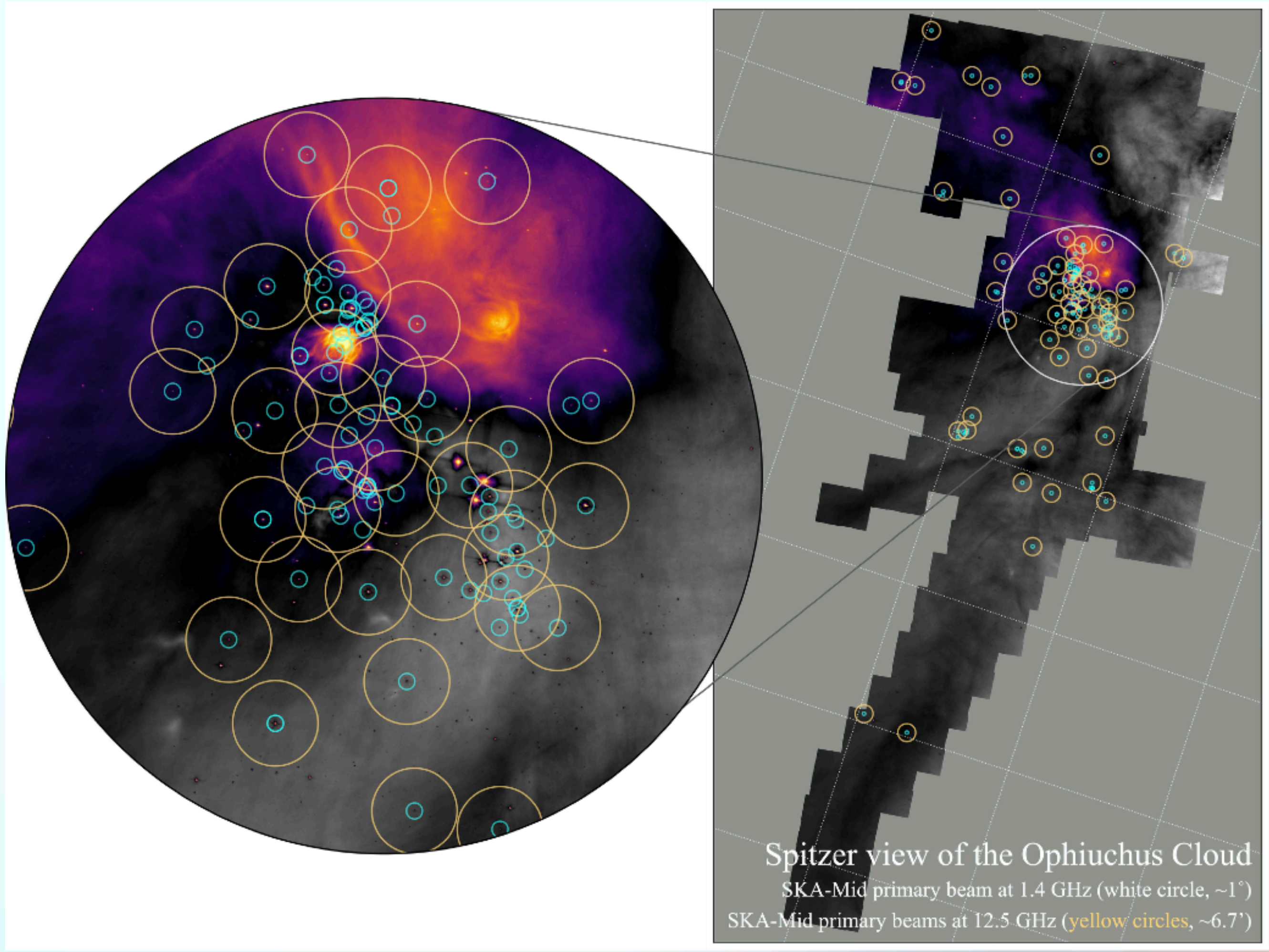
Disk surveys

Spitzer map of the Ophiuchus molecular cloud from the ‘Cores to Disks’ Legacy Project.



Cyan circles: locations of planet-forming disks detected in the ODISEA survey (Cieza et al., 2019).
Large white circle: SKA-Mid primary beam at 1.4 GHz (~1 deg).
Yellow circles: primary beams at 12.5 GHz (6.7’).

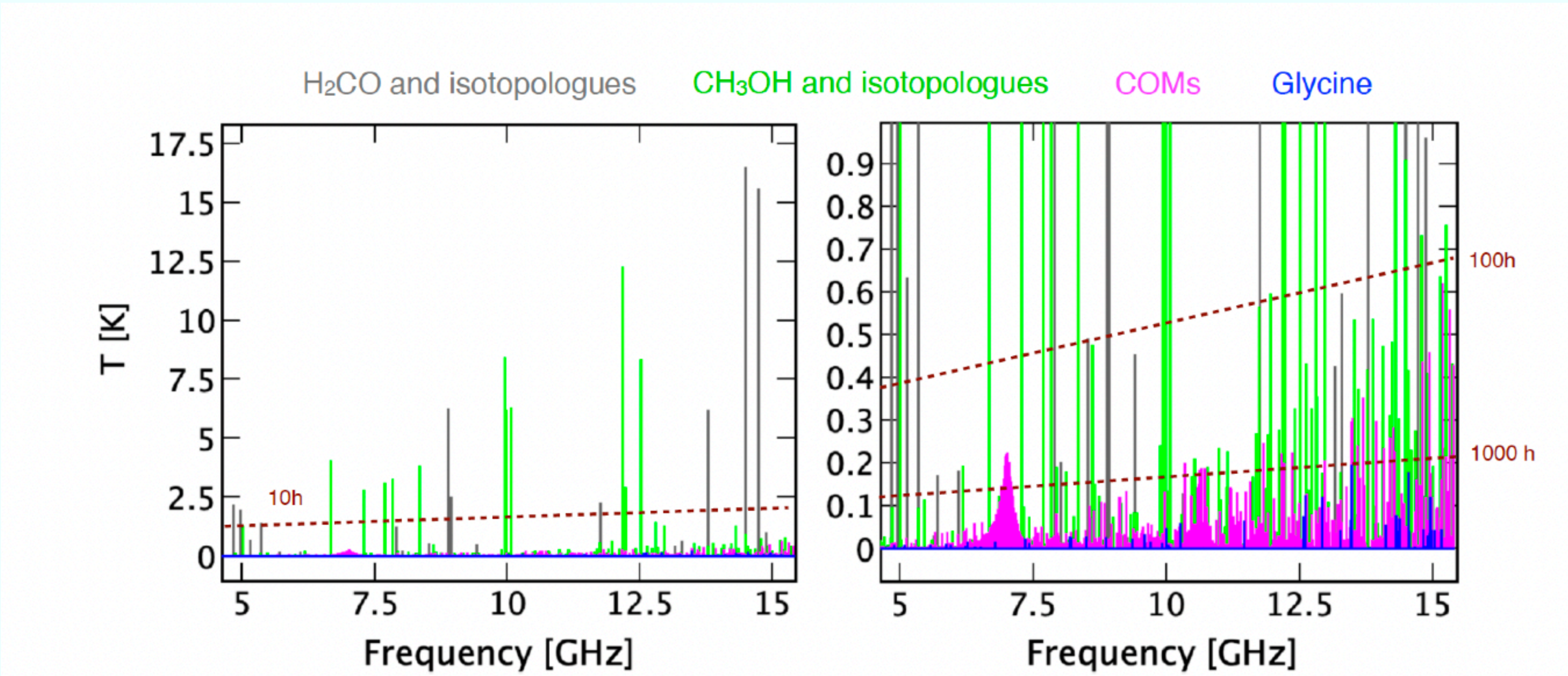
FOV: 6.7′ at 12.5 GHz (Band 5b), 12.5′ at 6.7 GHz (Band 5a)

Garufi et al., SKA AAII

Covering the entire disk population requires ~60 pointings at band 5b and ~20 at band 5a.
Free-free: ~1h for detection, ~10h for spatially resolve
$H\alpha$ lines: 10-100h for spectrally resolved detections

Chemistry in disks with the SKAO

"Unveiling complex chemistry in planet-forming disks with the SKAO"



Podio et al., SKA AAII

Integration times of ~1000 h, resolution of ~1"

Complex organic molecules, Cyanopolyynes (HC_5N, HC_7N, HC_9N), potentially aminoacids like glycine can be detected with SKA-Mid.
Insights on planet compositions, atmosphere chemistry, origins of prebiotic molecules.

Molecules	N_{min} (cm^{-2})	IRAS 16293B	V883 Ori
H_2CO	9×10^{14}	1.9×10^{18}	1.7×10^{15}
CH_3OH	2×10^{16}	1.0×10^{19}	4×10^{18}
CH_3CHO	4×10^{16}	1.2×10^{17}	9×10^{15}–7×10^{17}
C_2H_5OH	5×10^{16}	2.3×10^{17}	2.7×10^{16}
CH_3OCH_3	9×10^{16}	2.4×10^{17}	2×10^{16}–5×10^{17}
$HCOOCH_3$	1.2×10^{17}	2.6×10^{17}	5×10^{16}–1×10^{18}
CH_2OHCHO	8×10^{15}	6.8×10^{16}	
aGg-$(CH_2OH)_2$	1.3×10^{16}	1.1×10^{17}	
gGg-$(CH_2OH)_2$	2×10^{16}	1.0×10^{17}	3.6×10^{16}
CH_3COCH_3	1.3×10^{16}	1.7×10^{16}	1.7–4.4×10^{16}
NH_2CHO	5×10^{15}	1.0×10^{16}	6×10^{14}
$HOCH_2CN$	4×10^{16}	3.0×10^{15}	3.4×10^{16}
NH_2CH_2COOH	1.7×10^{17}		

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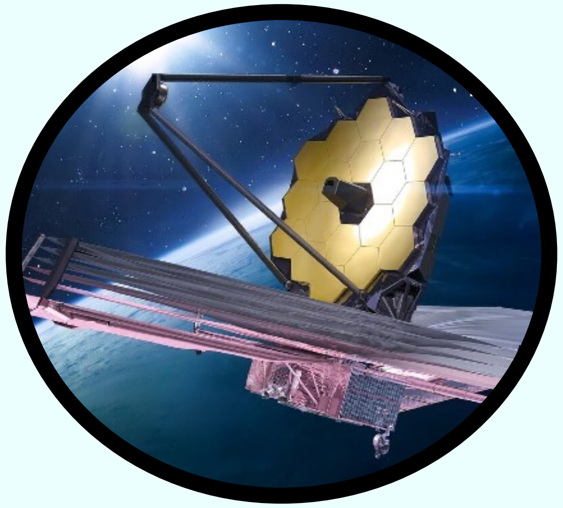
Synergies with other facilities

- Mm/cm facilities (ALMA/VLA): multi-wavelength studies to model dust continuum, free-free emission. Complement chemistry survey in studying abundances, distribution of molecules.



- JWST: mid-IR detection and characterization of a wide range of molecular features, including key volatile species such as H_2O, CO_2, CH_4, HCN, C_2H_2, and several hydrocarbons, including C_6H_6. Hydrogen recombination lines and forbidden lines of interest such as [Ne II], [S III], [Ar II], [AR III] provide spatially resolved detections of partially ionized winds

- Gravity+: milli-arcsecond angular resolution and high spectral sensitivity in the near-IR, directly resolving the launching regions of ionised winds and accretion flows traced by Brγ, He I, and other hydrogen recombination lines

Summary

- Low frequency observations of dust continuum are crucial to probe the distribution of large solids/optically thin range
- To resolve substructures in the brightest disks: ~1000h integration time with SKA-Mid Band 5b
- Ionized gas emission displays a high variability between sources at mm and cm wavelengths: need for multi-band simultaneous observations + time monitoring
- H recombination lines in Band 5 could be resolved spectrally by SKA-Mid -> this would help in distinguish between wind launching mechanisms
- Large FOV will be an advantage for disk surveys: dust and free-free emission can be detected (e.g. Ophiuchus 60 pointings at Band 5b, 20 at Band 5a)

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erc

NOEMA @ Plateau de Bure

Thank you!

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