PLANET-DISK INTERACTION IN SOLAR SYSTEM ANALOGS: LOOKING FOR PLANETS AND SUBSTRUCTURES IN DEBRIS DISK SYSTEMS.

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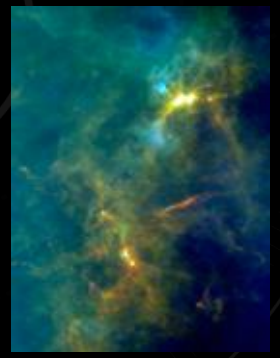
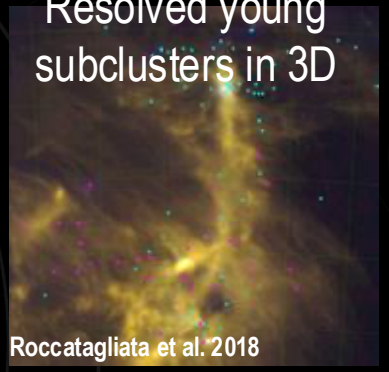
First stages of star formation: filamentary structures



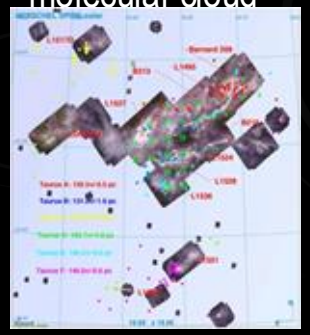
Roccatagliata et al. 2015

Resolved young subclusters in 3D



Roccatagliata et al. 2018

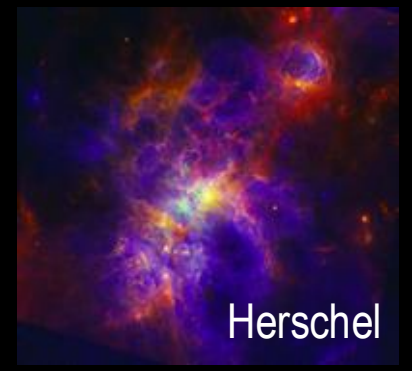
3D subclusters vs molecular cloud



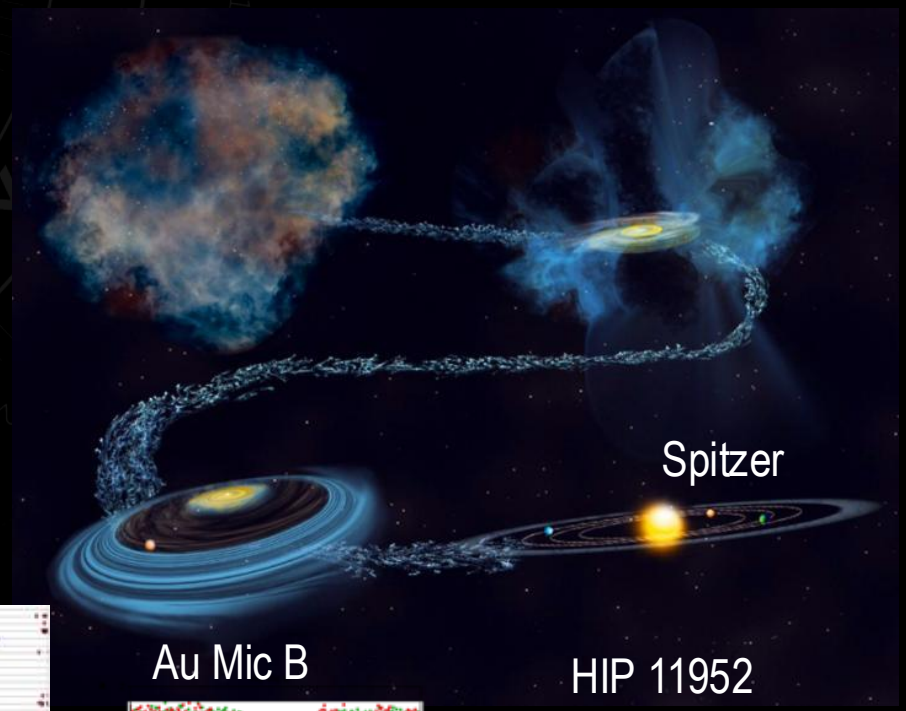
Roccatagliata et al. 2020

Binarity in young stars

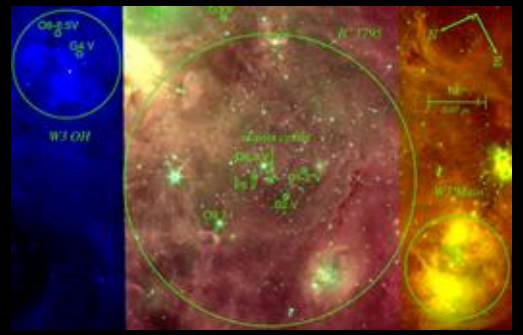
Roccatagliata et al. 2011a



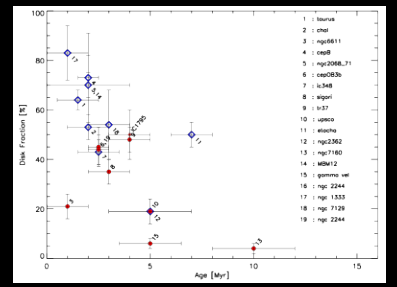
Roccatagliata et al. 2013
Roccatagliata et al. 2012

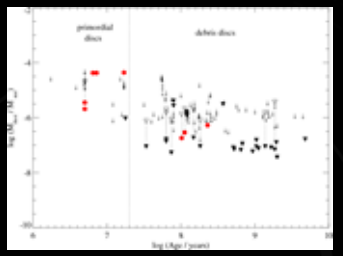


Evolution of protoplanetary disks
-> Feedback from high mass stars



Roccatagliata et al. 2011b

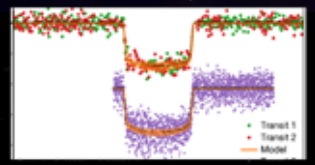




Roccatagliata et al. 2009

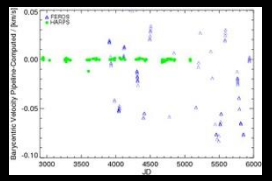
Bertini, Roccatagliata & Kim 2023

Au Mic B



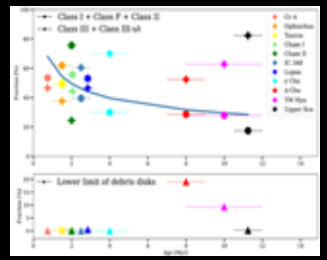
Plavchan et al. 2020

HIP 11952



Müller, Roccatagliata et al. 2013

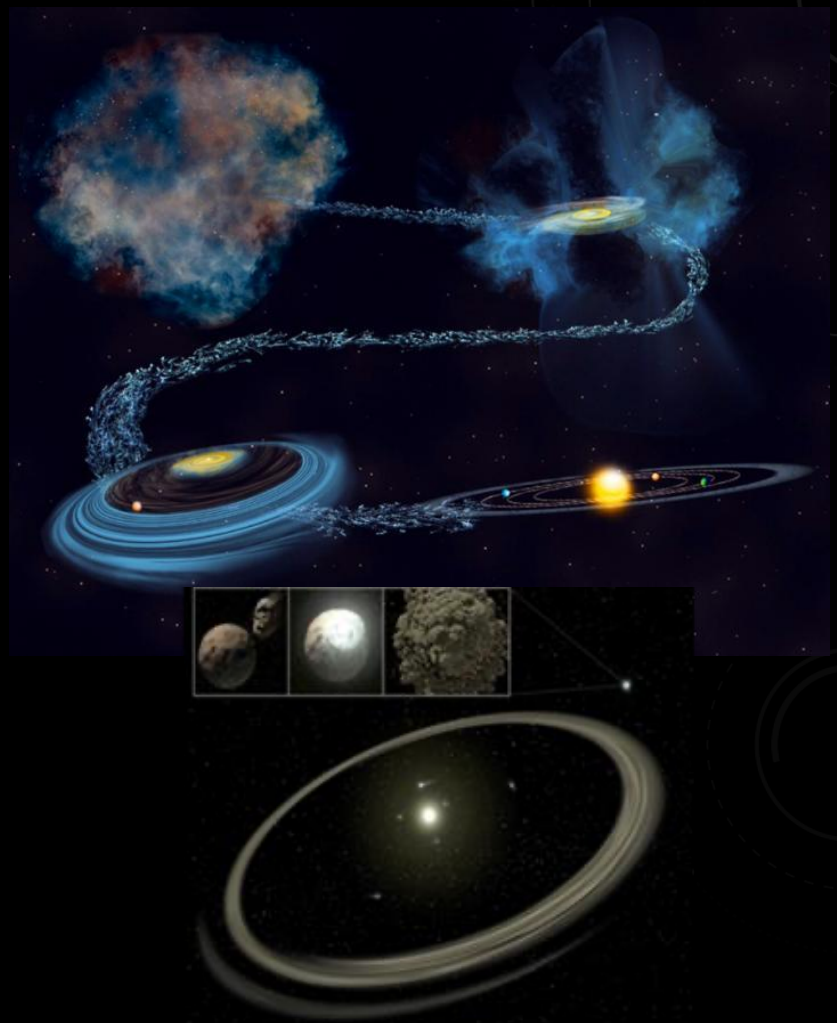
-> inner vs outer part of the disk



Roccatagliata et al. 2024

Outline

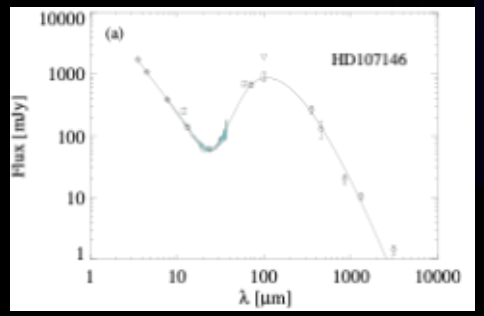
- ★ Motivation of the work
- ★ Impact of the flyby in debris disk
- ★ VLT/ERIS observations of debris disks
- ★ Perspective….



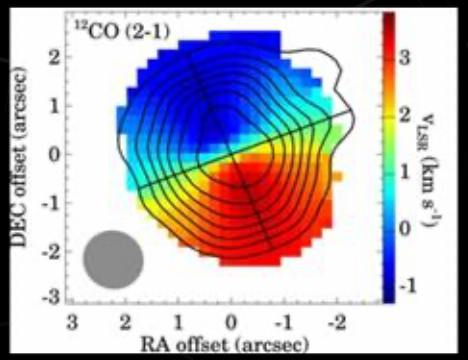
Debris disks

- Star in the pre- & main sequence
- Depletion of primordial gas and dust -> only II generation of dust
- Debris dust dynamics not dominated by the gas

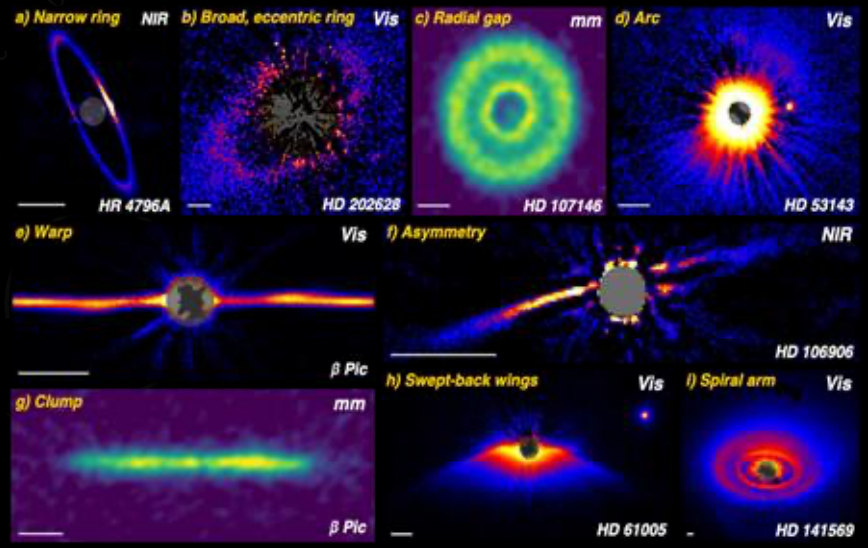
CREDIT BILL SAXTON (NRAO/AUI/NSF)



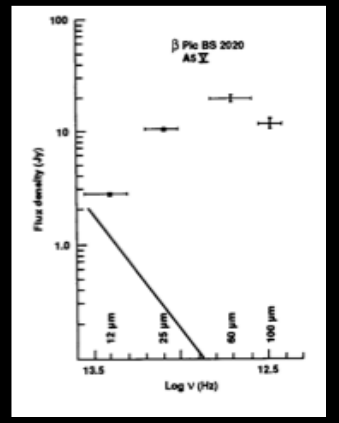
Roccatagliata+2009



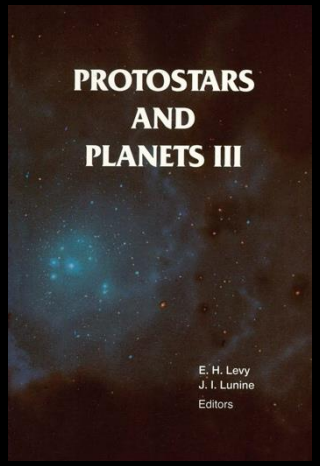
Moor+2011 – CO detection
Kospal+2013 – CO resolved



Hughes et al. 2018



Backman & Paresce 1993



Are we sure that debris disks are the last phase of protoplanetary disks?

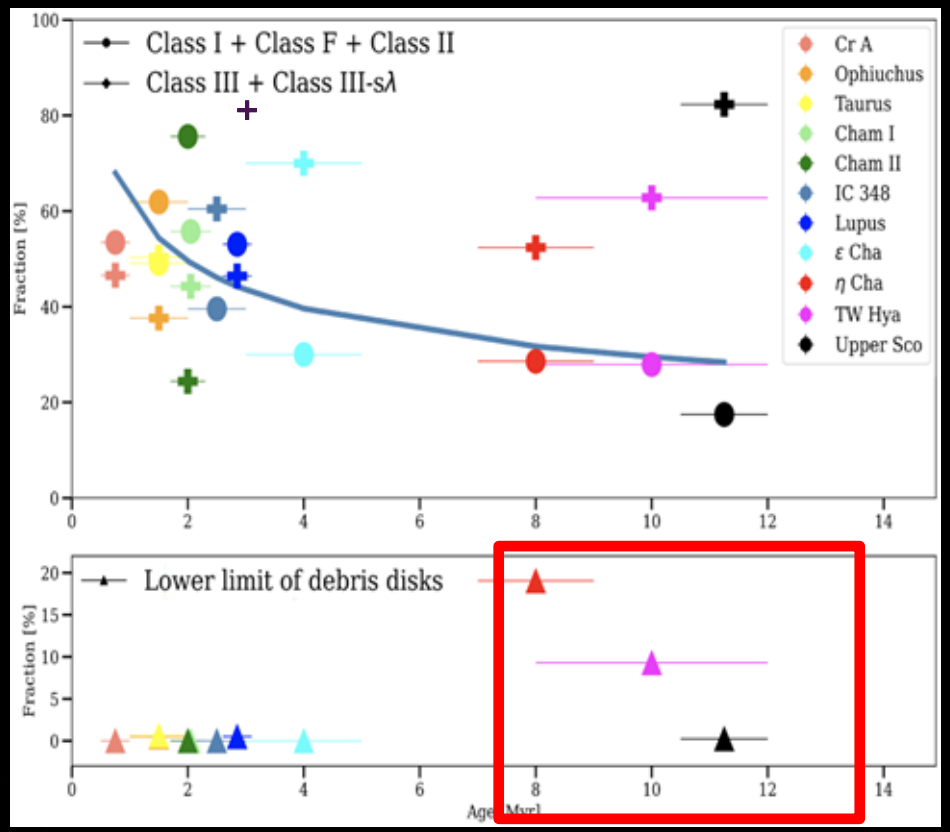
Debris disk session after planet session….

- When debris disks star to form?
- Planets always fundamental?

- Flybys might be fundamental in the evolution or even the formation of debris disks…
- What is the origin of the resolved substructures?

➢ When

Back to a definition of debris disk



Roccatagliata+2024

Class III disks with fractional dust luminosities f_{dust} ($\equiv L_{dust}/L_*$) < 10^{-2}

Debris Disk

- @ all ages!
- Small fraction for ~ 5 Mys
- After 5 Myrs DD fraction increases

-> Very efficient mechanisms responsible for DD which act in 5 Myrs!

Flybys in debris disk systems – Gaia eDR3

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Sample of 240 debris disks-> Gaia eDR3 astrometry

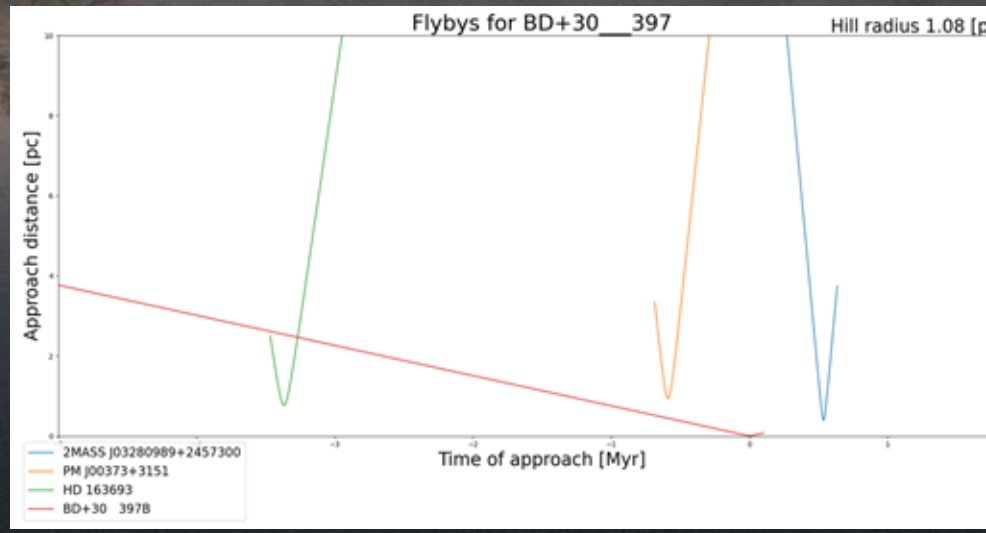
R_{HILL} for all debris disks (1-1.5 pc) $R_H \sim (R)\left(\frac{m_*}{3M_{enc}(R)}\right)^{\frac{1}{3}}$

- Positions reconstructed in the last 5 Myrs and in the next 2 Myrs in the future for all stars with RVs from Gaia in a certain area of the sky, assuming v=const.
- Distance between the main object and potential perturbers computed each 700 years
- Linear approximation valid to define the LAST flyby and its position

Flyby: $d_{min} < 1R_{HILL}$
Close encounter: $d_{min} < 0.5R_{HILL}$

50% of the ~ 240 debris of the compiled original sample with V_{rad}-> only for this sub-sample reconstructed the flyby

- Recovered the close encounter found by Ma et al. 2022 for HI 106906 and HD 115600 (wh computed only distances and time o flybys with a smaller sample o perturbers with Gaia DR2)



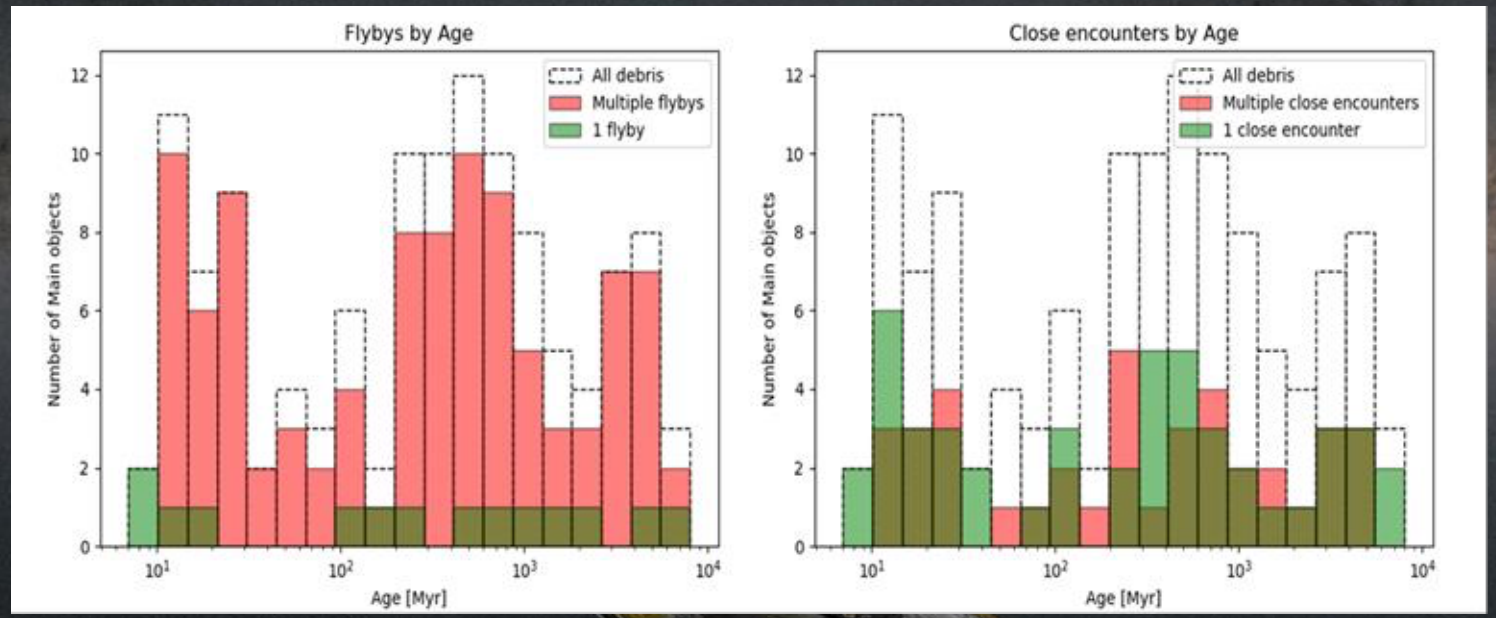
Bertini, Roccatagliata, Kim

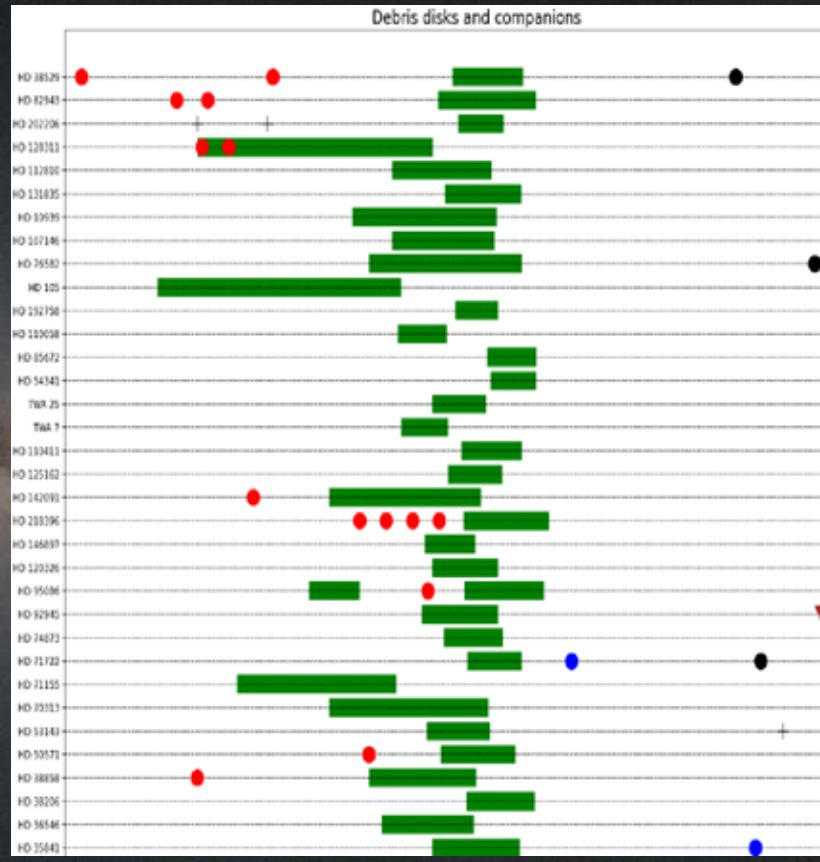
Flyby of BD+30 397 between 5 Myr in the past e 2 Myr in future. The companion BD+30 397B is still in the Hill radius i last 1 Myr. -> additional validation of the linear approximatio

Flybys in debris disk systems

In the last 5 Myrs and in the next 2 Myrs

- 90% of the sample: at least 1 close flyby @ d > 0.5 R_{Hill}.
- 80% of the subsample of resolved disks : at least a close flyby (d < 0.8 pc) in the last 5 Myrs (@any age or SpT)

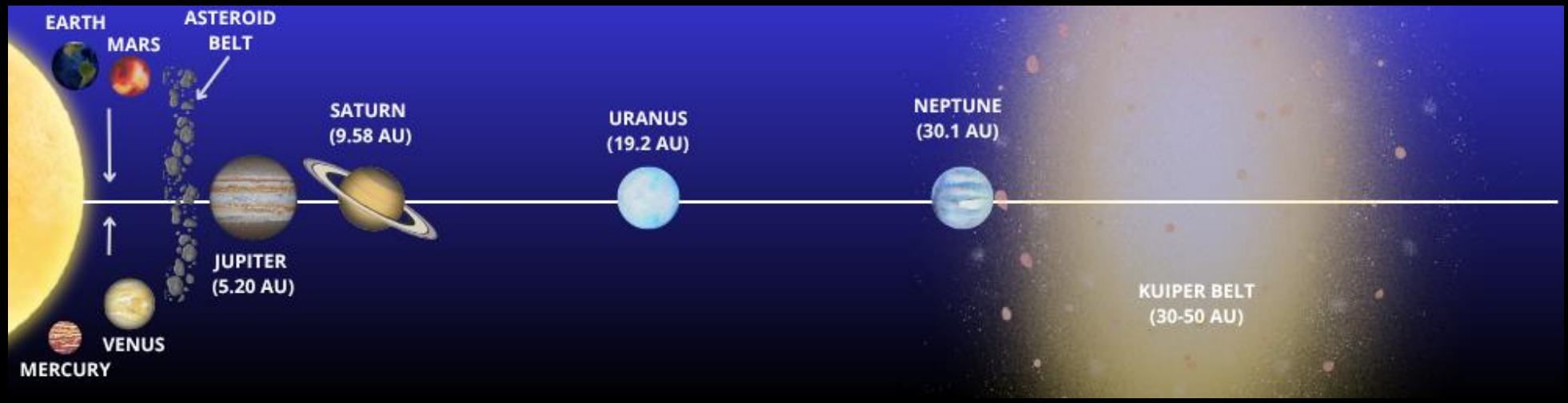


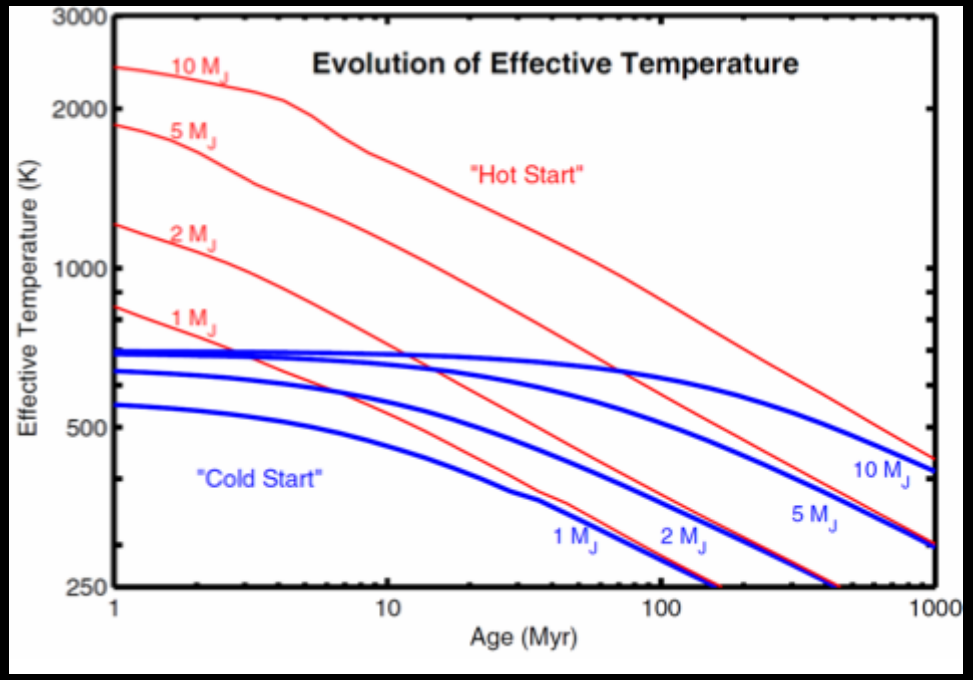


Perturbers with FIR excess possible sign of exchange of material during the flyby

Misalignment between planets/companions e disks orbits -> consequence of past flybys: HD 38529, 4 flybys in the last 3 Myr

***Bertini**, Roccatagliata & Kim 2*



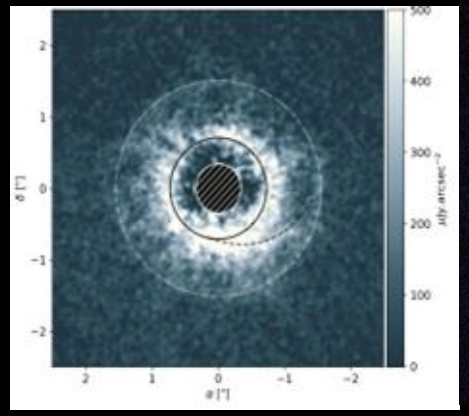


Spiegel and Burrows 2012: Linder + 2019

Debris disks:

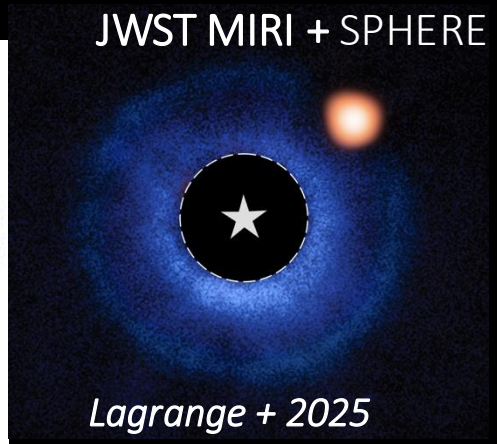
- Nearby
- With detected substructures
- At young but different ages –> possible distinction between hot and cold start planet formation…

TWA 7

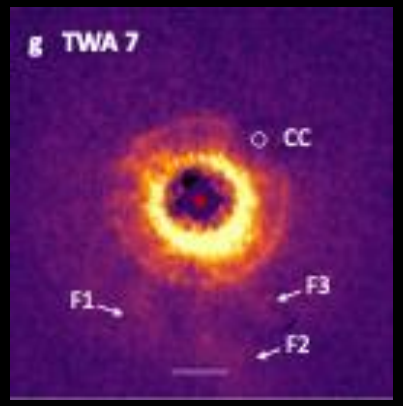


Olofsson + 2018
SPHERE/IRDIS DPI H-bands

$M_P = 0.3\ M_J$
JWST MIRI + SPHERE

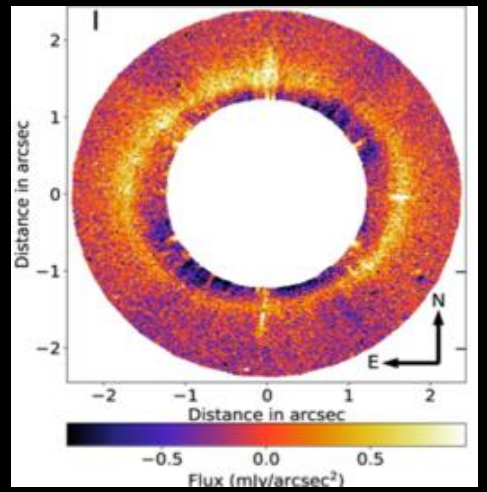


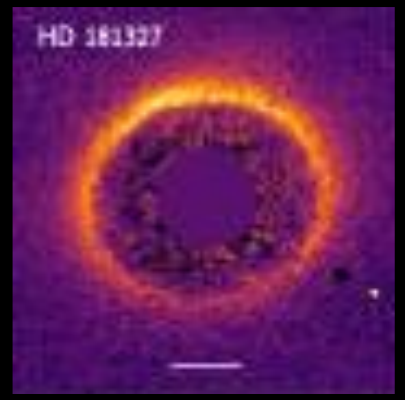
Lagrange + 2025
JWST MIRI + SPHERE



Engler et al. 2025

HD 181327



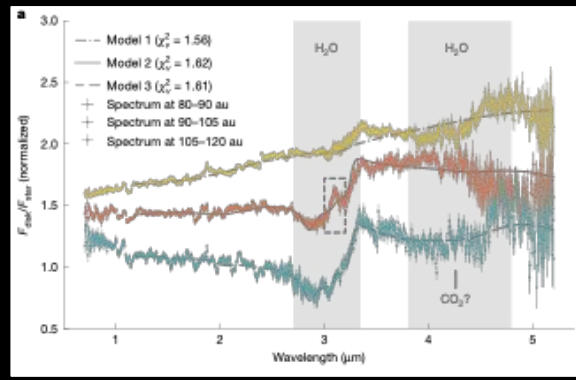


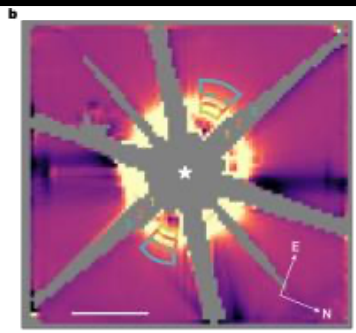
Engler et al. 2025

Bachelor thesis of Gloria Giamberardini!

HD 181327
SPHERE-IRDIS in the H band
Milli et al. 2024

crystalline water-ice ->
reservoir beyond snow line





Chen Xie et al 2025

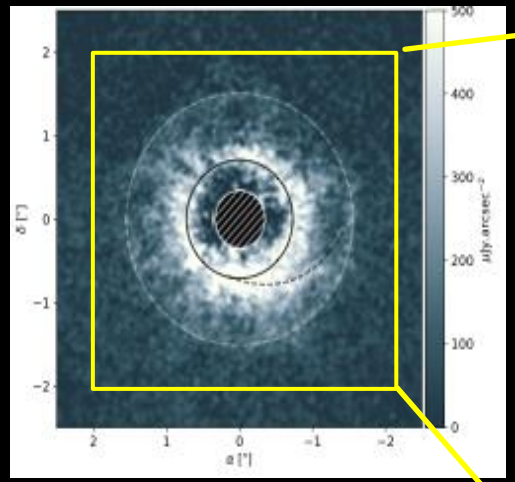
DEBRIS DISKS IN STEPS
TWA 7

Age: 6.4+/- 1 Myr

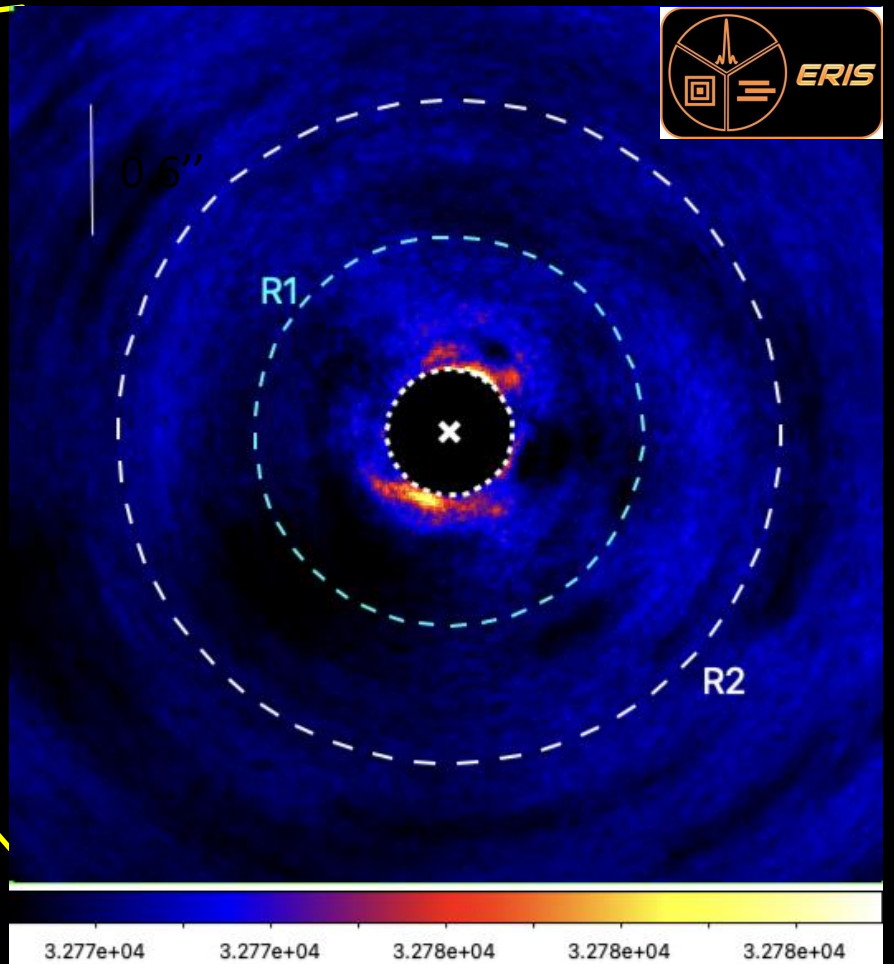
youngest debris disks known today.

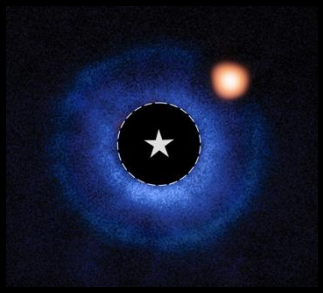
Distance : 34 pc

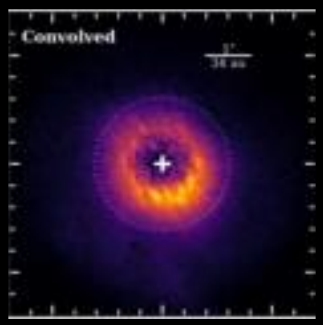
Low-mass member: 0.46 MSun

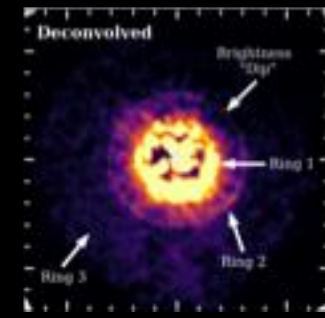


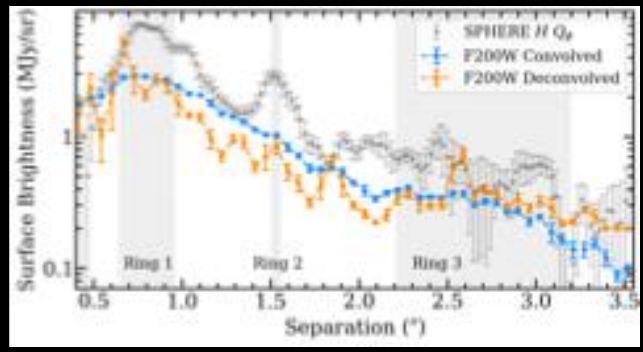
TWA 7
SPHERE+MIRI
Lagrange+2025



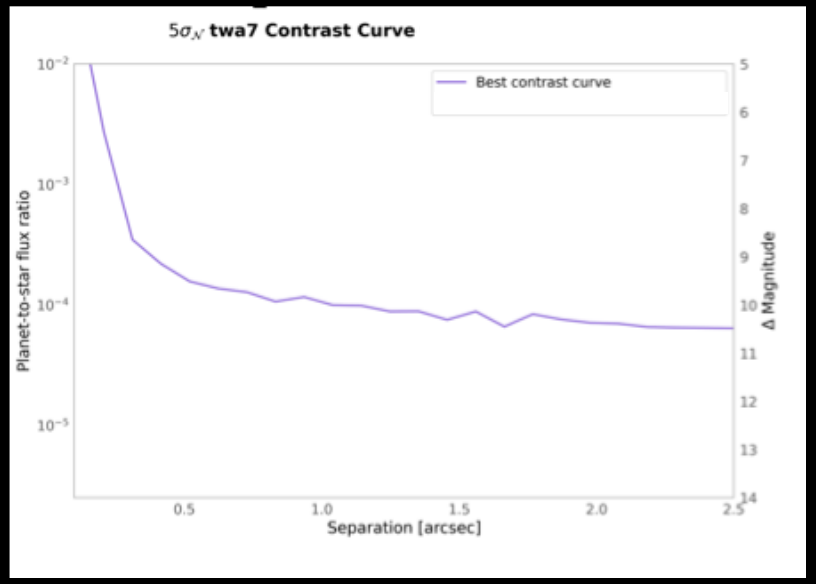


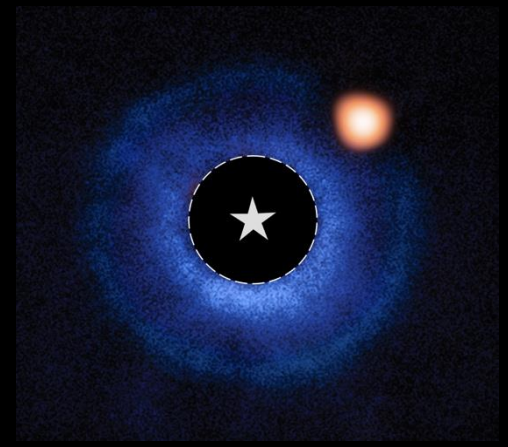


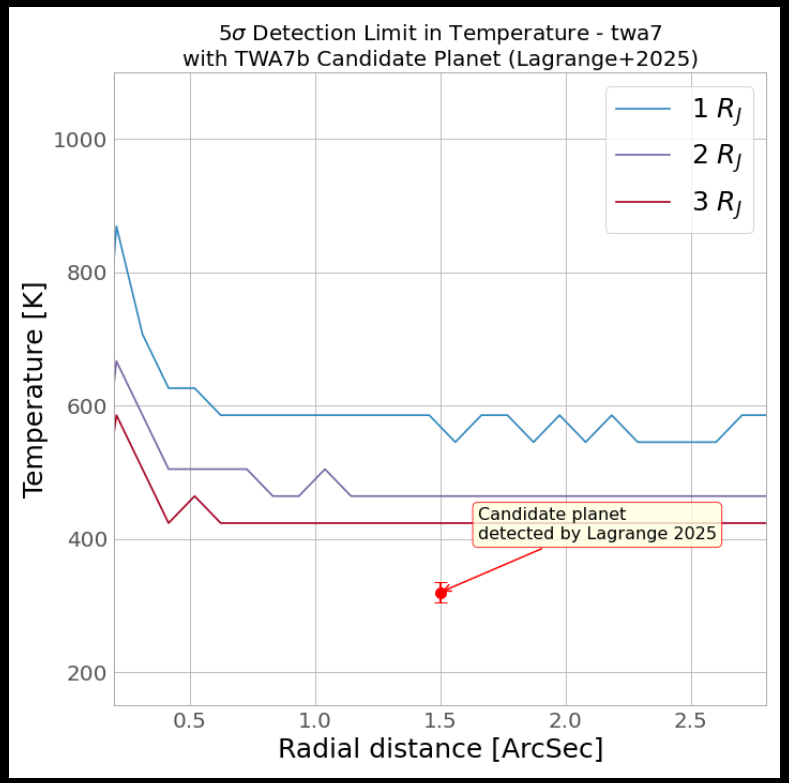


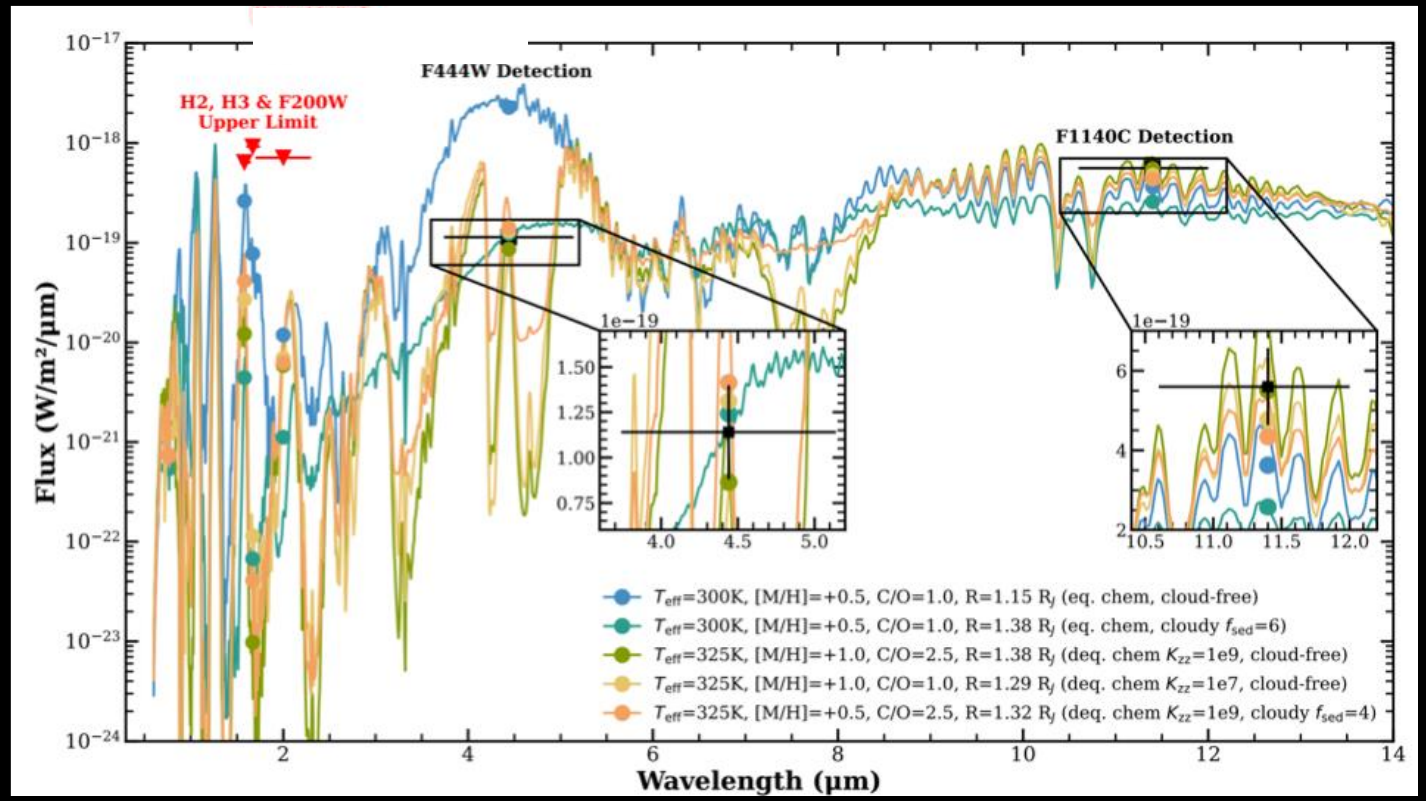


Lagrange + 2025, Krott + 2025
JWST + SPHERE


$5\sigma_{\mathcal{N}}$ twa7 Contrast Curve
Best contrast curve
Planet-to-star flux ratio
Δ Magnitude
Separation [arcsec]




5σ Detection Limit in Temperature - twa7
with TWA7b Candidate Planet (Lagrange+2025)
1 R_J
2 R_J
3 R_J
Temperature [K]
Candidate planet
detected by Lagrange 2025
Radial distance [ArcSec]


F444W Detection
H2, H3 & F200W
Upper Limit
F1140C Detection
Flux (W/m²/μm)
Wavelength (μm)
T_{eff}=300K, [M/H]=+0.5, C/O=1.0, R=1.15 R_J (eq. chem, cloud-free)
T_{eff}=300K, [M/H]=+0.5, C/O=1.0, R=1.38 R_J (eq. chem, cloudy f_{sed}=6)
T_{eff}=325K, [M/H]=+1.0, C/O=2.5, R=1.38 R_J (deq. chem K_{zz}=1e9, cloud-free)
T_{eff}=325K, [M/H]=+1.0, C/O=1.0, R=1.29 R_J (deq. chem K_{zz}=1e7, cloud-free)
T_{eff}=325K, [M/H]=+0.5, C/O=2.5, R=1.32 R_J (deq. chem K_{zz}=1e9, cloudy f_{sed}=4)

Krott + 2025

DEBRIS DISKS IN STEPS
HD 181327

Age: 18.5 Myr

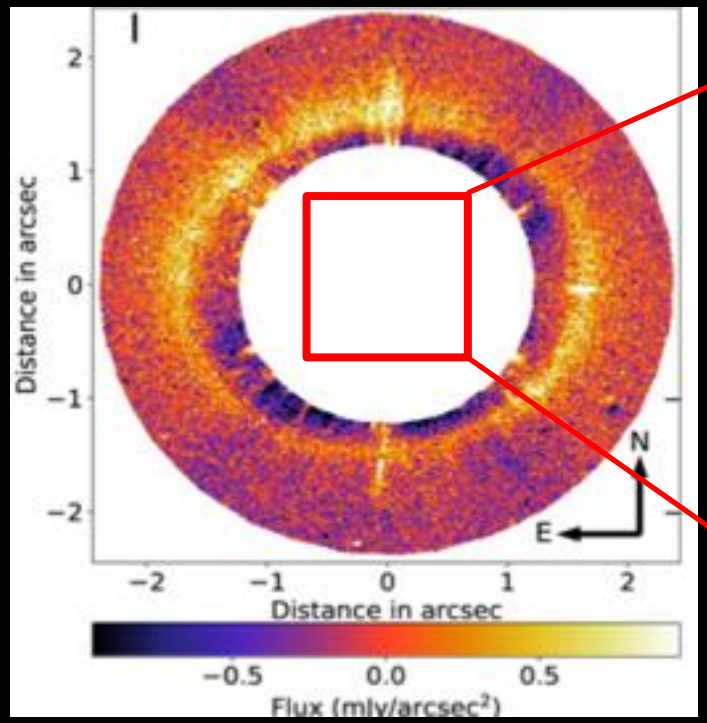
Distance : 47.72 ± 0.05 pc

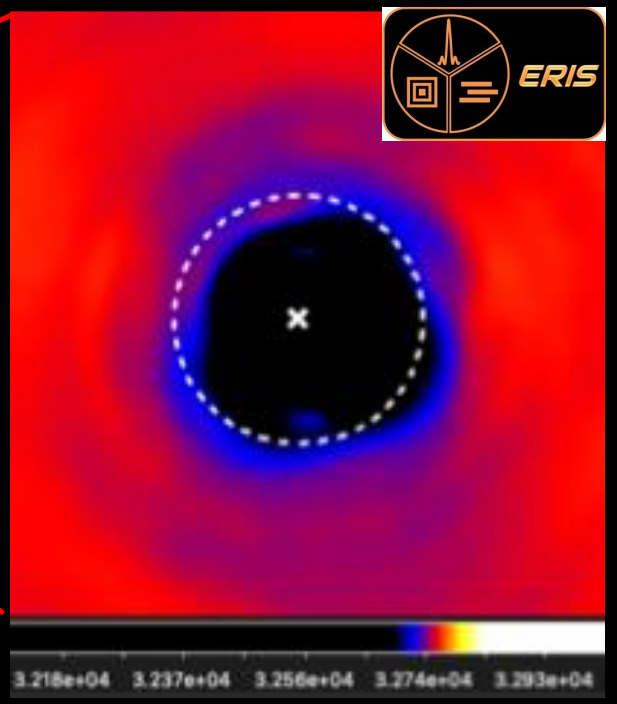
β Pic moving group SpT F6/F5

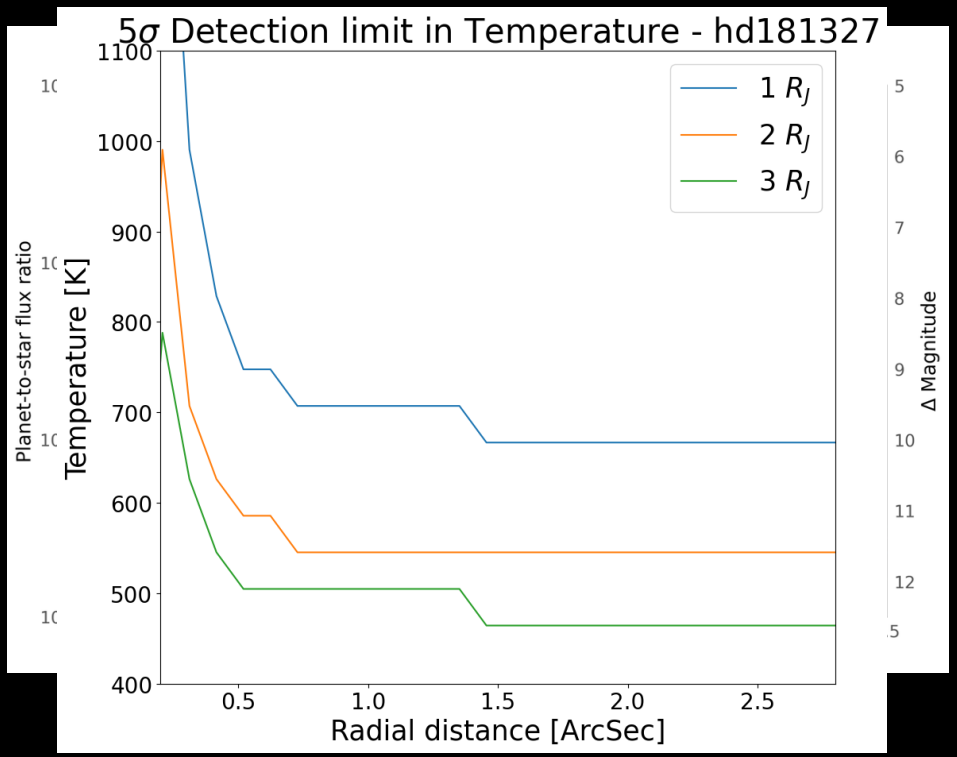
Debris disk with - crystalline water ice @3.1 mm

- Resolved disk asymmetries

-> Theoretical studies predicted a 2-5 M_J planet

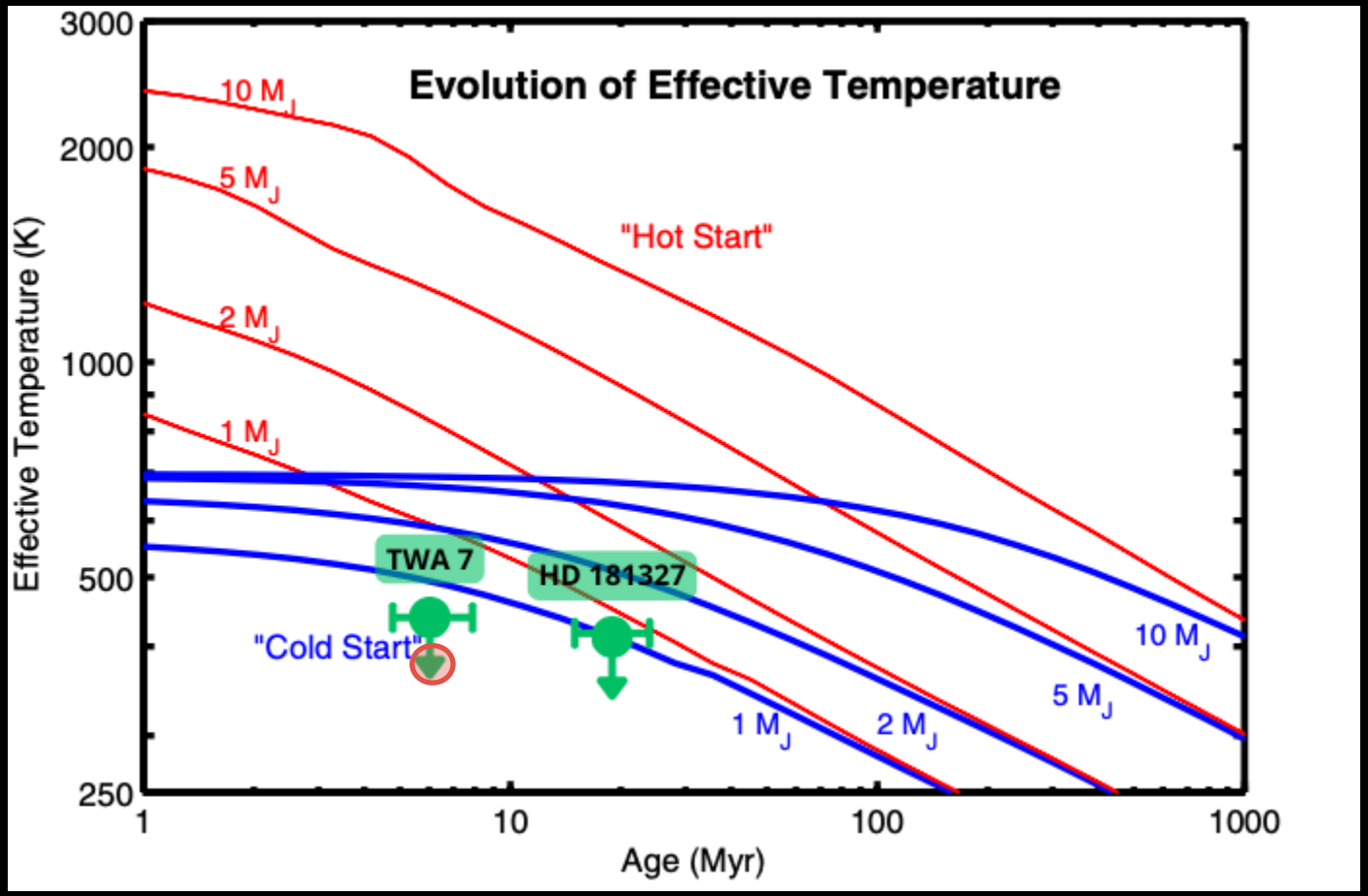






Milli et al. 2024

TWA 7 & HD 181327 IN CONTEXT



Take home messages

- Debris disk fraction vs age: very efficient mechanisms responsible for DDs which act in less than 5 Myrs!
- Flybys -> fundamental in the evolution or even the formation of debris disks!
- Sign of exchange of material during the flyby
- **Inner part of the disk : ~0.3'' -> ~10 AU (TWA 7) & ~15 AU (HD 181327)**
- **No massive planets detected with T > 600–800 K-> masses > 1 M_J**

-> ....

Perspective… ’What’s next…’

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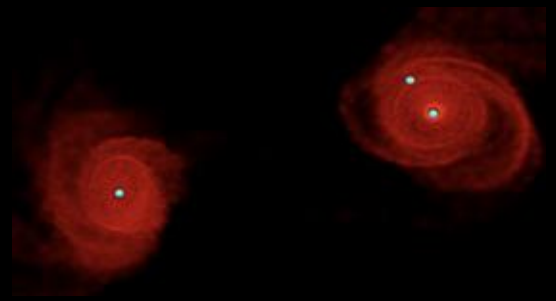
Short timescale….

- Simulation of flybys+/-planet-induced structures in debris disks



Kim, Roccatagliata+2026, in prep.

12.2026  DR4:

- planets + flybys

Long timescale….

- Be prepared for ELT
- VLT in the ELT era
  - 3m class telescopes

Thank you Thomas!