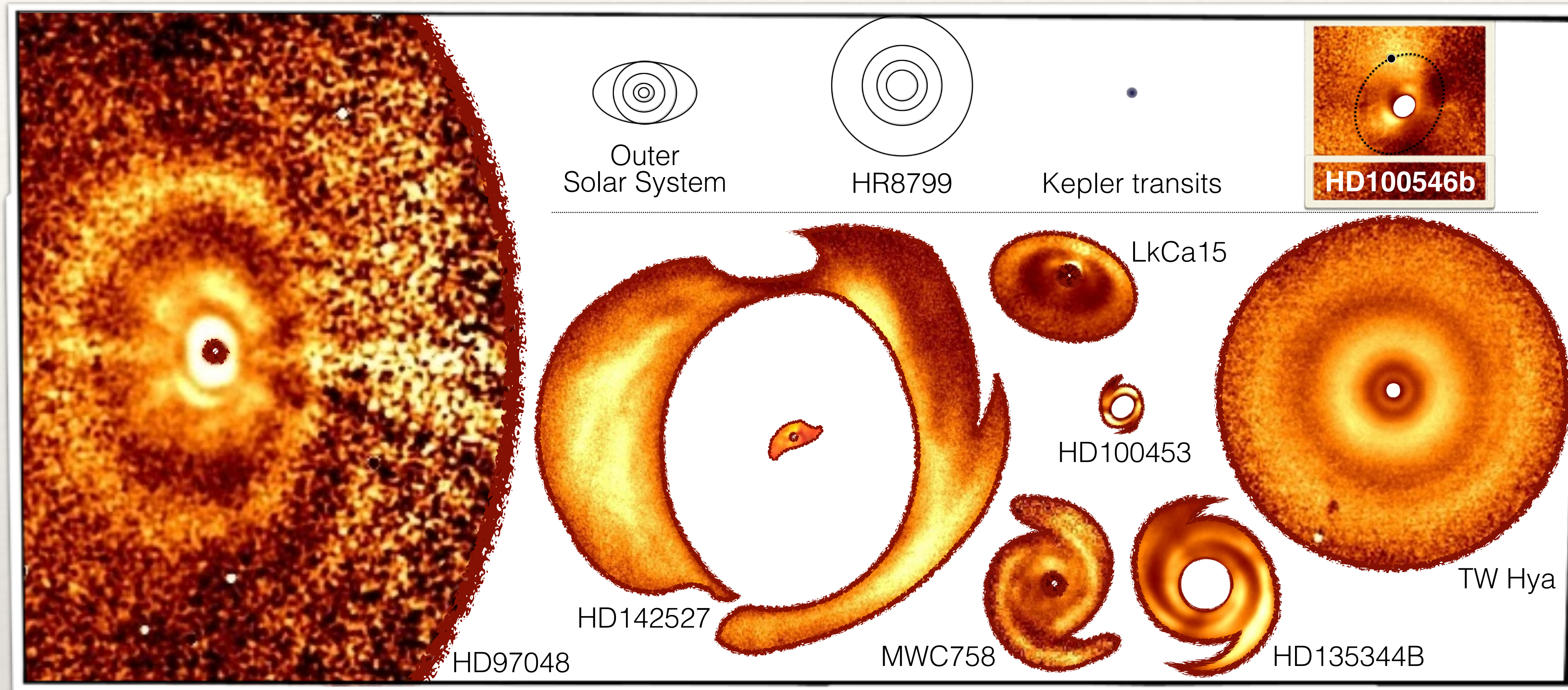


Planet-forming disks. March 6, 2019, Menaggio (IT)

Evolution of protoplanetary disks from their taxonomy in scattered light

Antonio Garufi
OA Arcetri, INAF
with H. Avenhaus, F. Bacciotti, A. Banzatti, M. Benisty, C. Dominik, M. Kama, G. Meeus, L. Podio, P. Pinilla, S. Quanz, SPHERE/GTO

The first 100 protoplanetary disks in PDI

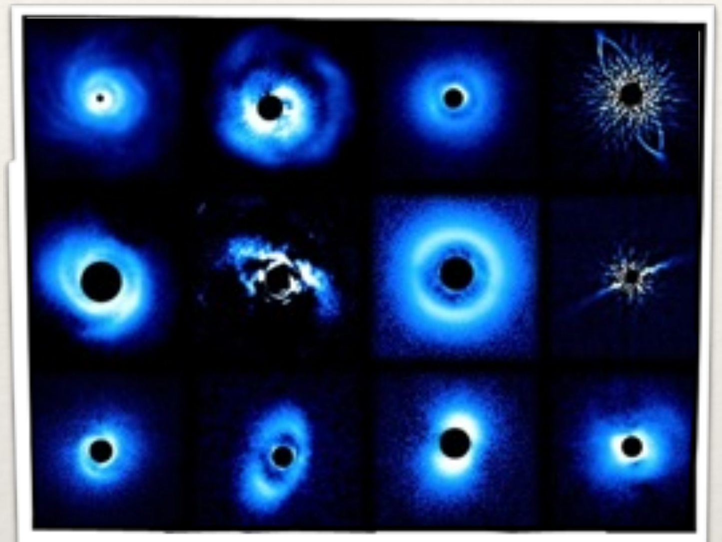
Nearly 100 disks observed in NIR between 2010 and 2019
(HiCiao, NACO, GPI, MagAO, SPHERE papers…)

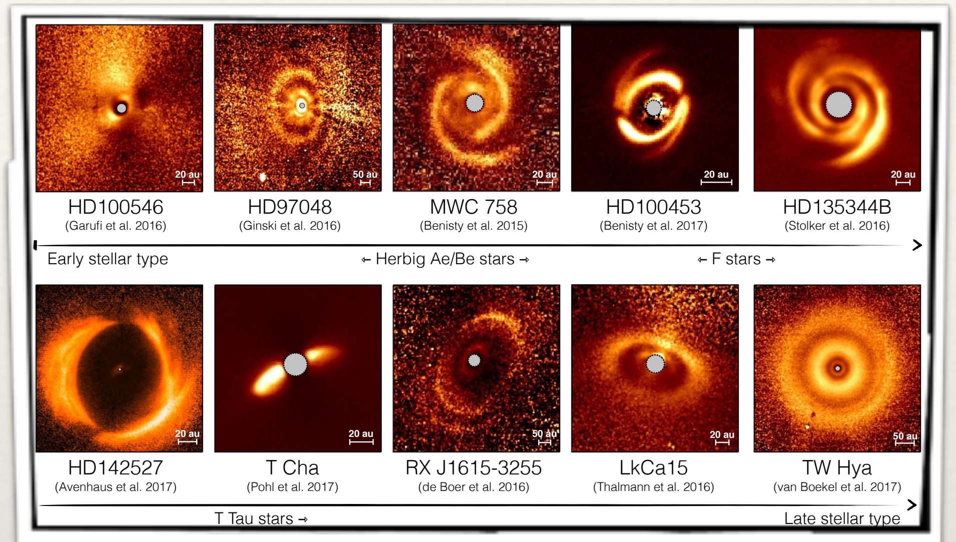
Most obvious finding.
Disks often (always?) host sub-structures.

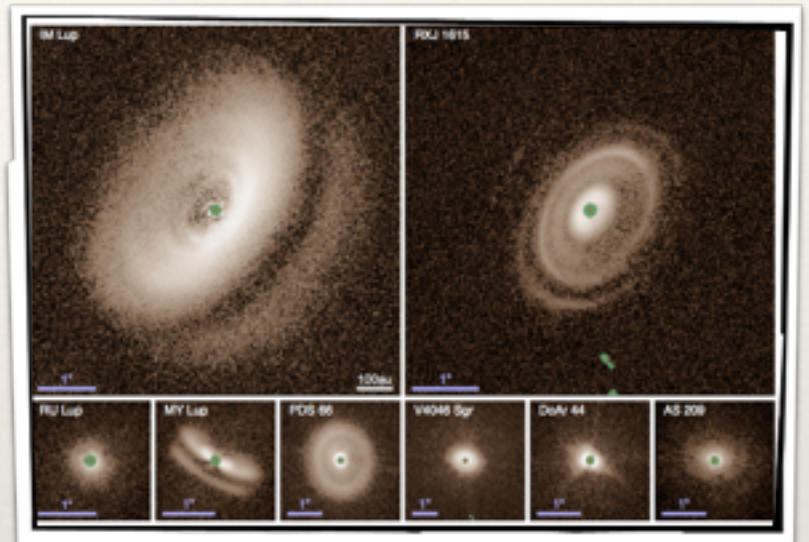
Key-questions.
What is their relation with the planet formation?
Do they scale with other properties?
How do they evolve with time?

The first 100 protoplanetary disks in PDI

Key-surveys.







SEEDS
Subaru/HiCiao
Hashimoto et al.
www.nao.ac.jp

DISK GTO
VLT/SPHERE
Garufi et al. 2017b
+references therein

DARTTS-S
VLT/SPHERE
Avenhaus et al. 2018
+follow-up in prep.

Disk cavity

Fact #1:

Very high occurrence: resolved in ~⅔ of the PDI sample.

(To be compared to the 10% from photometric surveys.)

Disk cavity

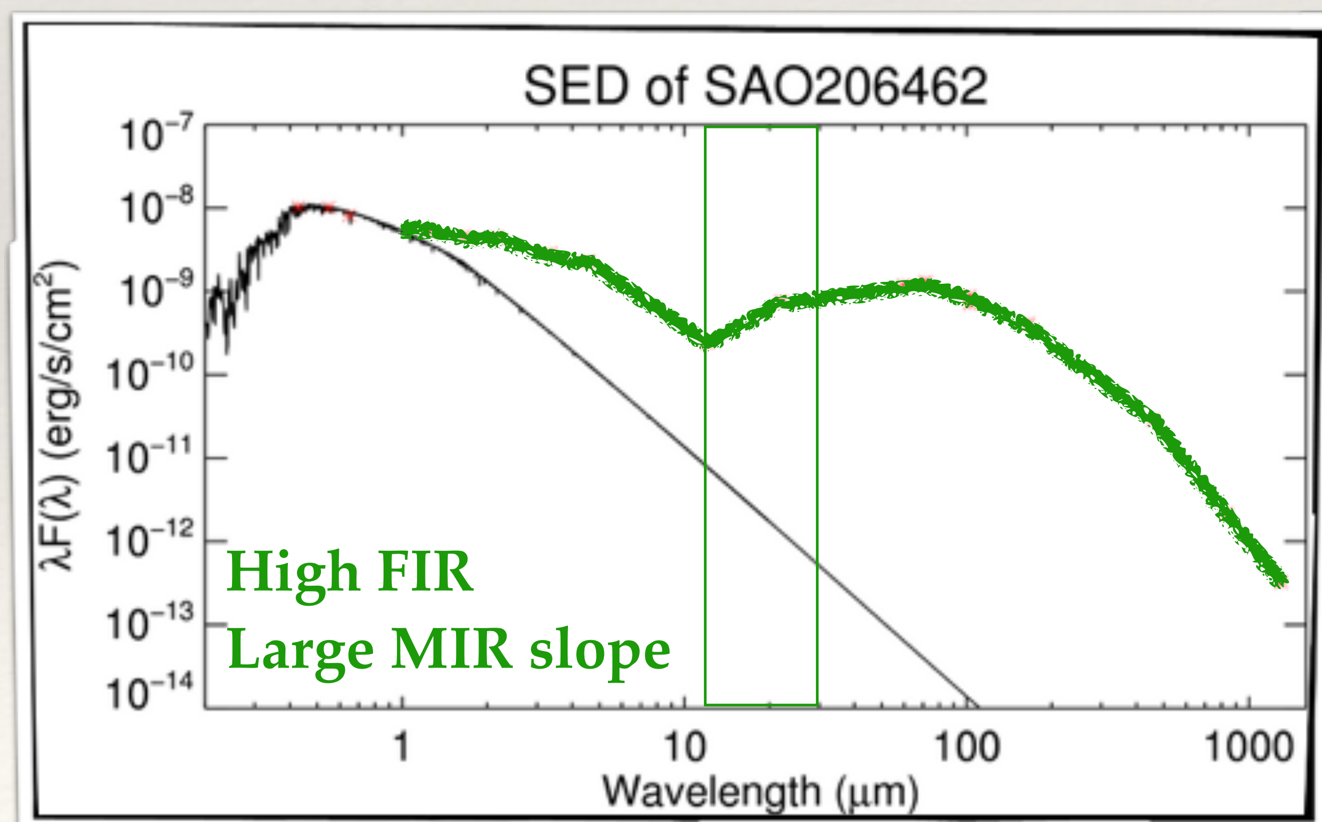
Facts #1 and #2:

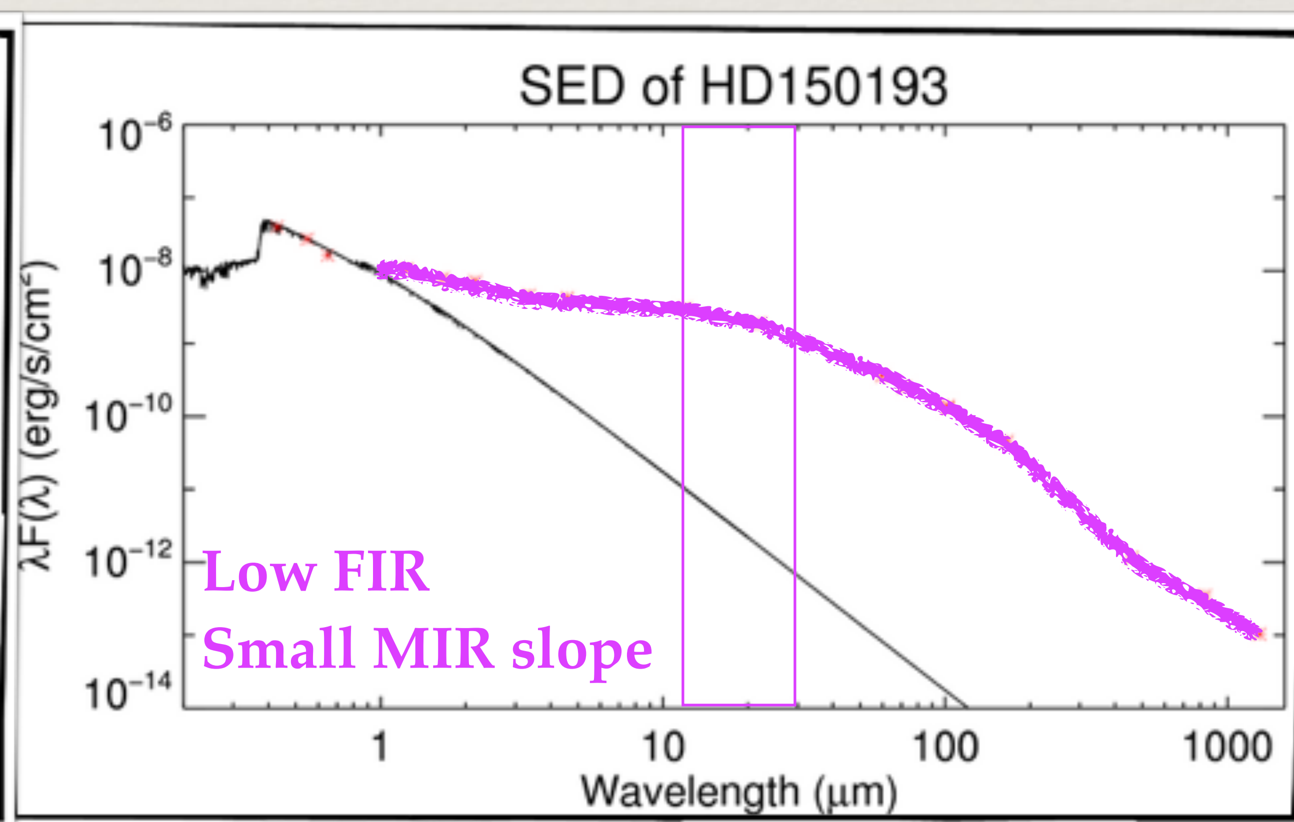
Very high occurrence: resolved in ~⅔ of the sample.

(To be compared to the 10% from photometric surveys.)

Cavities explain the Meeus observational dichotomy

Group I vs **Group II**





Disk cavity

Cavities explain the Meeus observational dichotomy

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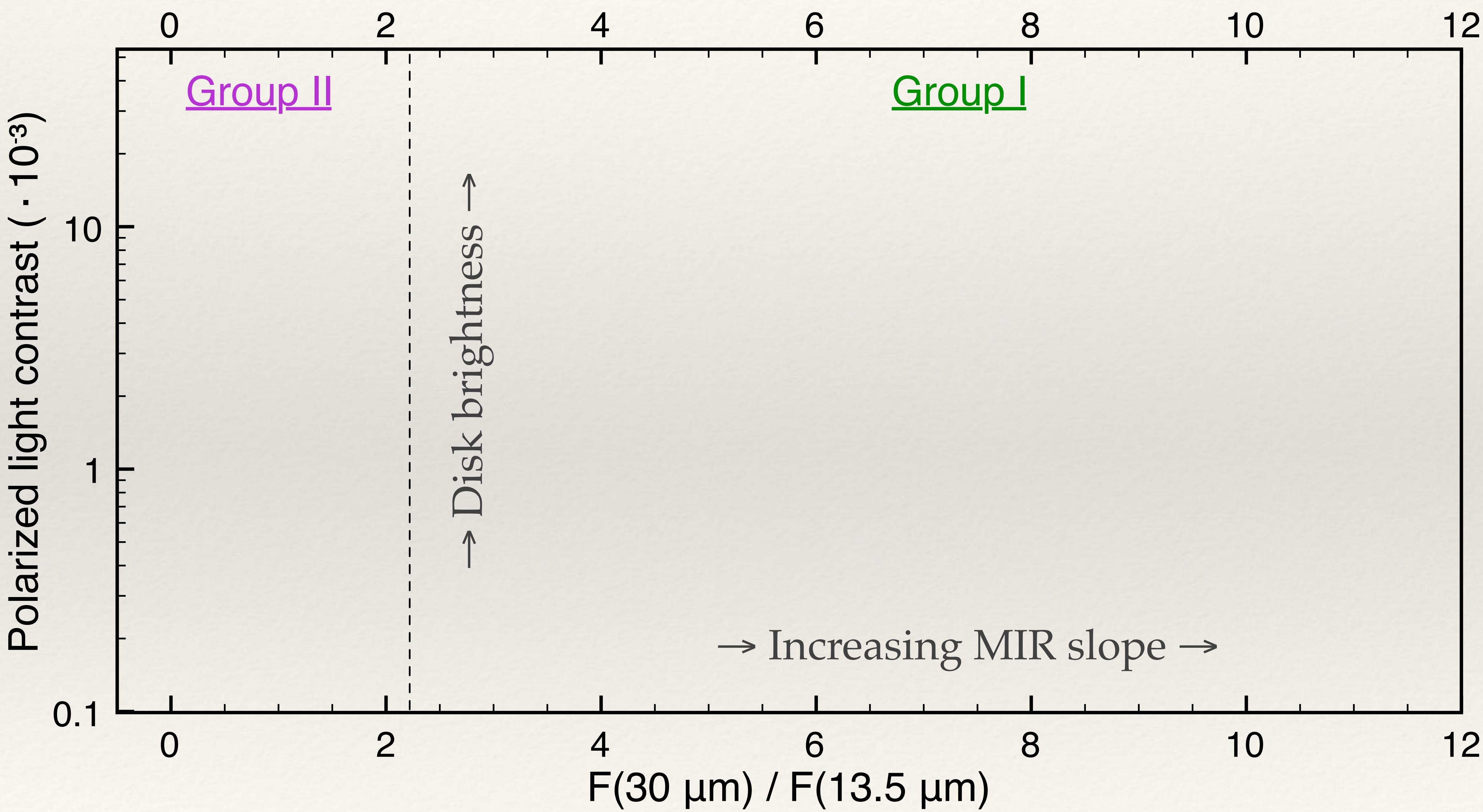
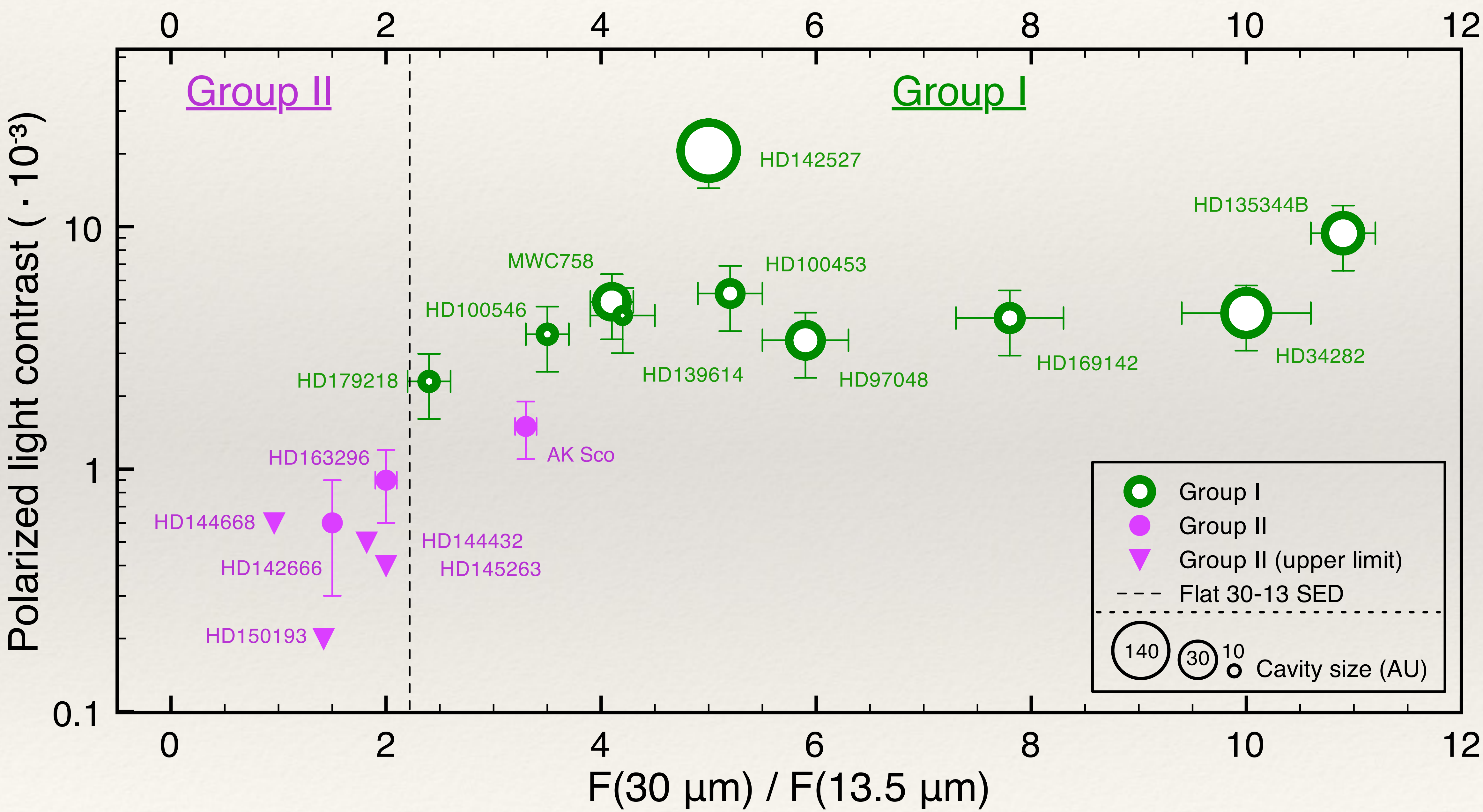


Disk cavity

Cavities explain the Meeus observational dichotomy

Group I vs **Group II**



Garufi et al. 2017a. See also Currie 2010, Maaskant et al. 2013, Menu et al. 2015.

Disk cavity

Fact #3:

Very high occurrence: resolved in ~⅔ of the sample.

(To be compared to the 10% from photometric surveys.)

$\Uparrow$

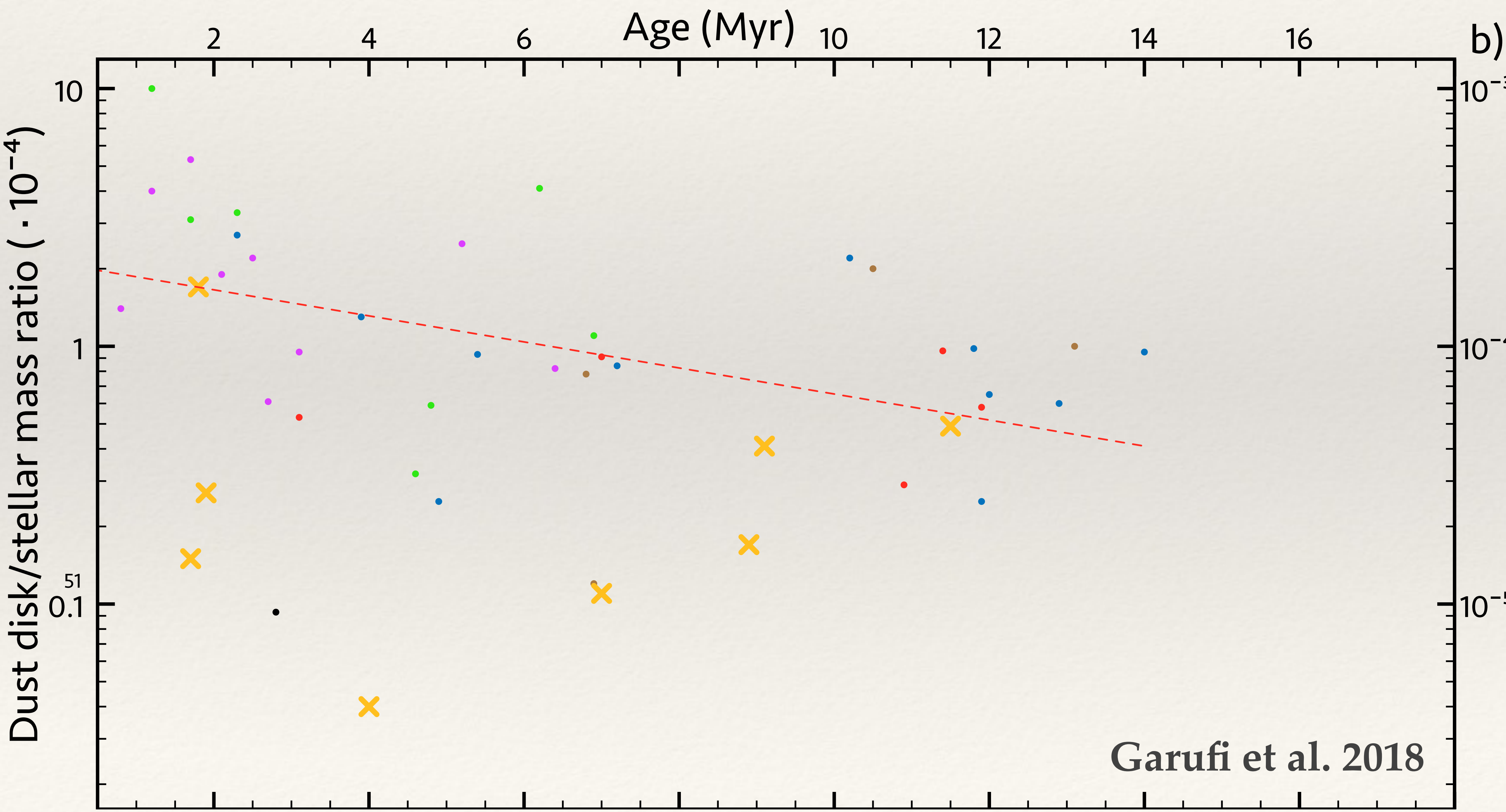
Disks with a cavity are brighter in scattered light.

We have an observational bias.

Disk cavity

Fact #3:

We have more observational biases.
Primarily, massive disks around old stars have been observed.



Garufi et al. 2018

Disk cavity

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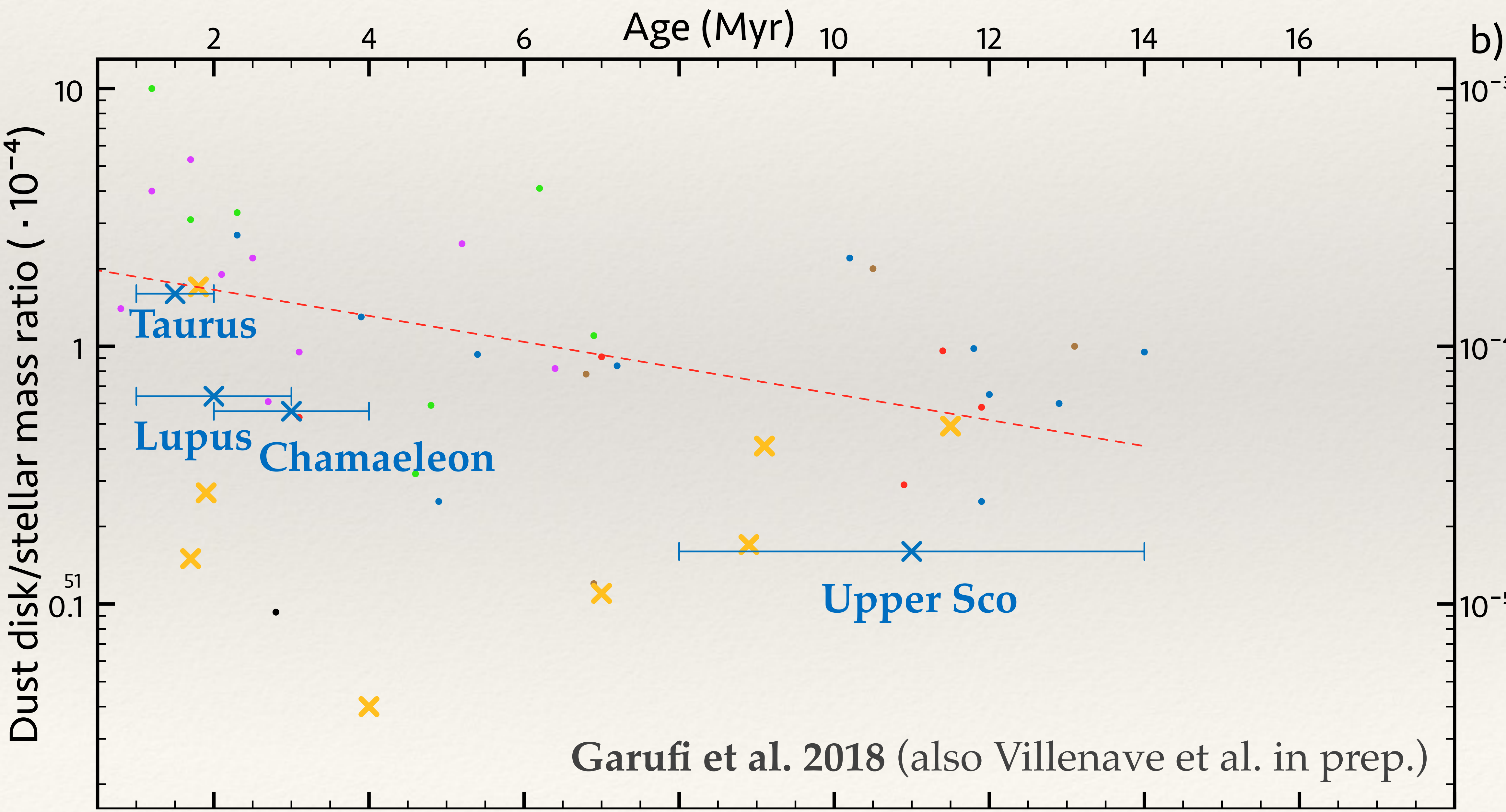

Disk cavity

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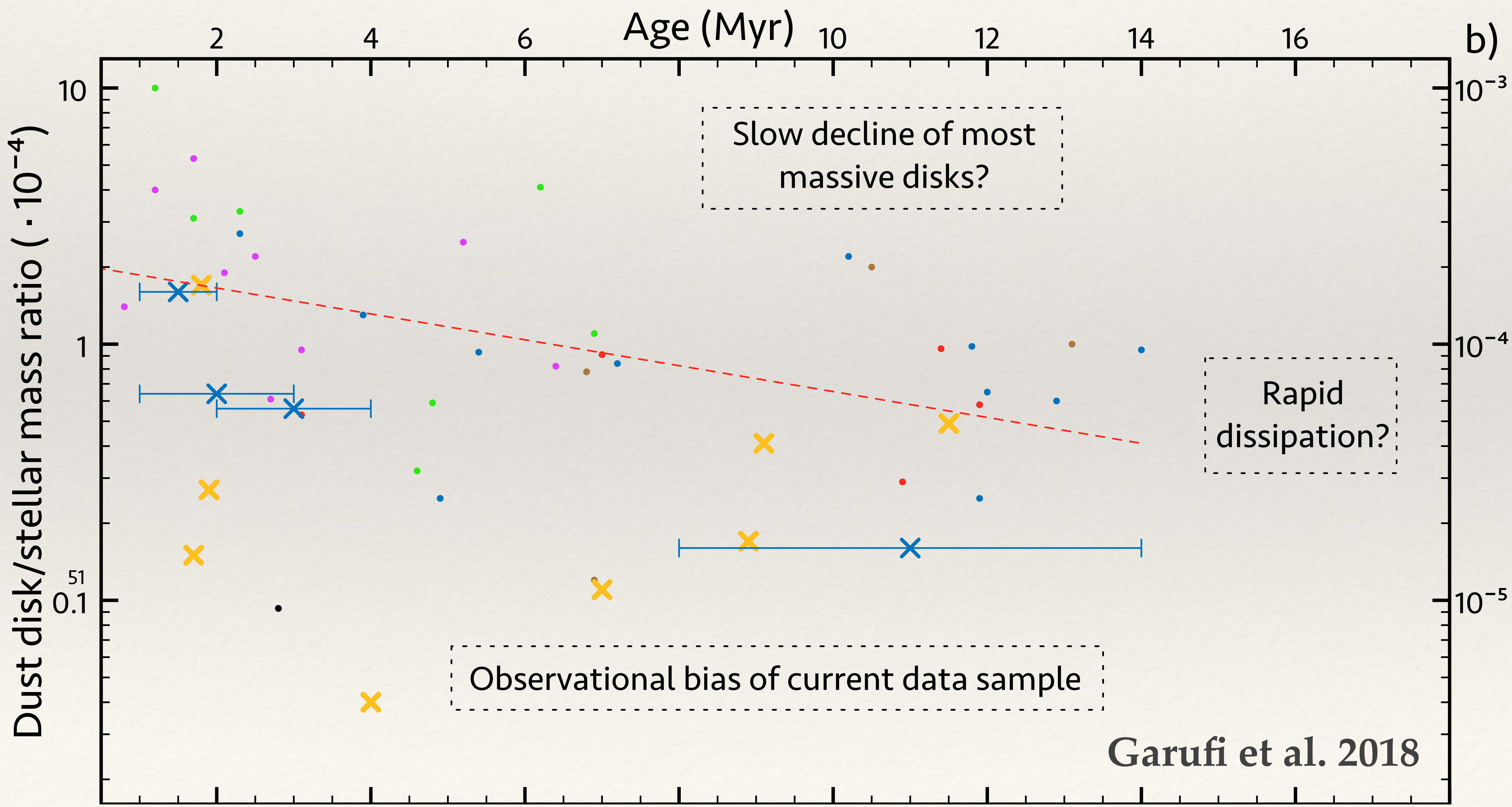
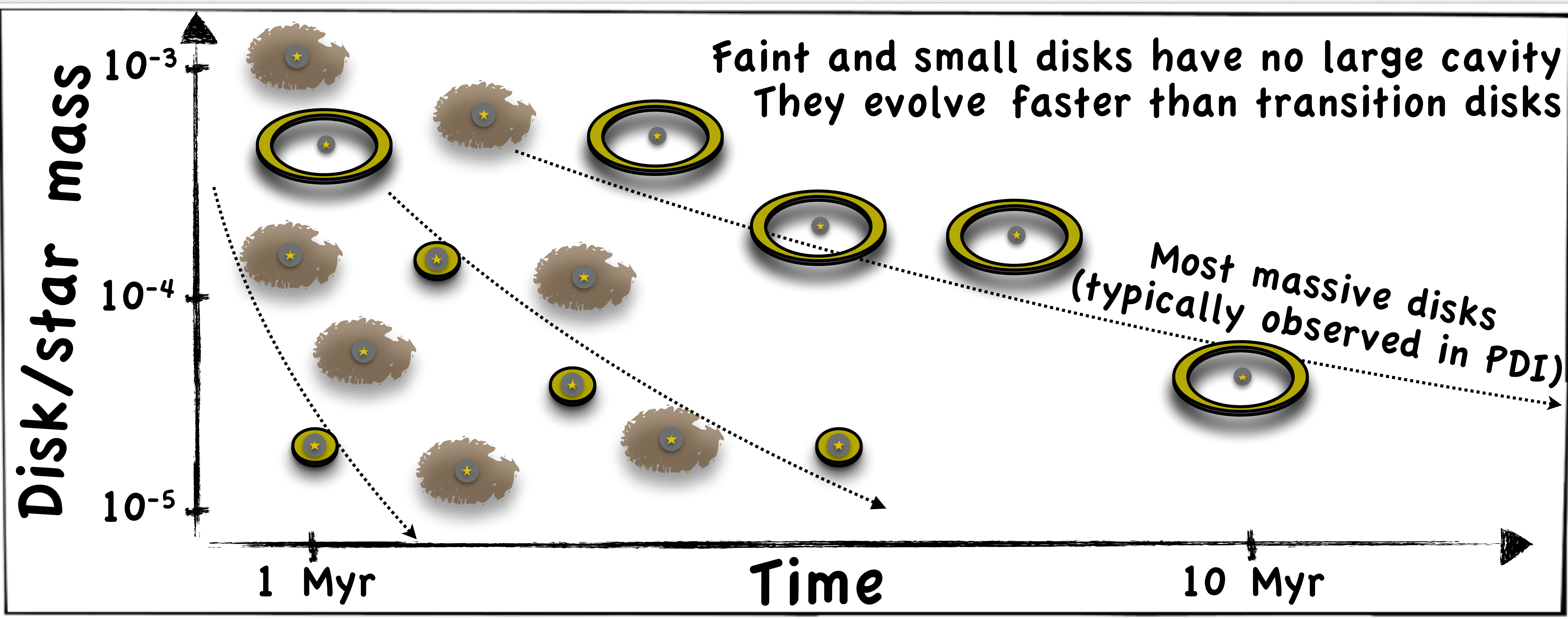


Garufi et al. 2018

Disk cavity

Conclusion #1:

We have mostly observed long-living, massive disks with a cavity
(see also Owen 2015, Pinilla et al. 2018).

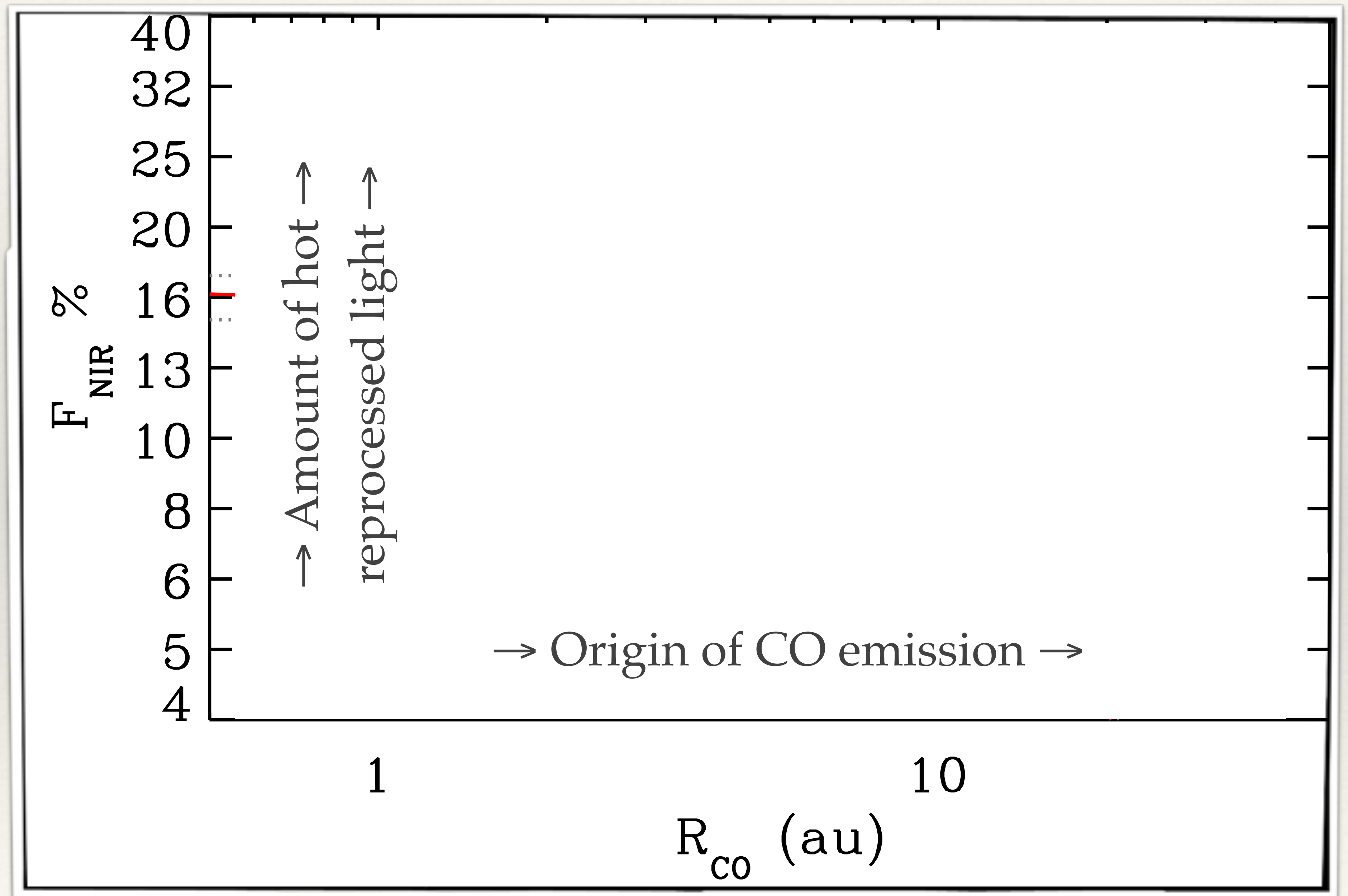


Garufi et al. 2018

Within the disk cavity

Fact #4:

Another observational dichotomy is among the transition disks (Group I).



Banzatti et al. 2018

Within the disk cavity

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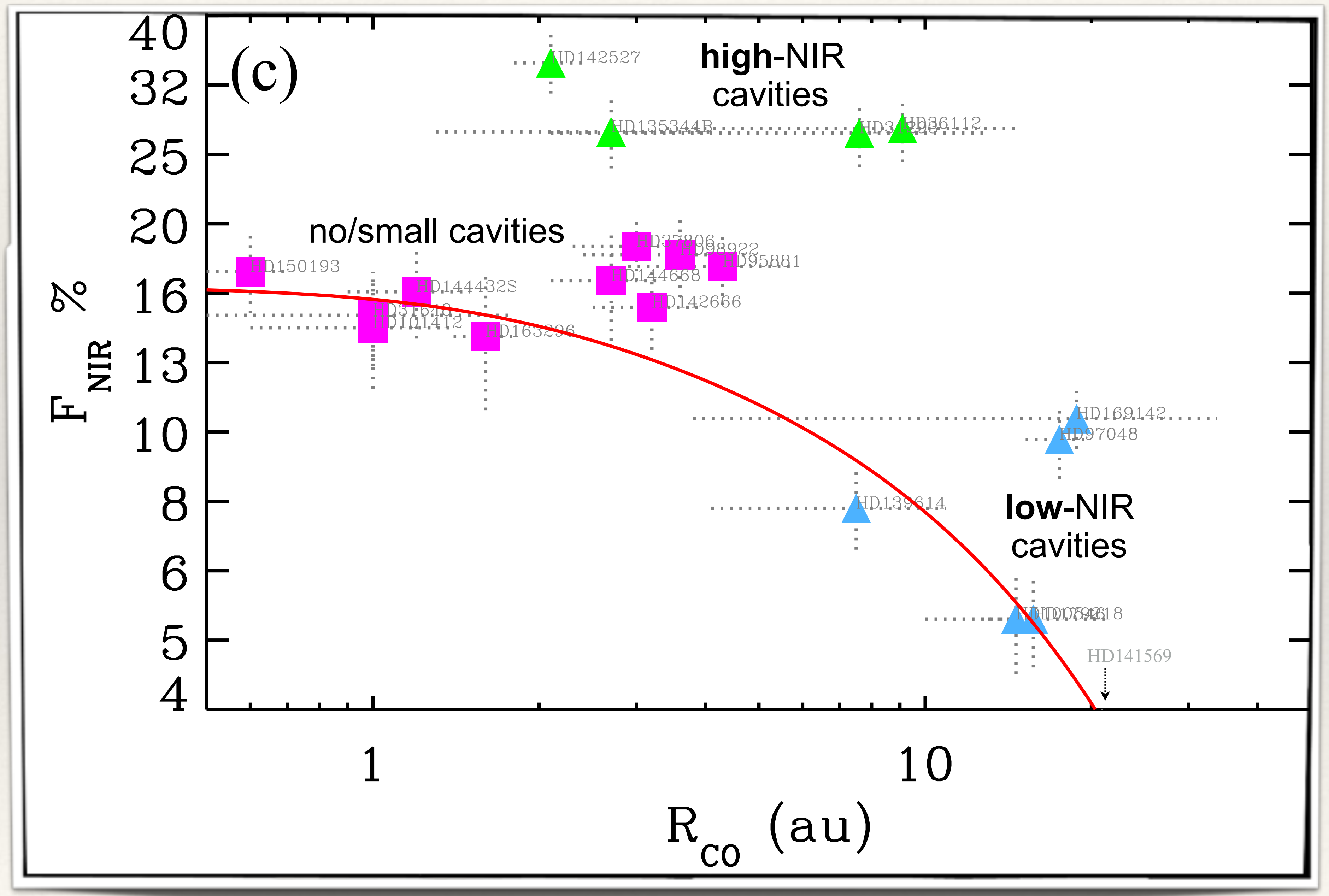

Banzatti et al. 2018

Within the disk cavity

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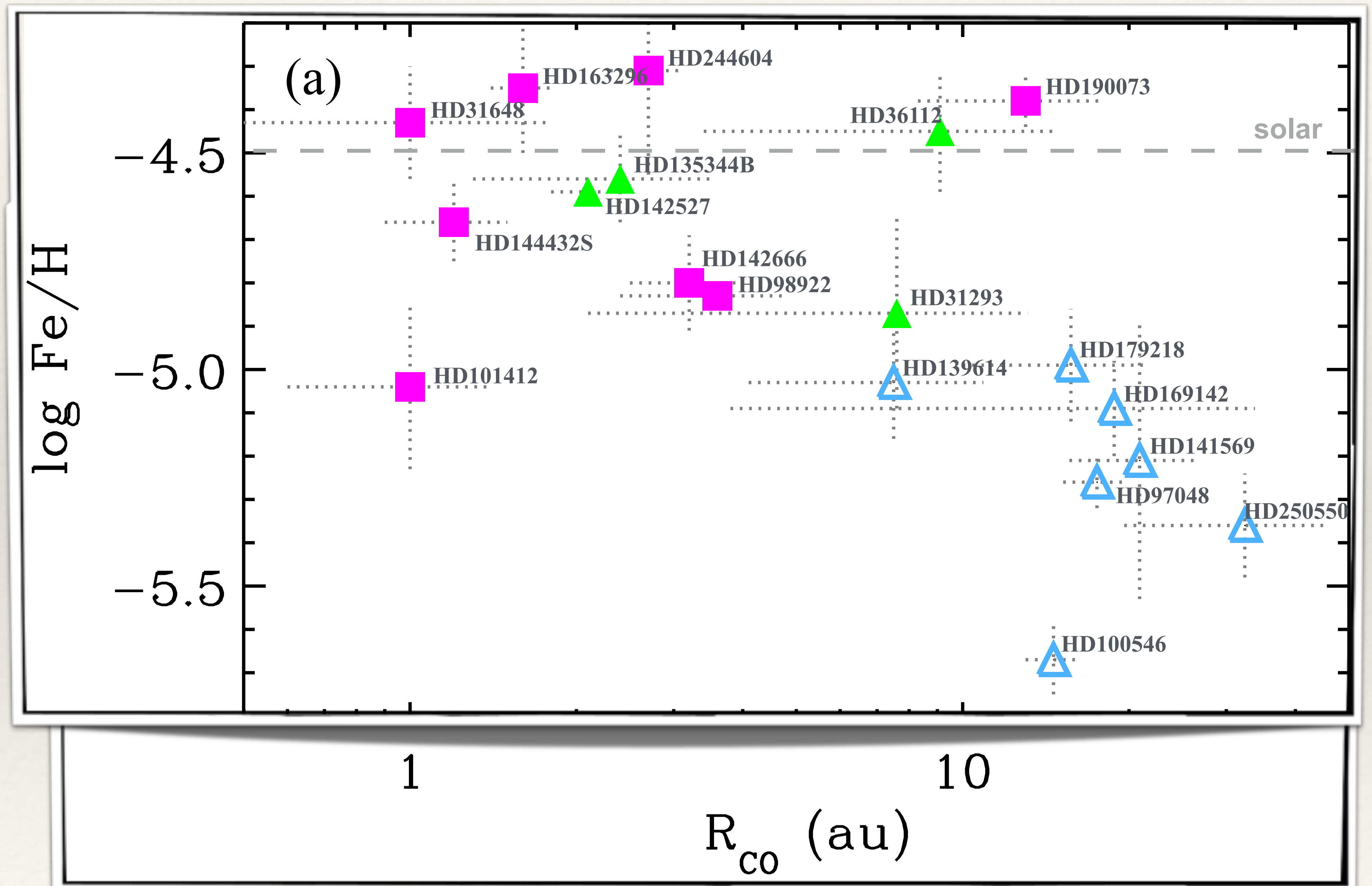


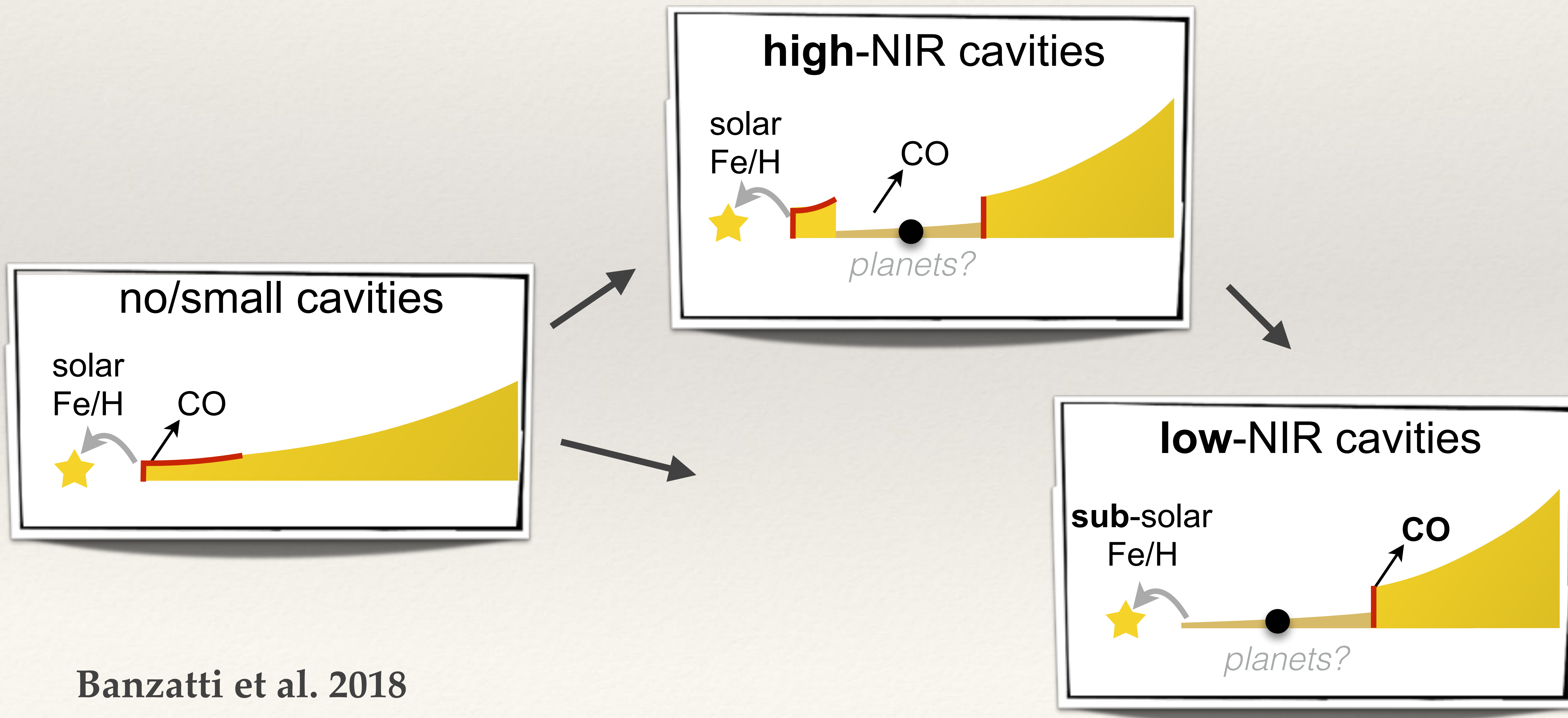
Banzatti et al. 2018 (see also Kama et al. 2015)

Within the disk cavity

Conclusion #2:

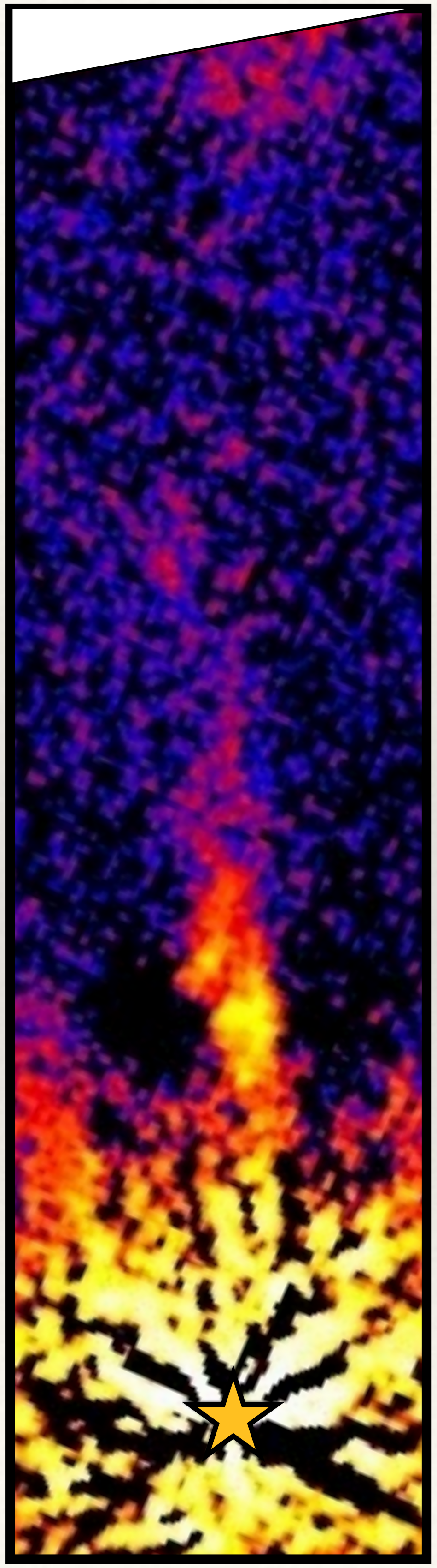
There are two families of disk cavities.

Transition disks have depleted / increased NIR and low / solar abundance of refractory elements, with CO emission from large / small radii.



Banzatti et al. 2018

Within the disk cavity



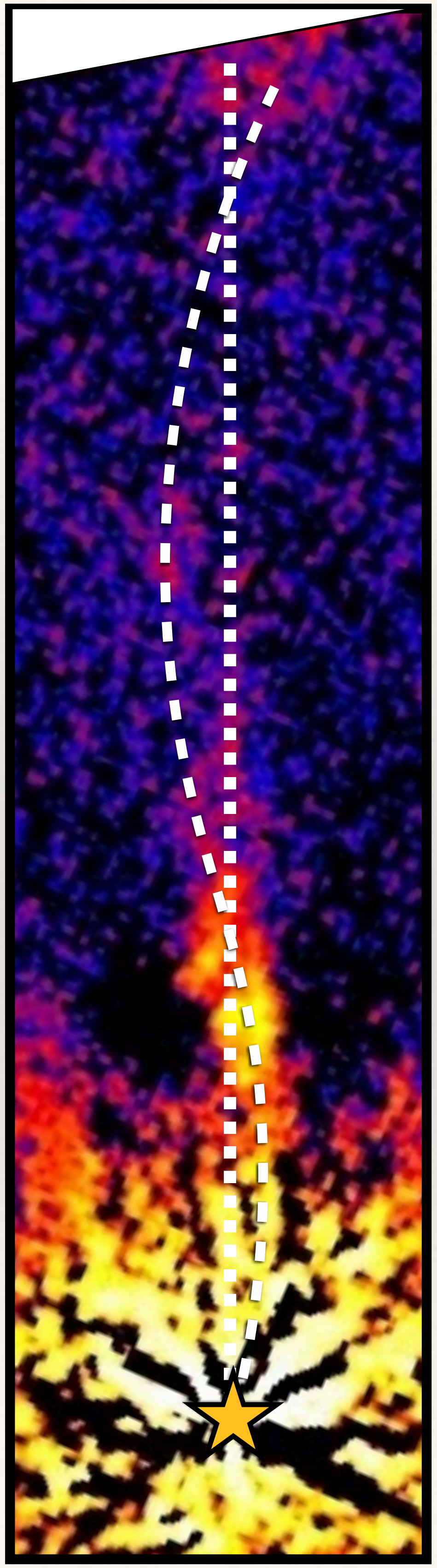
Fact #5:

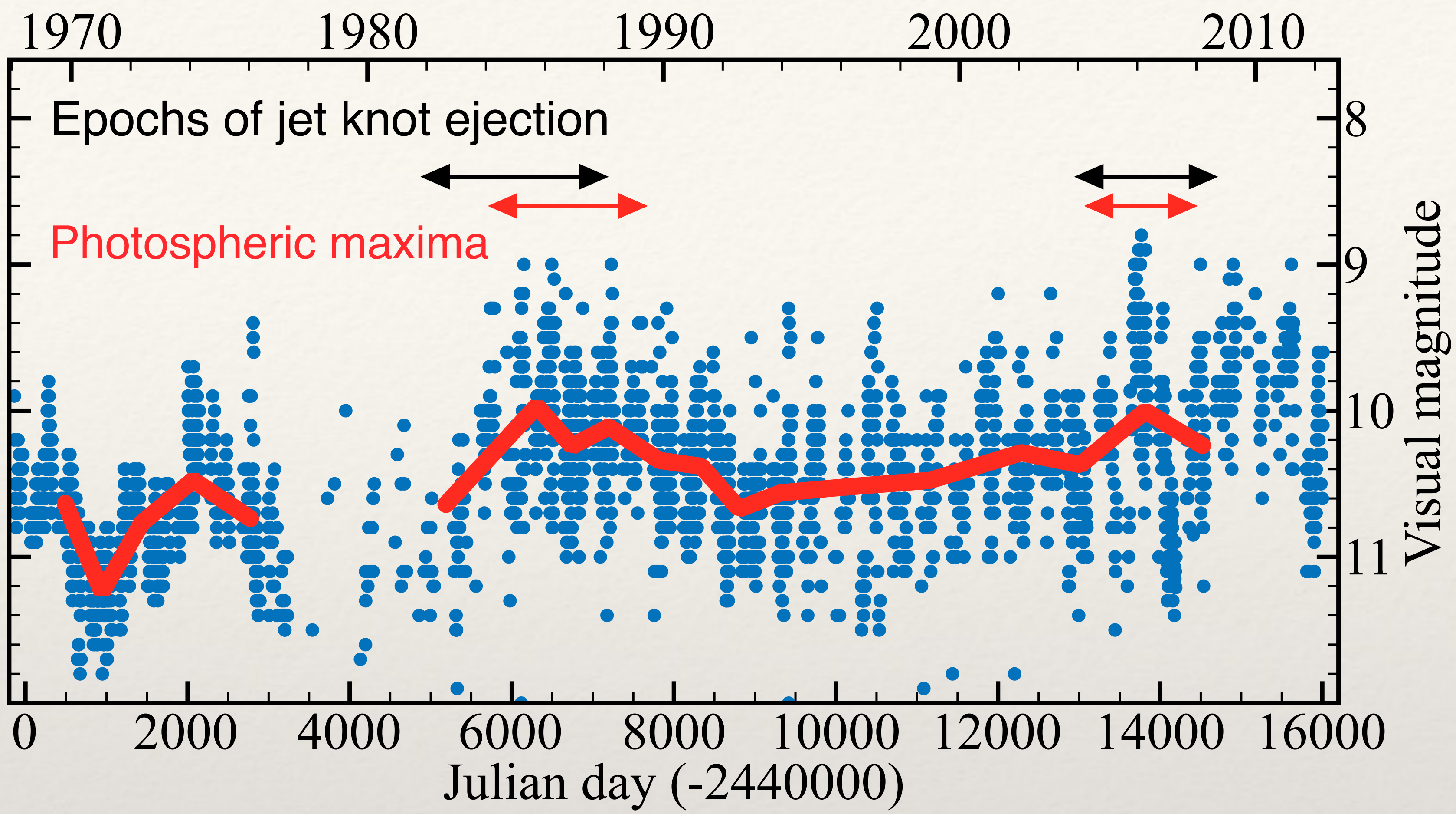
The morphology of optical jets bears record of the stellar physics and geometry of the inner disk.

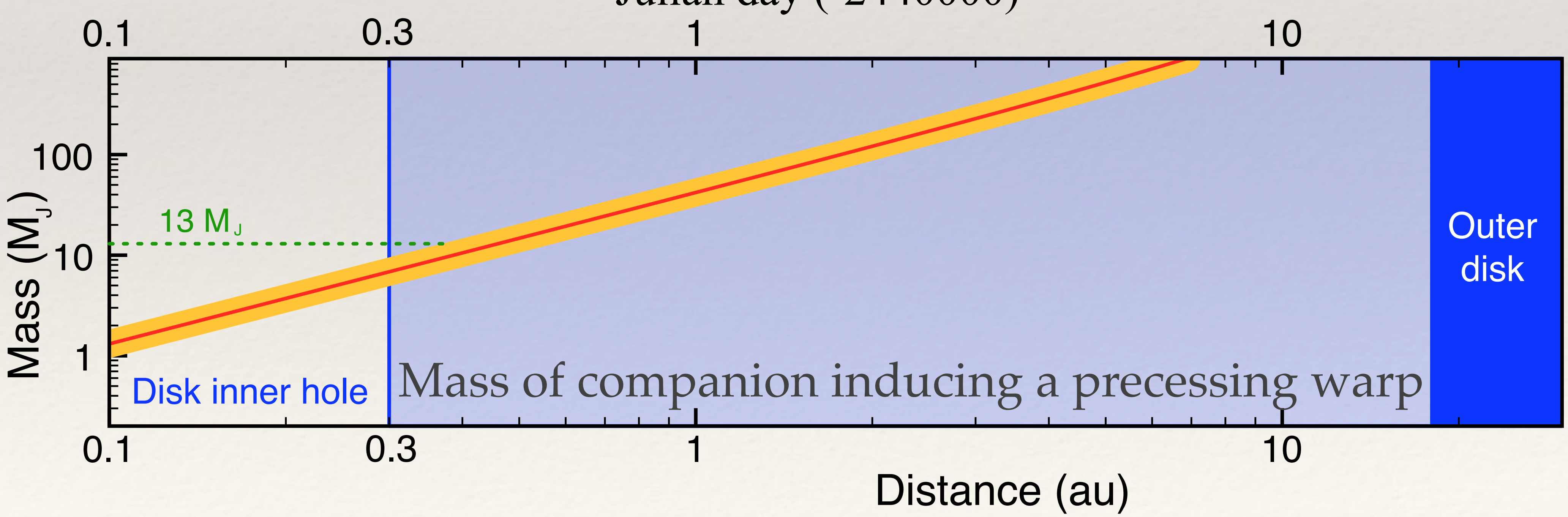
Jet knots → Increased accretion / ejection events.
Jet wiggling → Disk warp, misalignment?

Garufi et al. to be submitted

Within the disk cavity





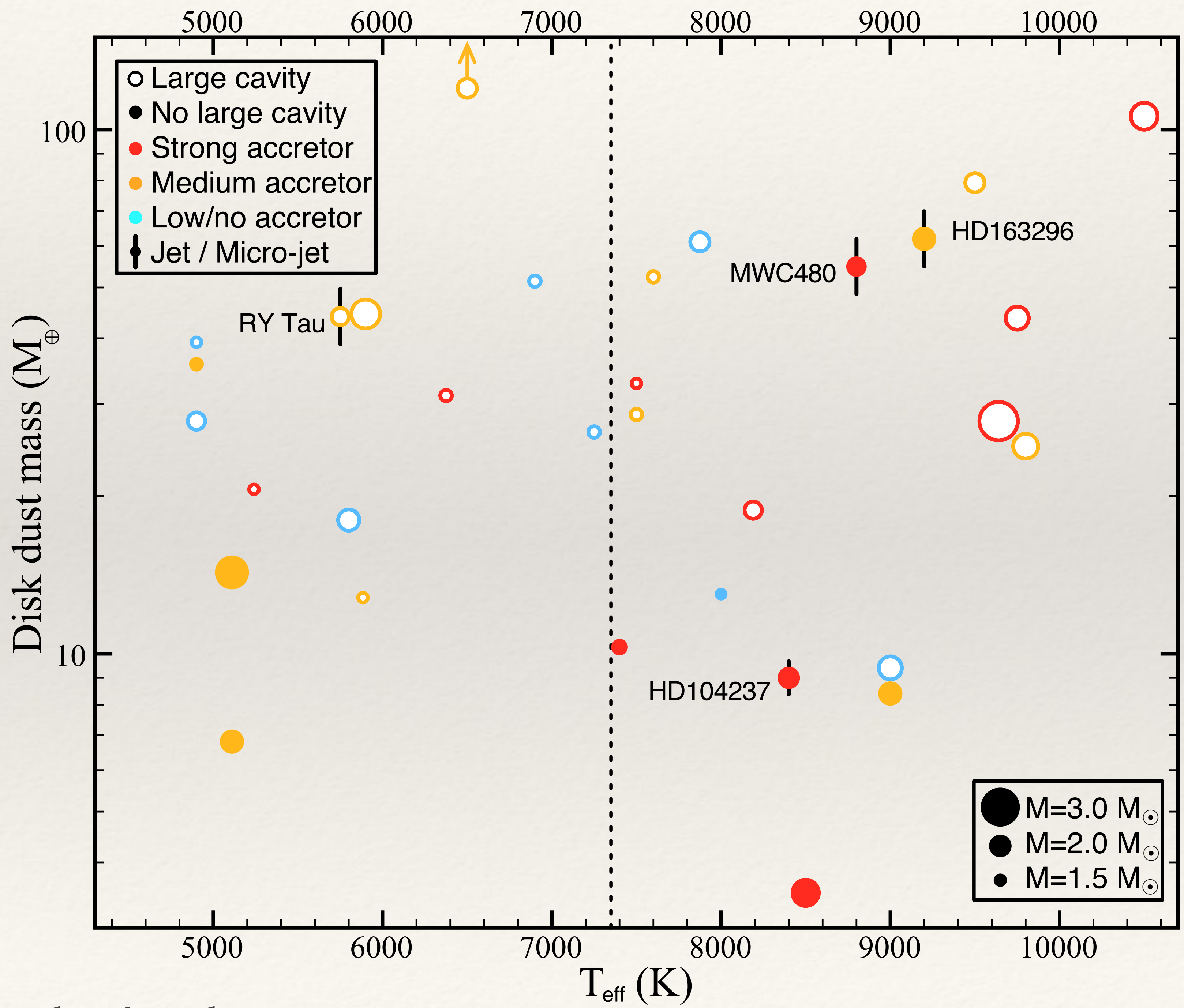


Garufi et al. to be submitted (following Zhu 2019)

Within the disk cavity

Conclusion #3:

The brightness and morphology of jets depend on the inner disk properties.



Garufi et al. to be submitted

Spirals & Shadows

Fact #6:

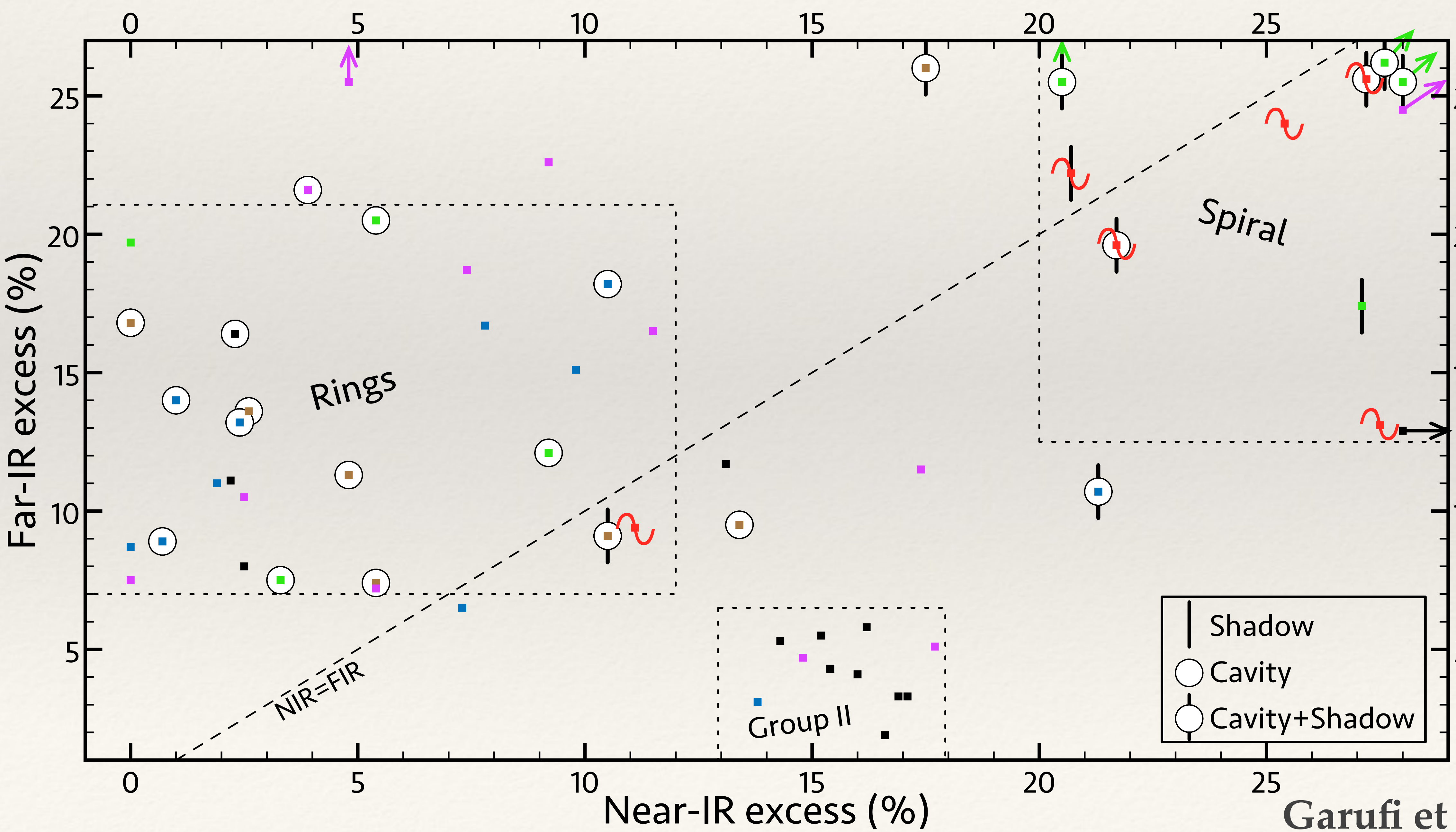
Spirals are detected in ~10% of Herbig stars. Never detected in TTSs.

Spirals & Shadows

Fact #6 and #7:

Spirals are detected in ~10% of Herbig stars. Never detected in TTSs.

Both spirals and shadows are associated with a high NIR.



Garufi et al. 2018

Spirals & Shadows

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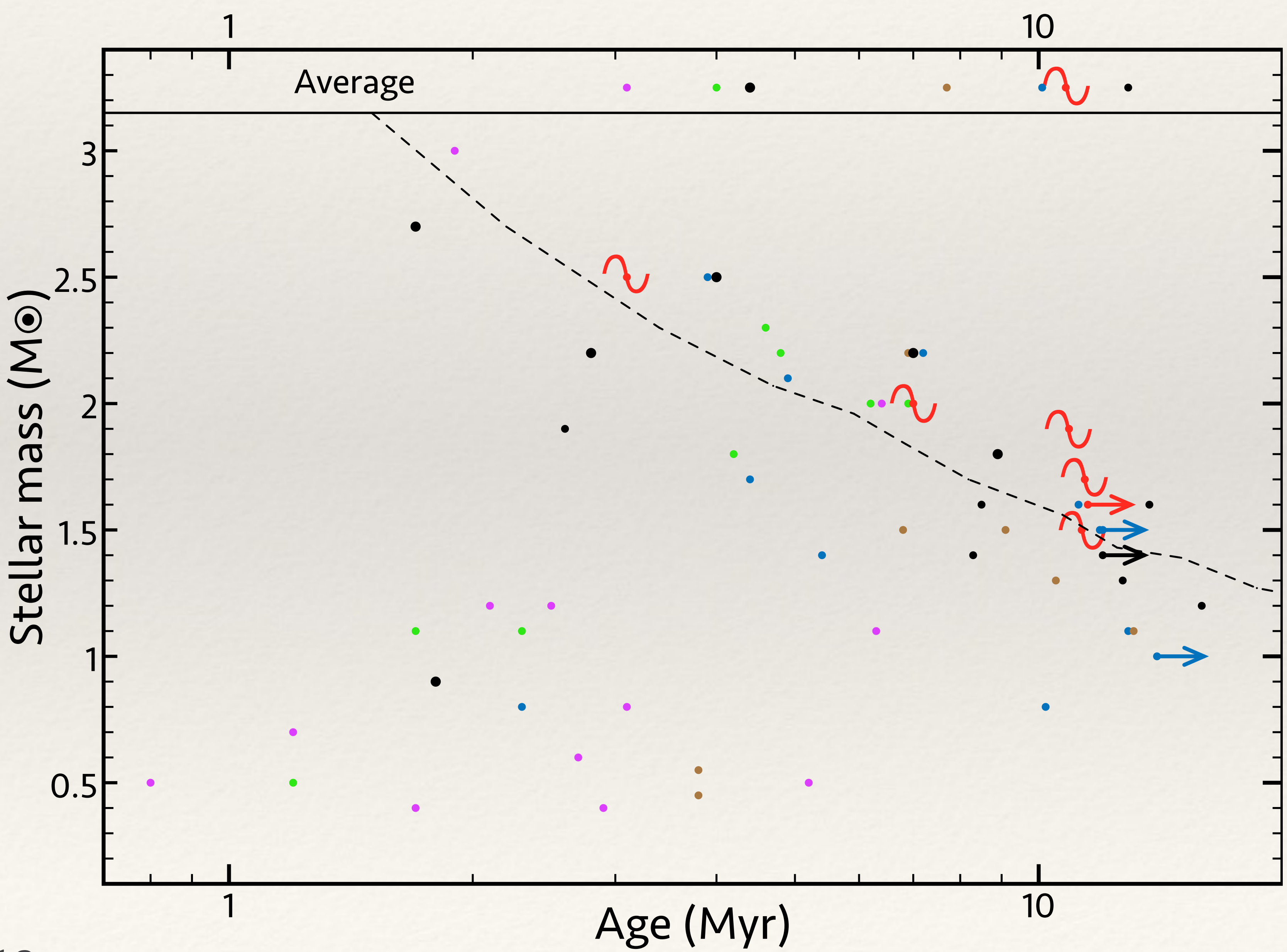
Possibly, spirals are “late” structures. We do not observe late TTSs.



Garufi et al. 2018

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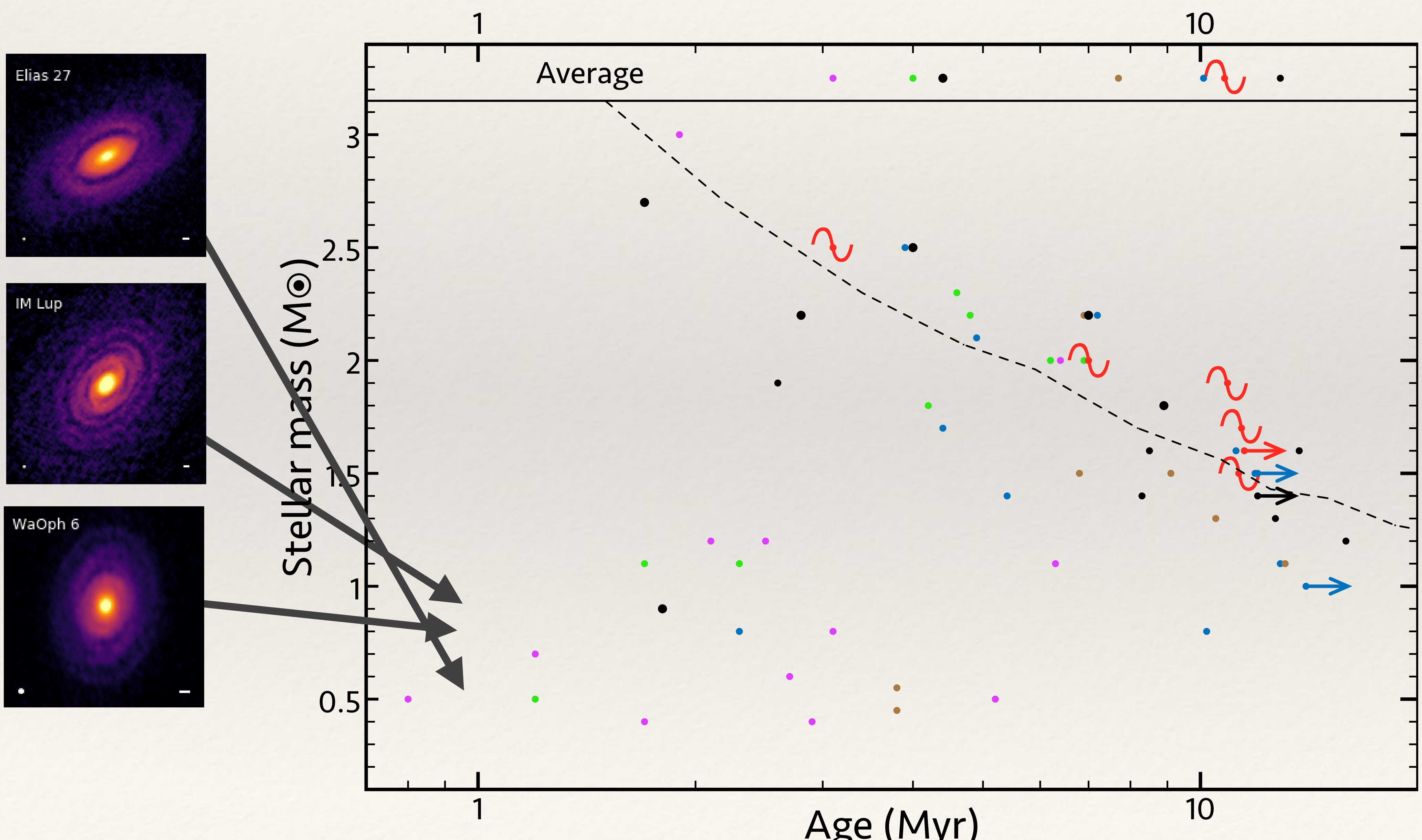

Garufi et al. 2018 (vs DSHARP)

Spirals & Shadows

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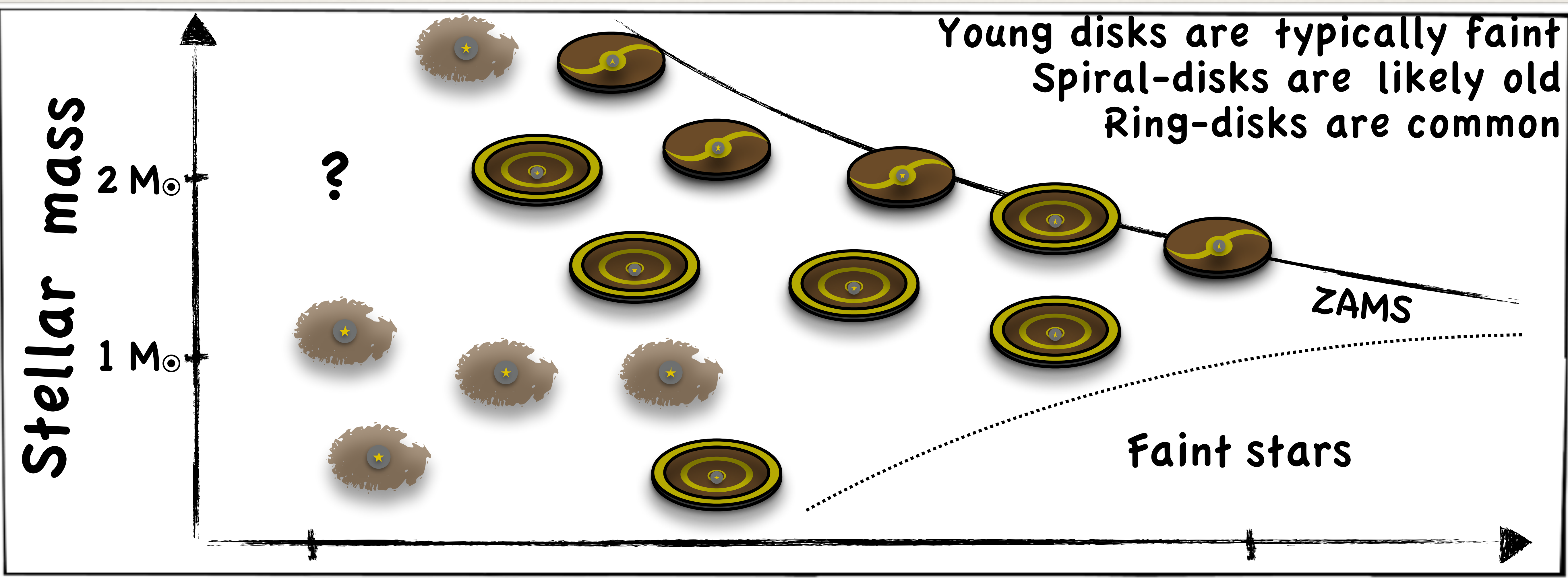
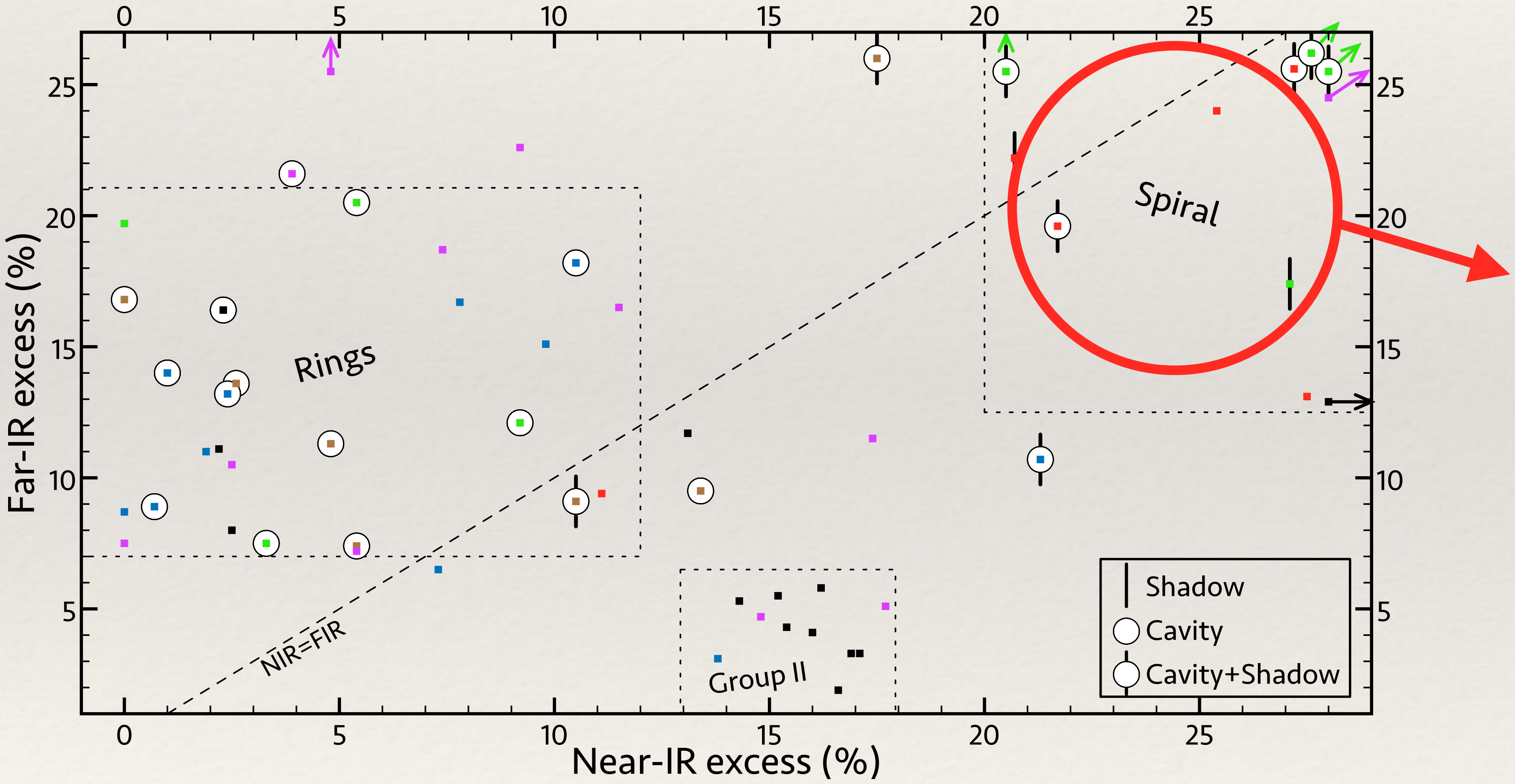


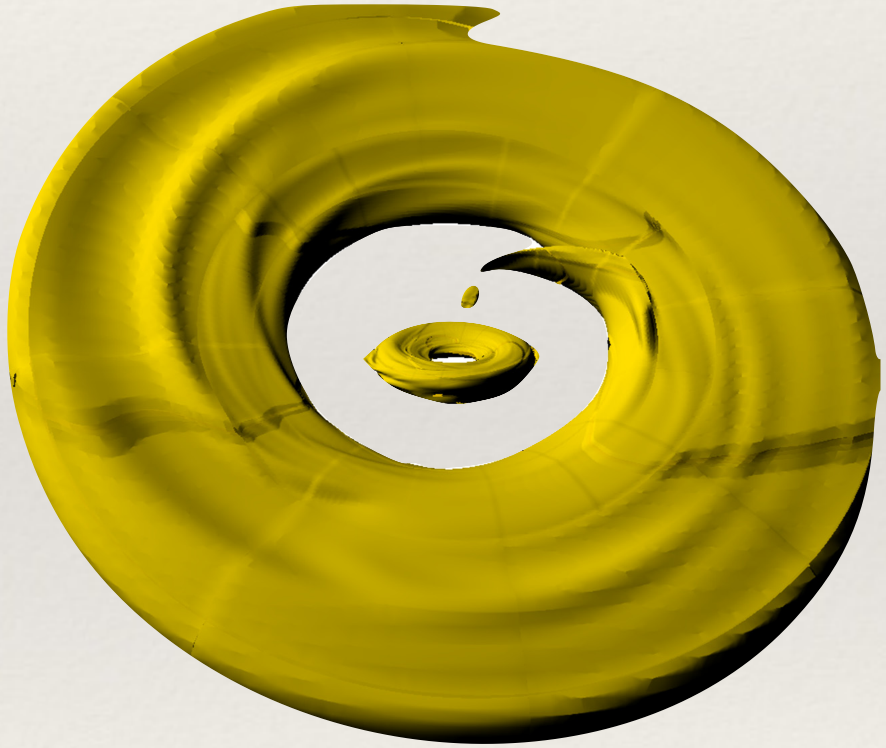
Garufi et al. 2018

Spirals & Shadows

Conclusion #4:

The link between high NIR, shadows, and spirals could be a misaligned companion that stirs up the inner disk, induce a warp, and excite spirals.





Garufi et al. 2018

Zhu 2019

Spirals & Shadows

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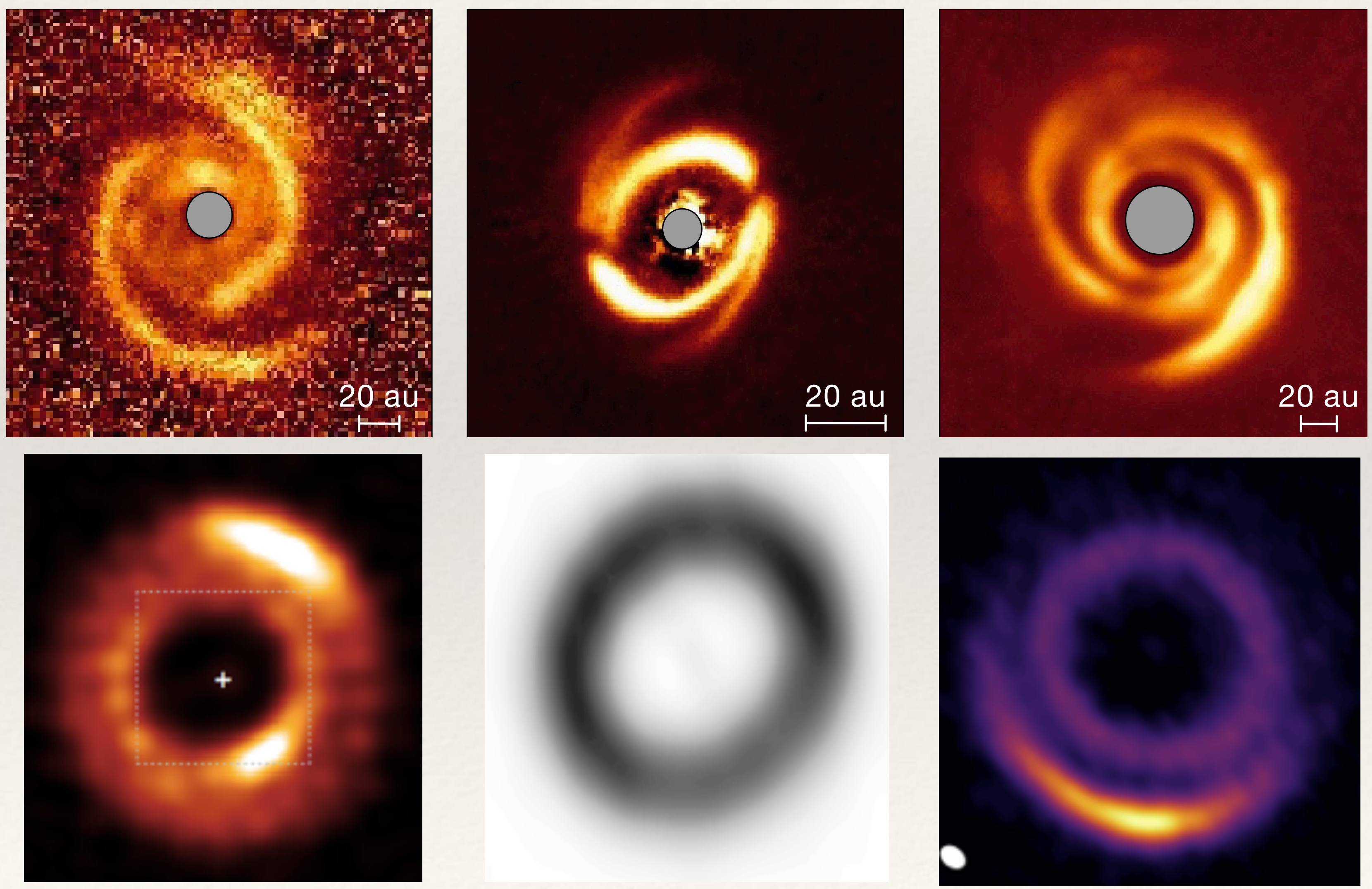
But what about the relative azimuthal asymmetries in the mm?



Benisty et al. 2015, 2017, Stolker et al. 2017, Boehler et al. 2018, van der Plas et al. 2019, Cazzoletti et al. 2018

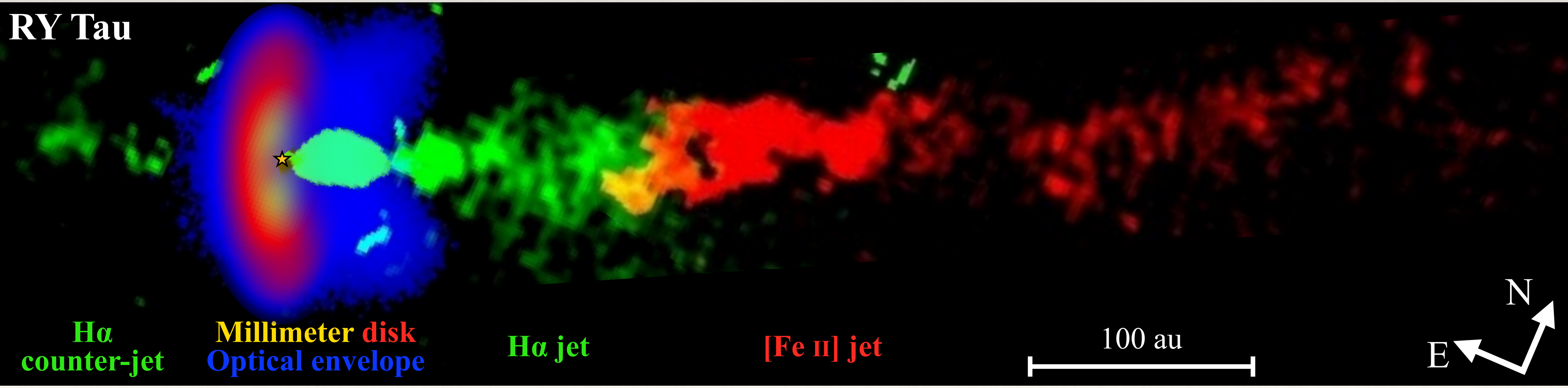
Conclusions

#1: We have mostly observed long-living, **massive disks** with a **cavity**. Cavities explain the Group I/II dichotomy.

#2: There are two families of disk cavities, **high-NIR** and **low-NIR**. The gas/dust interplay from the two is clearly different.

#3: The inner disk morphology leaves an imprint on the optical **jet**. Wiggling is a possible evidence of the presence of a disk **warp**.

#4: Spirals and **shadows** could be associated with misaligned **companions** responsible for a puffed-up and warped inner disk portion.



The system of RY Tau, Garufi et al. to be submitted (+ Long et al. 2018b)