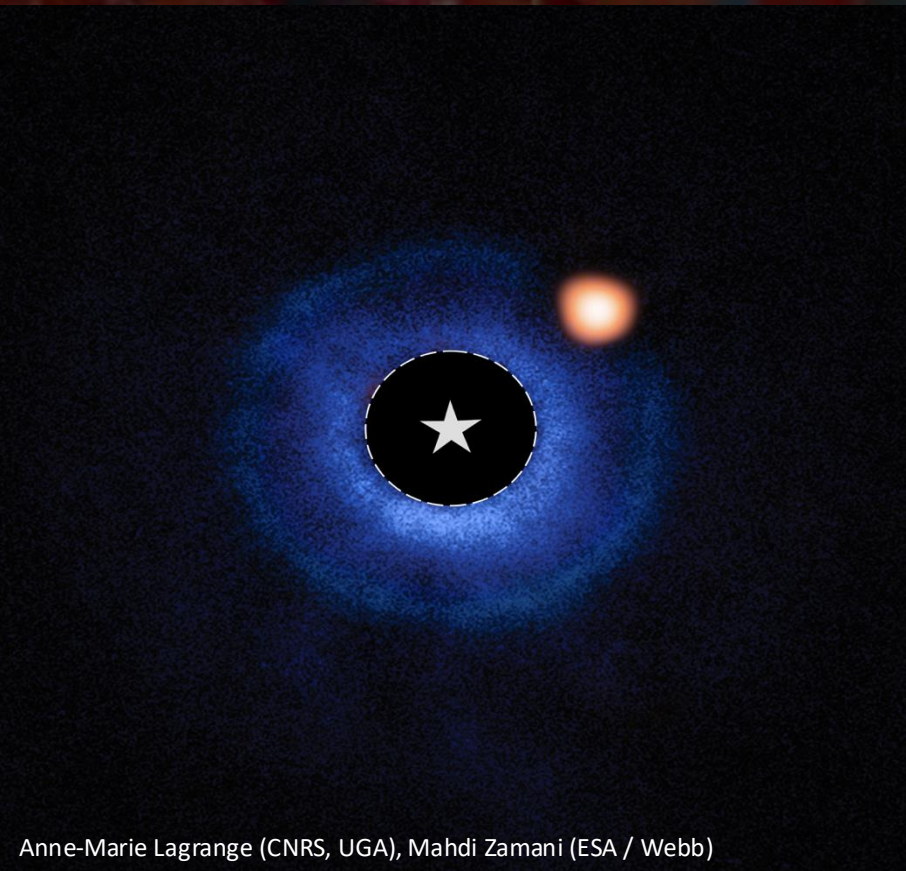


Resolving Architectures of Planetary Systems: the case for a sub-arcsecond far-infrared interferometer in space

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Key Questions in Astro2020

E-Q1b. What Are the Typical Architectures of Planetary Systems?

E-Q1c. How Common Is Planetary Migration, How Does It Affect the Rest of the Planetary System, and What Are the Observable Signatures?

E-Q1d. How Does the Distribution of Dust and Small Bodies in Mature Systems Connect to the Current and Past Dynamical States Within Planetary Systems?

E-Q3d. What Are the Key Observable Characteristics of Habitable Planets?

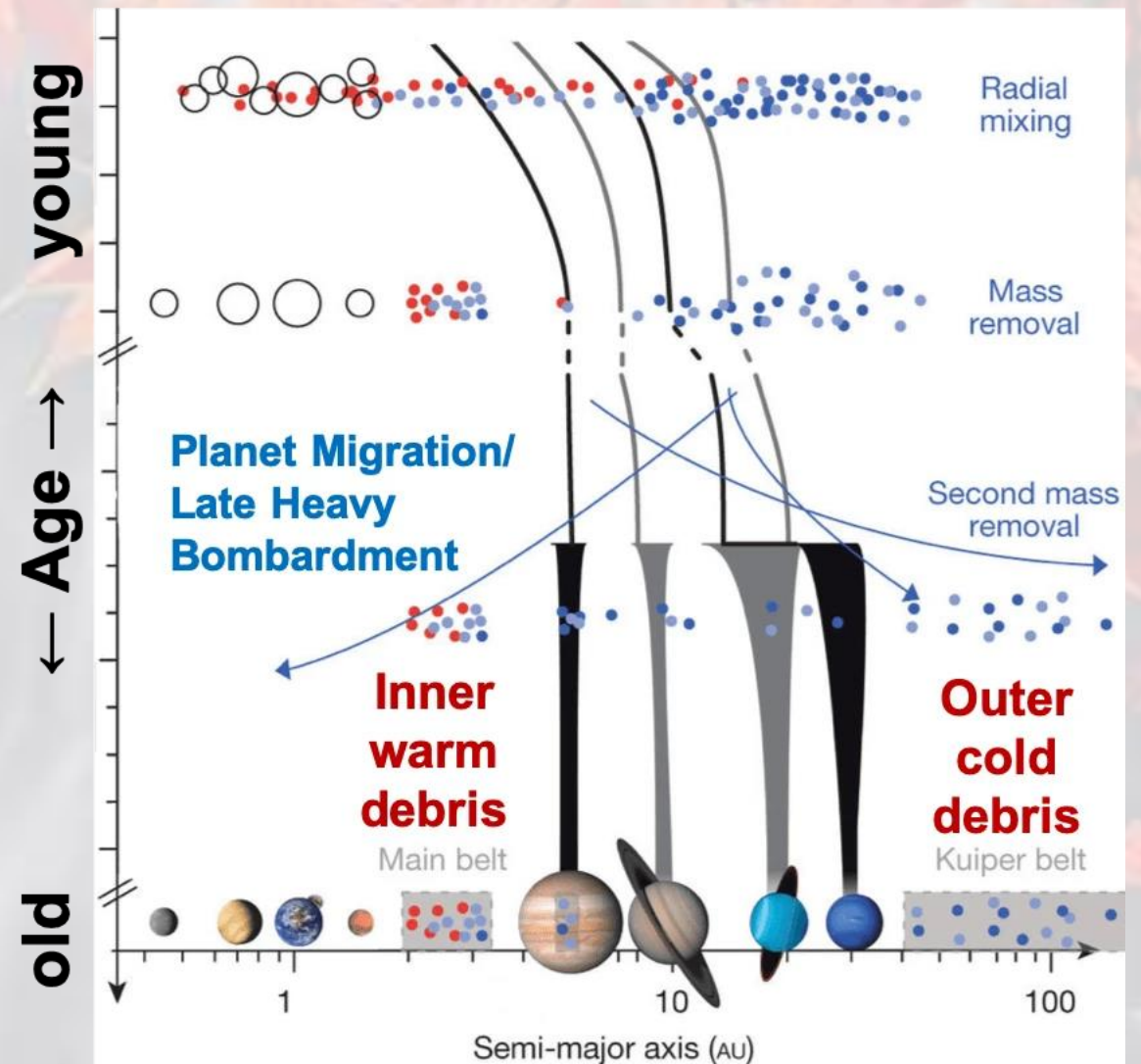
F-Q4. Is Planet Formation Fast or Slow?

F-Q4a. What Are the Origins and Demographics of Disk Substructures?

A multiwavelength, mid- to far-infrared survey that resolves disk emission in hundreds of potential exoplanetary systems across different masses and ages of stars will provide significant constraint to these questions!

Disks and Planetary Systems

- Disks are an integral part of planetary systems that shape planetary architectures and are later shaped by them in turn
 - Location of planet formation in young disks
 - Planet/disk interaction, dynamical evolution of planetary systems
 - Windows into outer planetary systems in mature systems when the structure of debris disks reveals planet architectures undetectable by other methods (e.g., ice giants)

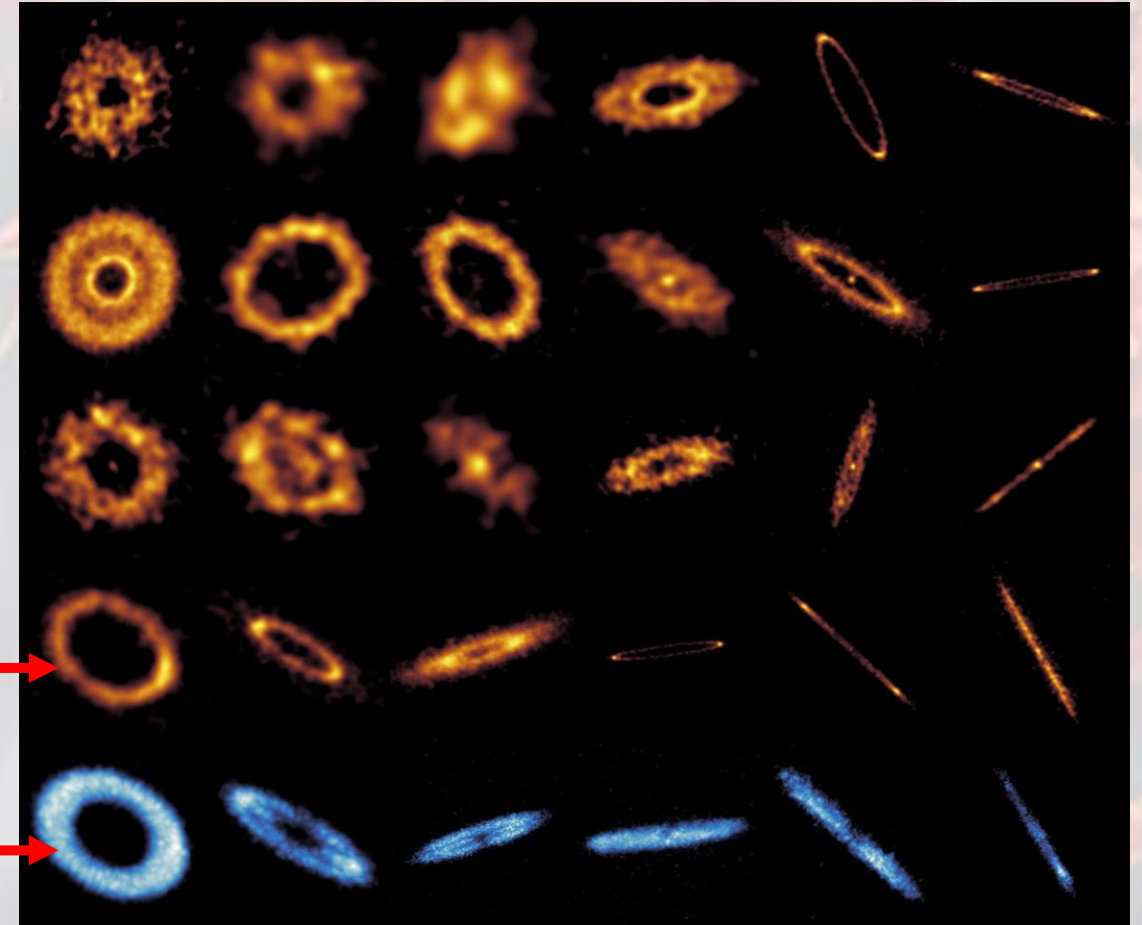


Planets shape disks over time

- The signatures of planets are imprinted in planetesimal belts, which evolve collisionally and enable sustained detectability over ***billions of years***
- ***Debris disks*** are optically thin at all wavelengths, and gas poor, with gas associated mainly with young A stars

Dust emission

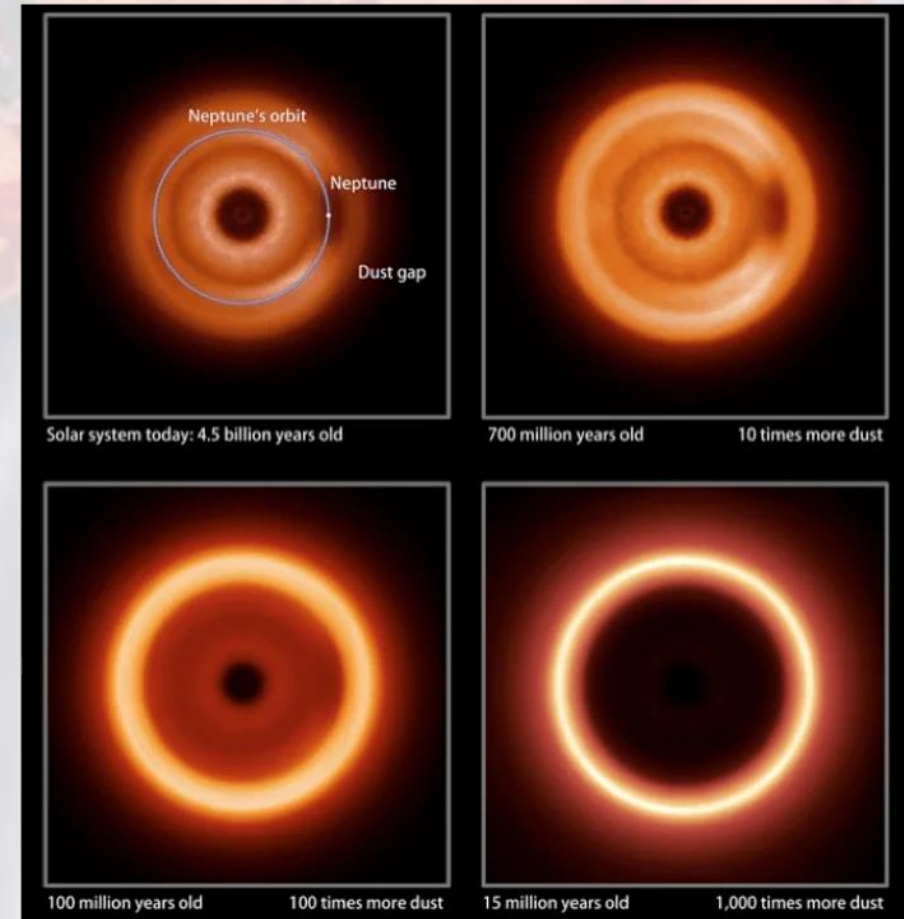
CO emission



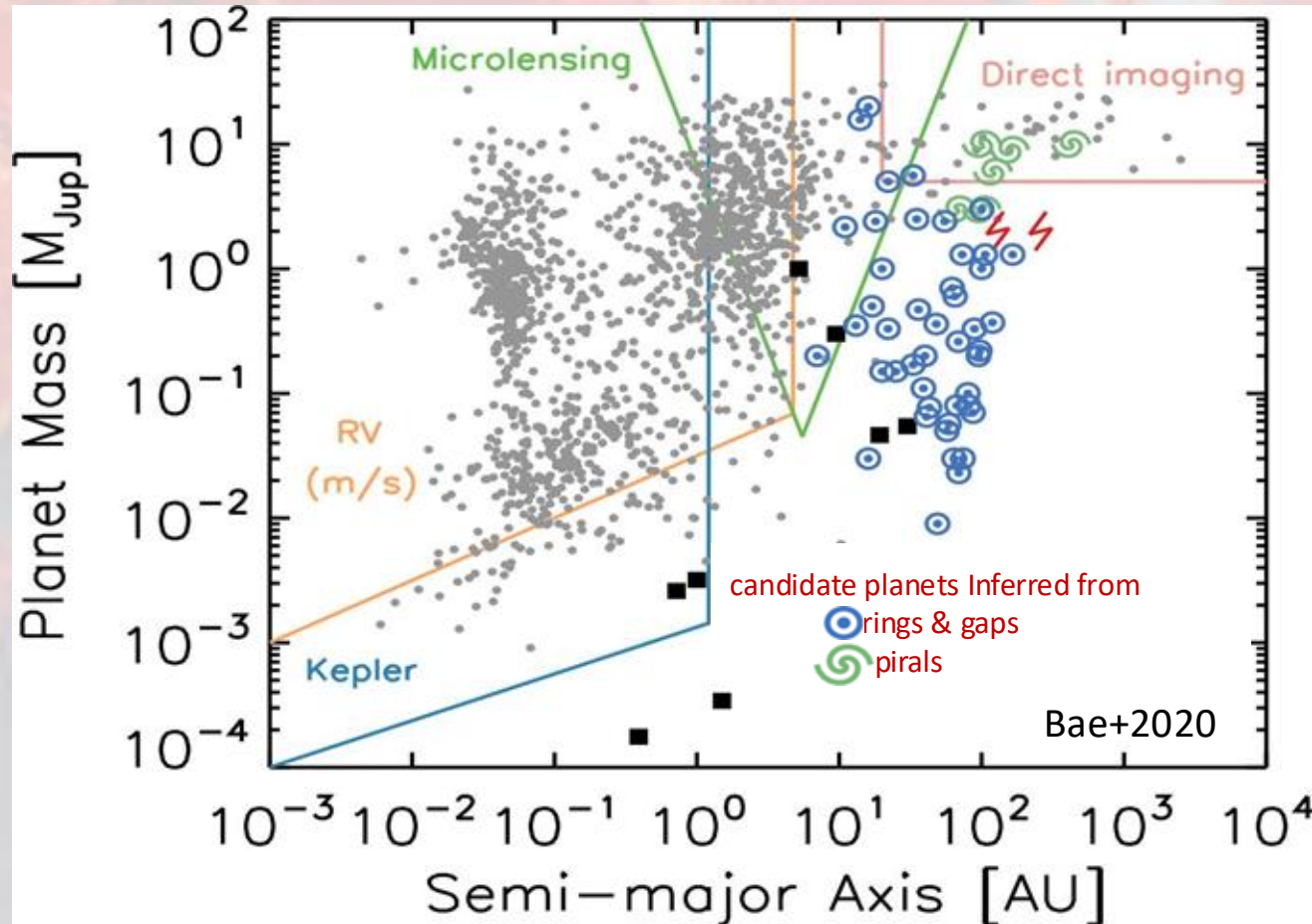
ARKS large ALMA survey of 24 debris disks, Marino+2026

Evolution of the Solar System debris disk

- In our own Solar System, the architecture of the asteroid and comet belts provide strong constraints on how the planets, particularly the outer gas and ice giants, formed and evolved if detected from another star
- Its current faintness means we have yet to detect a true Solar System analogue



Planet architecture from disk substructure

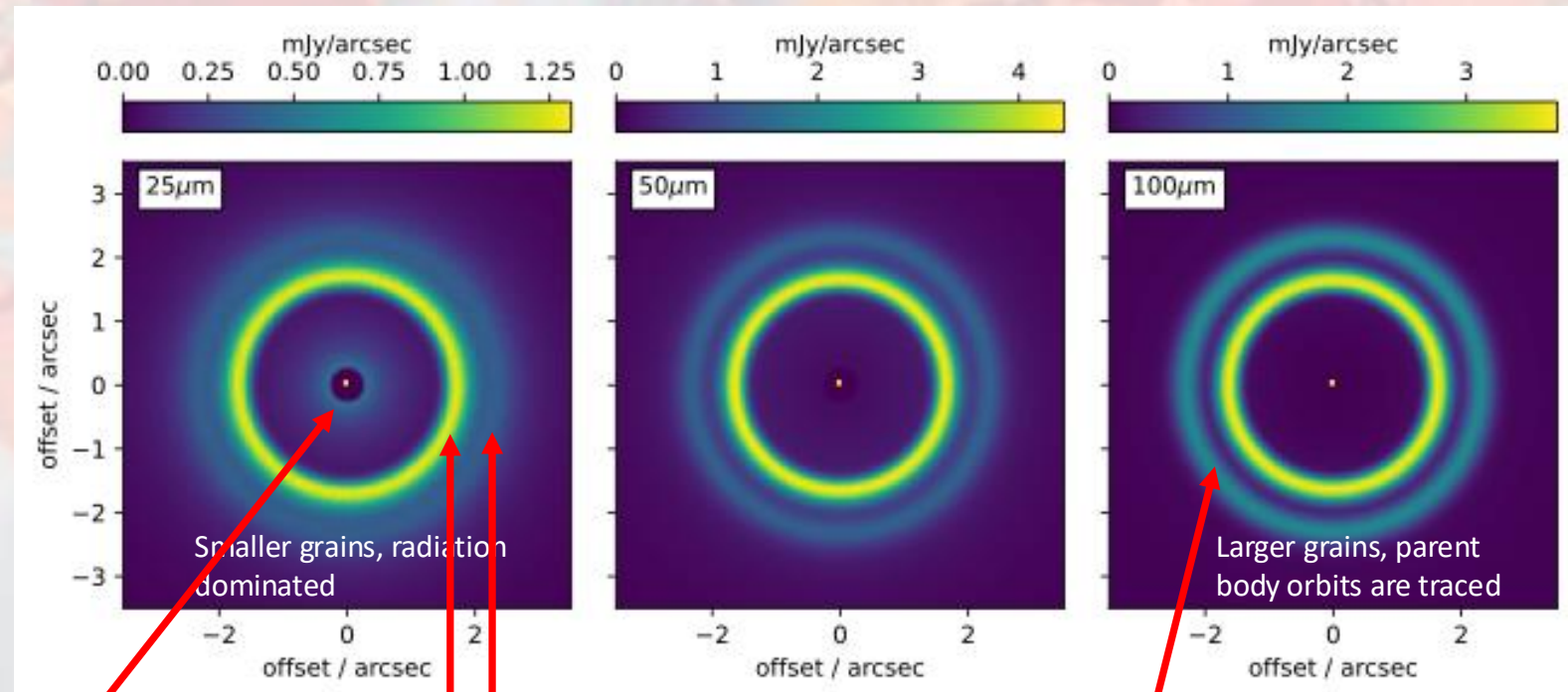


- Grey dots are planetary detections
- Squares are Solar System planets
- Inferred planets from disk structure are shown in blue and green
- Unlike microlensing planetary detections, a disk/planet system can be fully modeled

Resolved disk imaging reveals underlying planetary architecture

**Resolved multiwavelength
resolved imaging reveals
different aspects of the disk.**

Models for a 30-50 au disk
with a 6 au gap around a
Sun-like star at 10 pc.



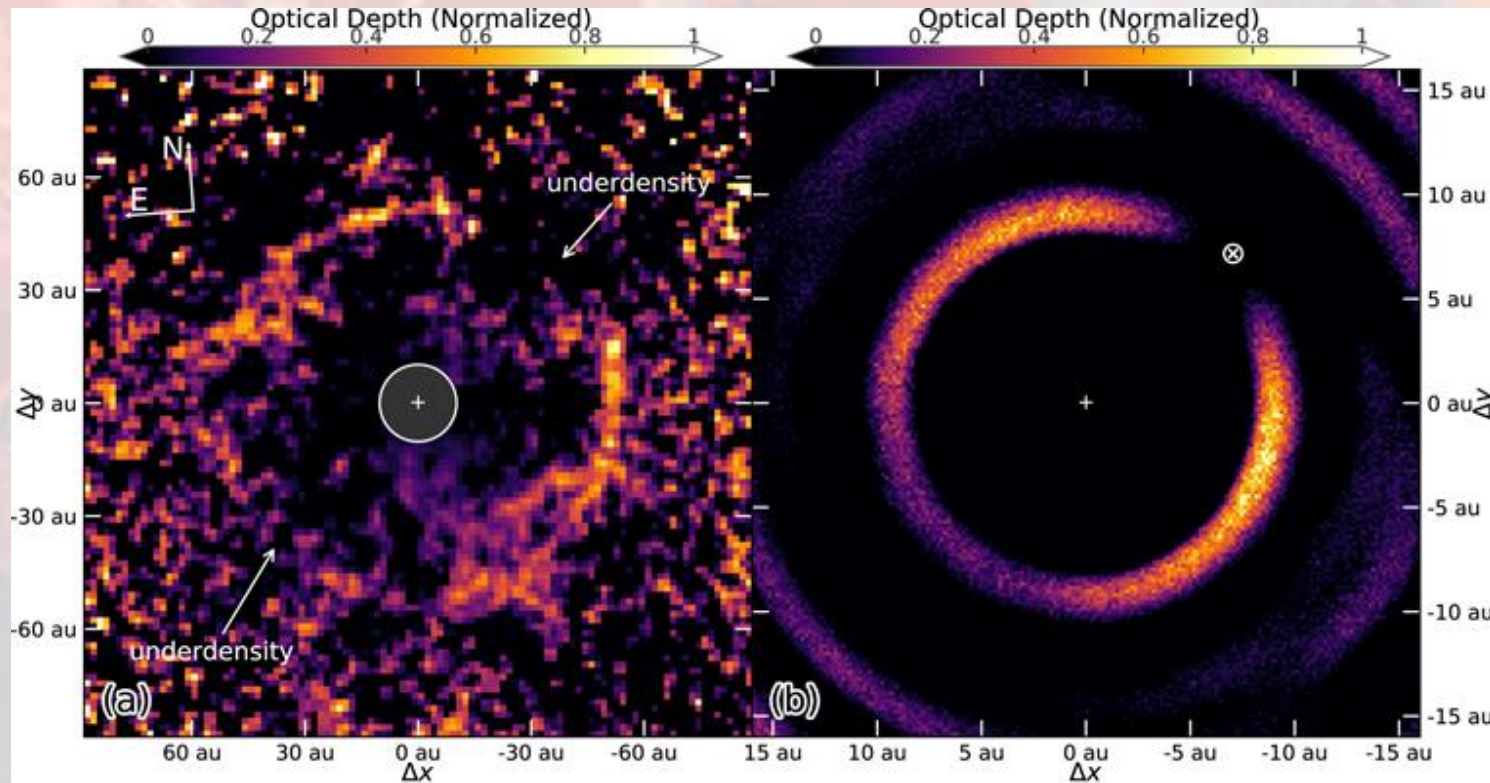
Mathews+ (in prep)

Rings appear more diffuse

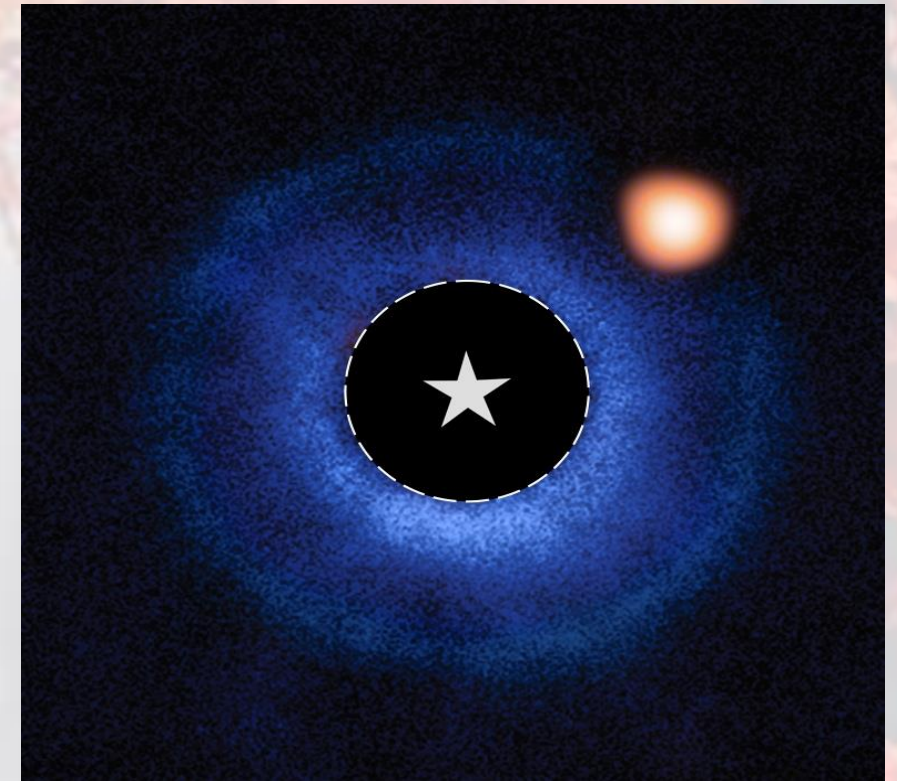
Warm component near the star is detectable

Gap is most pronounced

e.g. TWA 7



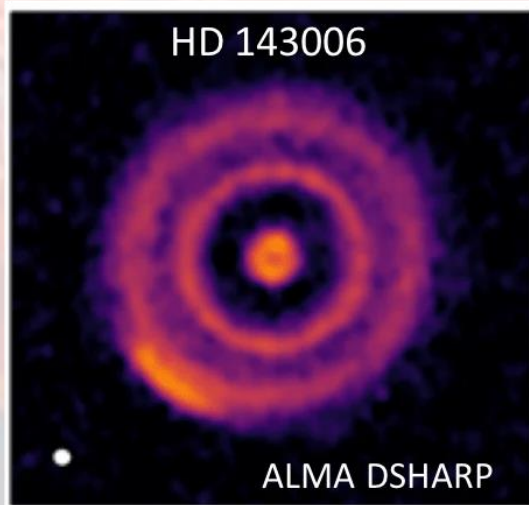
Ren+ 2021, SPHERE/VLT imaging of Ring 2 shows an underdensity.



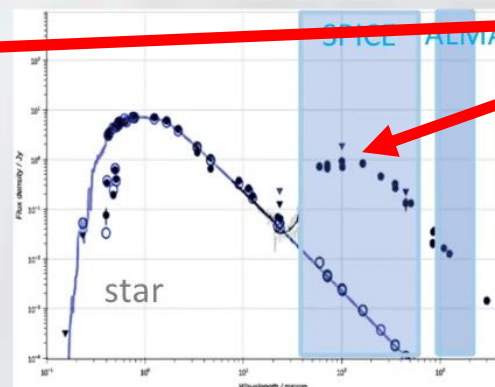
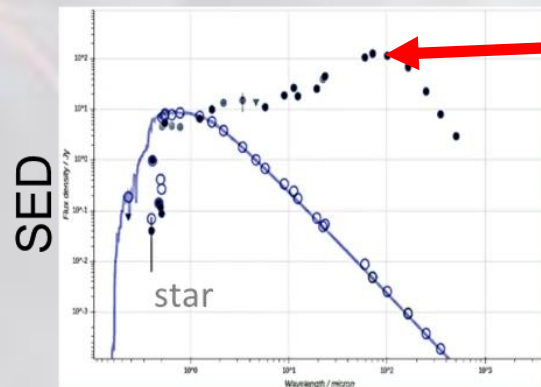
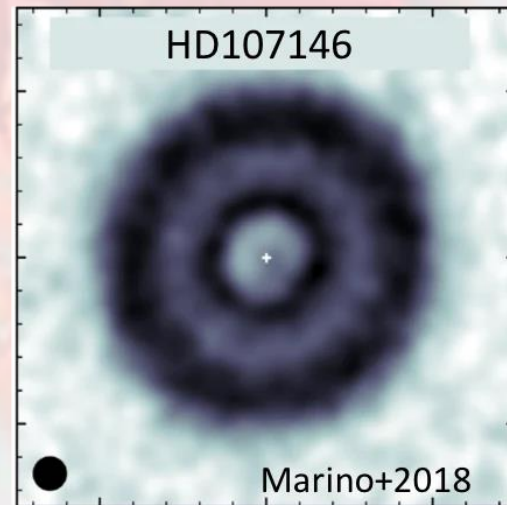
Lagrange+ 2025, SPHERE in blue with JWST 25 micron detection of Saturn-mass TWA7b in orange.

Mature disks are typically faint disks

Protoplanetary Disk



Debris Disk

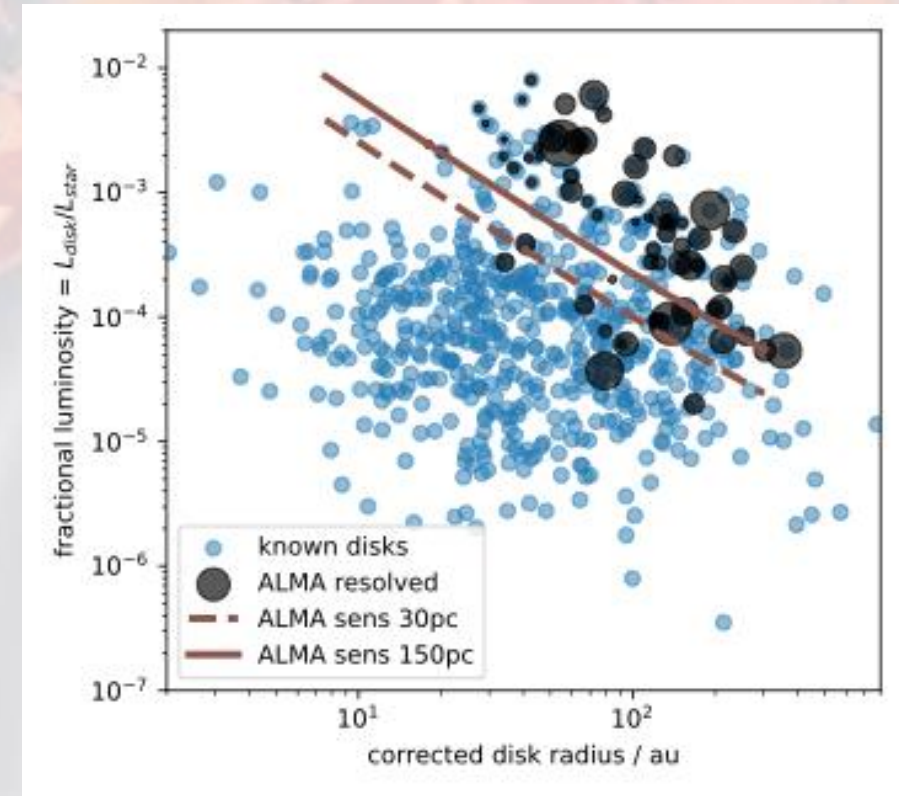


- ALMA has imaged protoplanetary and debris disks with exquisite resolution in the millimetre/submillimetre
- Many more protoplanetary disks are bright enough for ALMA imaging
- Debris disks are 2-3 orders of magnitude fainter than protoplanetary disks, *even at the peak of their emission* around 70-100 micron

How many known debris disks can be resolved by ALMA?

- ALMA can image protoplanetary disks at excellent resolution in nearby star-forming regions (e.g. DSHARP)
- Nearly 100 mature debris disks have also been imaged with ALMA (Matra et al. 2025; Marino et al. 2026) but not all at comparable resolution
- Matthews et al. (in prep) have compiled a robust, well-characterized sample of ~600 debris disks within 200 pc, of these, only a fraction have been observed with ALMA

THIS IS DUE TO LIMITATIONS IN SENSITIVITY

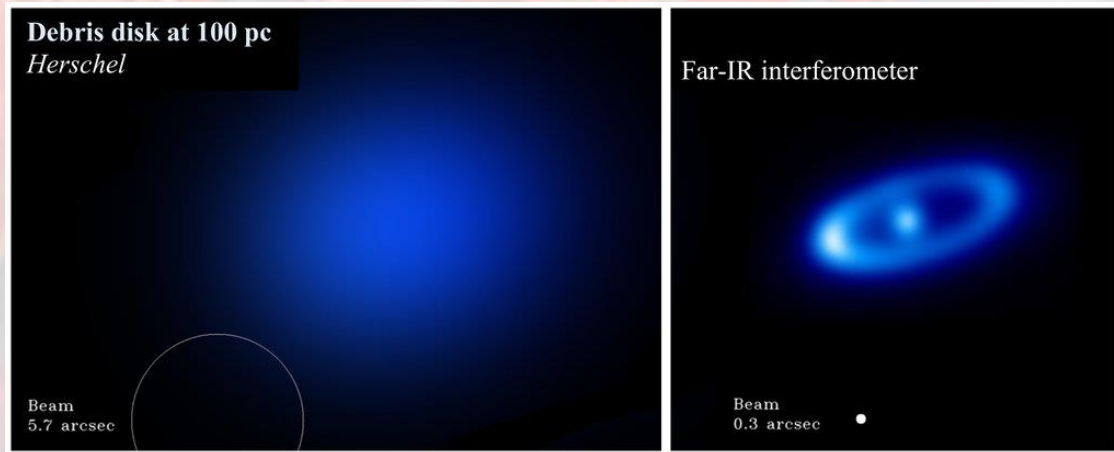


Matthews+ (in prep)

Black dots are in proportion to the resolution of the disk. Many disks are marginally resolved with ALMA.

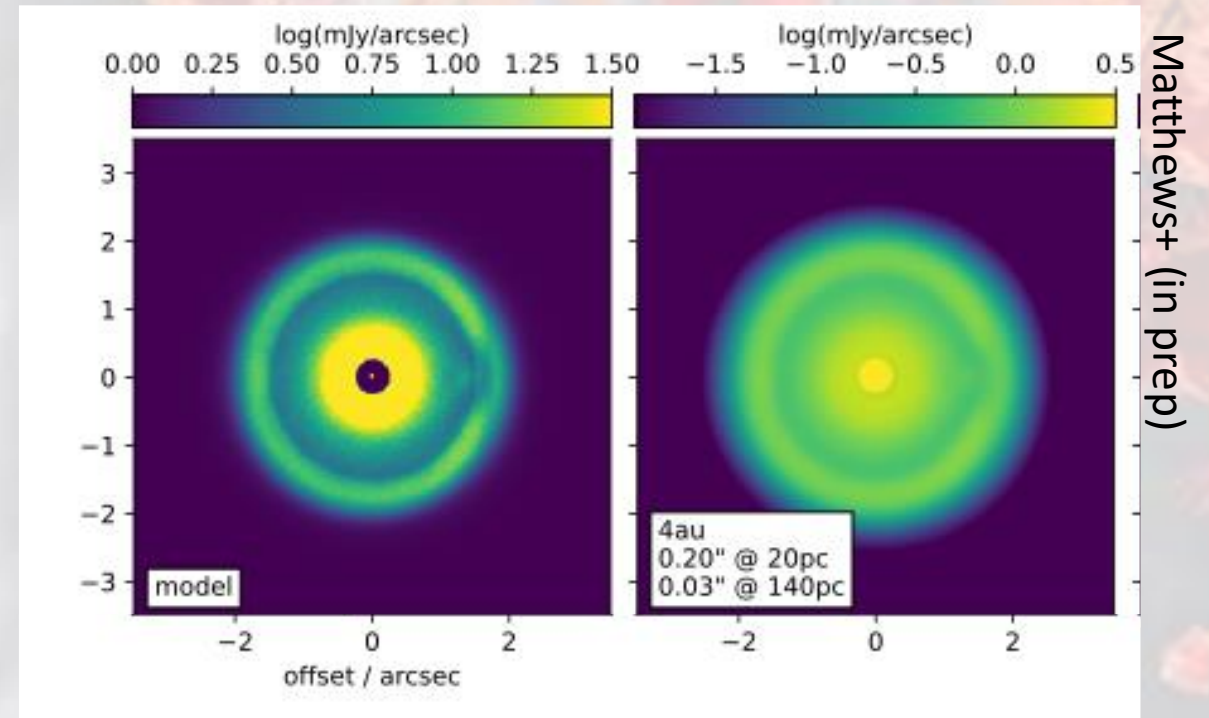
What we have been missing is a means to observe the diversity of substructure in a significant number of debris disks.

Achieving this requires unprecedented spatial resolution in the far-infrared, where these disks emit most strongly.



Sub-arcsecond resolution would provide resolved imaging at 100 pc comparable to Herschel imaging of Fomalhaut at 7.7 pc.

0.03" resolution
would resolve features of 4au at 140 pc.



Only a FIR interferometer is capable of delivering this scientific dividend for the maximum number of planetary systems.