Characterization of planetesimal belts through the study of debris disks

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Debris disks host planetary systems

Protoplanetary disks dissipate in about 6 Myr, but there is evidence of dust around 7-15% of mature stars (10-10,000 Myr) of a wide range of stellar masses (0.5-3 M_{sun}).

Dust lifetime < 0.01-1 Ma

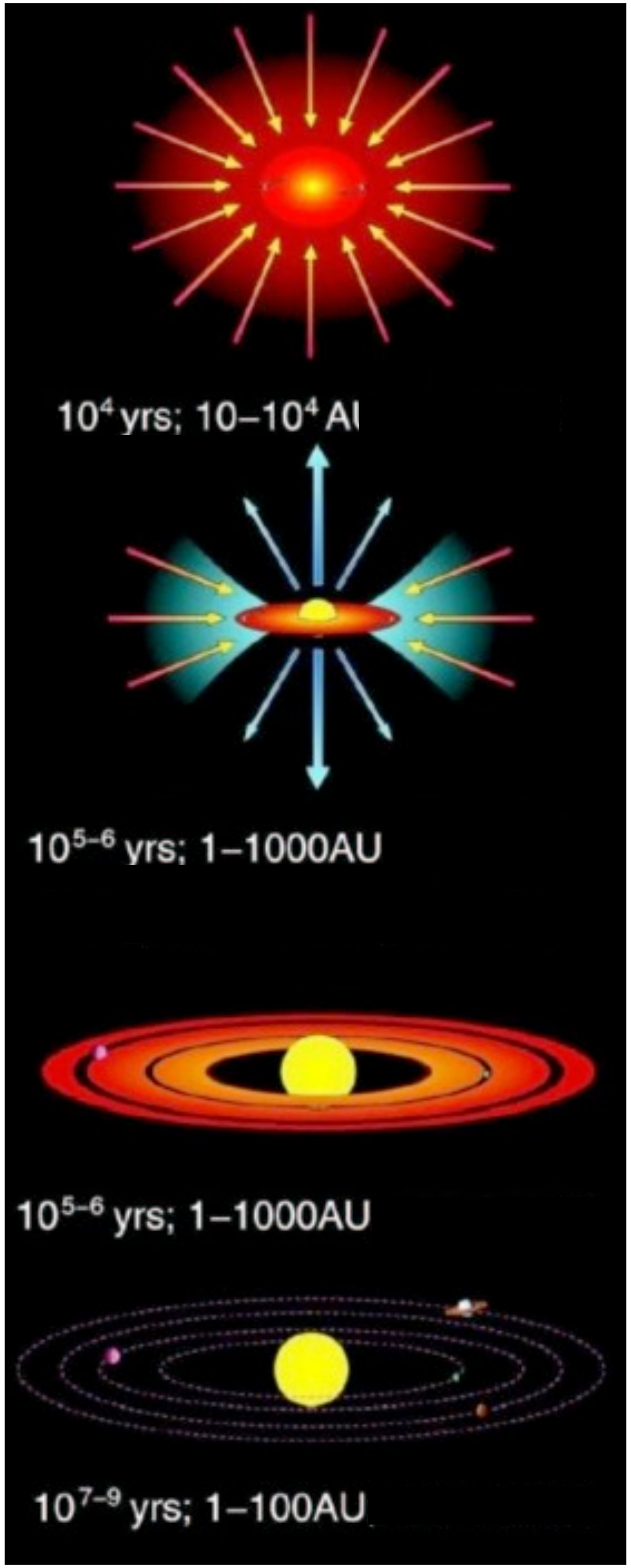
Poynting-Robertson: $t_{PR} = 710 \left(\frac{s}{\mu m}\right)\left(\frac{\rho}{g/cm^3}\right)\left(\frac{R}{AU}\right)^2\left(\frac{L_\odot}{L_*}\right)\frac{1}{1+albedo}$ years

Grain-grain collisions: $t_{col} = 1.26 \cdot 10^4 \left(\frac{R}{AU}\right)^{3/2}\left(\frac{M_\odot}{M_*}\right)^{1/2}\left(\frac{10^{-5}}{L_{dust}/L_*}\right)$ years

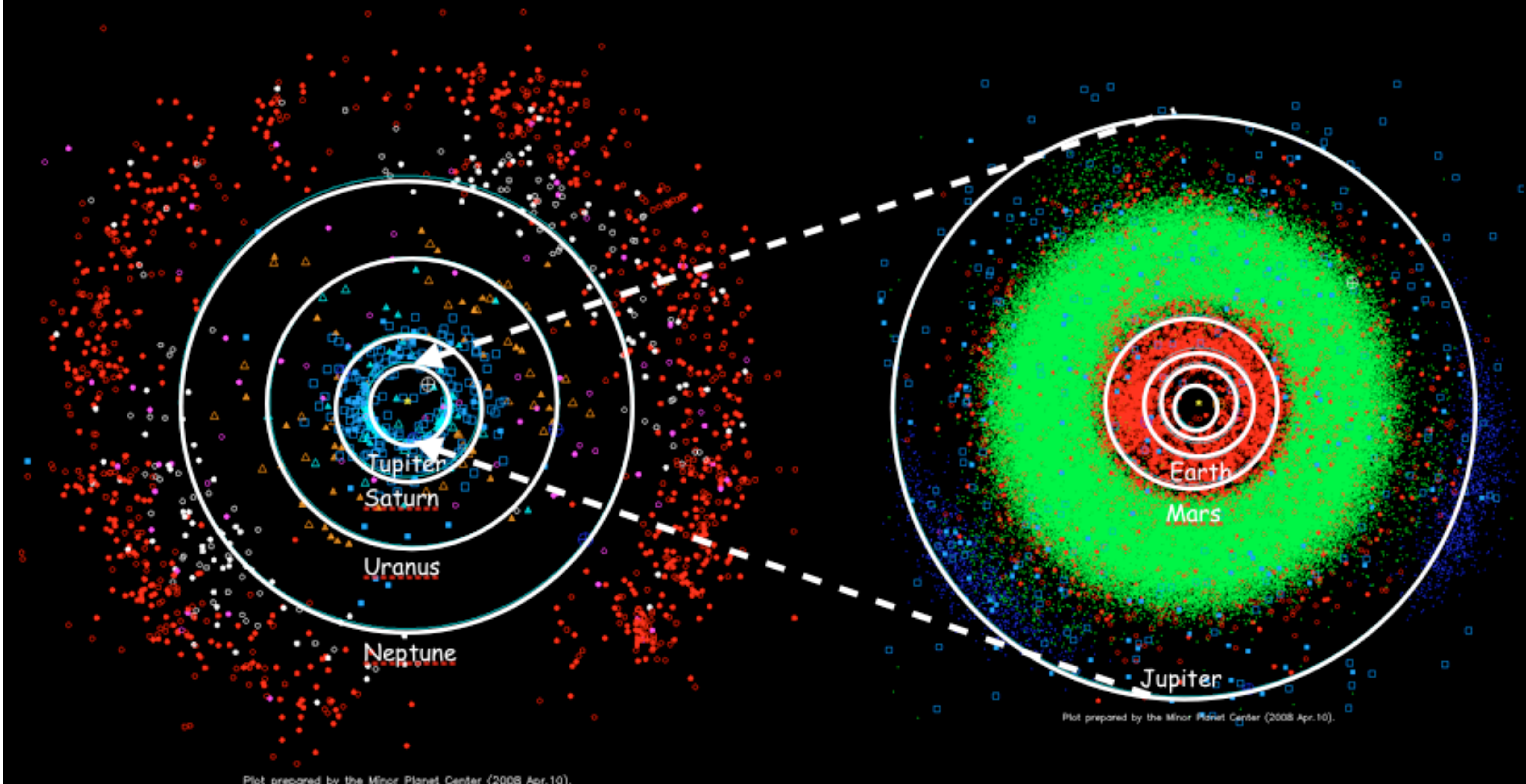
Radiation Pressure: $t_{blow} = \frac{1}{2}\left(\frac{(R/AU)^3}{M_*/M_\odot}\right)^{1/2}$ years

<< **stellar age > 10 Ma**

Debris dust cannot be primordial; it must be generated by planetesimals (like asteroids, comets and KBOs)



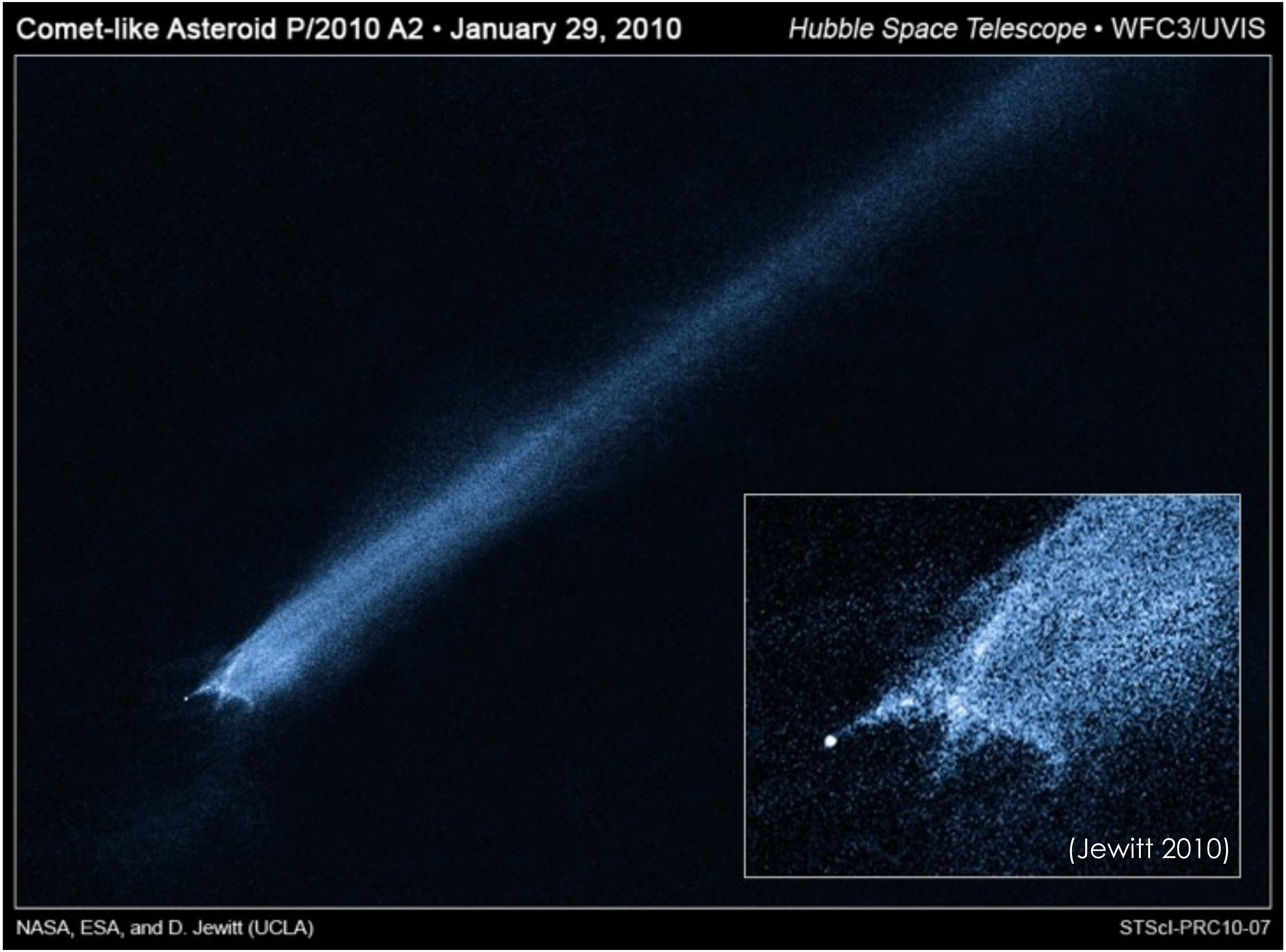
Sources of Solar System Dust



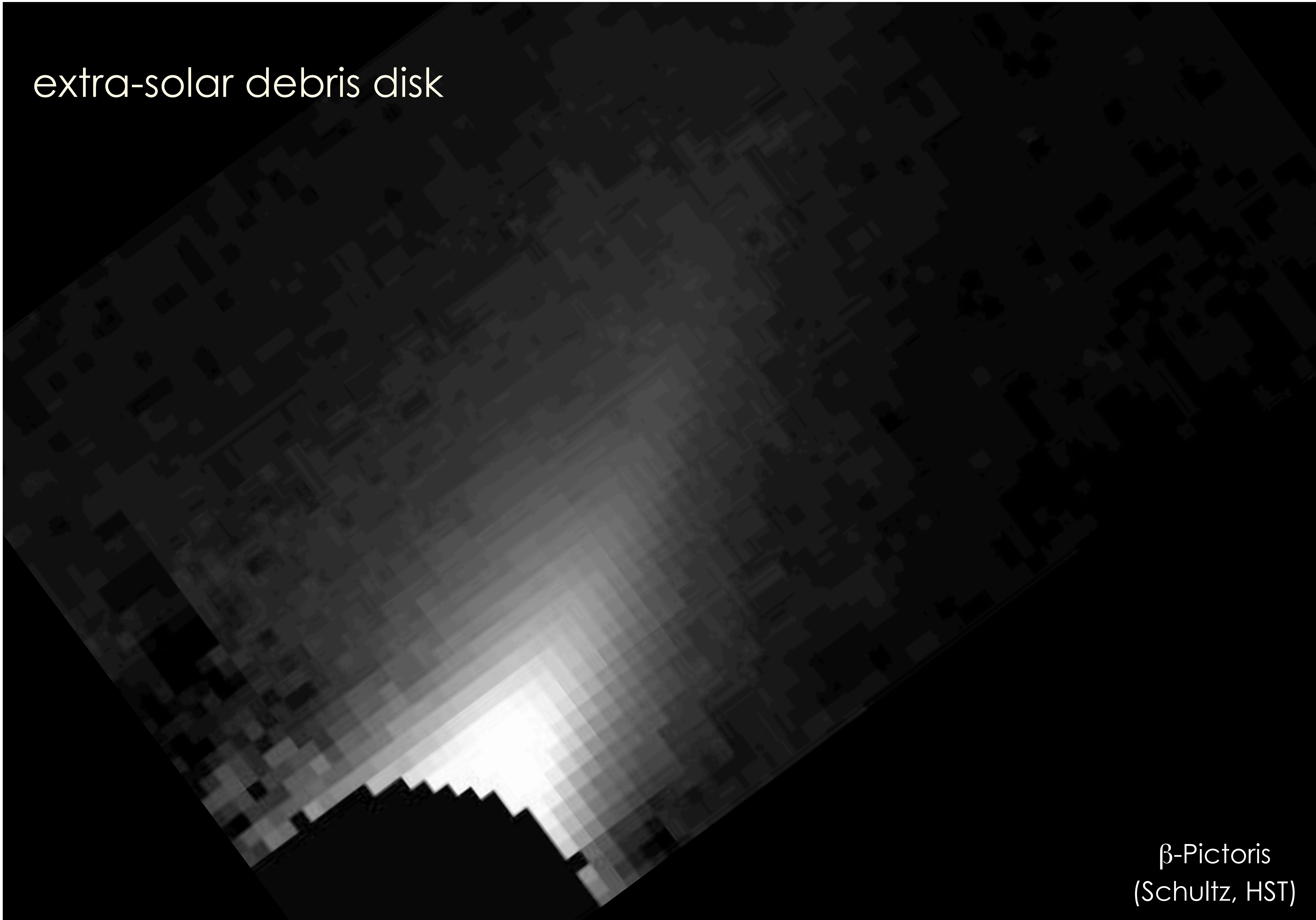
Kuiper Belt

Asteroid Belt

Minor Planet Center


Comet-like Asteroid P/2010 A2 • January 29, 2010
Hubble Space Telescope • WFC3/UVIS
(Jewitt 2010)
NASA, ESA, and D. Jewitt (UCLA)
STScI-PRC10-07

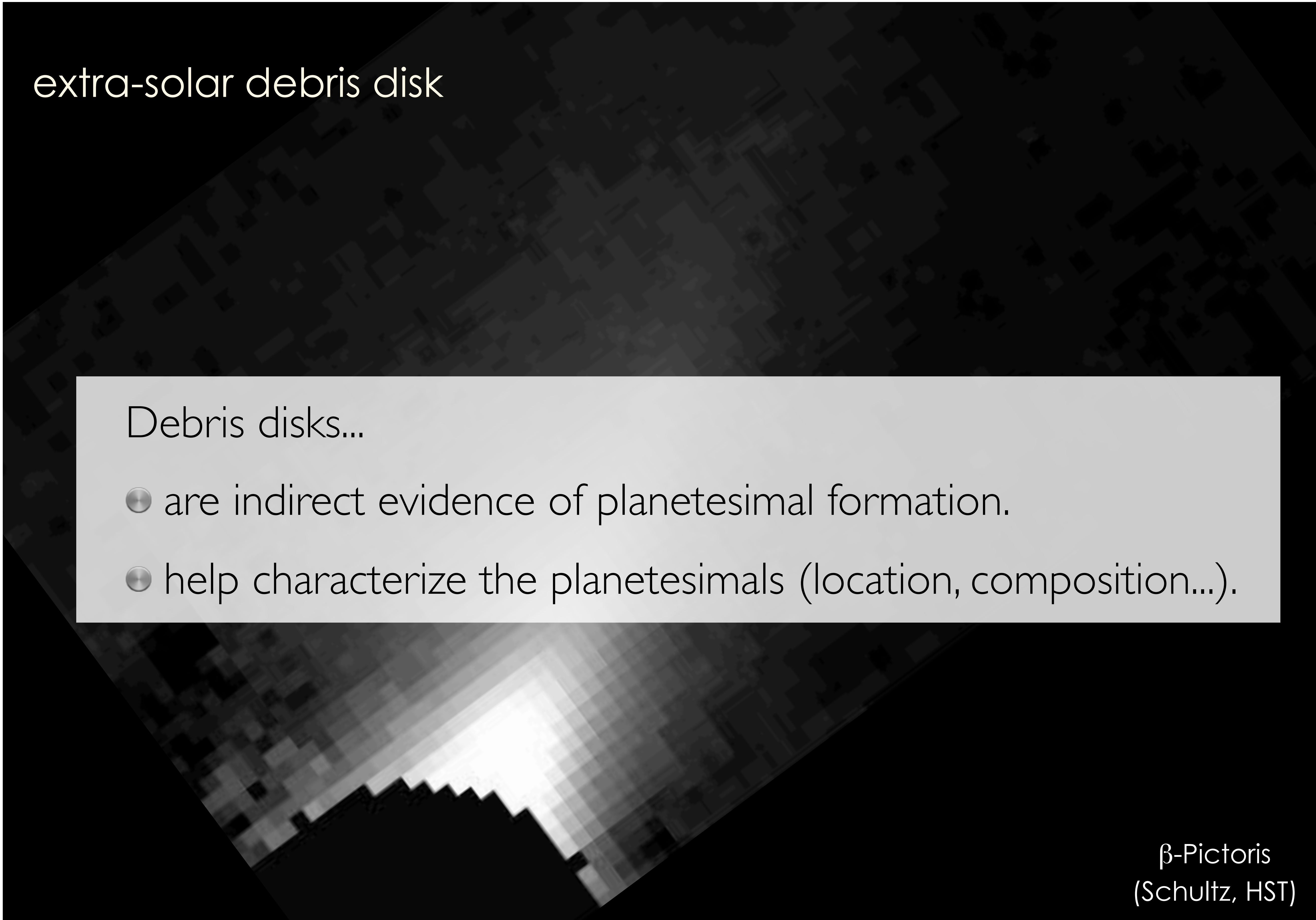

Solar System debris disk


extra-solar debris disk
β-Pictoris
(Schultz, HST)

extra-solar debris disk

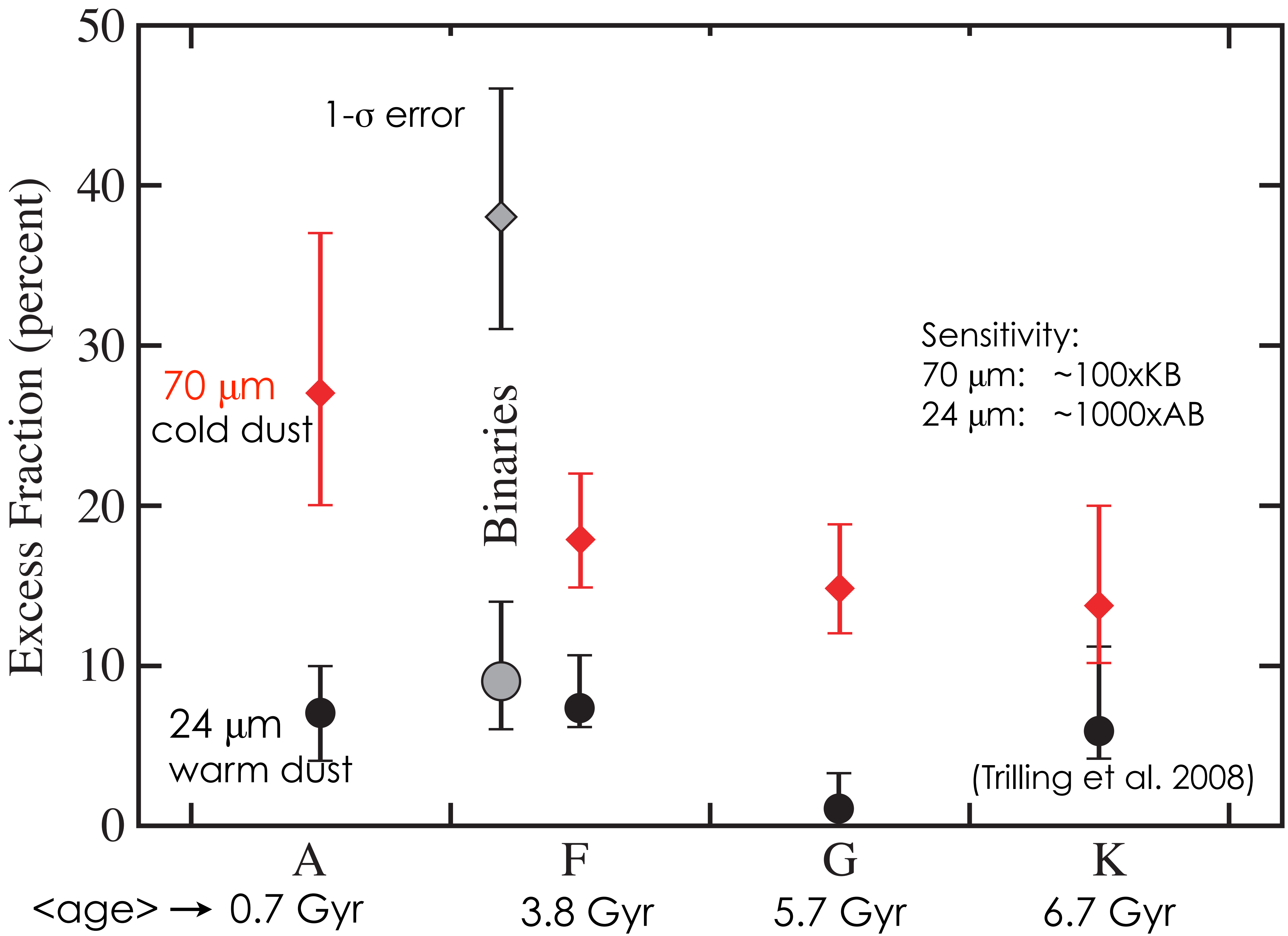
Debris disks...

- are indirect evidence of planetesimal formation.
- help characterize the planetesimals (location, composition...).



β-Pictoris
(Schultz, HST)

debris disks are found around stars with a wide range of stellar properties (M_*, L_*, $[M/H]_*$)



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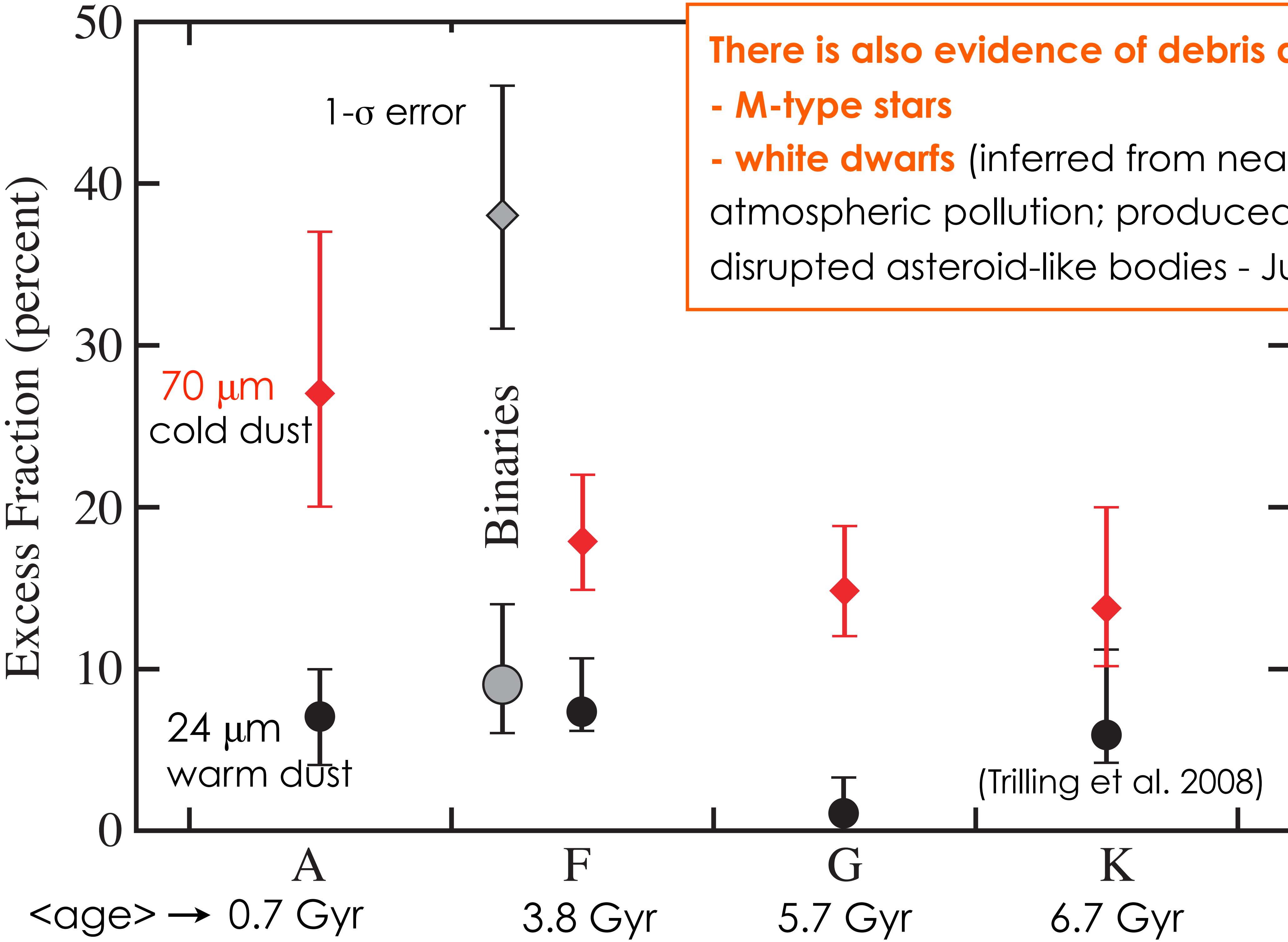

There is also evidence of debris disks around...

- **M-type stars**
- **white dwarfs** (inferred from near IR excess + atmospheric pollution; produced by tidally disrupted asteroid-like bodies - Jura, 2006, 2007).

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→ **Planetesimal formation takes places under a wide range of conditions.**

↑

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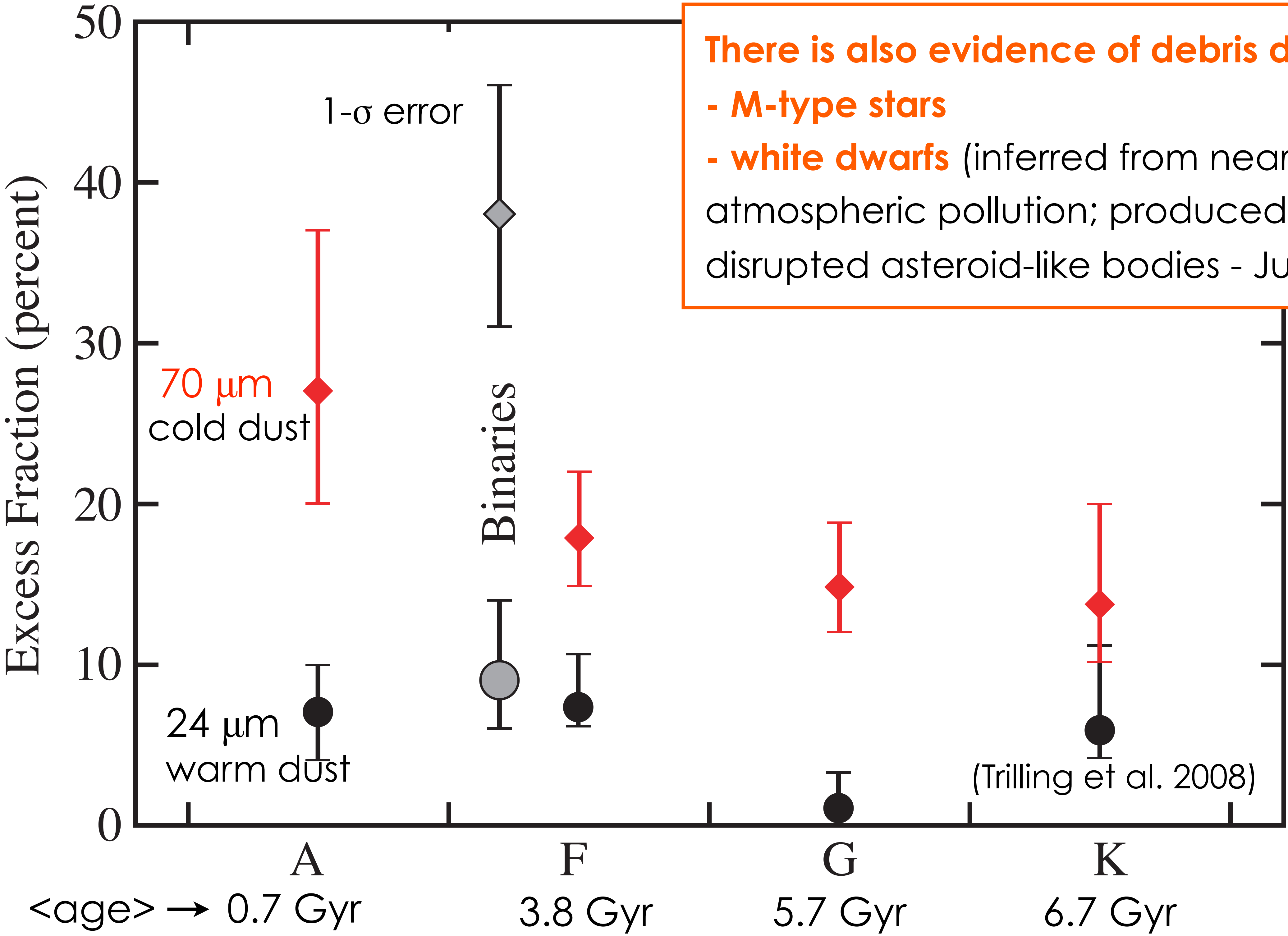
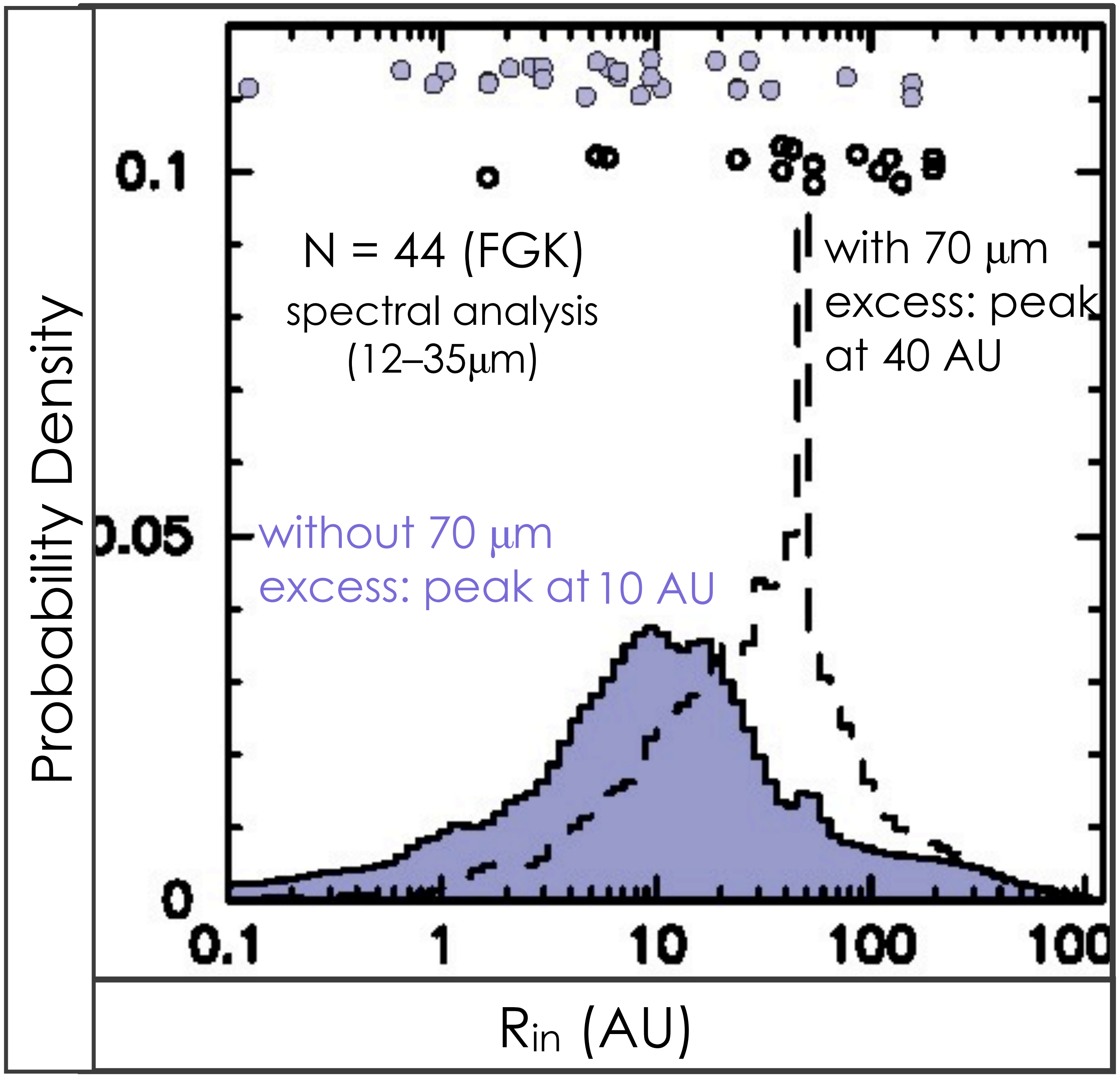


**Cold dust is more common:
the SEDs indicate the presence of large inner gaps (KB-like)**

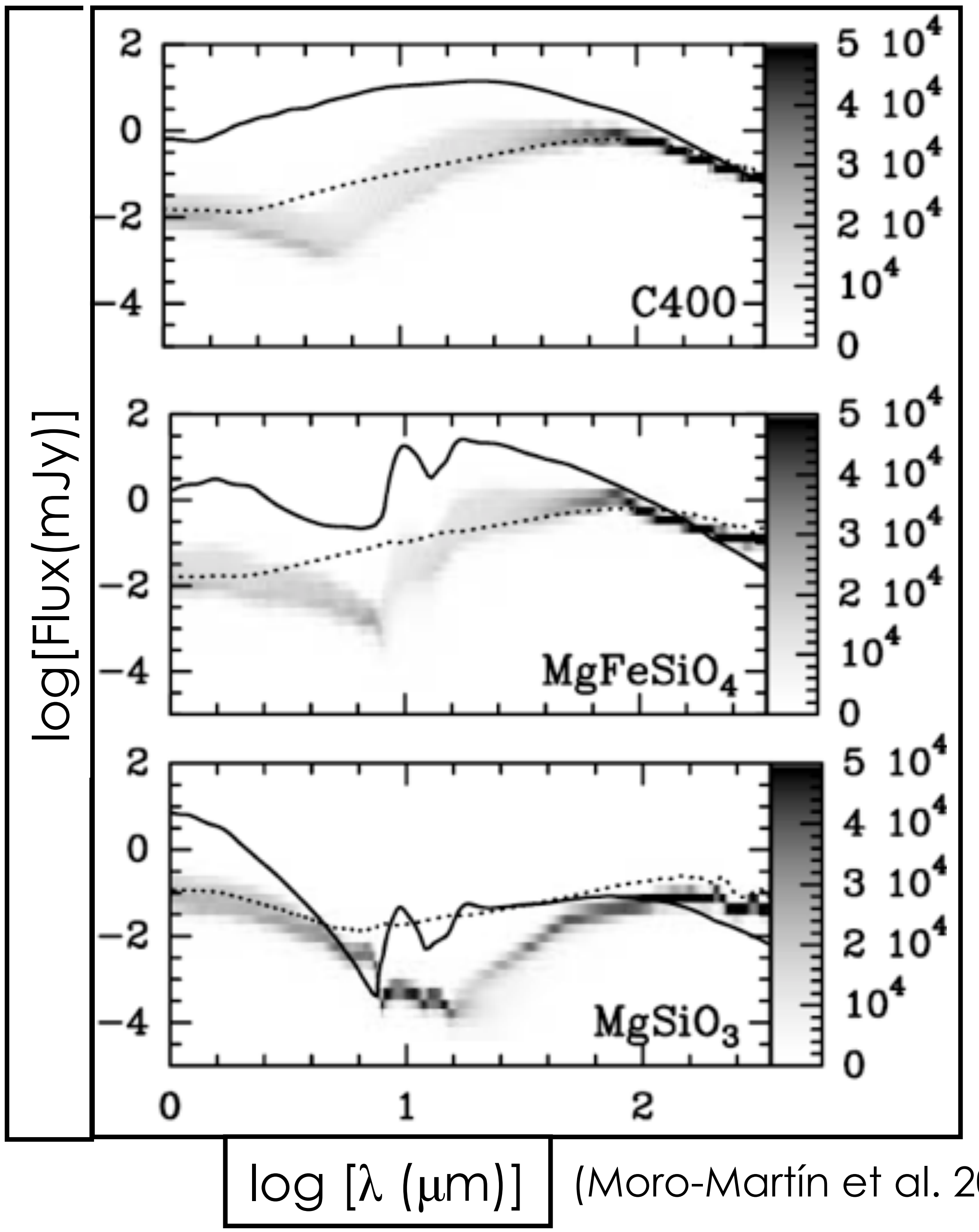


(Carpenter et al. 2009)

Massive planets may be responsible for the formation of the inner gaps in disks

lines: disk w/o planets (no gap) —— 135 μm ······ 0.7 μm

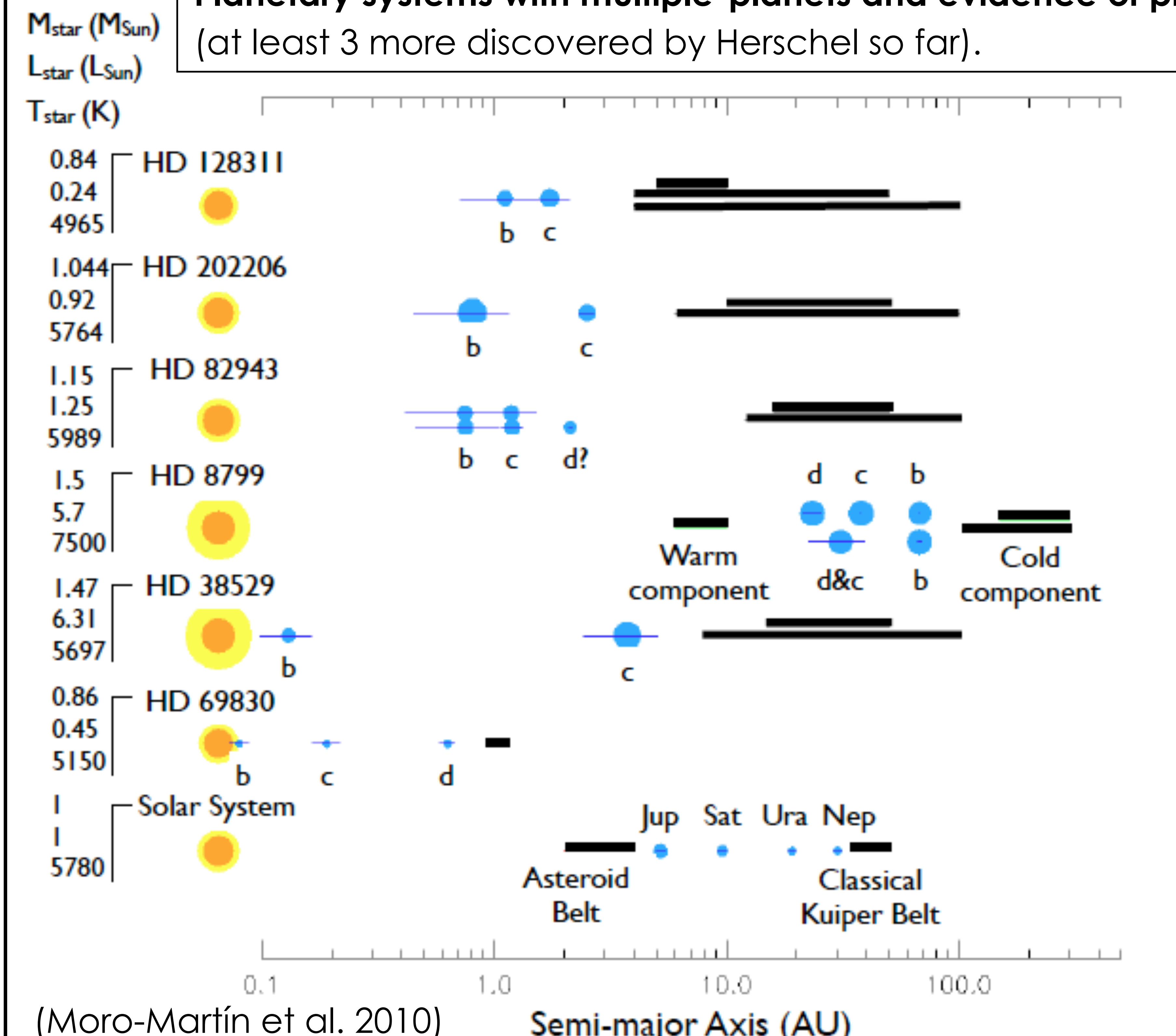
grey scale: disk with planets at 1-30 AU (with gap)and dust grain with a power-law distribution.



(Moro-Martín et al. 2005b)

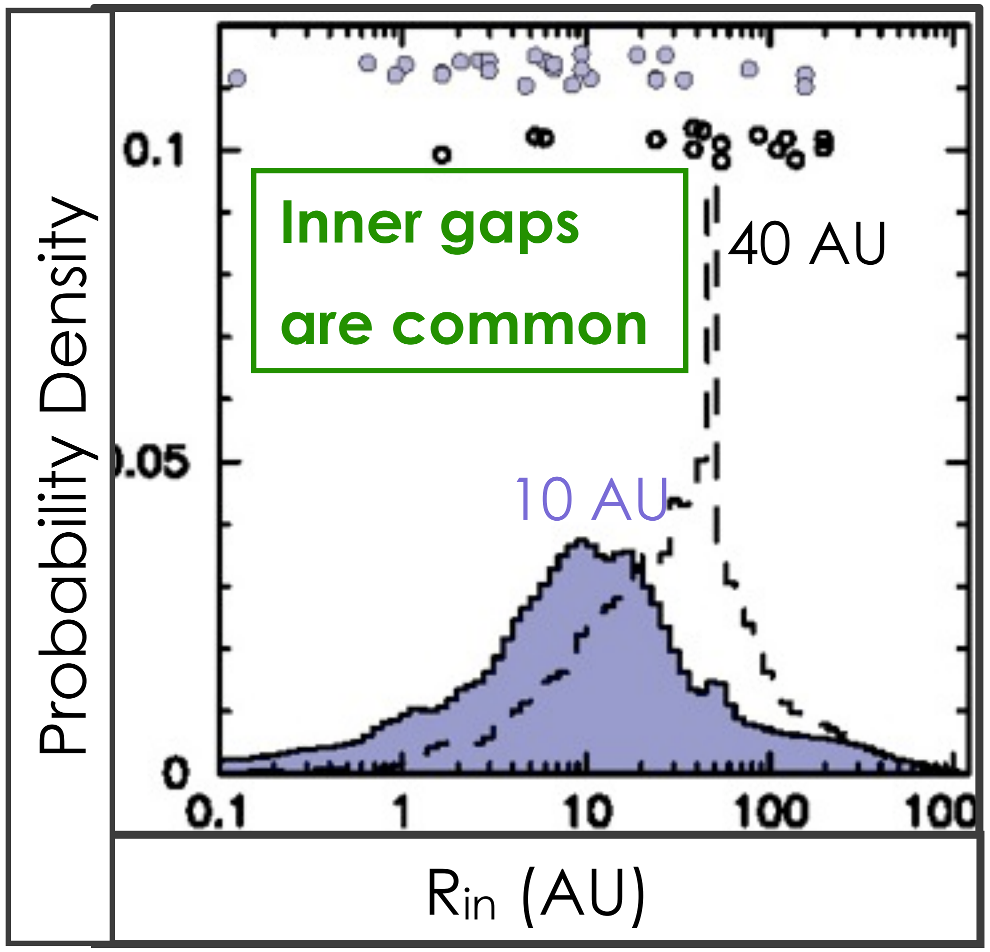
Need of spatially resolved observations....

Planetary systems with multiple-planets and evidence of plantesimals
(at least 3 more discovered by Herschel so far).



(Moro-Martín et al. 2010)

Need R_{out}



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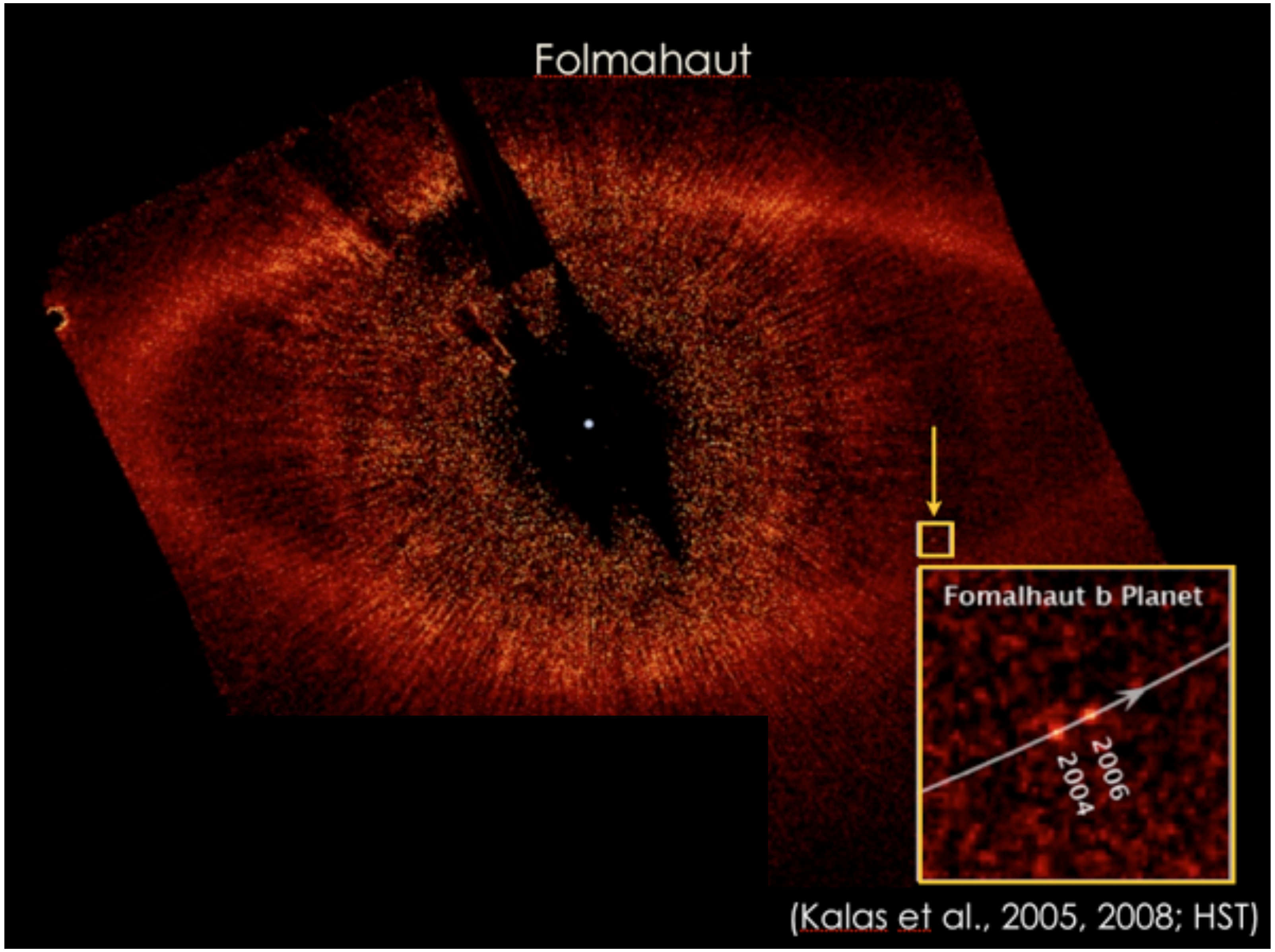
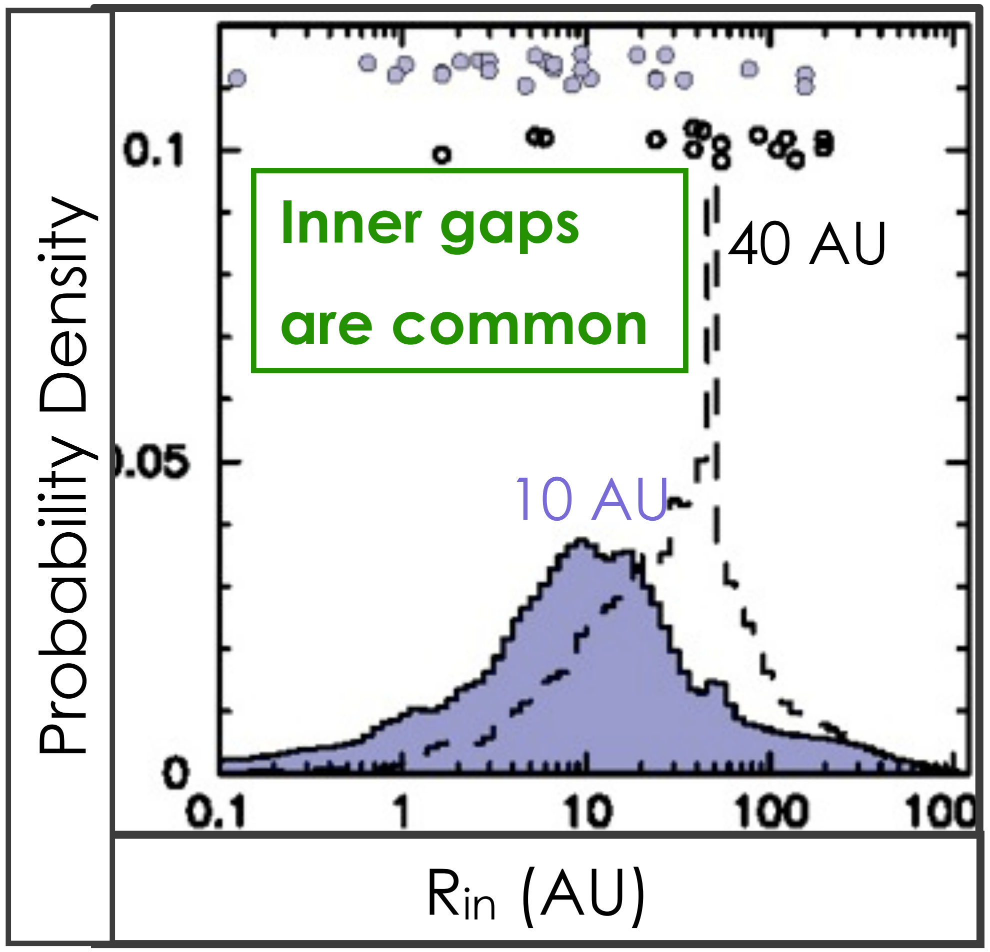
...and massive planets may be responsible for the formation of some of these inner gaps.





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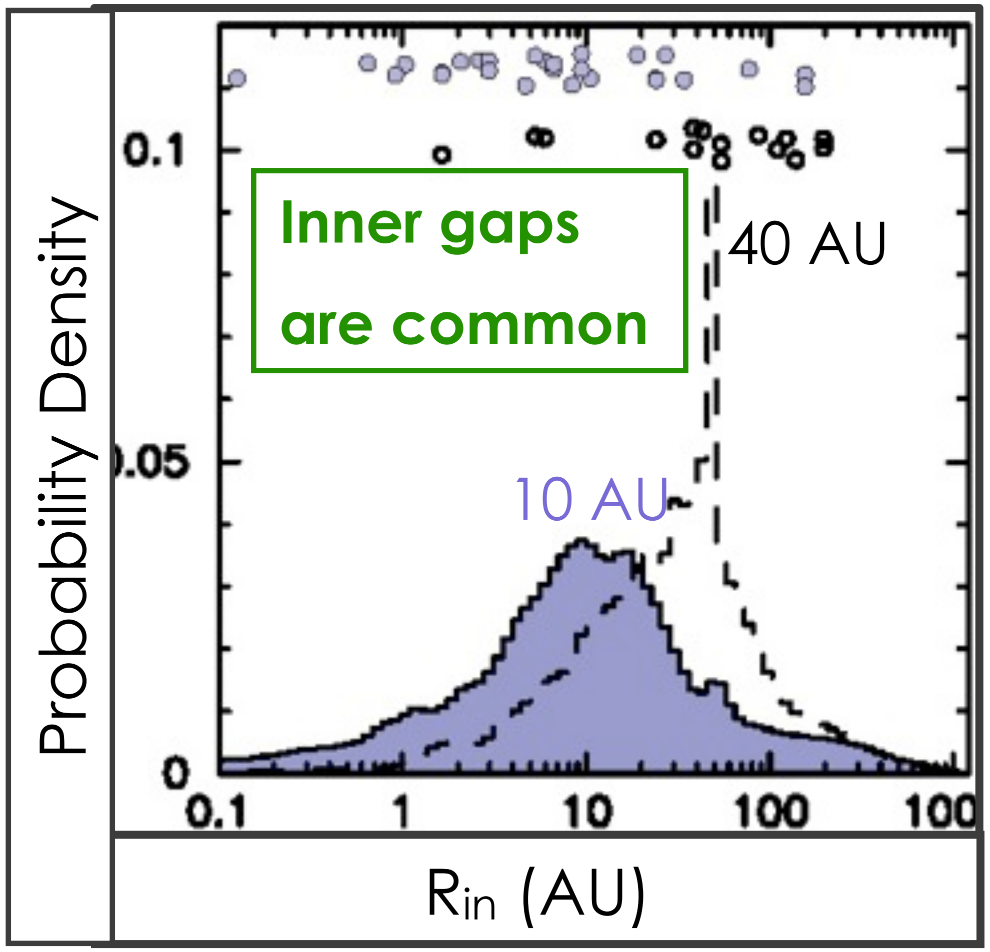
Search for giant planets in debris disks with large inner gaps (inferred from spatially resolved images or from SEDs).

Subaru program "SEEDS" (Strategic Exploration of Exoplanets and Disks with HiCIAO/AO188 **(P.I. M. Tamura)**

- high resolution imaging
- large dynamic range
- small inner working angle (0.08'')



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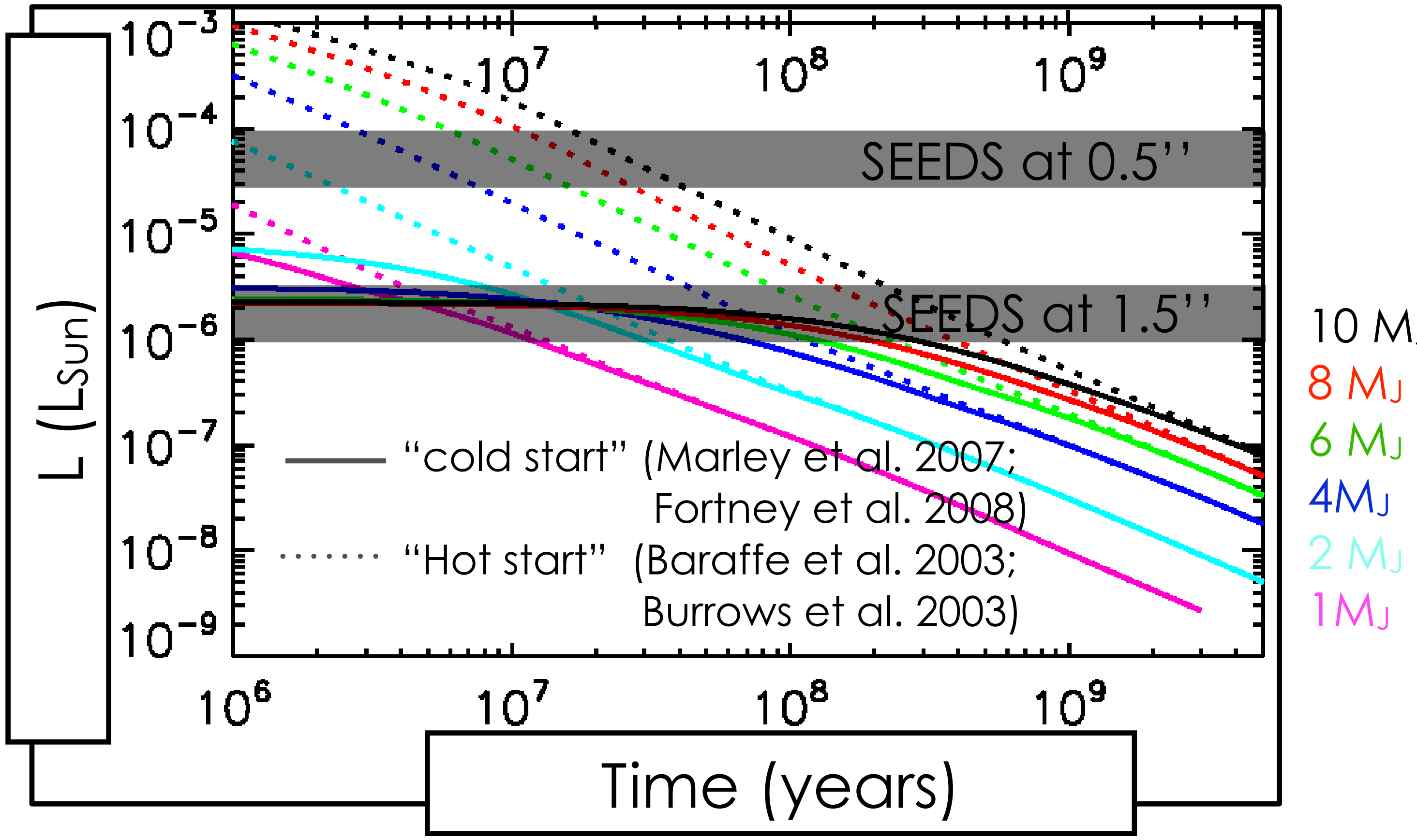

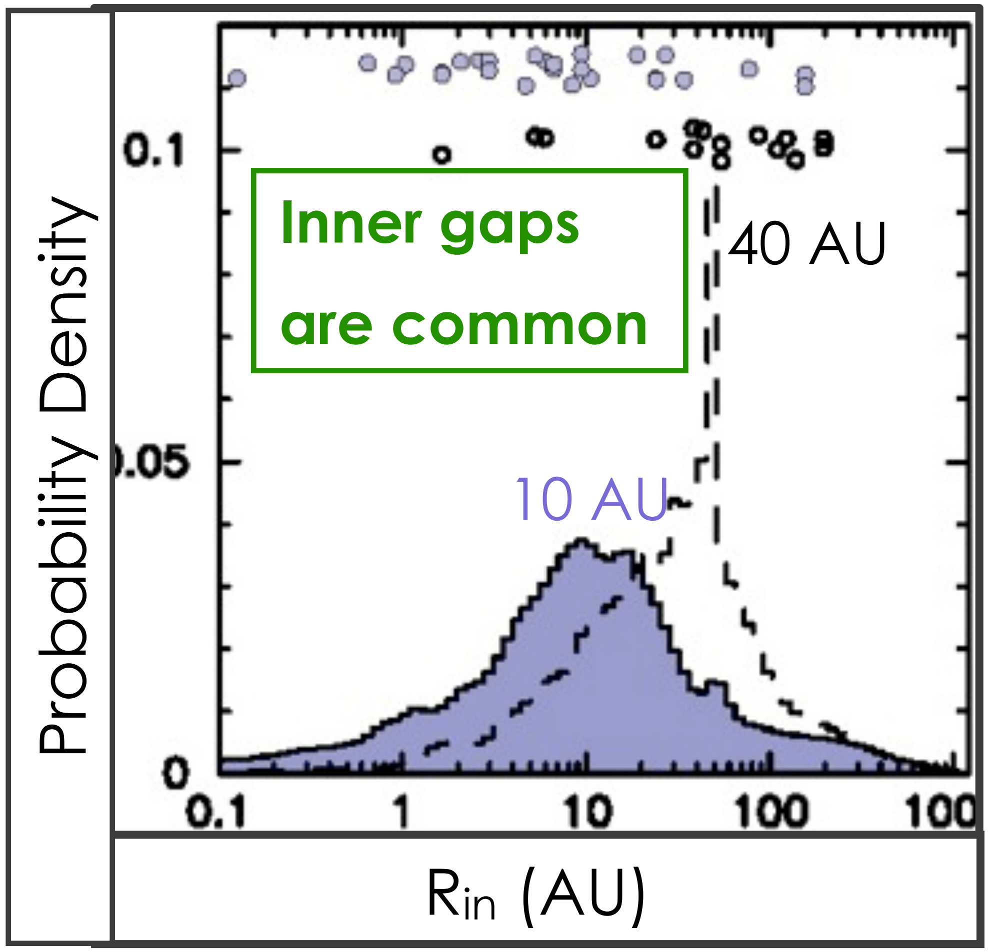

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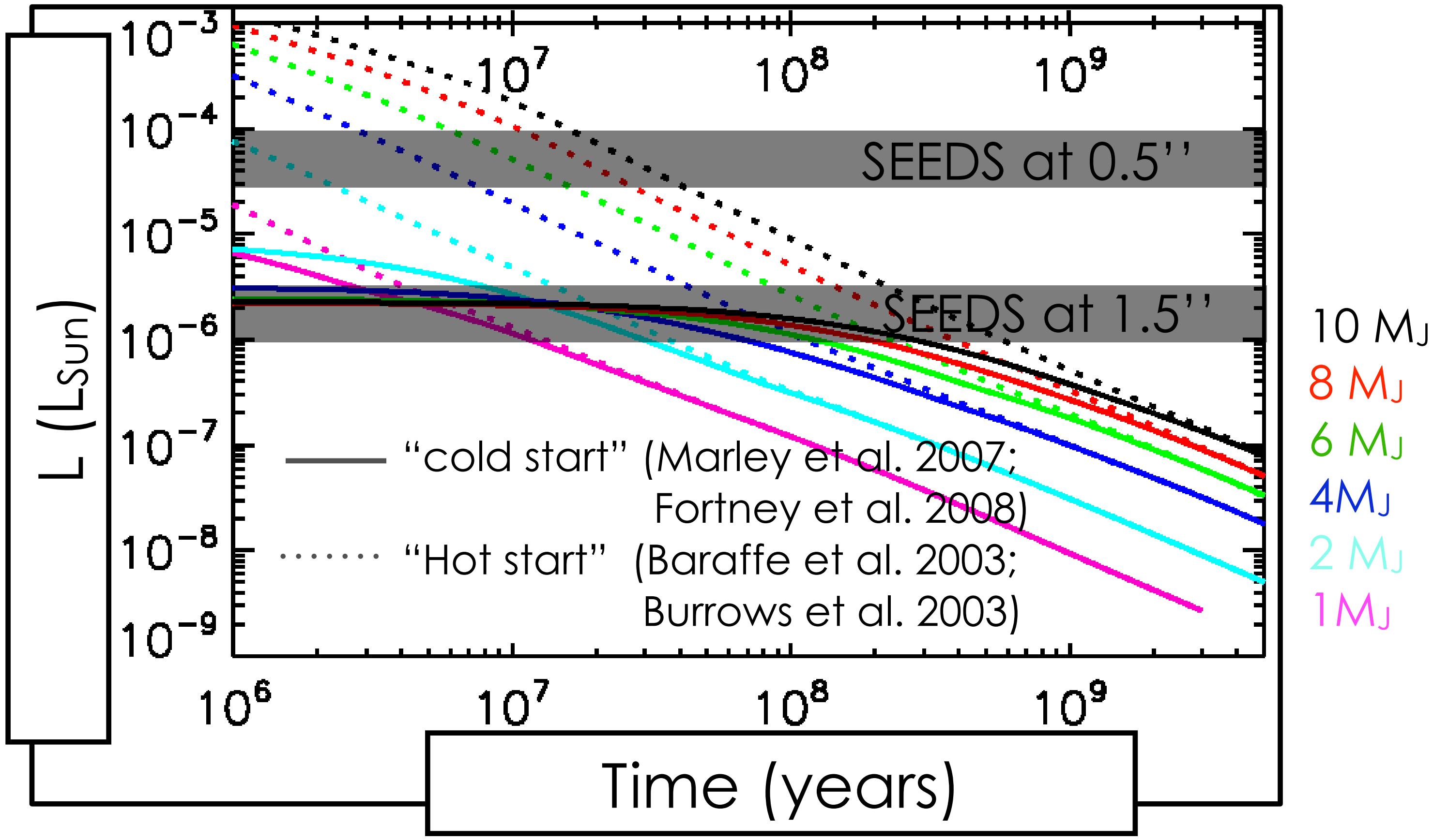


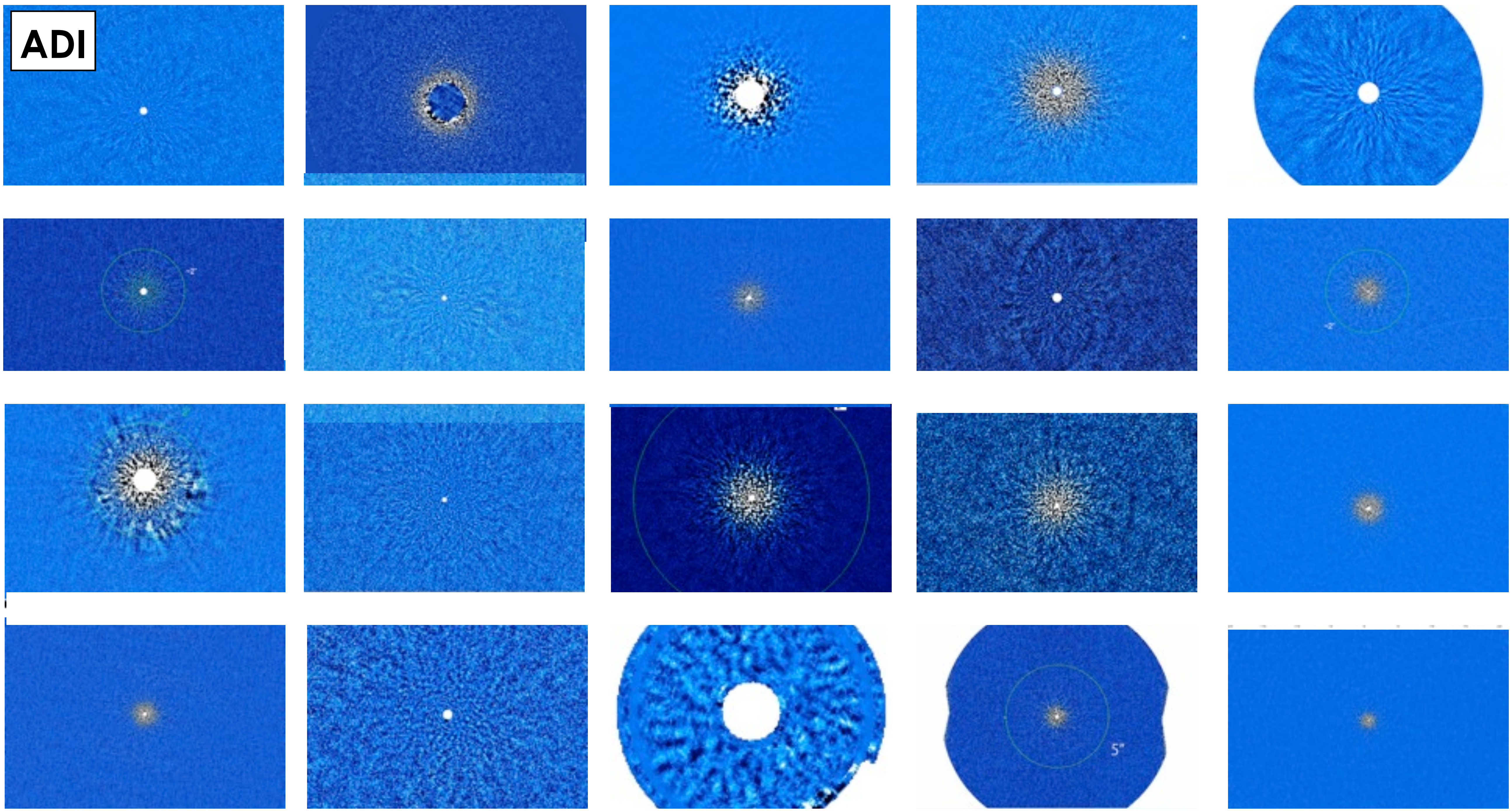
SEEDS-DD targets:

- approx. 80 debris disks studied by Spitzer.
- mostly systems with inferred large inner gaps.
- few systems with warm dust (uncommon).

On-going survey.

27 targets observed up to date.

No new planetary companions found (...so far)



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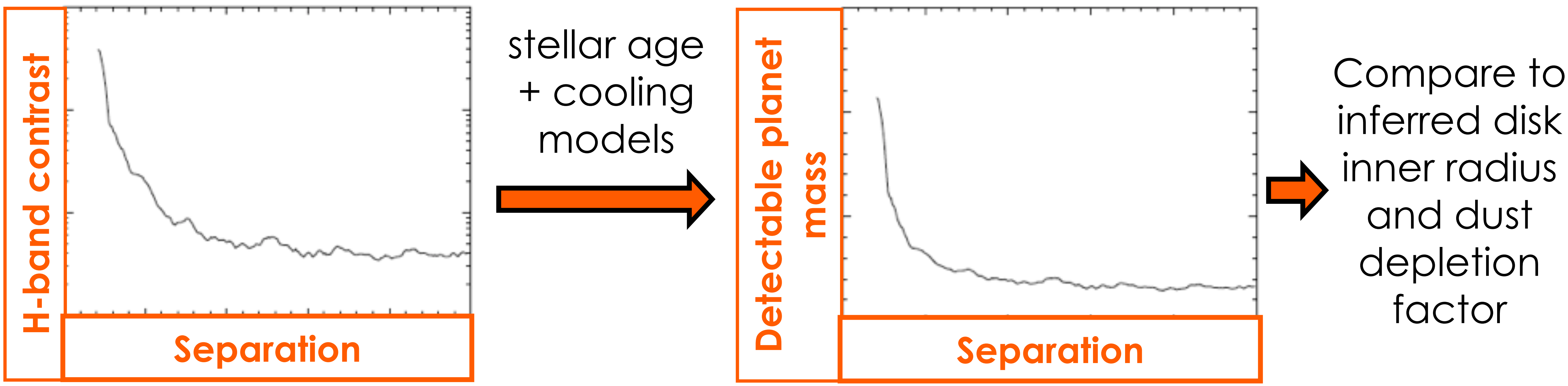
AO188 → SCExAO

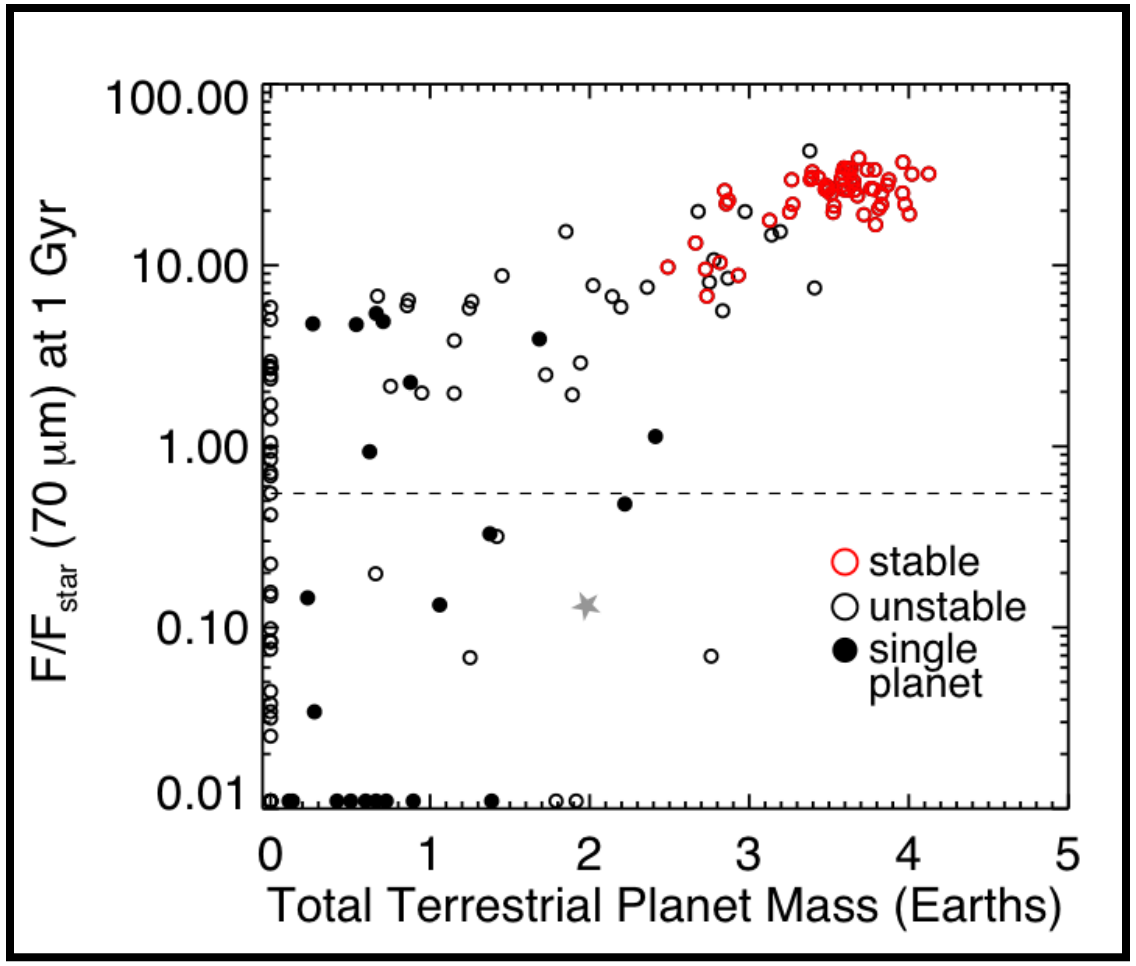


Search for warm dust at small inner working angles:

Non-detections are important because cold disks without warm dust are good candidates for the search of terrestrial planets because...

- Low zodi (contaminant) light.

- The presence of cold dust seems to be correlated with the presence of terrestrial planets (because the former implies the system has undergone mild dynamical evolution with moderate gravitational instabilities).



(Raymond et al. 2011)

Herschel-DEBRIS Key Program

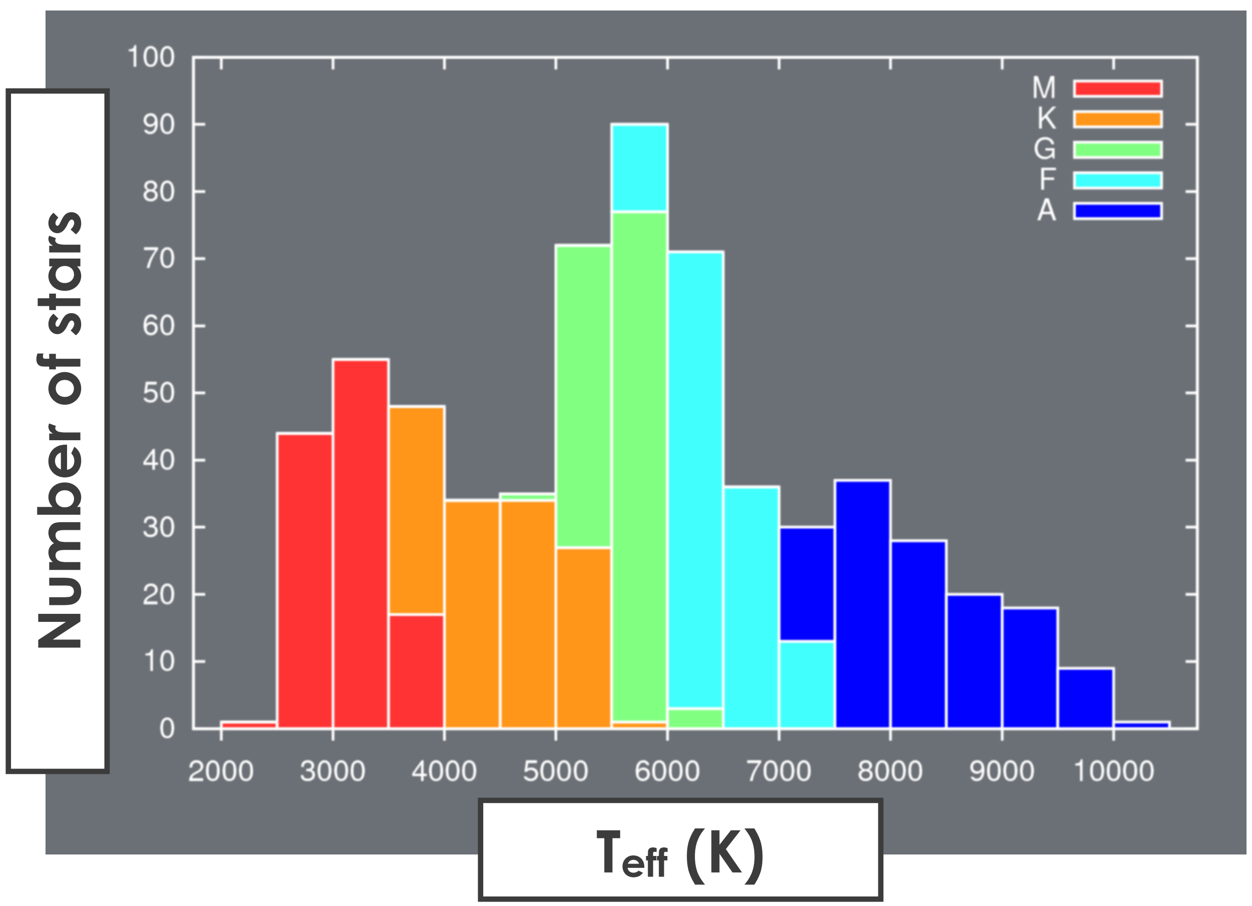
(P.I. Brenda Mathews)

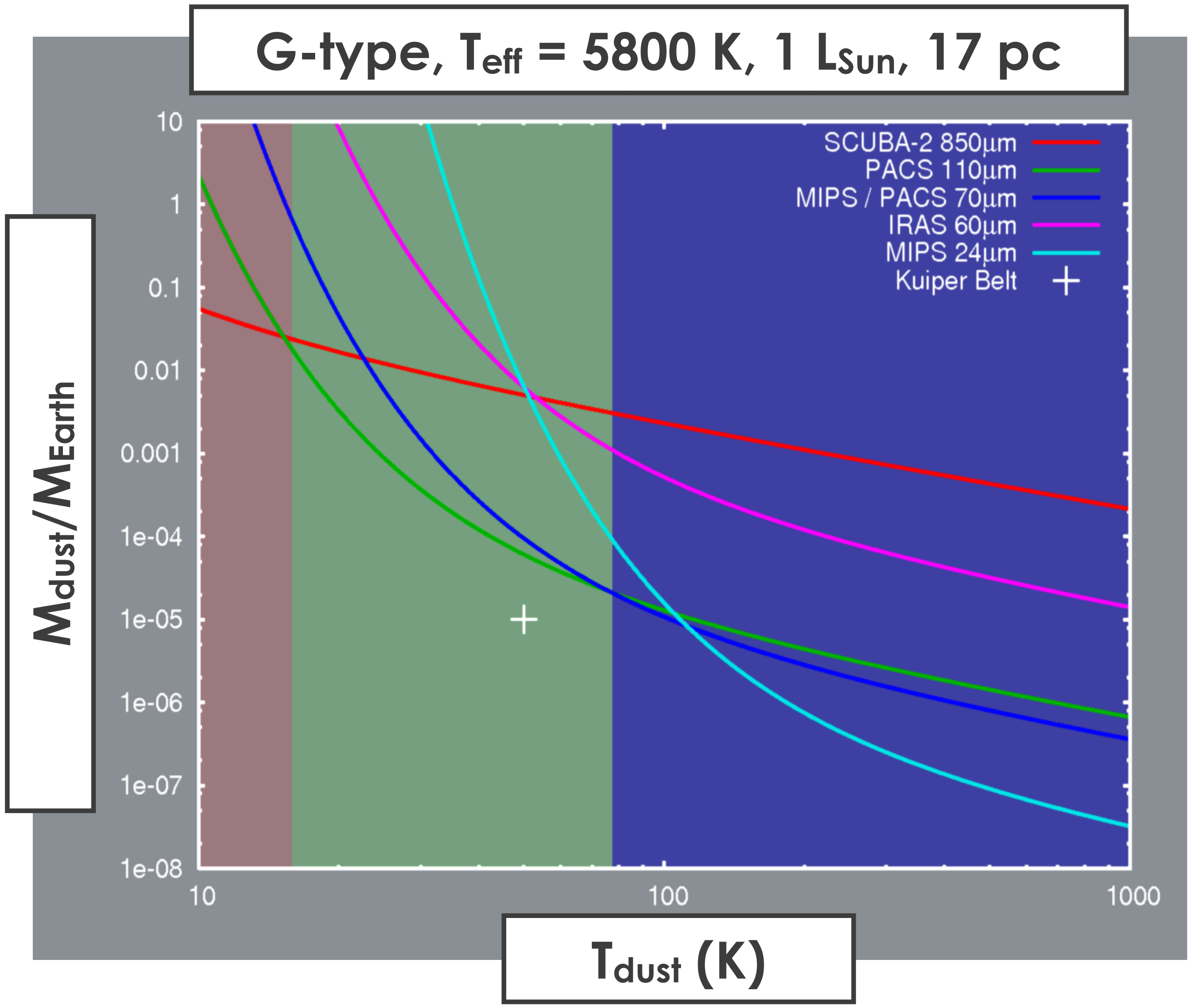
Survey at 100 and 160 μm to search and characterize debris disks around 446 nearby stars.

- Targets from the Unbiased Nearby Stars sample in Phillips et al. (2010)
- ~90 stars of each type: A, F, G, K, M
- Sp.Type samples volume-limited w. confusion cut.

	A	F	G	K	M
Volume limits (pc):	46,	24,	21,	16,	8.6

- Follow-up of 110 stars @250,350,500 μm
- Flux-limited, uniform depth, driven by 100 μm sensitivity (1σ rms = 1.5 mJy).

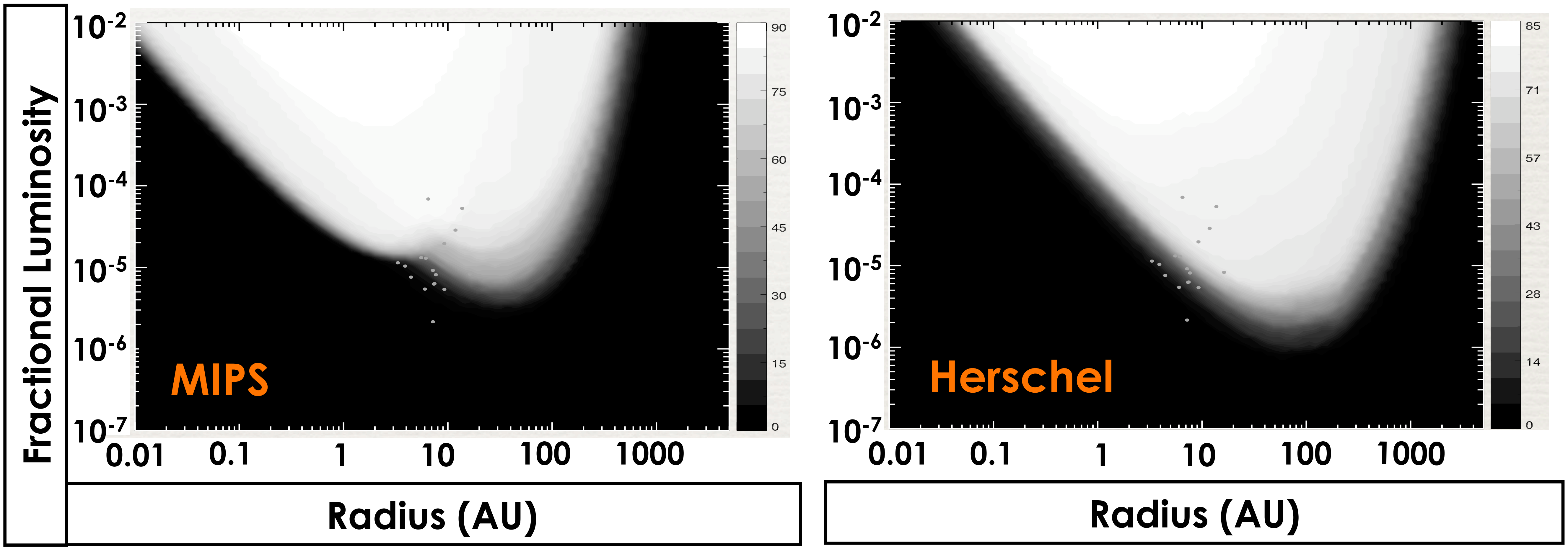




Herschel-DEBRIS Key Program

Preliminary Results

Disk parameter space
G-type



(Kennedy in prep.)

Herschel-DEBRIS Key Program

Preliminary Results

- Herschel is identifying new debris disks. **Increasing the debris disk frequencies around cold late-type stars.** Most of the other debris disks had been detected previously by Spitzer.

Sp. Type	A	F	G	K	M
Frec.	26%	24%	19%	9.5%	1.3%

(Kennedy in prep.)

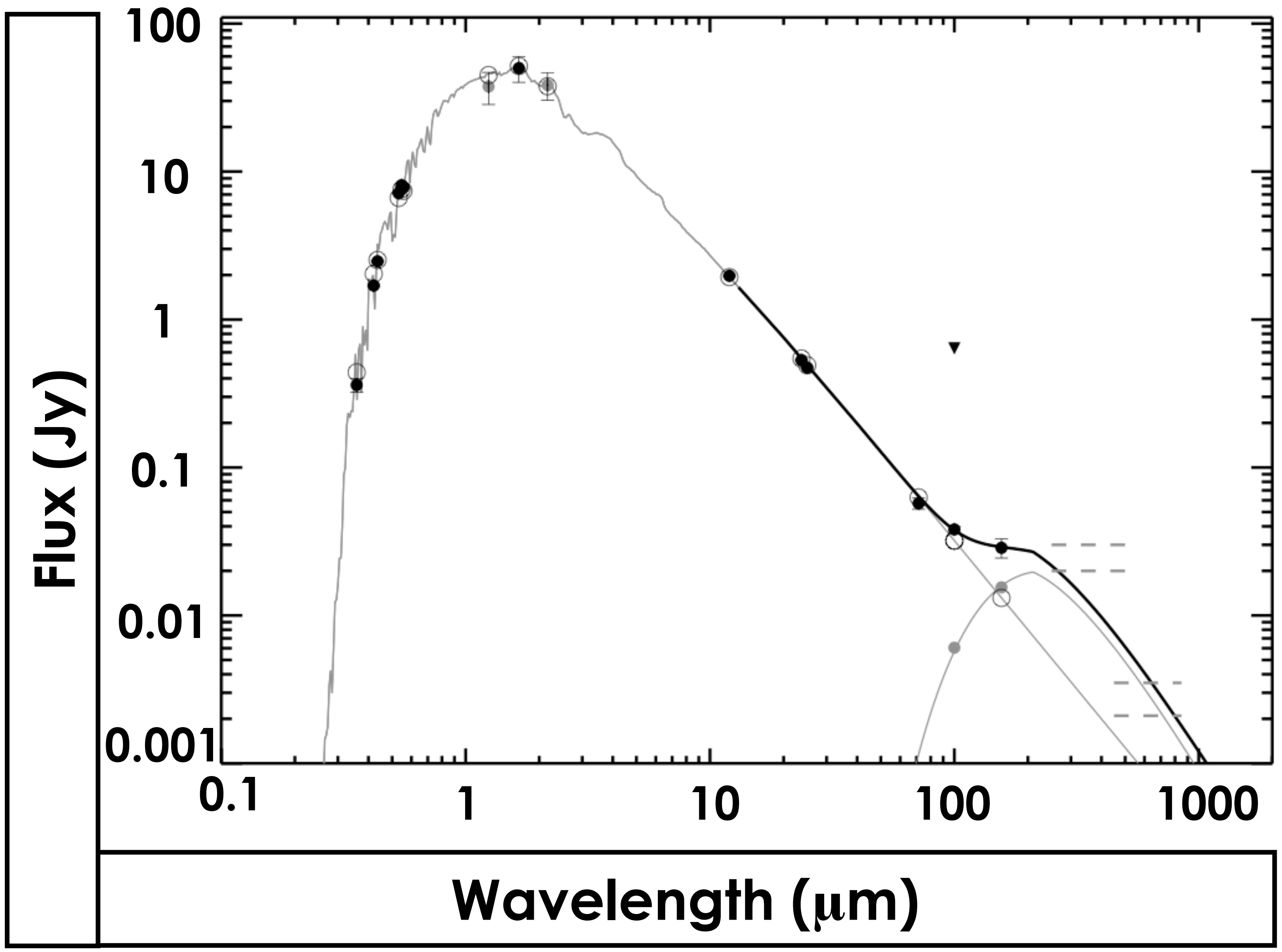
A, F: decreased wrt Spitzer (identification of background sources)

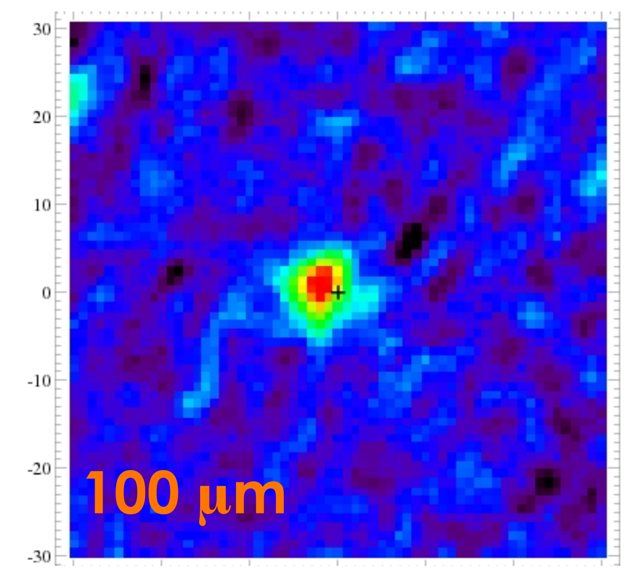
M: increased wrt Spitzer

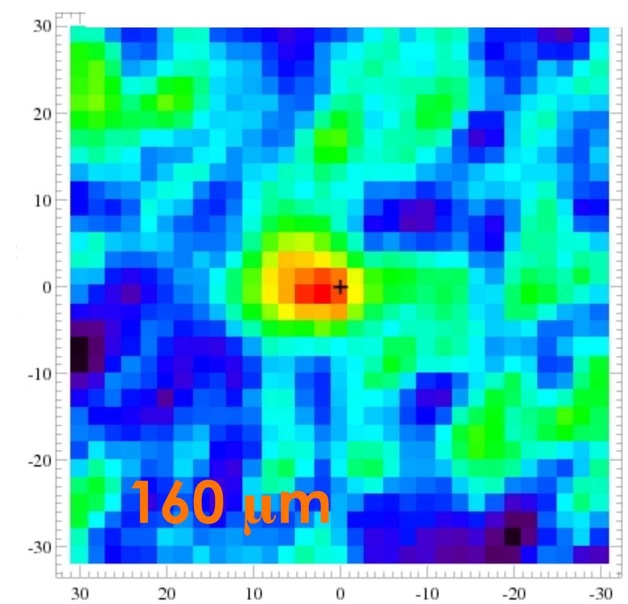
Herschel-DEBRIS Key Program

Preliminary Results

- **New type of debris disks found: very cold disks**, with excesses > 160 um, T_{dust} < 30 K, very faint, more common around late-type stars (difficult to account for the lack of warm dust).



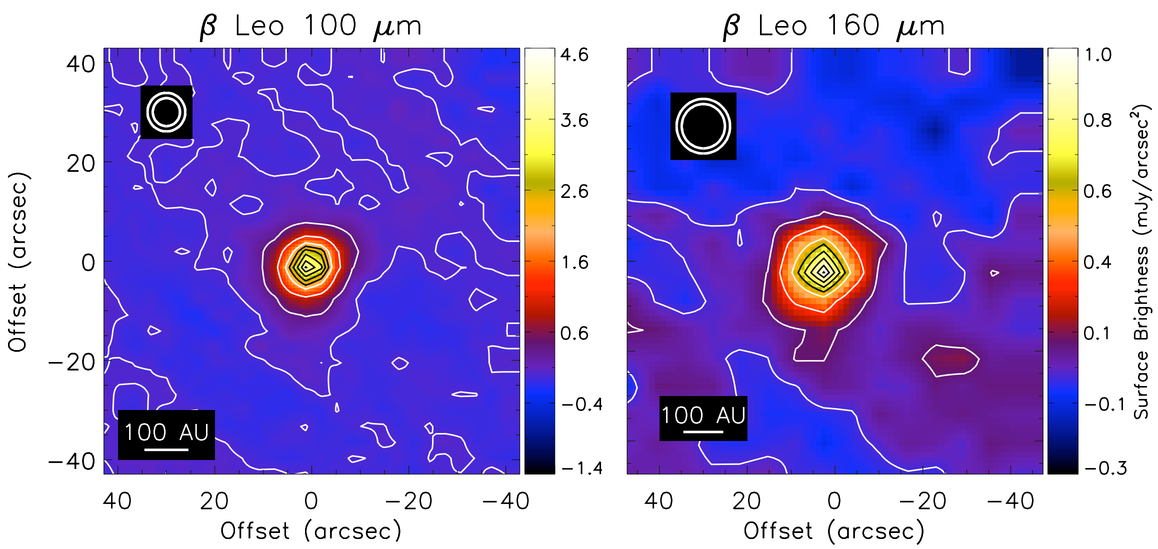




Herschel-DEBRIS Key Program

Preliminary Results

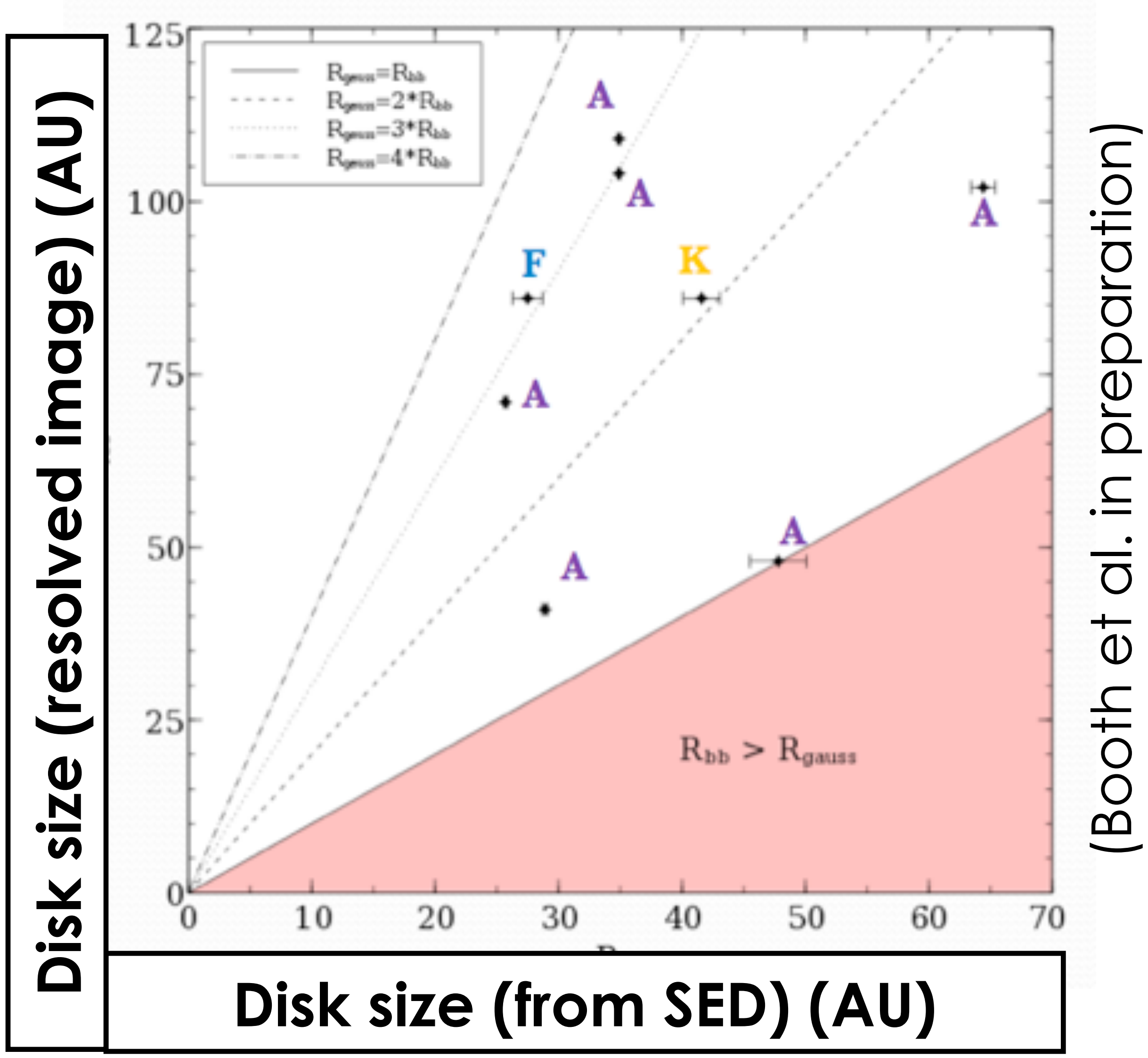
- **Increasing the number of spatially resolved disks; some very compact** (e.g. a 40 AU disk, **smaller than the solar system** debris disk).



A-type
11 pc
SED: T_{dust} ~ 112 K
Images: R_{disk} ~ 39 AU

(Matthews et al. 2010)

- $R_{disk\ (resolved)}/R_{bb\ (sed)}$ **~ 1-4** implies a range of composition and/or grain sizes.



(Booth et al. in preparation)

See Mark Booth's poster

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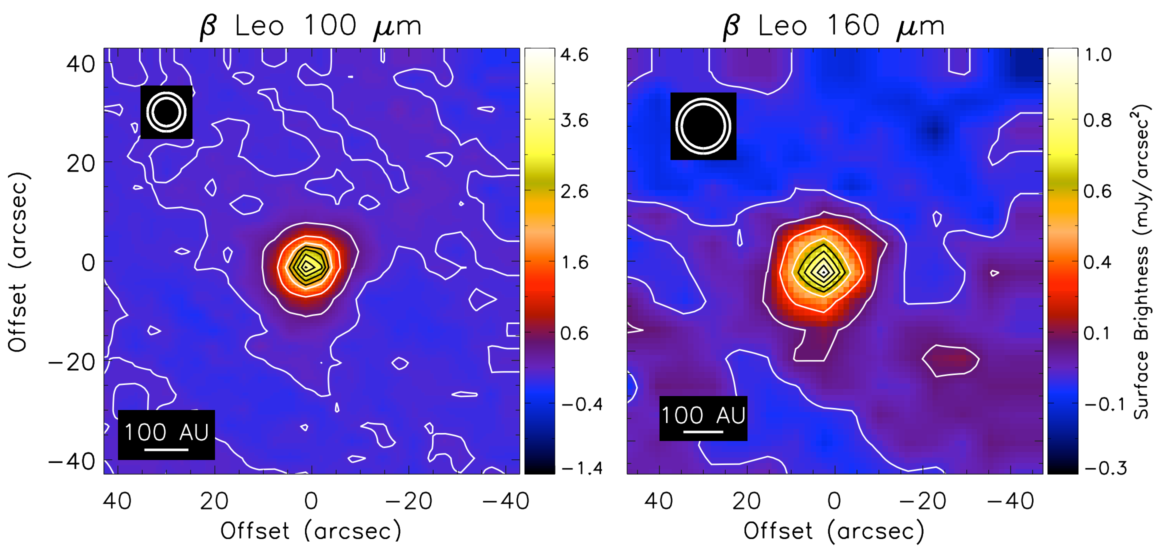

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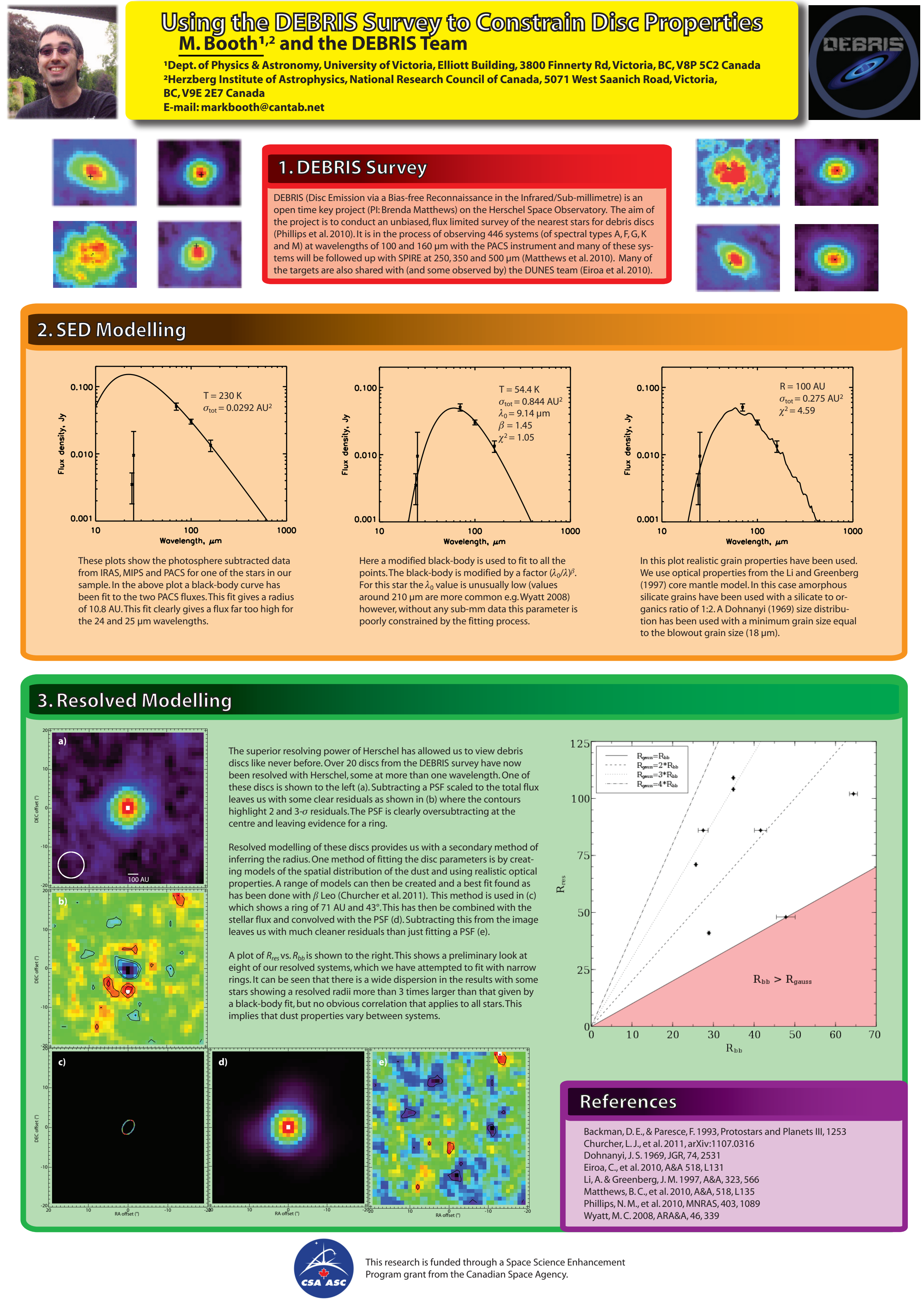


Herschel-DEBRIS Key Program

Preliminary Results

- **Characterization of the first debris disks around mature M-type stars.**
- Identification of **new debris disks around planet-host stars** (including multiple-planet systems; characterization of planetary systems: planets + planetesimals).
- Approaching **KB dust disk flux level for nearest targets**.

Exchange of debris between planetary systems

Exchange of debris between planetary systems

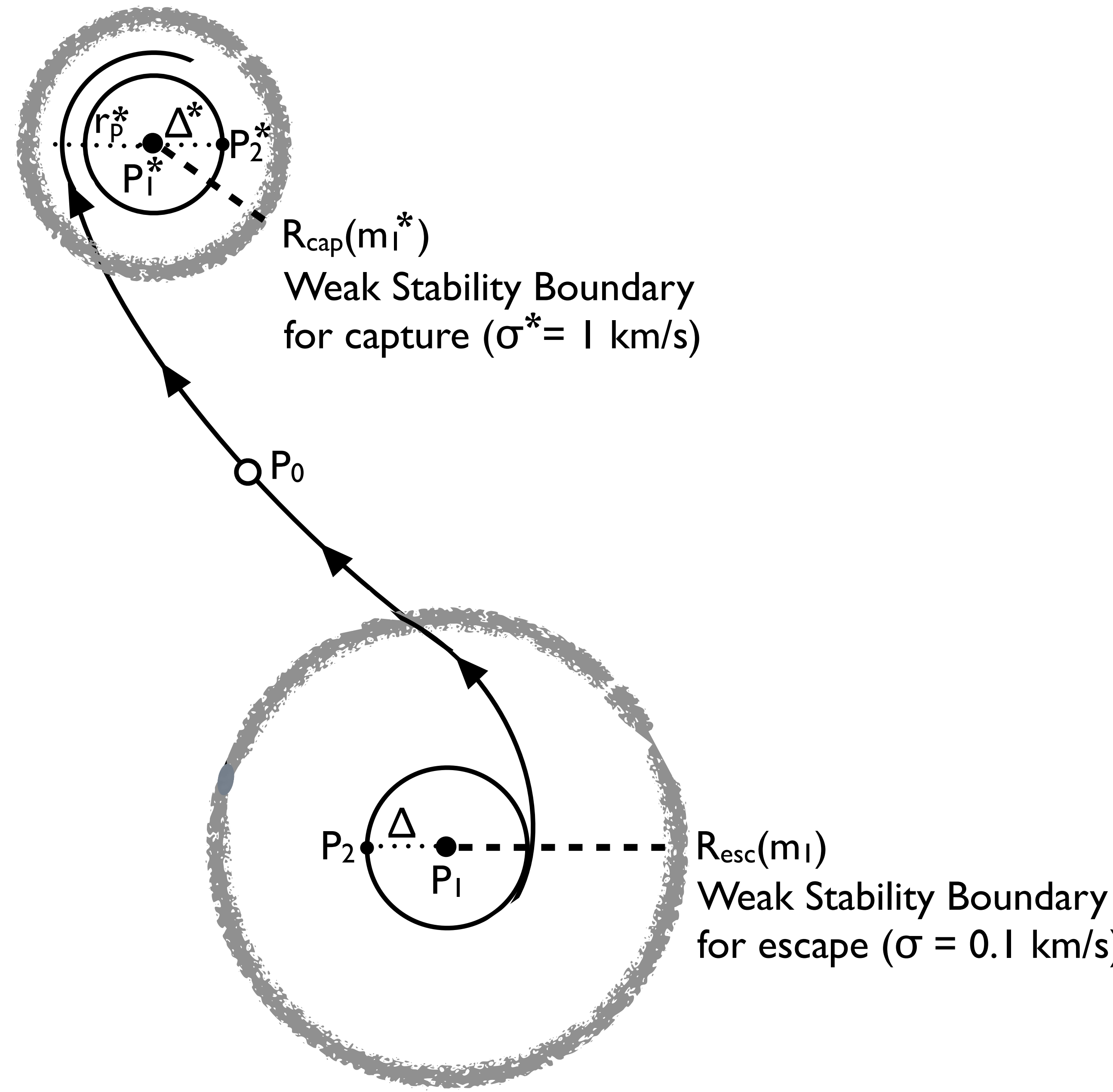
- Debris disk frequency indicate that planetesimal formation is common.
- ~20% of stars harbor giant planets < 20 AU.
- Giant planets eject planetesimals efficiently.

The interstellar medium must be filled with planetesimals

Is the exchange of solid material possible between planetary systems?

Exchange of debris between planetary systems

- There is a minimum energy transfer mechanism that allows and maximizes the capture of debris by other planetary systems (quasi-parabolic orbits).



(Belbruno, Moro-Martín, Malhotra, Savransky, submitted)

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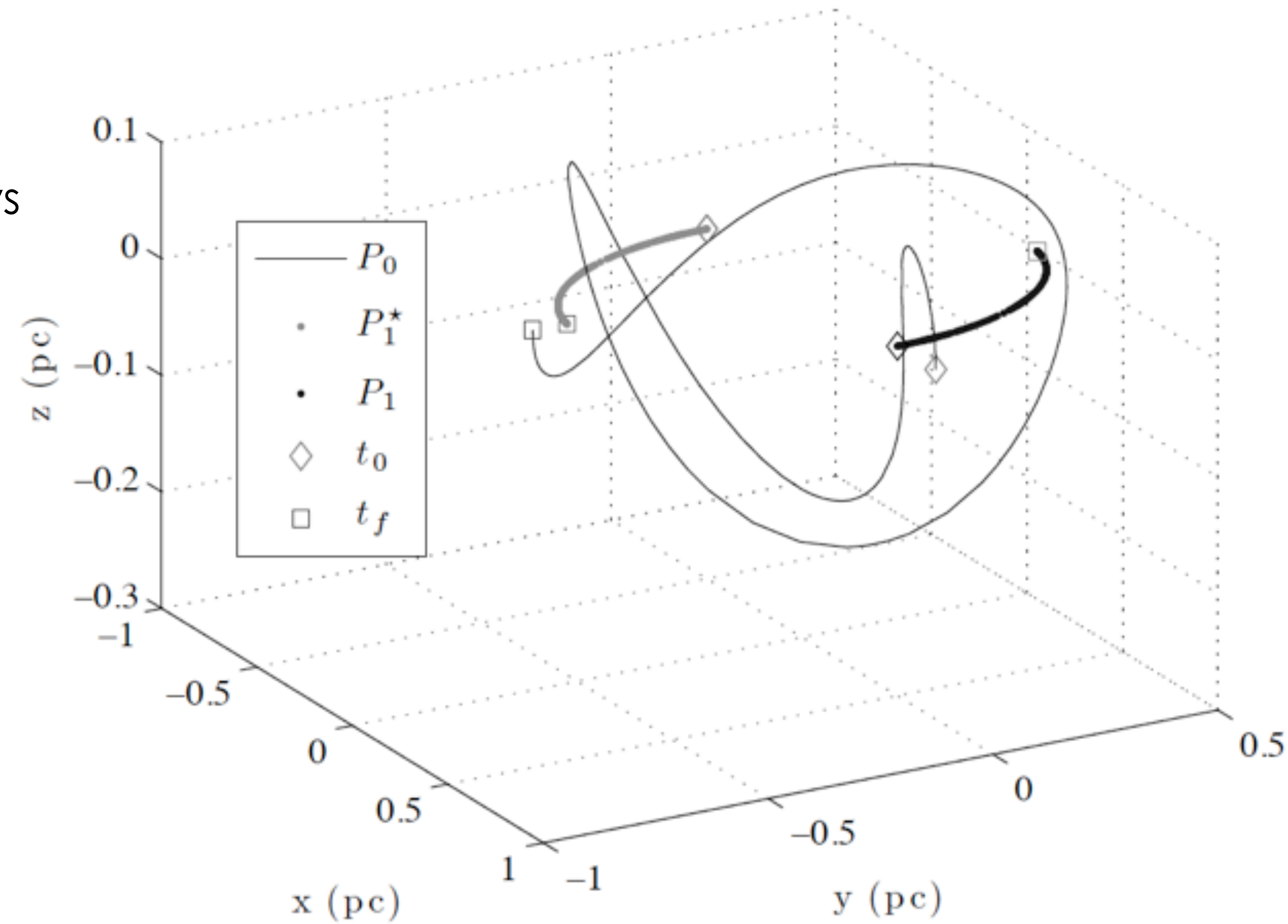

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Exchange of debris between planetary systems

Properties of solar birth cluster (Adams 2010)

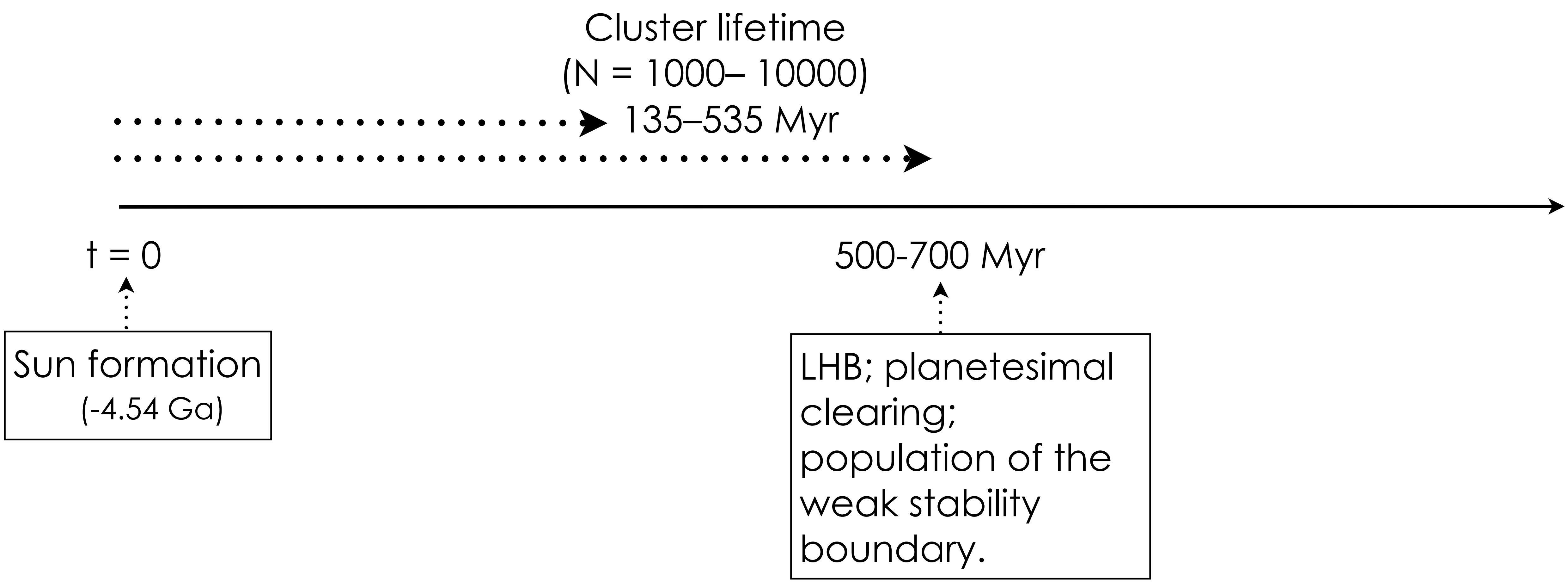
- $N = 4300$ ($N=1000$-10000)
- $M_{total} = \langle m_{star} \rangle N \sim 0.88N = 3784\ M_{sun}$ (IMF; ignoring the gas).
- Cluster size: $R \sim 1\text{pc}\ (N/300)^{0.5}$
- Average distance between stars: $D = n^{-1/3} = 19\ \text{pc}^{-3} \longrightarrow D = 0.375$ pc
- Cluster lifetime: $t = 2.3\text{Myr}\ M^{0.6} = 322.5$ Myr

$M_{*\ source}$ (M_{sun})	$M_{*\ target}$ (M_{sun})	Capture probab.
1.0	1.0	0.15%
1.0	0.5	0.05%
0.5	1.0	0.12%

Using this mechanism, a large number of debris could have been transferred to the nearest planetary system (of the order of 10^{14}-10^{17} with masses > 10 kg).

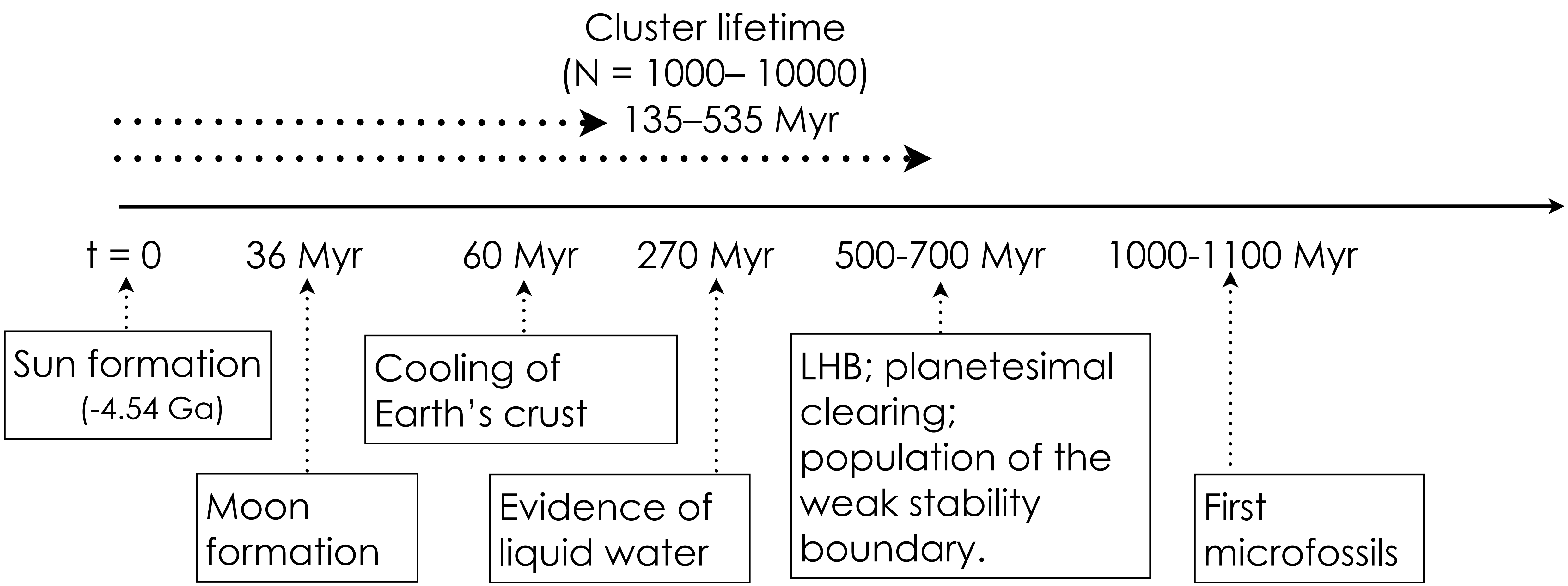
(Belbruno, Moro-Martín, Malhotra, Savransky, submitted)

Exchange of debris between planetary systems



The characteristic timescale for populating the weak stability boundary with debris overlaps marginally with the expected cluster lifetime.

Exchange of debris between planetary systems



Lithopanspermia from the Solar System to the nearest neighbor in the cluster is a possibility if life on Earth had an early start.

Can microorganisms survive long interstellar journeys?

Characteristic time

~ 6 Myr: transfer timescale to nearest planetary system.

~ 10s Myr: to land on a terretrial planet.