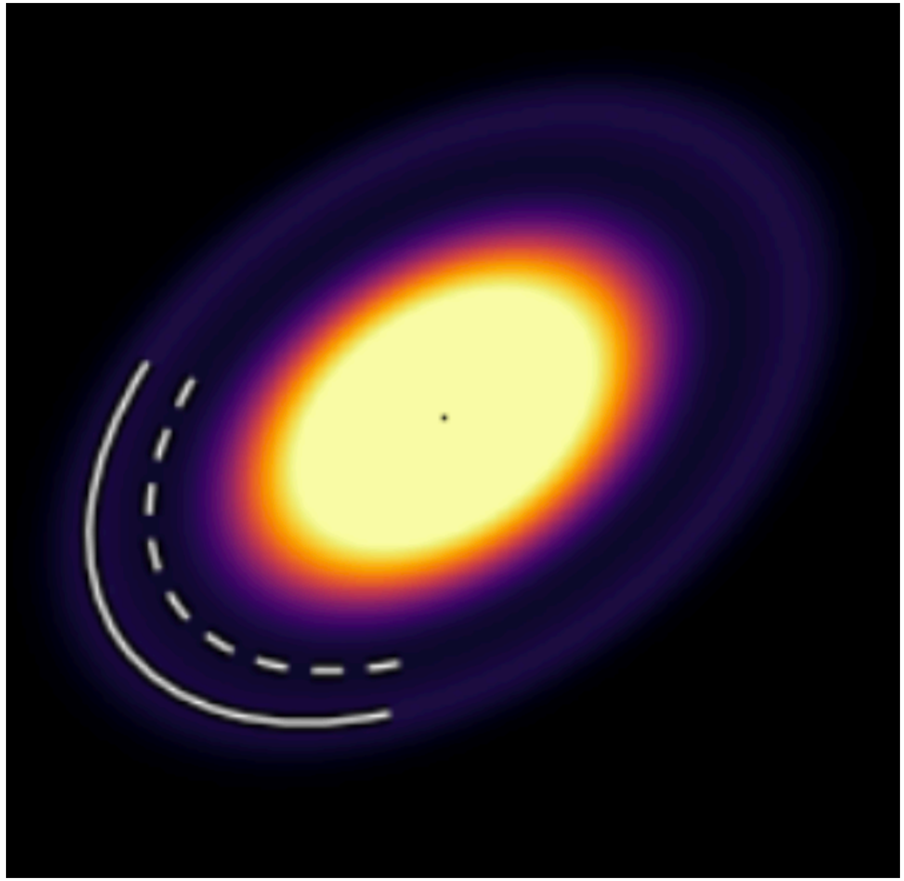
Hints of Disk Substructure in the First Brown Dwarf with a Dynamical Mass Constraint



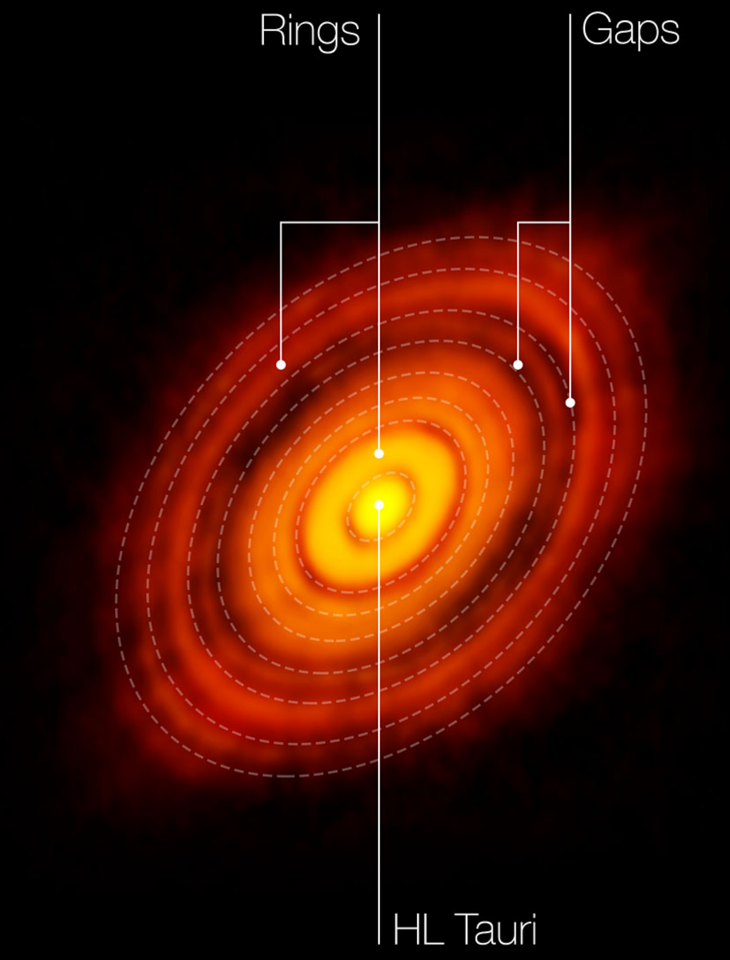
Alejandro Santamaría Miranda

(Observatorio Astronómico Nacional)

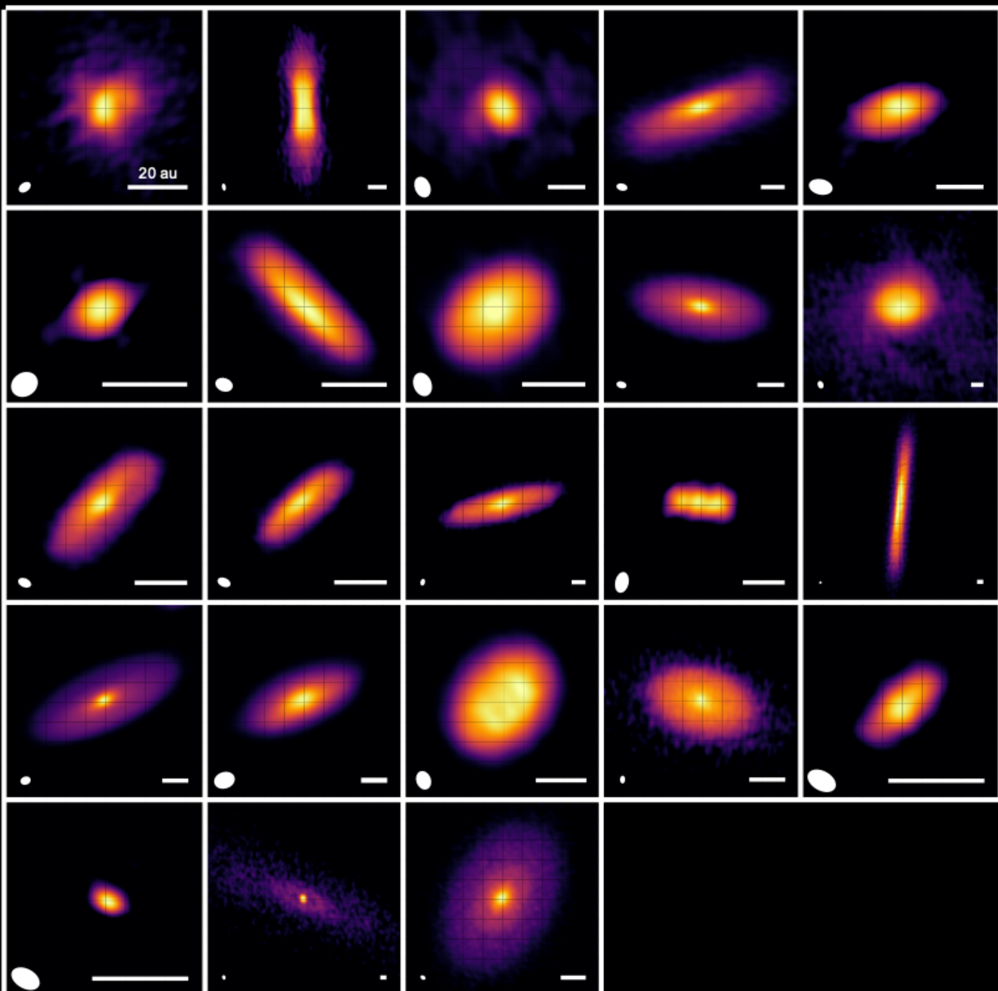
Pietro Curone (U. De Chile), Laura Perez (U. De Chile) et al.

The Astrophysical Journal Letters, 986:L11, 2025

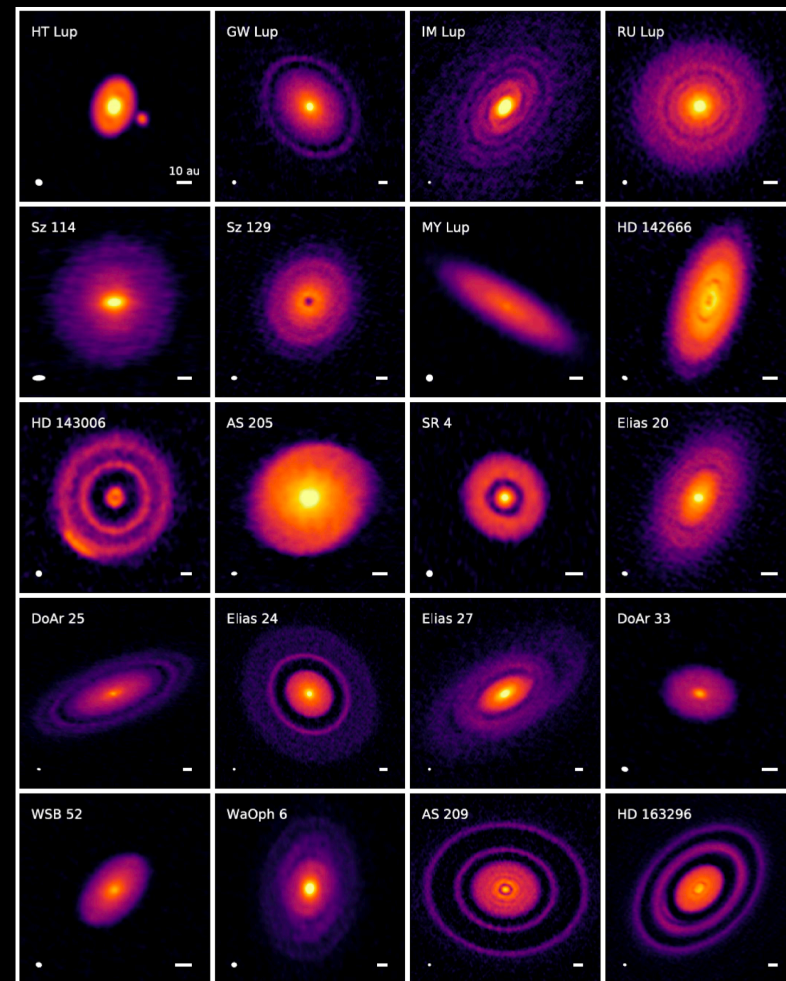
HL Tau and the revolution in disk studies



When do substructures appear in disks?

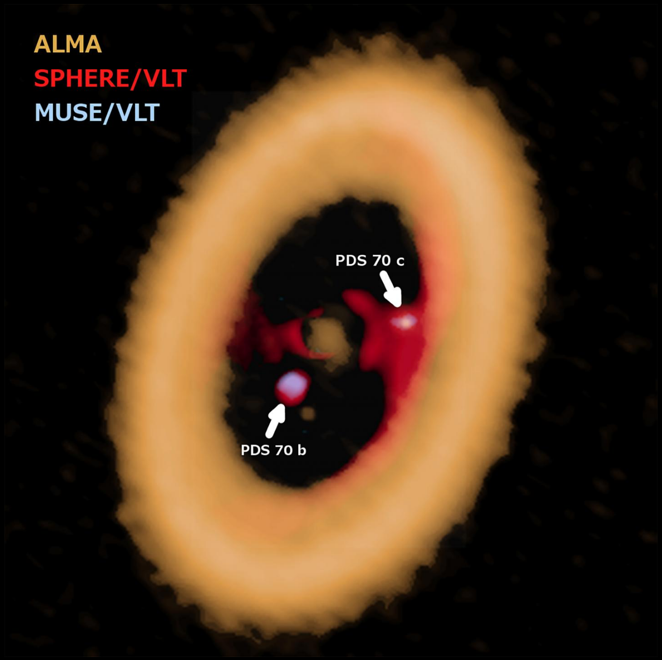


eDisk (resolution of ~7 AU: Ohashi et al. 2023)
Class 0/I



DSHARP (resolution of ~5 au: Andrews+ 2018)
Class II

Protoplanets emerging in disk gaps



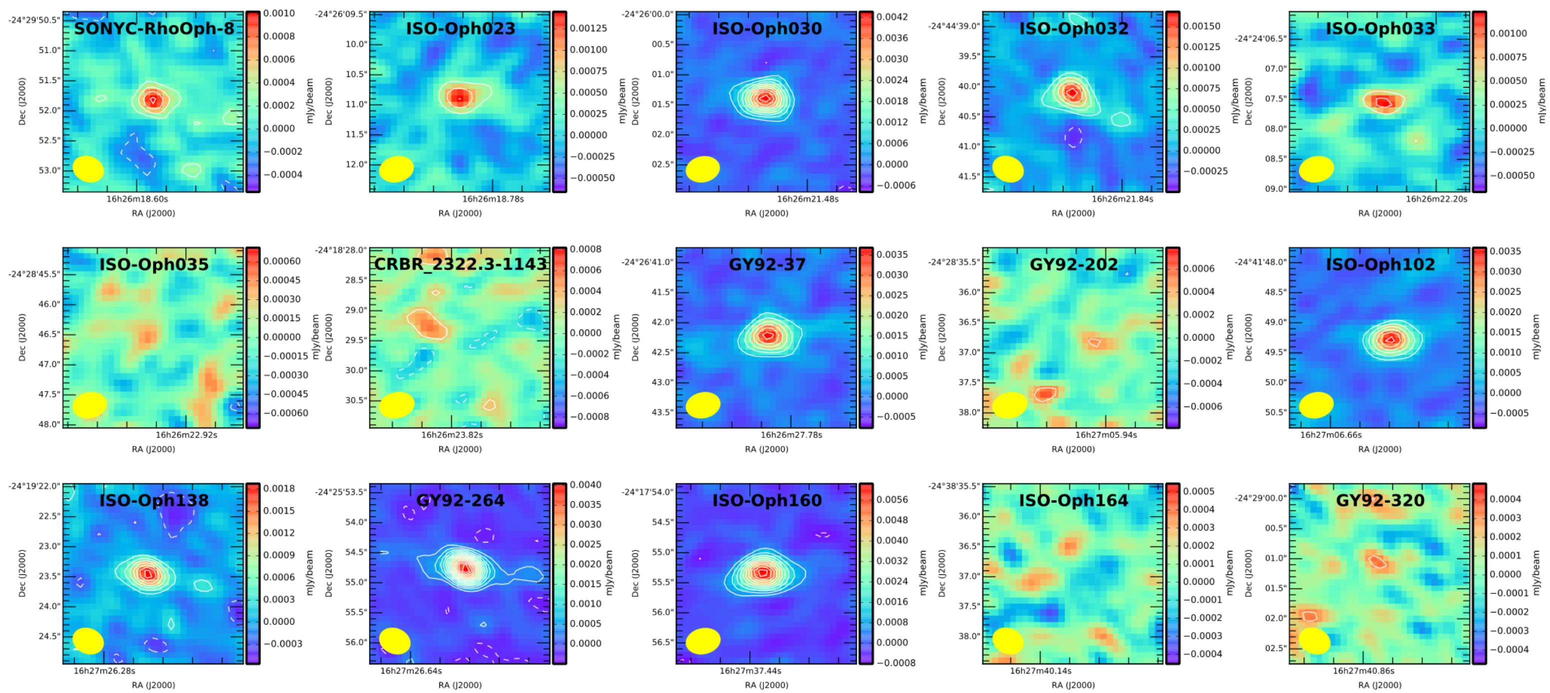
PDS 70 A. Isella

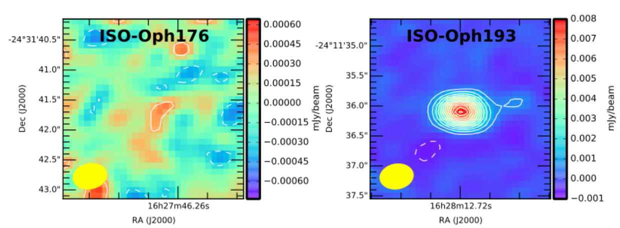
WISPIT2b van Capelleveen et al. 2025

Disks around VLMs and BDs are an excellent laboratory to investigate planet formation in extreme conditions

- BD disk are:
  - ➢Low mass
  - ➢Smaller
  - ➢Colder

"these disks contain too little mass to form planetary companions"

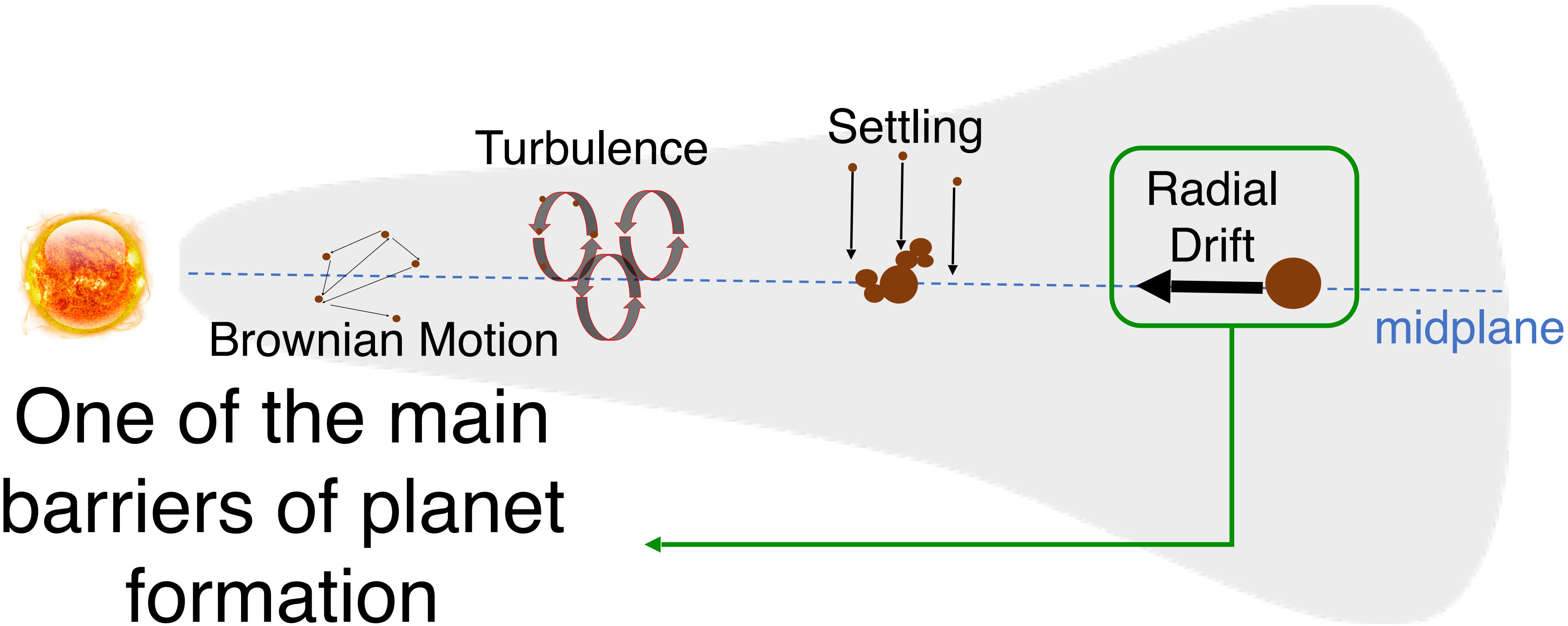




ALMA first survey of young brown dwarfs in the ρ Oph star-forming region.

Dust Evolution in protoplanetary disks

Collisions ⟷ Transport



One of the main barriers of planet formation

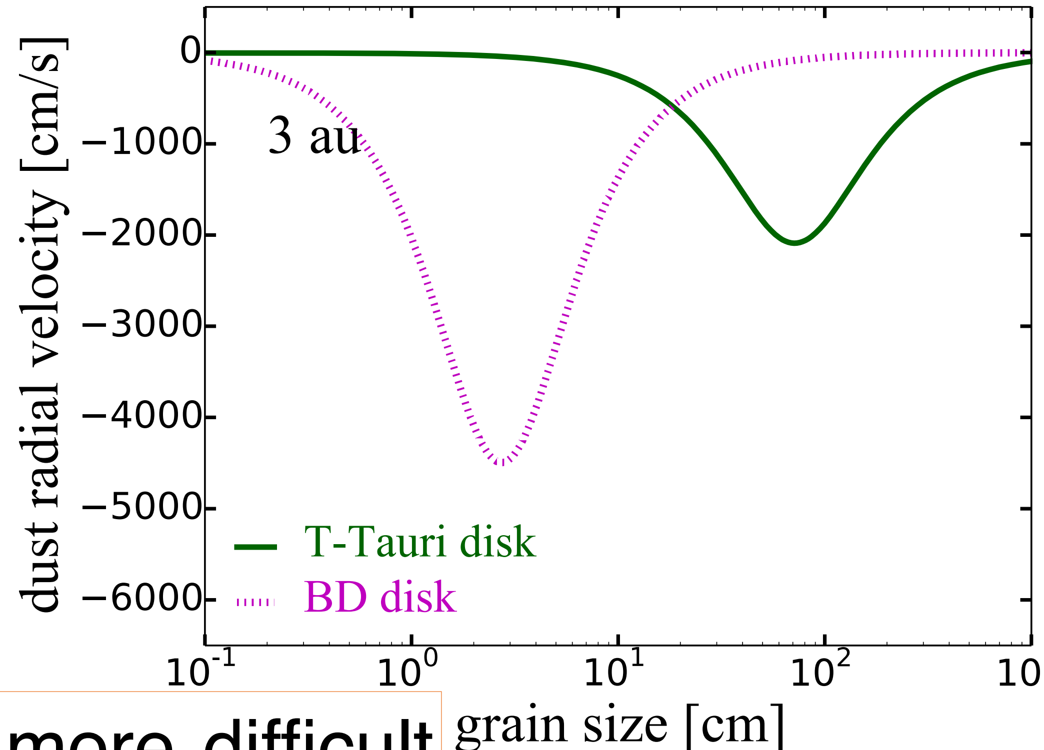
$t_{drift} << t_{growth}$

Dust lost to the radial drift

$$v_{\substack{dust\\drift}} \propto v_{gas} - v_{Kepler}$$

$$v_{gas} - v_{Kepler} \propto \frac{L_*^{1/4}}{\sqrt{M_*}}$$

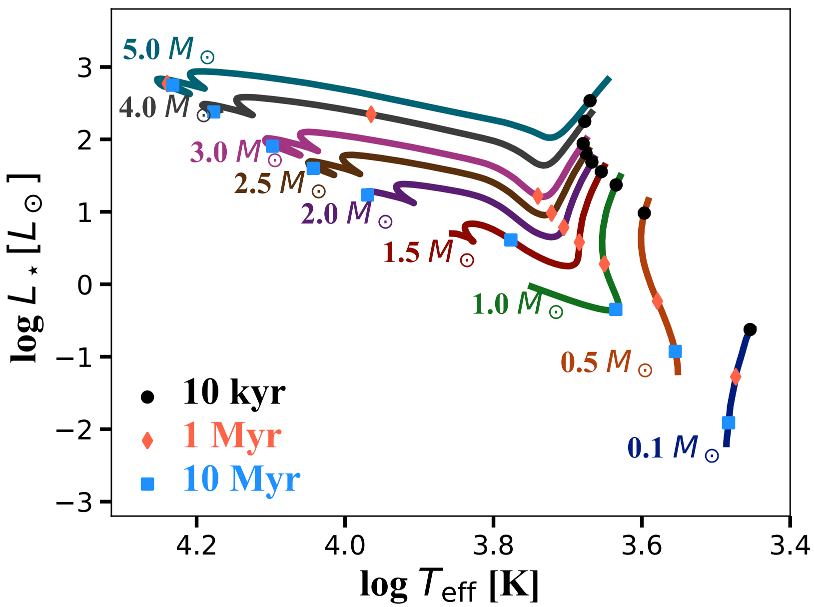
$$v^{BD}_{\substack{dust\\drift}} > v^{T-Tauri}_{\substack{dust\\drift}}$$

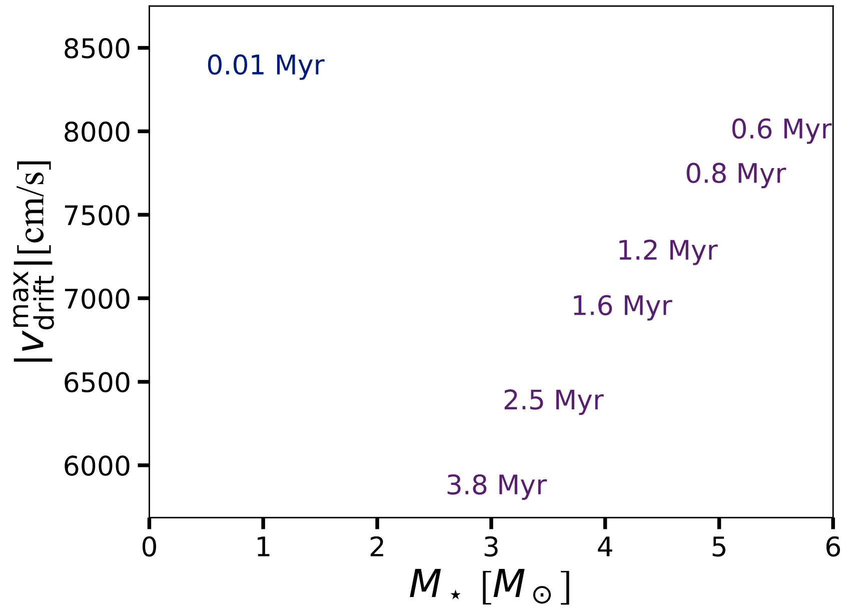


The radial-drift barrier is more difficult to overcome for the dust around Brown Dwarfs disks than around typical T-Tauri disks

Pinilla et al. (2013)

Dependency of radial drift with stellar mass



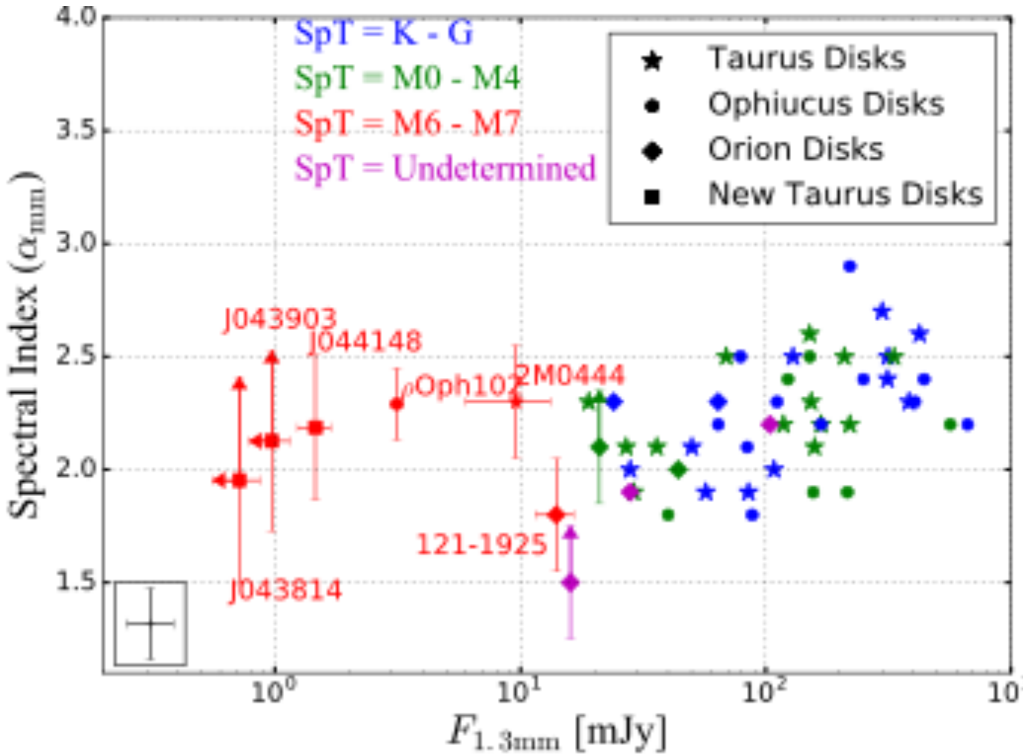


Pinilla et al. 2022
van der Marel & Pinilla (2023)

For low-mass stars (0.2-0.5 M_{sun}) the drift velocity is higher than for a Solar-mass star throughout the disk lifetime.

While for stars more massive than 2.5 M_{sun}, the drift velocities are lower at early times and sharply increase when the stellar luminosity also increases within the disk lifetime (<5-10Myr).

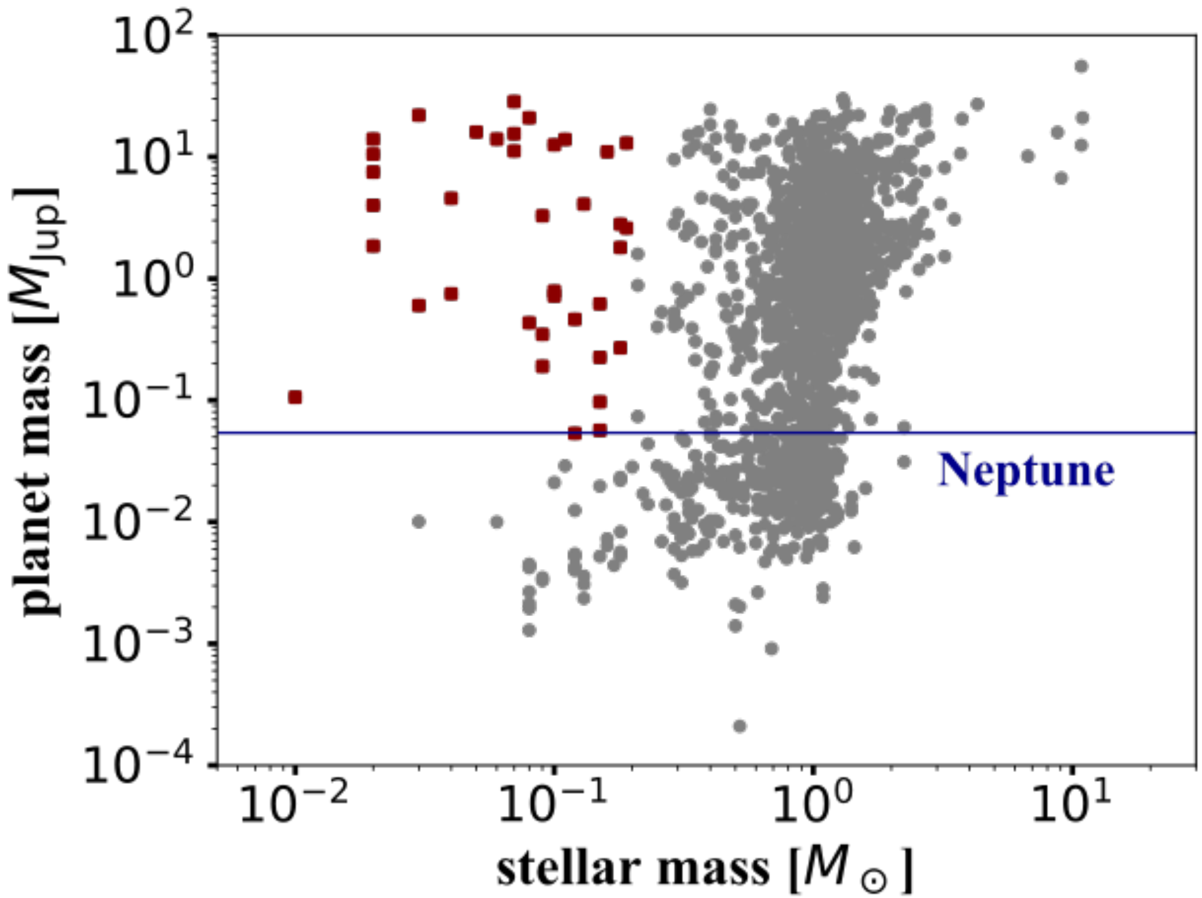
Spectral indices in disks around VLMS and BDs evidence grain growth



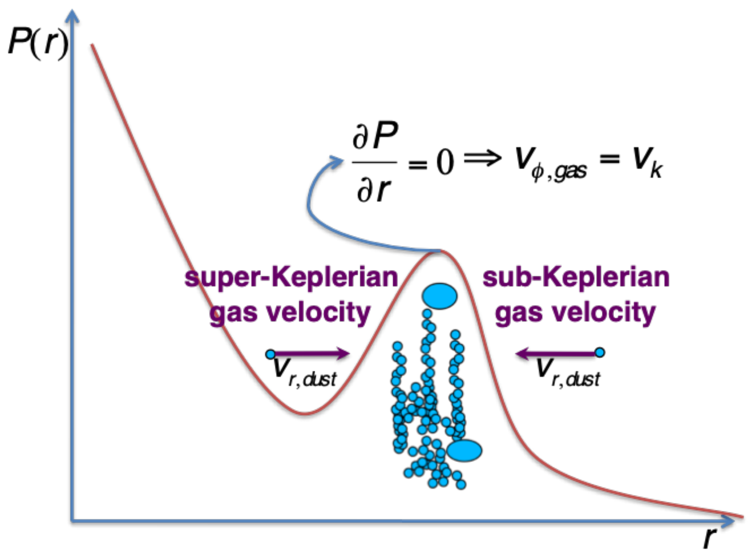
Pinilla et al. (2017)

How to explain the existence of mm-grains in these disks where radial drift is a more extreme problem?

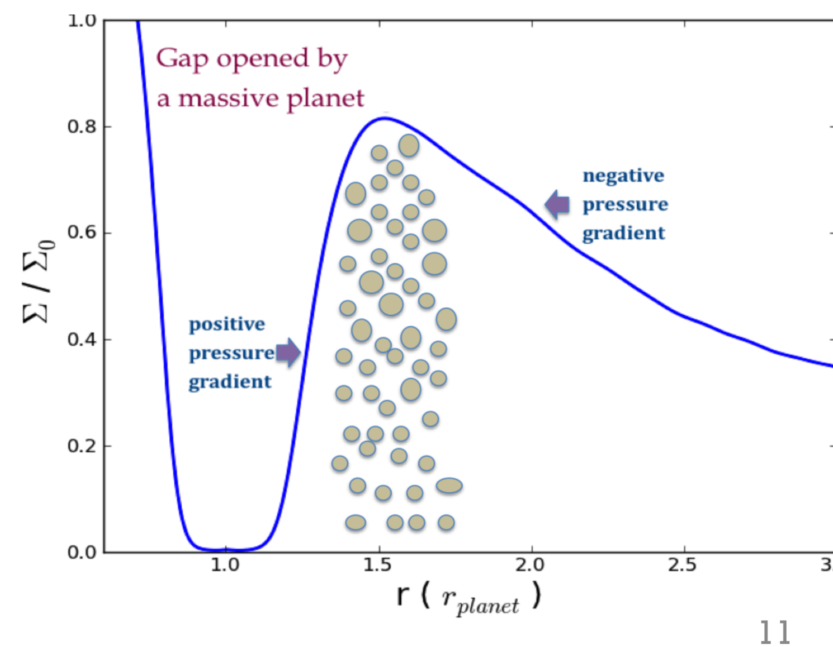
Planets have been found around VLM and BDs



Particle Trapping! One possibility: massive planets



A pressure bump is formed at the outer edge of a gap carved by a massive planet

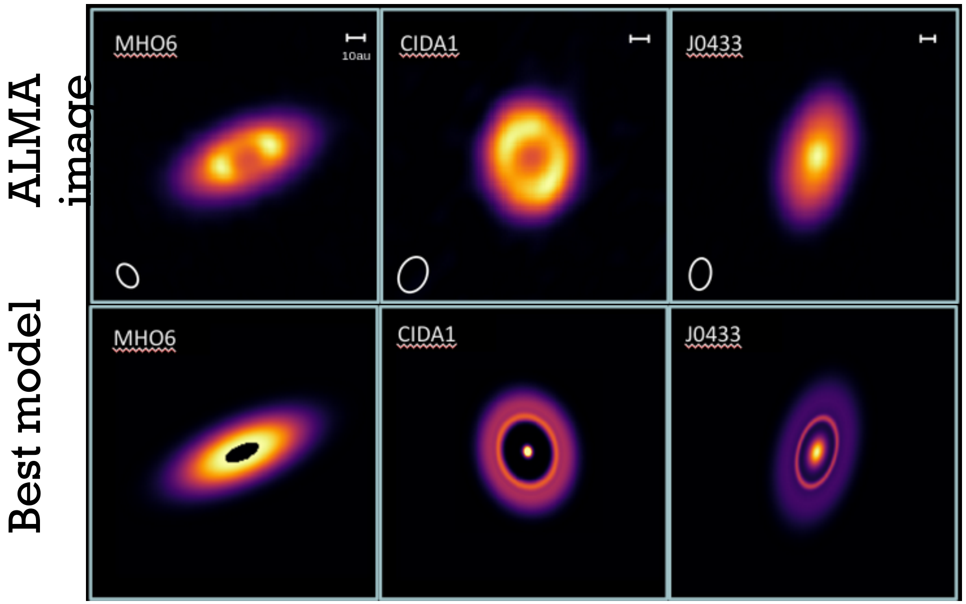


Particle Traps

- Dead Zones
- Vortices
- Planets
- Zonal flows
- Self-gravitating spiral arms

e.g. Pinilla et al. (2012)

Substructures in very low mass star disks



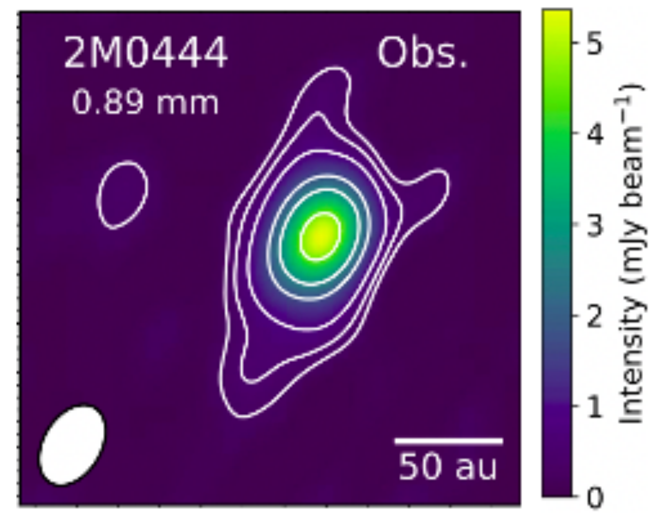
6 disks in Taurus observed at high angular resolution (~0.1’’). Continuum, ^{12}CO and ^{13}CO

Structures in 50% of the sample

Pinilla, Kurtovic, et al. (2021),
Kurtovic & Pinilla (2024)

Searching for substructures in the best possible candidate

- Spectral type M7.25
- ~140 pc
- M = 0.05 Msun
- Brighest BD disk
- Grain growth
- Dust disk size ~70 au



Ricci et al. 2014

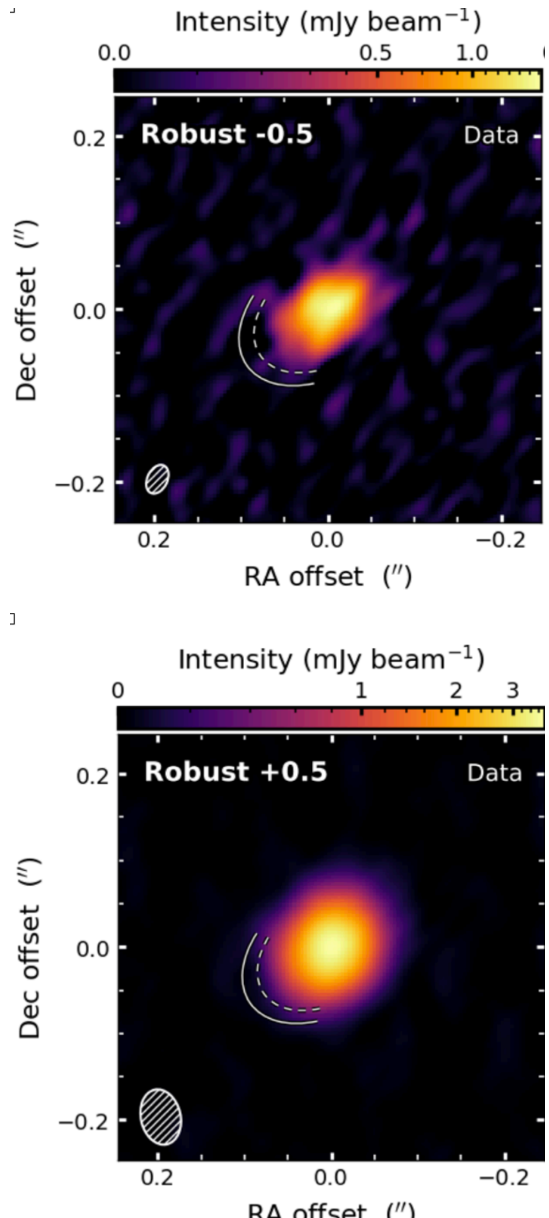
ALMA CYCLE 10 OBSERVATIONS

- Resolution ~0.043”
- Band 7 (~0.89 mm)

ALMA CYCLE 11 OBSERVATIONS (Coming!)

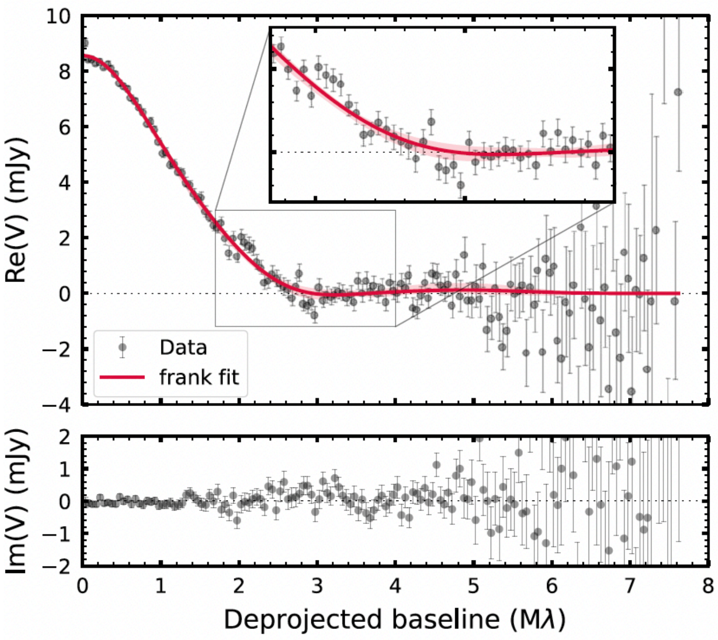
- Resolution ~0.020”

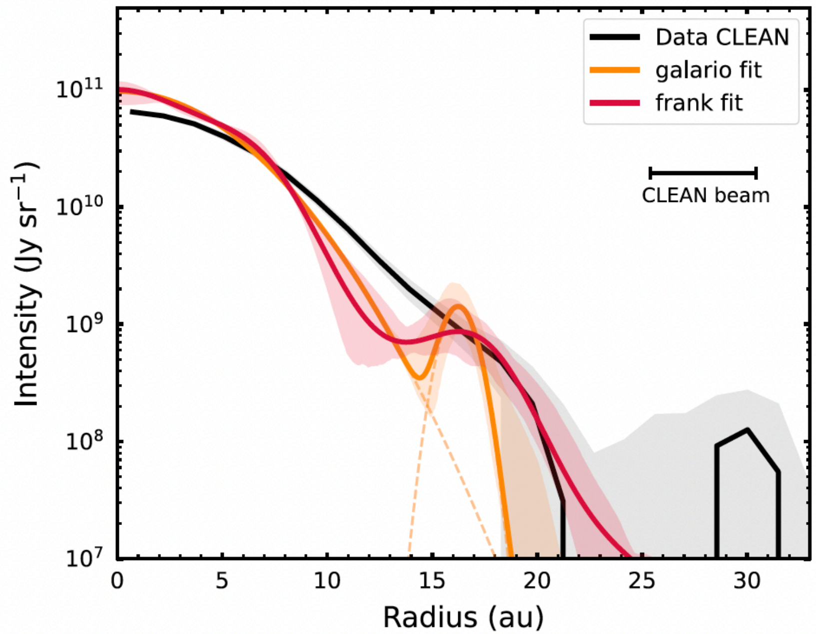
Not clear substructures at first sight



Not clear substructures at first sight

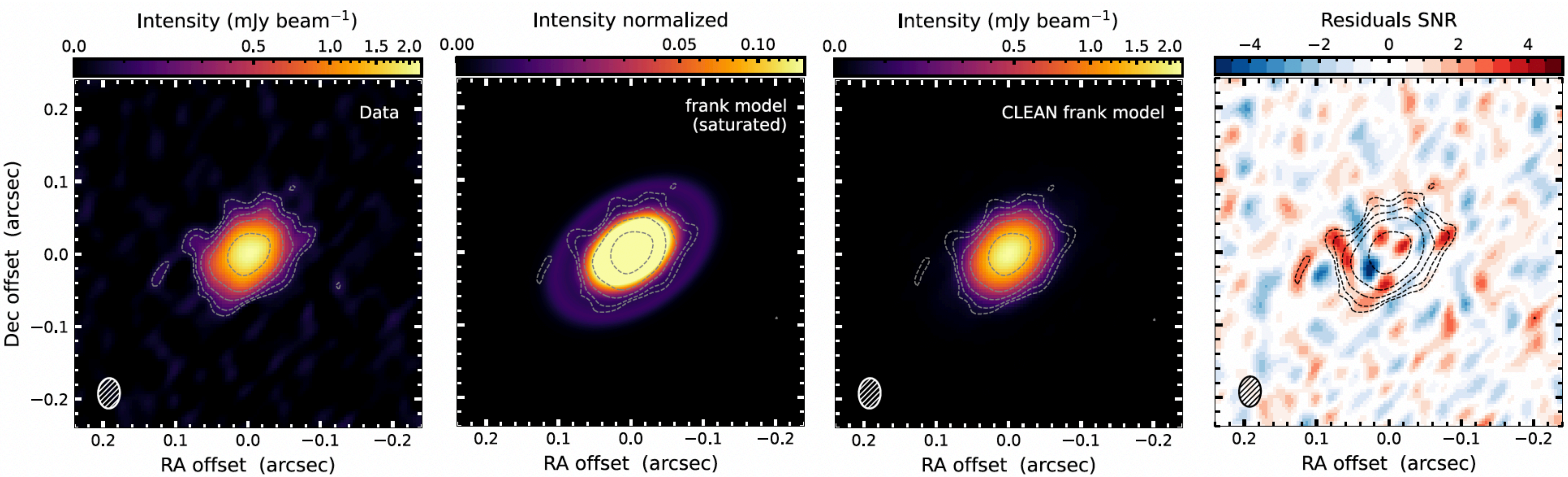
Eureka!



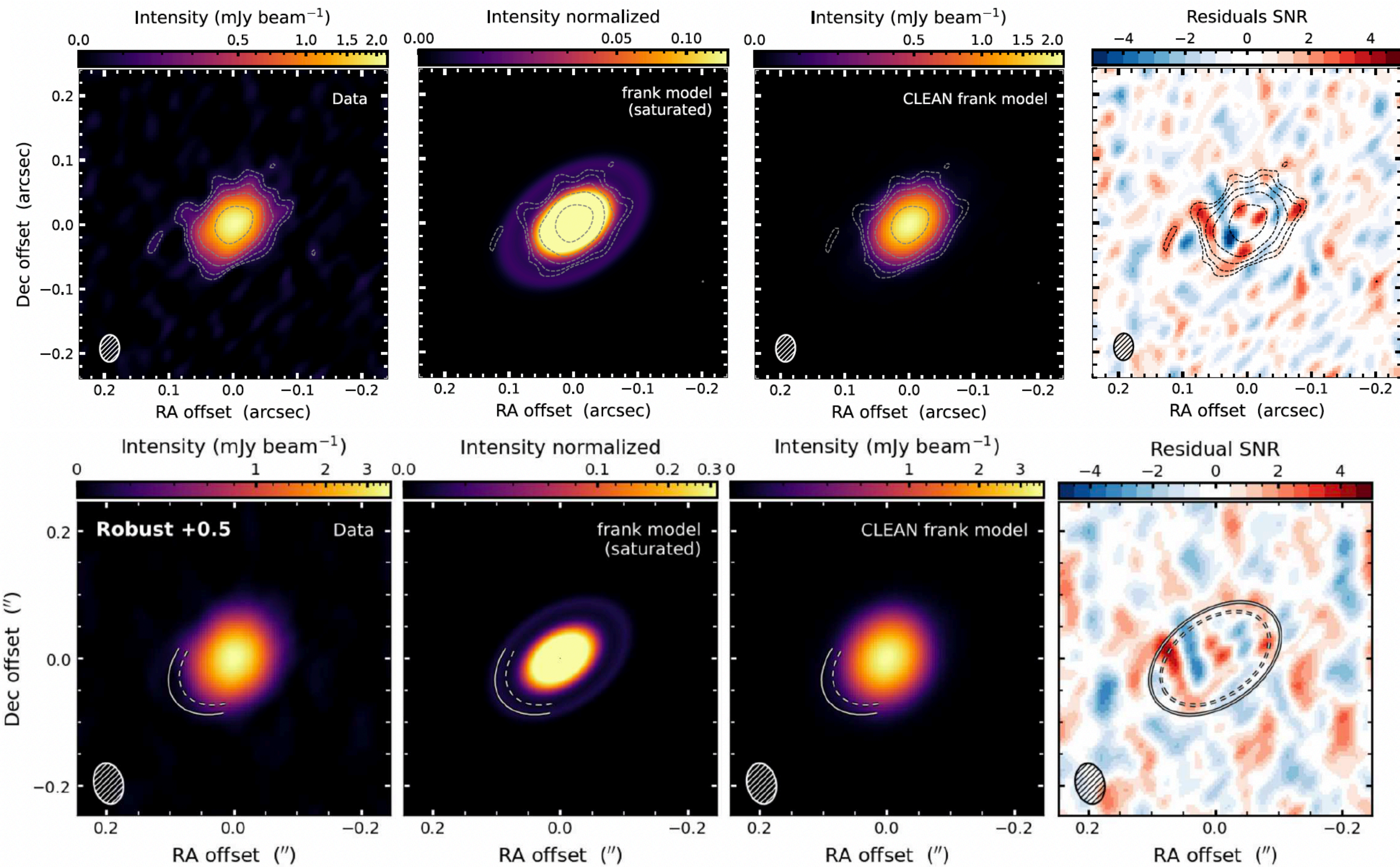


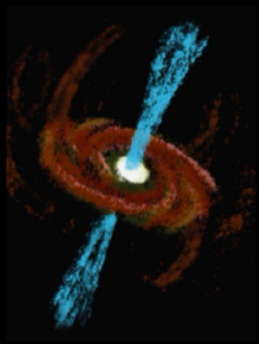
Posible mass of the planet carving the disk is 0.3-7.7 Earth masses

First hints of substructure in a BD disk



First hints of substructure in a BD disk





proto-BD

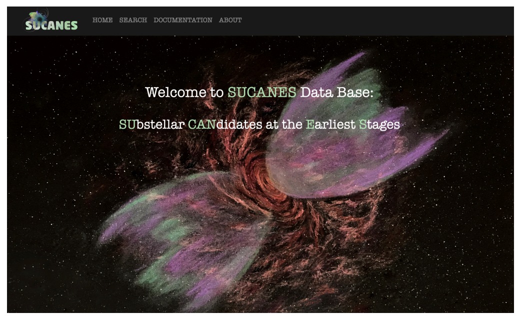
$L_{int} < 0.13\ L_{\odot}$
$T_{bol} = 20 - 650$ K
$M_{env} < 0.3\ M_{\odot}$

Proto-BDs are deeply embedded objects that will remain substellar after their evolution:

$M_{acc} + M_{future} < 75\ M_{jup}$
$T_{bol} < 650$ K → Class 0/I

Bonus:Proto-BD candidates

SUCANES: a database of pre- and proto-BD candidates



https://sucanes.cab.inta-csic.es/

Pérez-García, Huélamo+ 2025

Conditions applied in SUCANES to isolate the best proto-BD candidates:

$L_{int} < 0.13\ L_{sun}$
$T_{bol} < 670$ K
$M_{env} < 0.3\ M_{sun}$

68 fona-fide proto-BD candidates

Review by Palau, Huélamo et al.+2024

Summary

- Planets seem to form in the substructures of protoplanetary disks
- BD should not have grain growth
- BD should not have planets

→ Particle Traps

- ALMA observations of 2M0444 (0.043" spatial resolution)
- Hints of a gap-ring pair for first time in a BD (dynamical mass ~50 M Jup)
- Possible mass of the planet (0.3-7.7 Earth masses)

Dynamical masses from the gas disks!