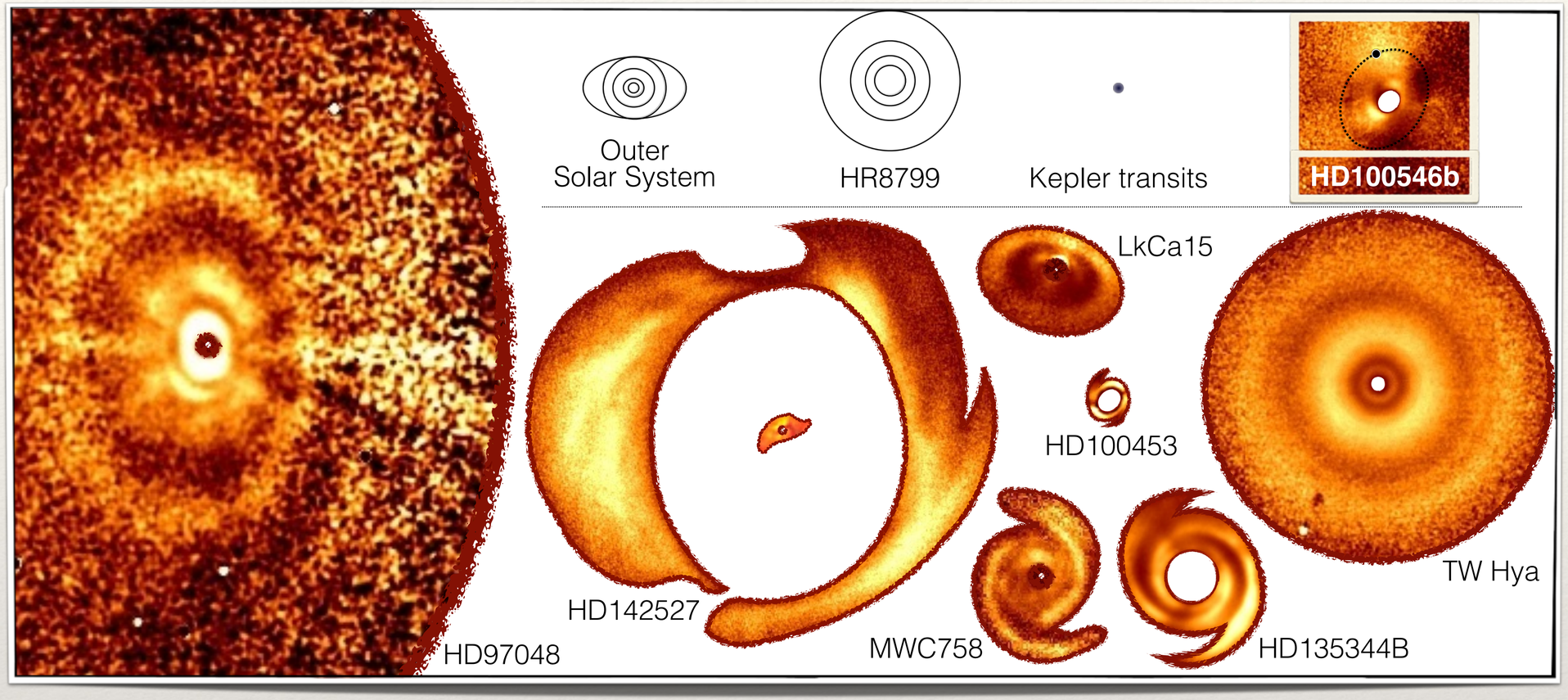


Great Barriers in Planet Formation, Palm Cove, Australia, 22 July 2019

OUR FIRST 100 PROTOPLANETARY DISKS

Morphology and evolution from high-resolution images

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, J. Szulágyi, SPHERE/GTO consortium

High-resolution images

Disk taxonomy ⇔ Morphology ⇔ ≲ **0.15**″ resolution.

Near-IR (scattered light).

Resolution naturally achieved.

Need long exposure; surveys are demanding.

Talks: Benisty, Mauco, Hunziker

Millimeter (continuum emission).

Only ALMA (for now); specific configuration required.

Snapshot exposures are also possible.

Talks: previous, Huang, Perez, van der Marel…

High-resolution images

Disk taxonomy ⇔ Morphology ⇔ ≲ **0.15**″ resolution.

Near-IR (scattered light).

Approximately 50 disks with published observations.

(>40 observed and yet unpublished)

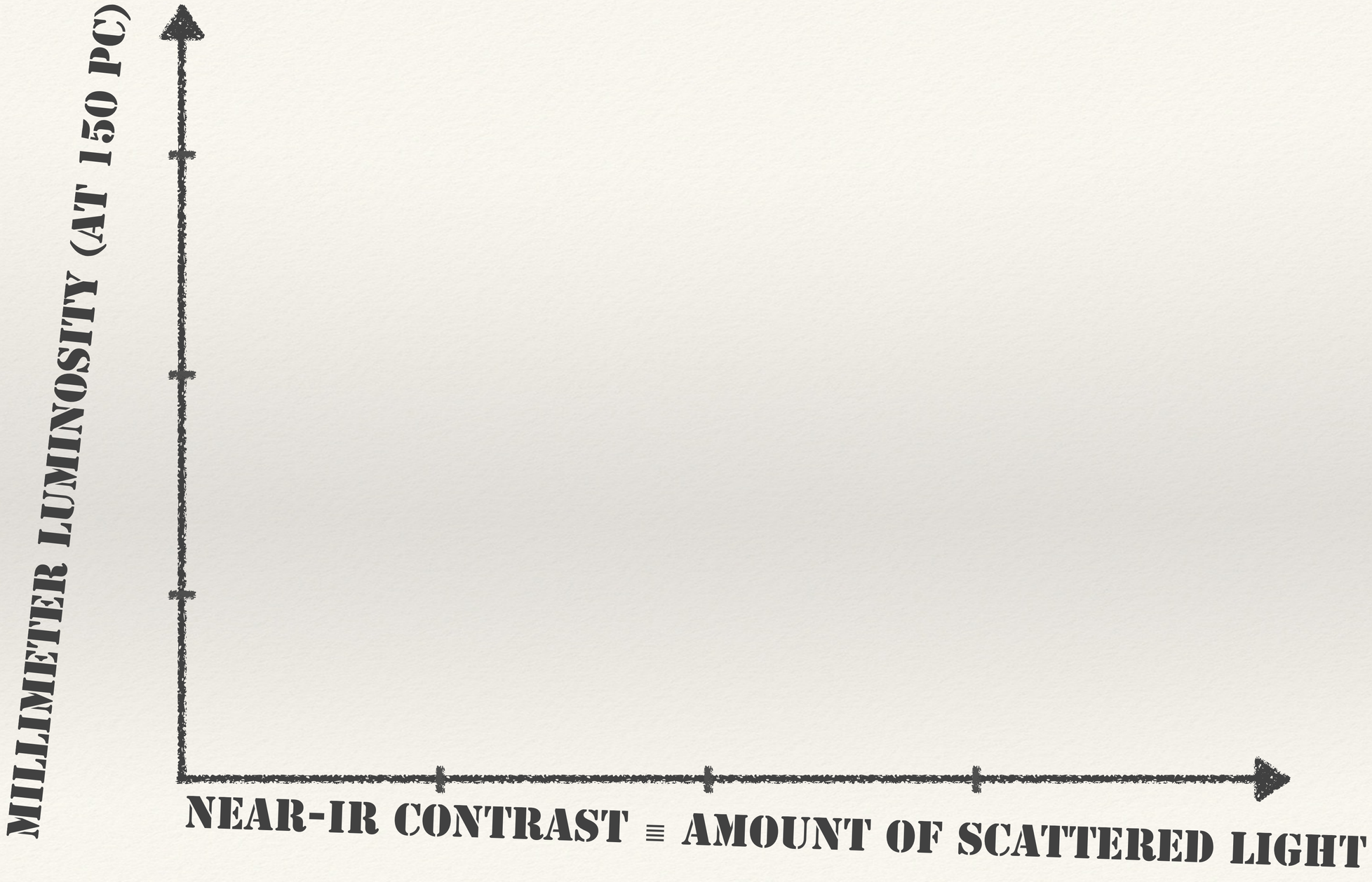
Millimeter (continuum emission).

Over 50 disks with published observations.

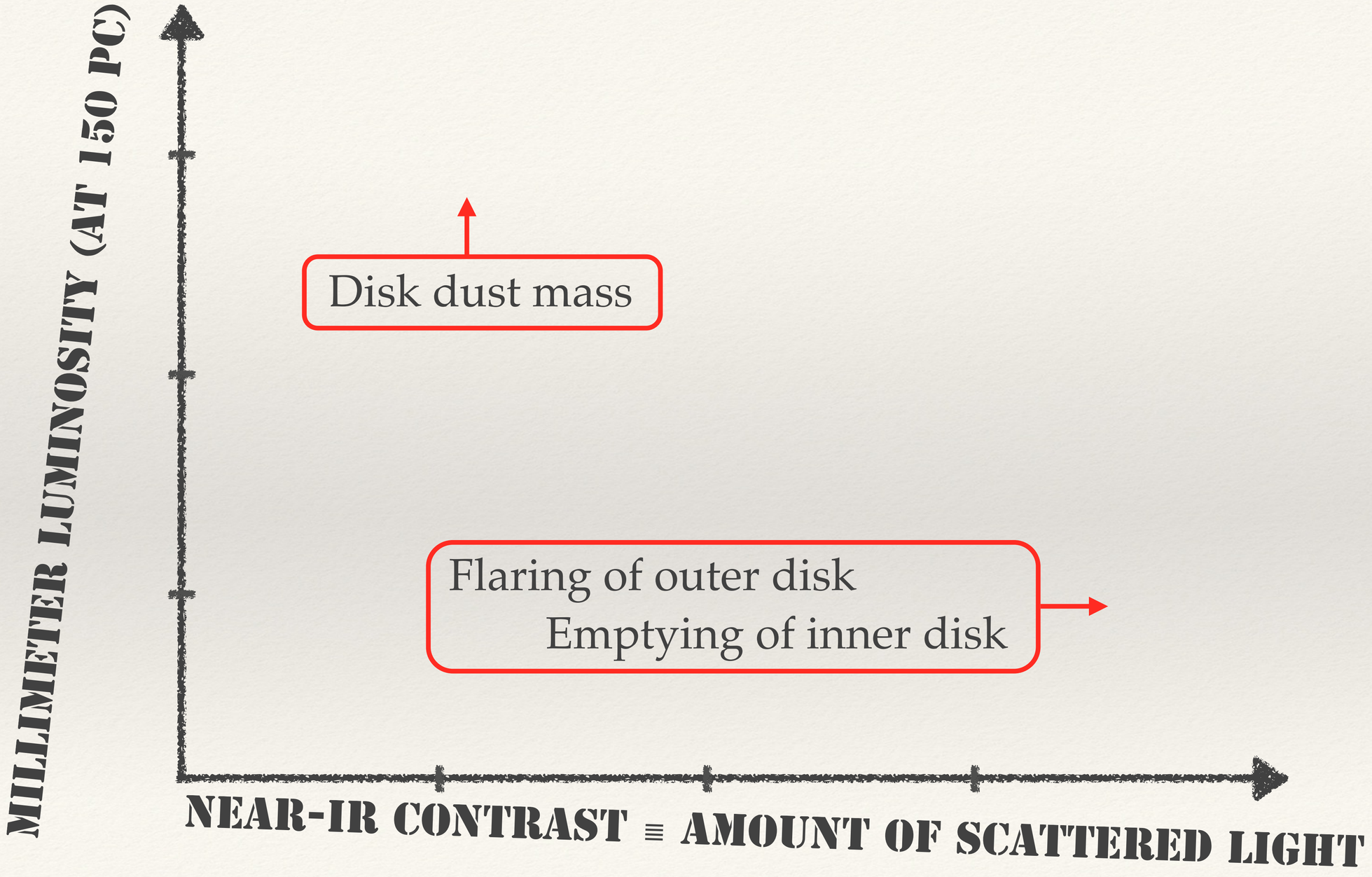
(depending on the desired resolution)

Only 30 disks with both, more than **100** in total.

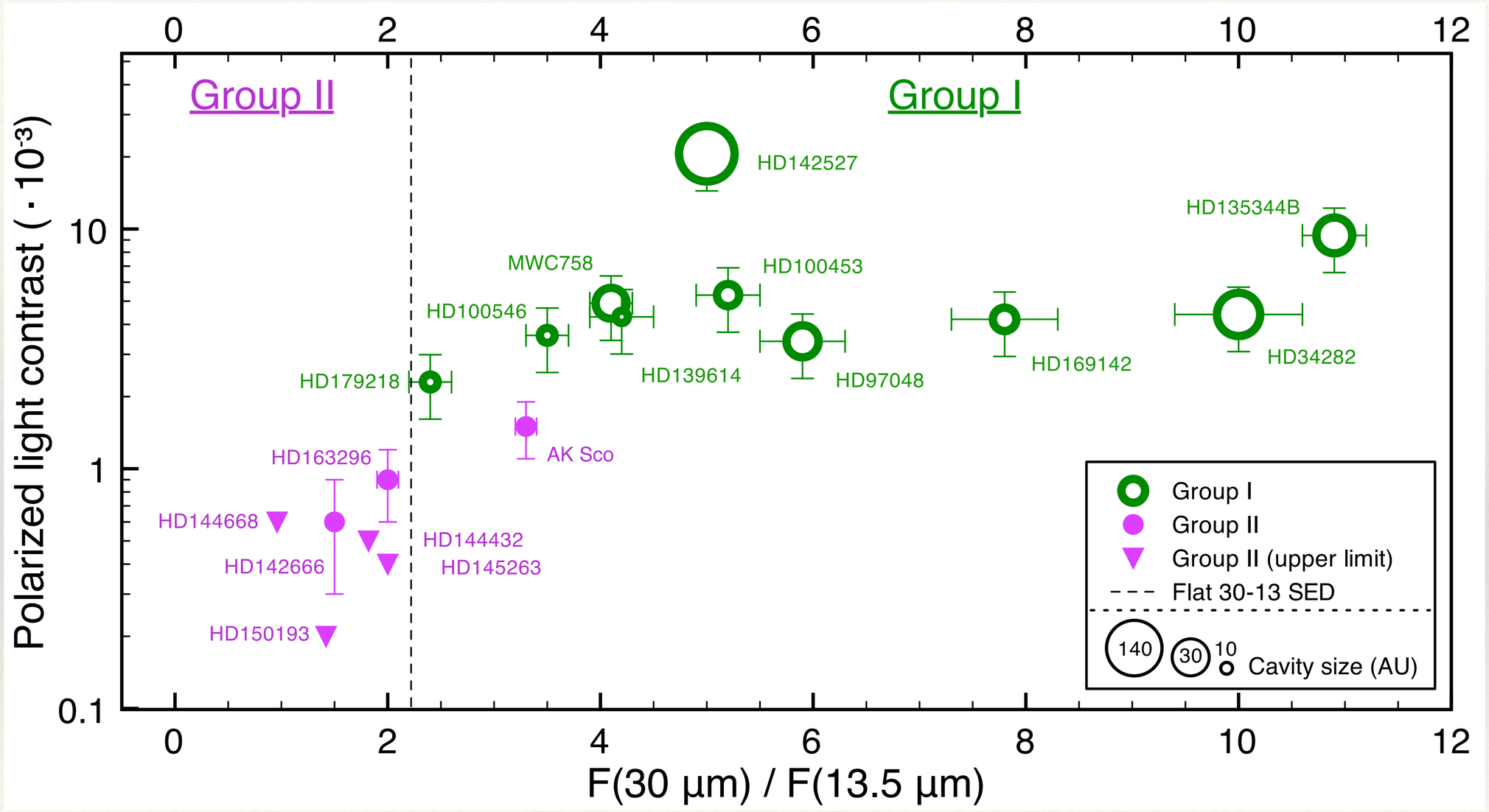
NIR-millimeter diagram



NIR-millimeter diagram

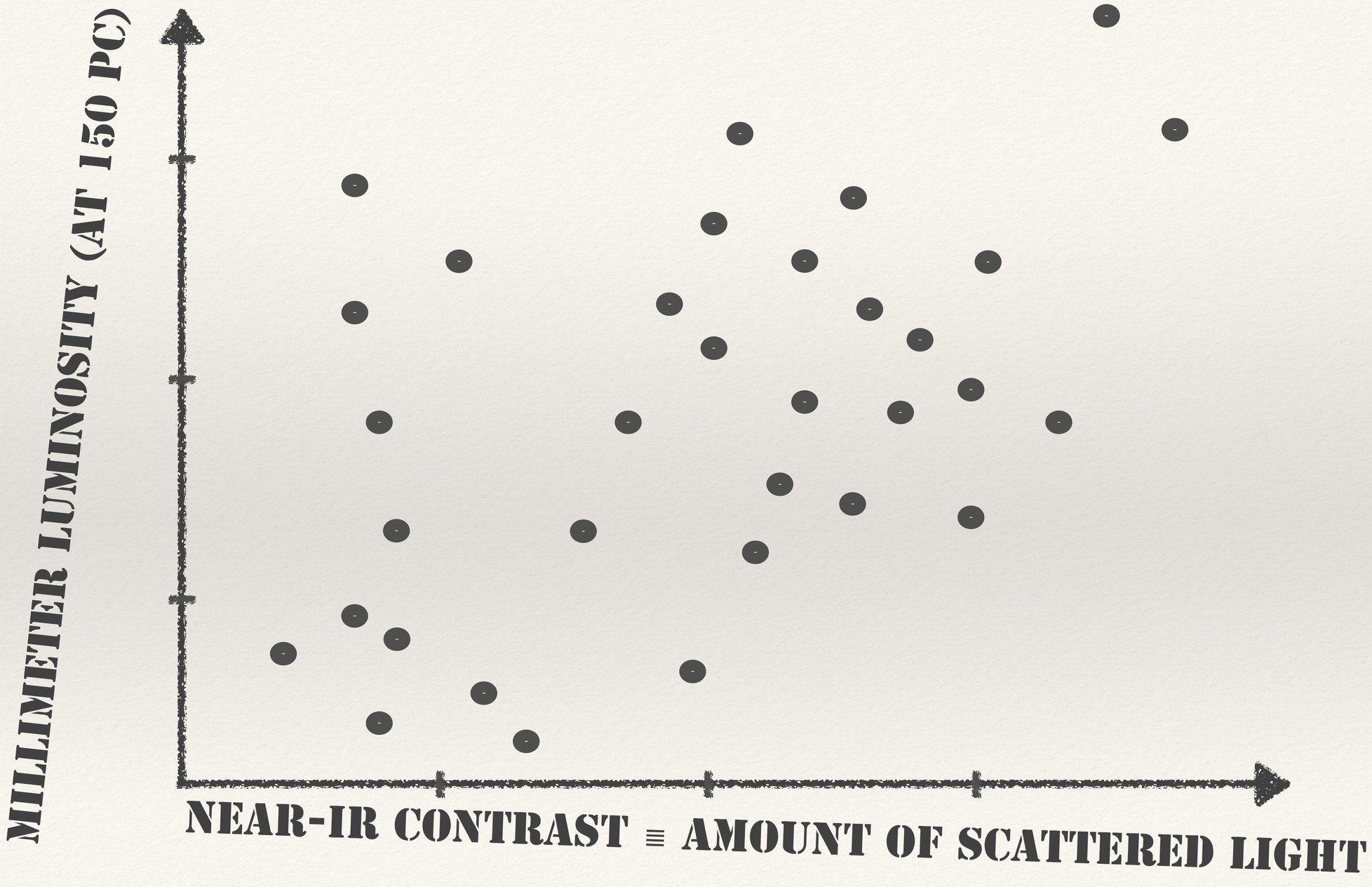


NIR-millimeter diagram

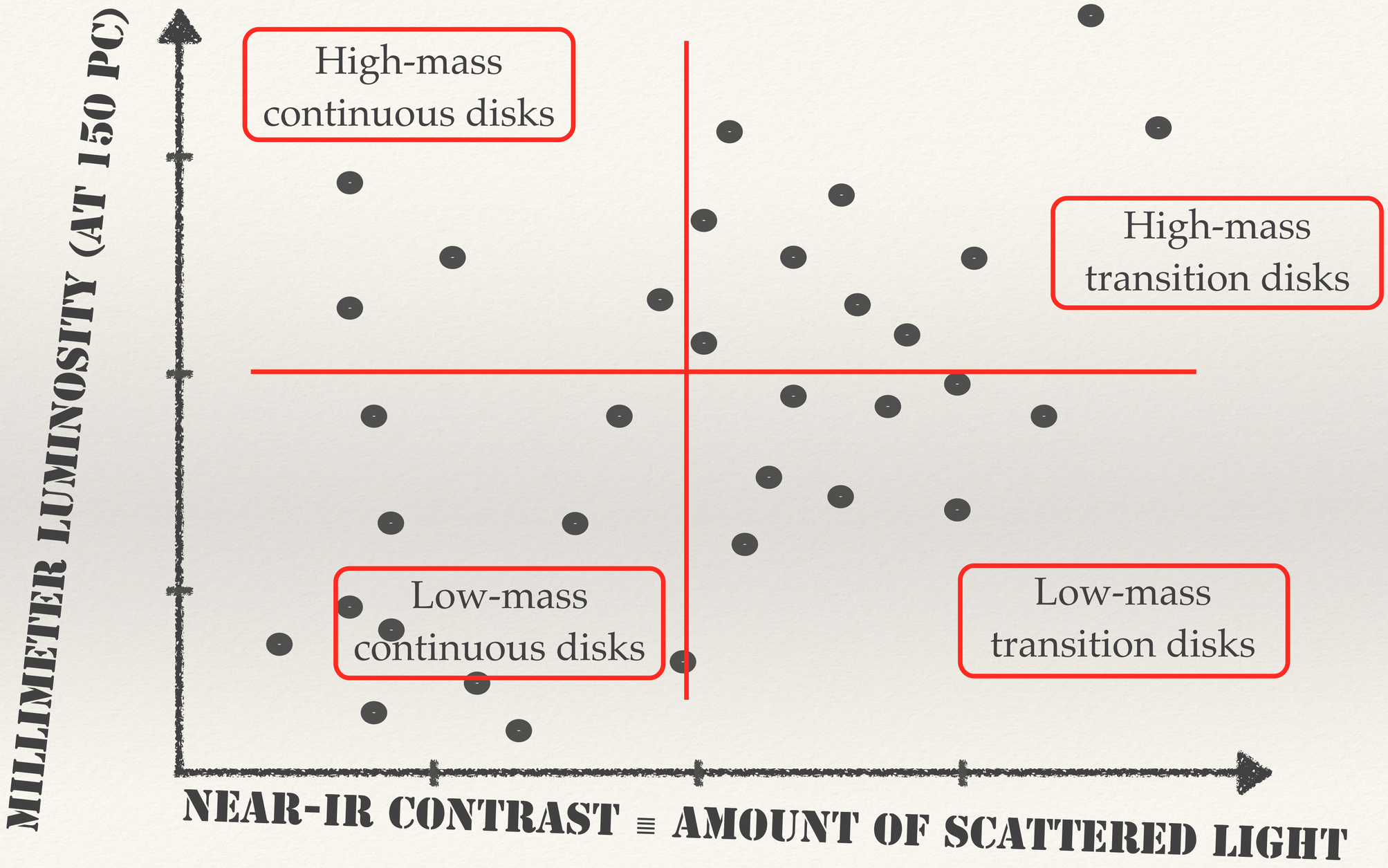


Disks with a cavity are brighter in scattered light. **Garufi, Meeus, Benisty et al. 2017**

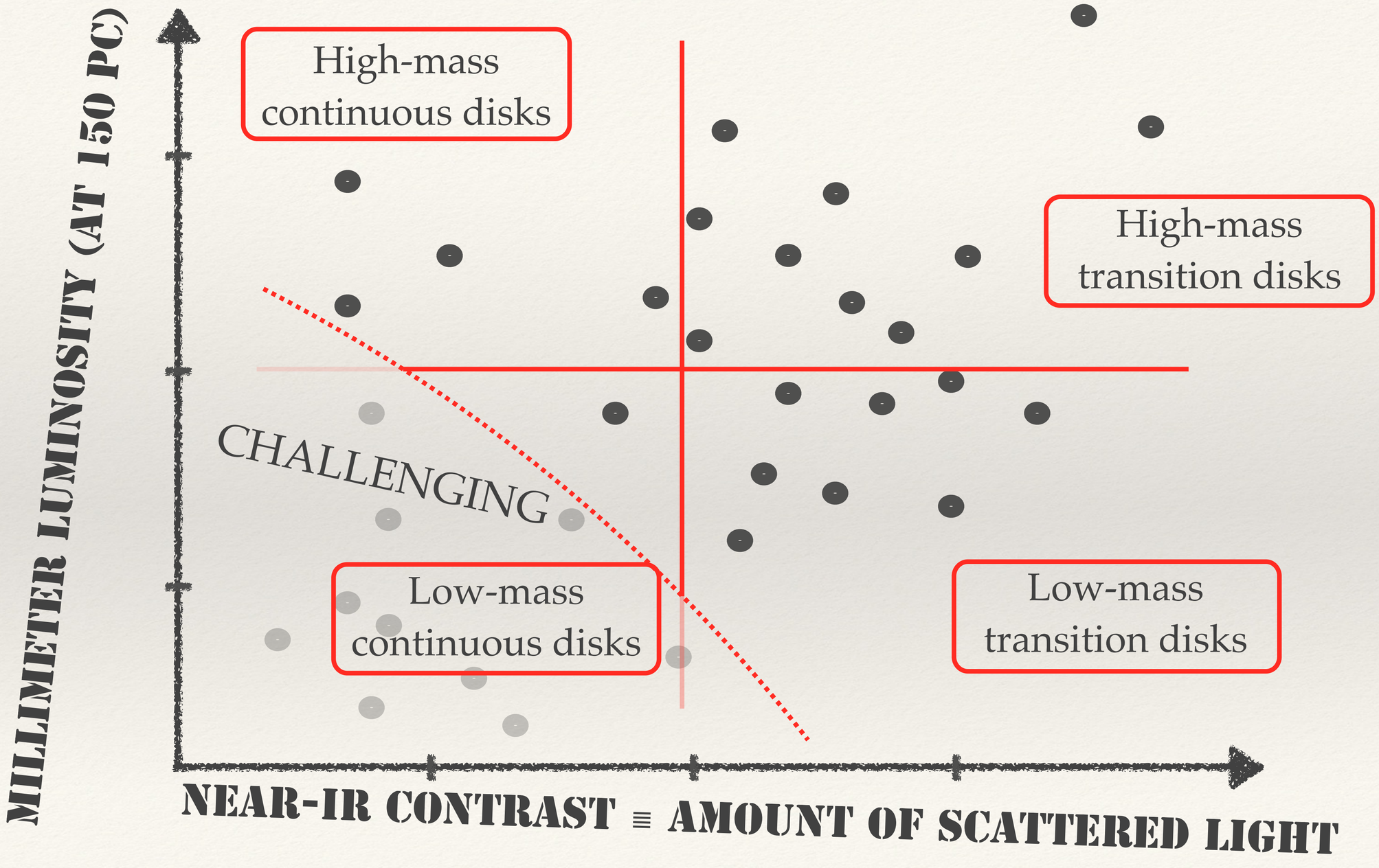
NIR-millimeter diagram



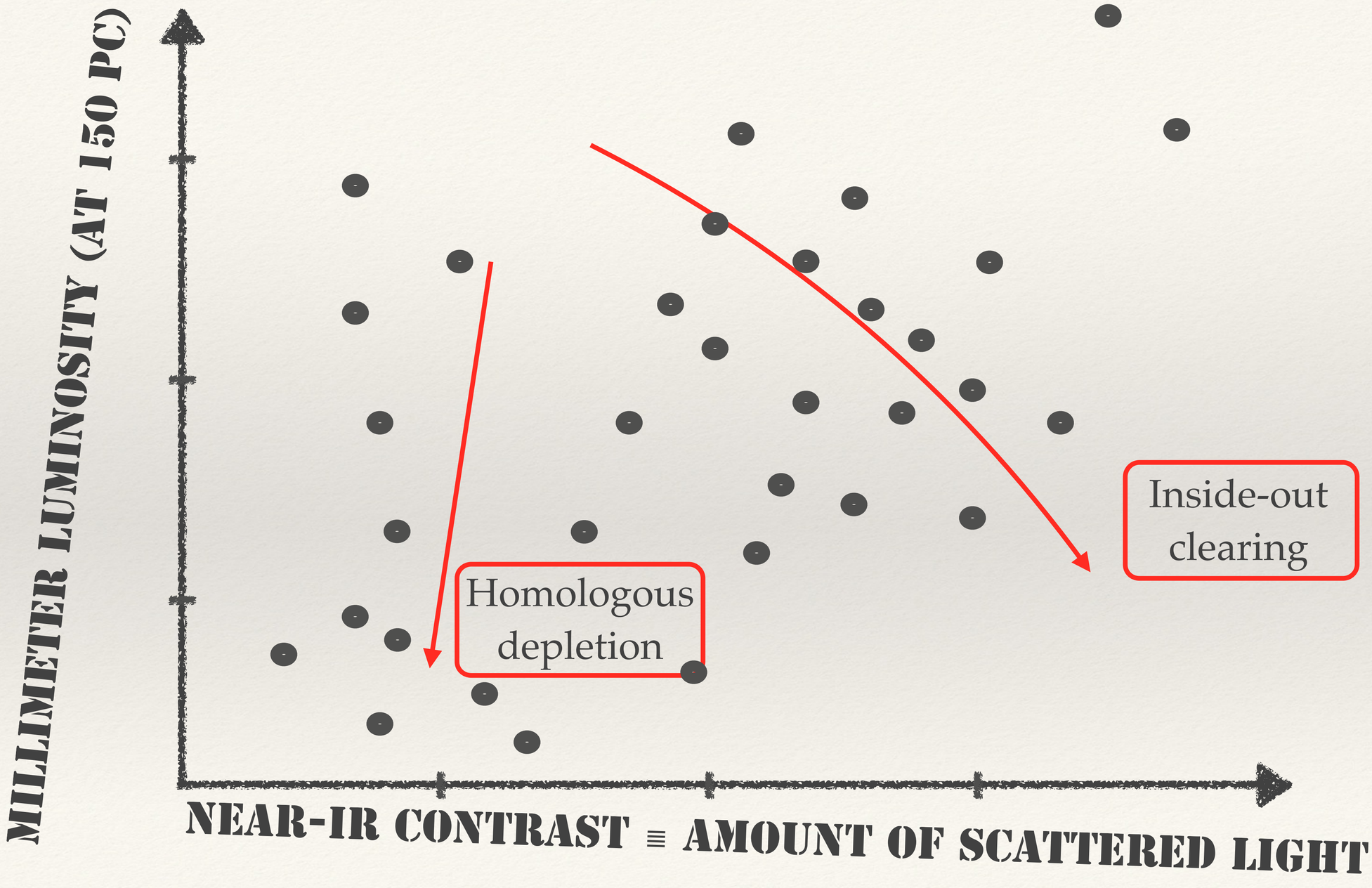
NIR-millimeter diagram



NIR-millimeter diagram

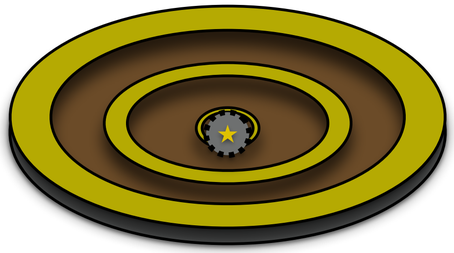


NIR-millimeter diagram



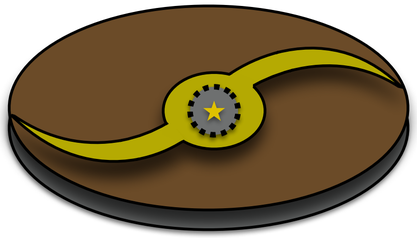
Taxonomy in the NIR

Rings



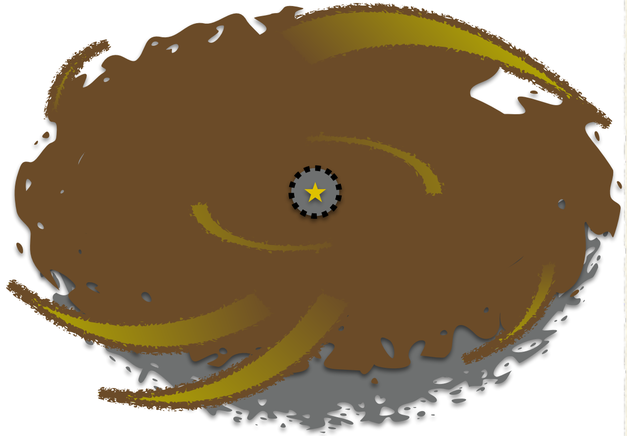
Multiple symmetric, bright annuli.
Prototypes: TW Hya, HD97048.

Spirals



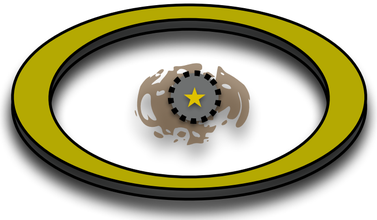
Symmetric, bright spirals on small scale.
Prototypes: HD135344B, MWC758.

Giant



Wrapped, asymmetric arms on large scale.
Prototypes: HD100546, HD34282.

Rim



Mainly one ring around a cavity.
Prototypes: J1604, PDS70.

Faint

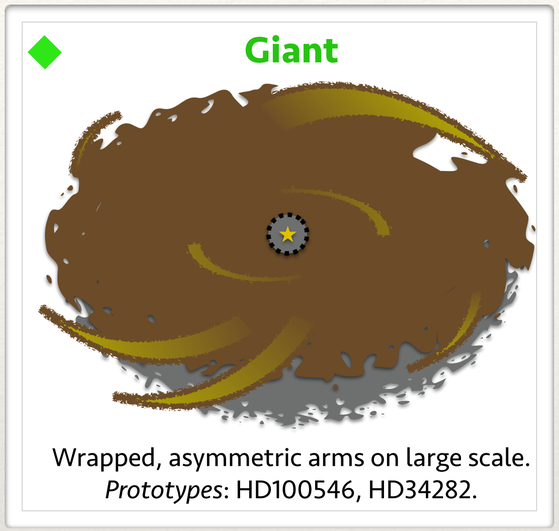
Low signal. No feature visible.
Prototypes: RU Lup, MWC480.

Small

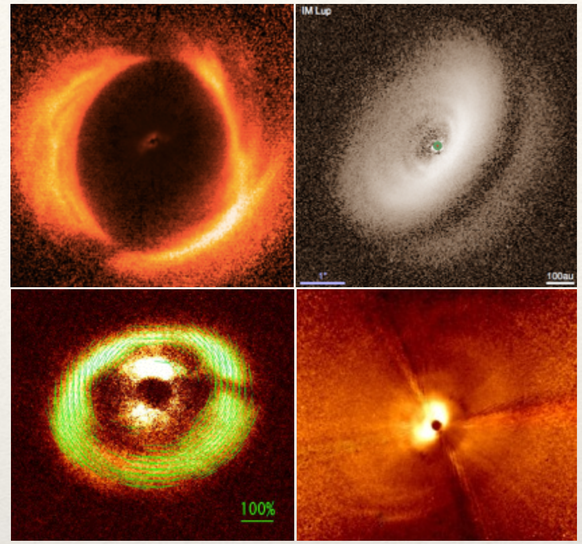
Signal on very small scale.
Prototypes: HD150193, CS Cha.

Garufi, Benisty, Pinilla et al. 2018

The extremes: giant vs small disks



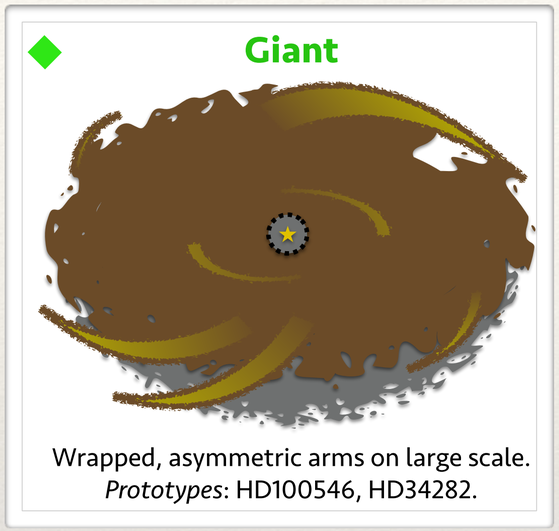
Abnormally massive, large disks.
All known and characterized.
Precursor of HR8799?
Special formation, slow evolution?



Avenhaus et al. 2017, 2018
Itoh et al. 2014, Sissa et al. 2018

Normally small disks?
Routinely imaged, not characterized
Truncated or smaller version?
What planetary systems from them?

The extremes: giant vs small disks



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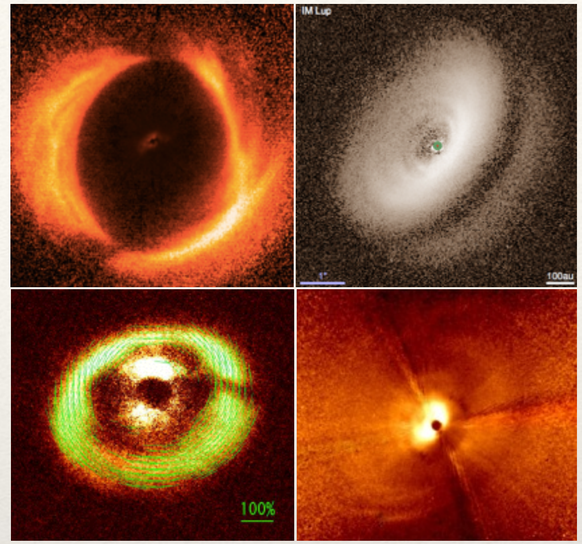

Avenhaus et al. 2017, 2018
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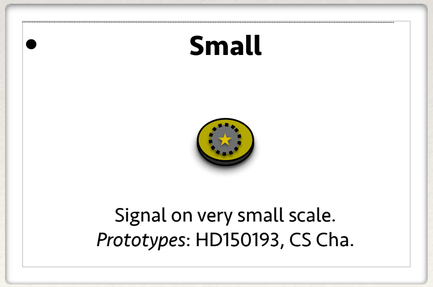
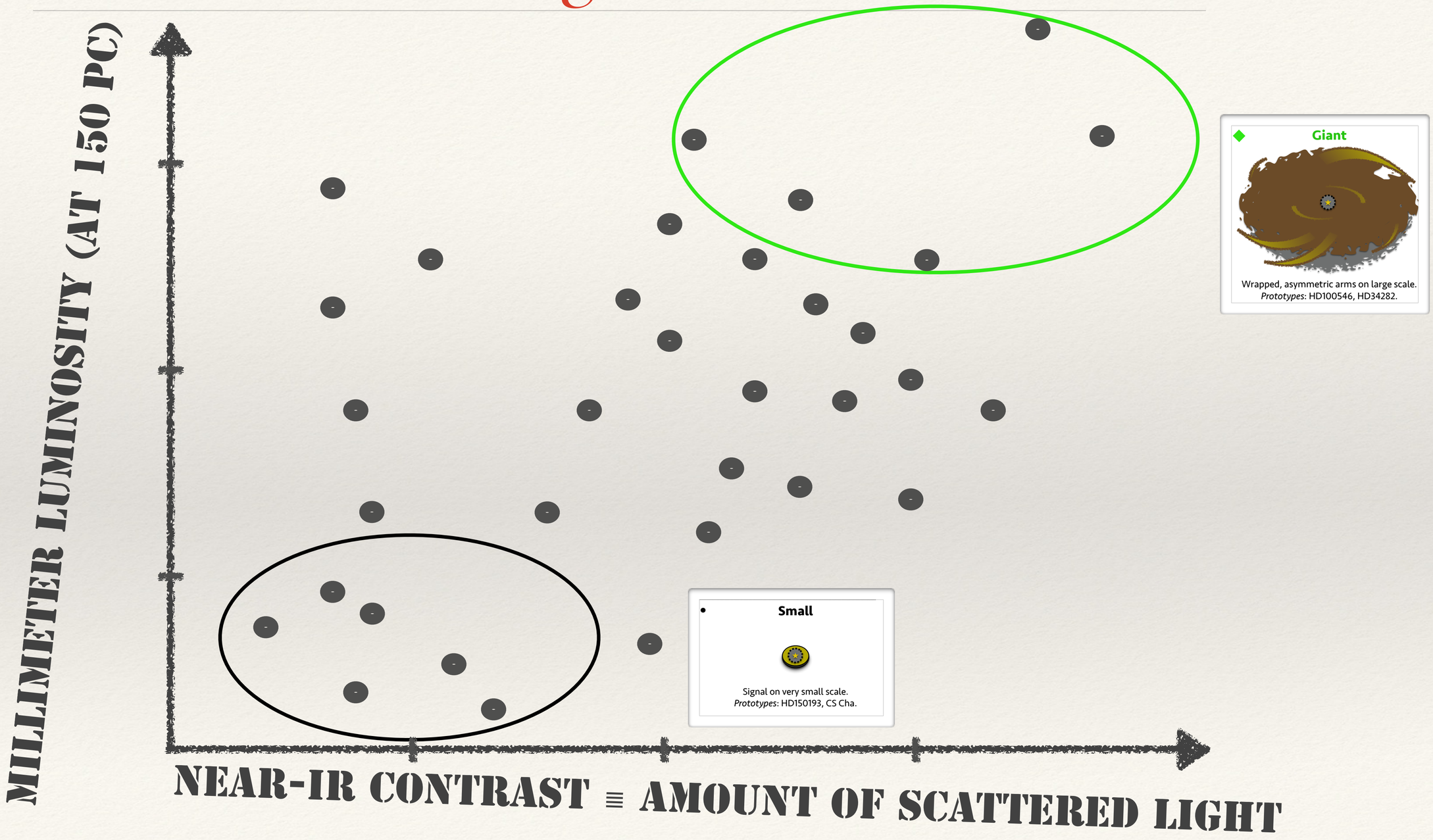
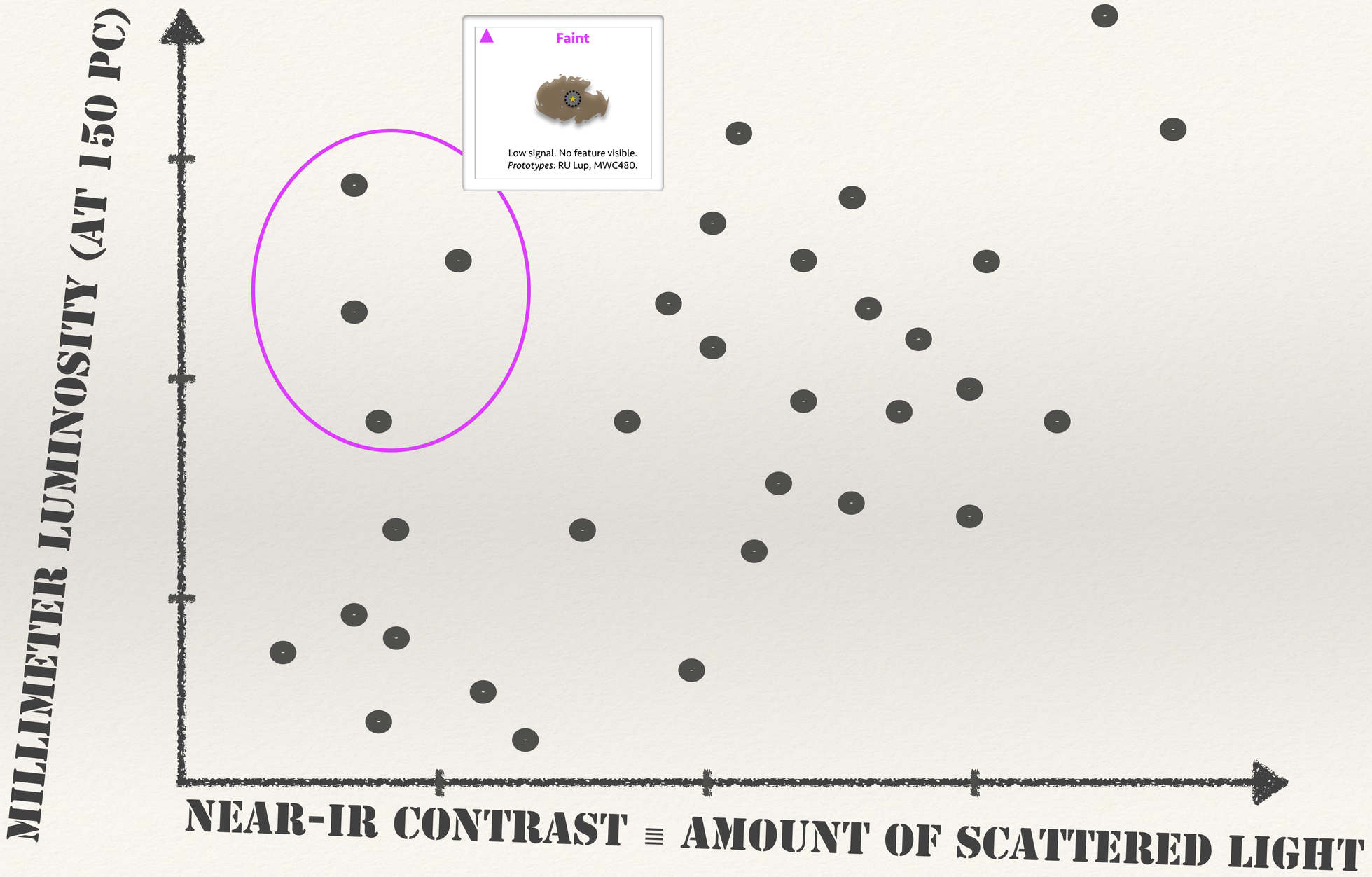


Normally small disks? (e.g., Barenfeld et al. 2017)
Routinely imaged, not characterized (e.g., Dominik et al. in prep.)
Truncated or smaller version? (e.g., Manara et al. 2019)
What planetary systems from them?

The extremes: giant vs small disks



The surprise: faint disks (in NIR)



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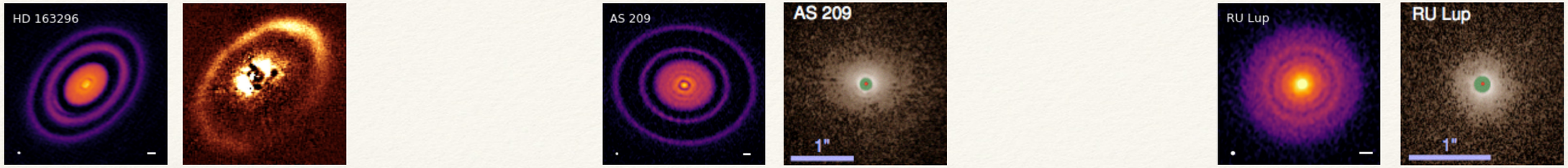
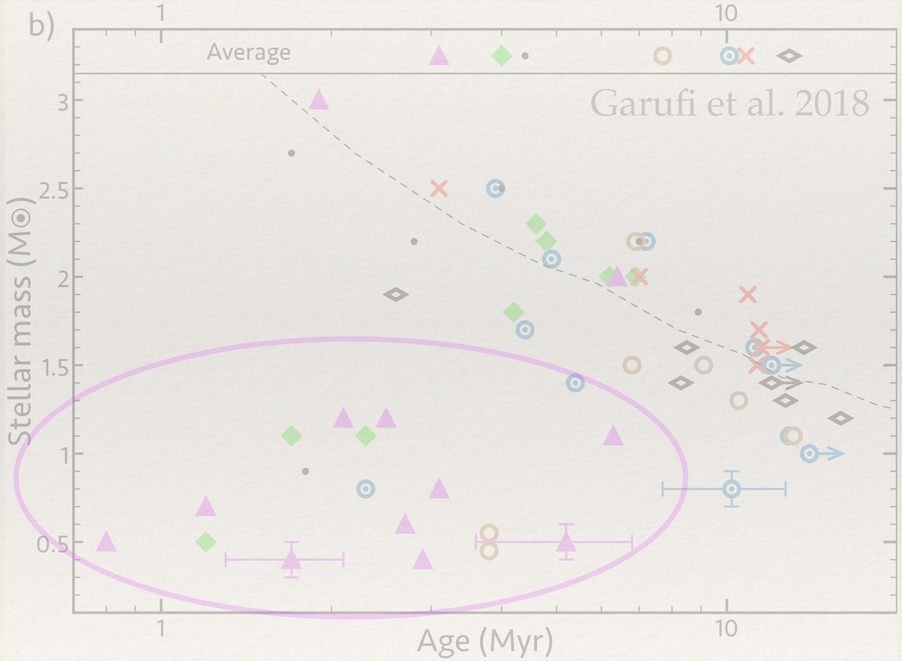


Andrews et al. 2018 vs Muro-Arena et al. 2018 and Avenhaus et al. 2018

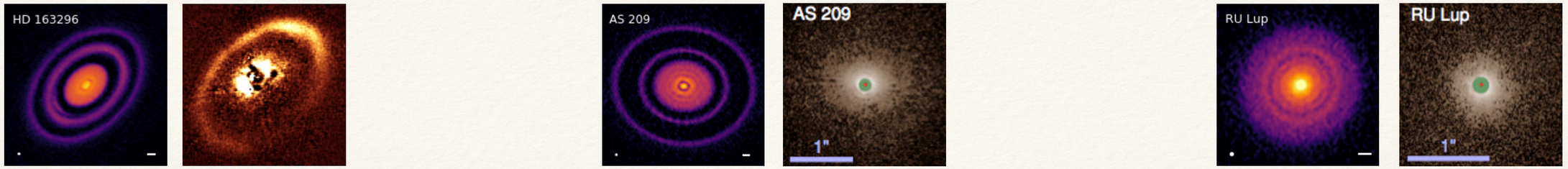
Even massive disks can be faint in the NIR, if there is no **cavity**.



Faint disks are typically young.

Does it mean that cavity has not yet formed or that these disks will not make it to >5 Myr?

The surprise: faint disks (in NIR)



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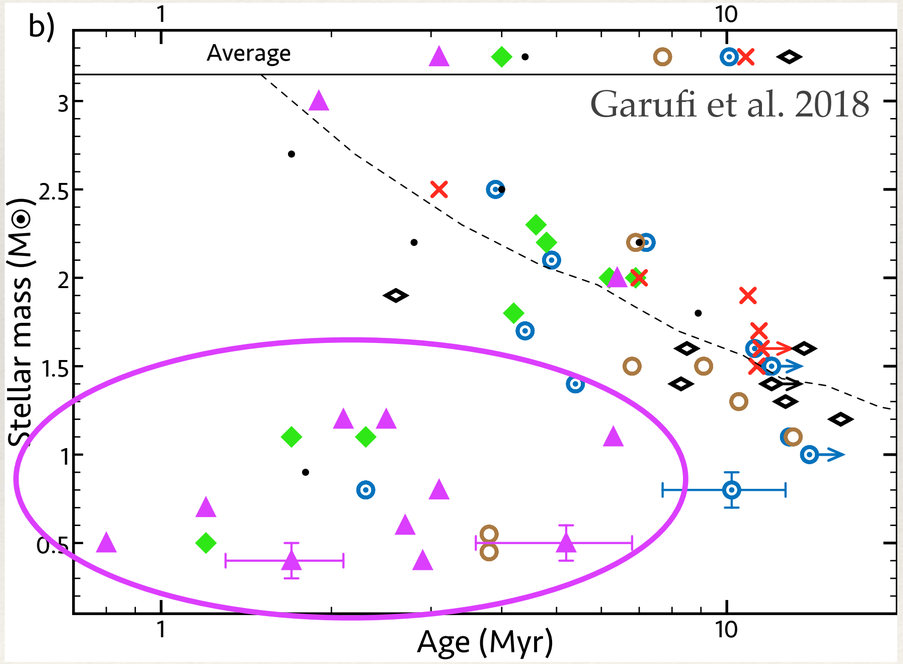

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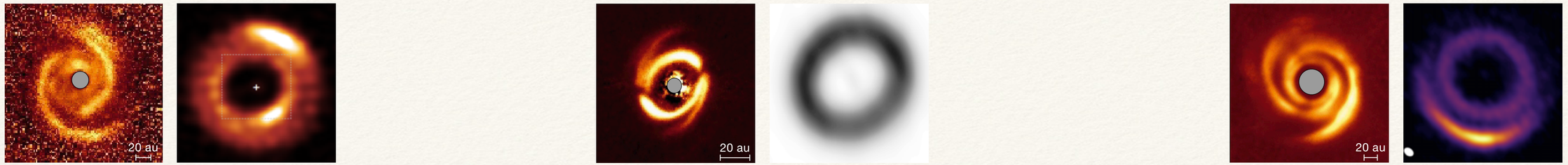
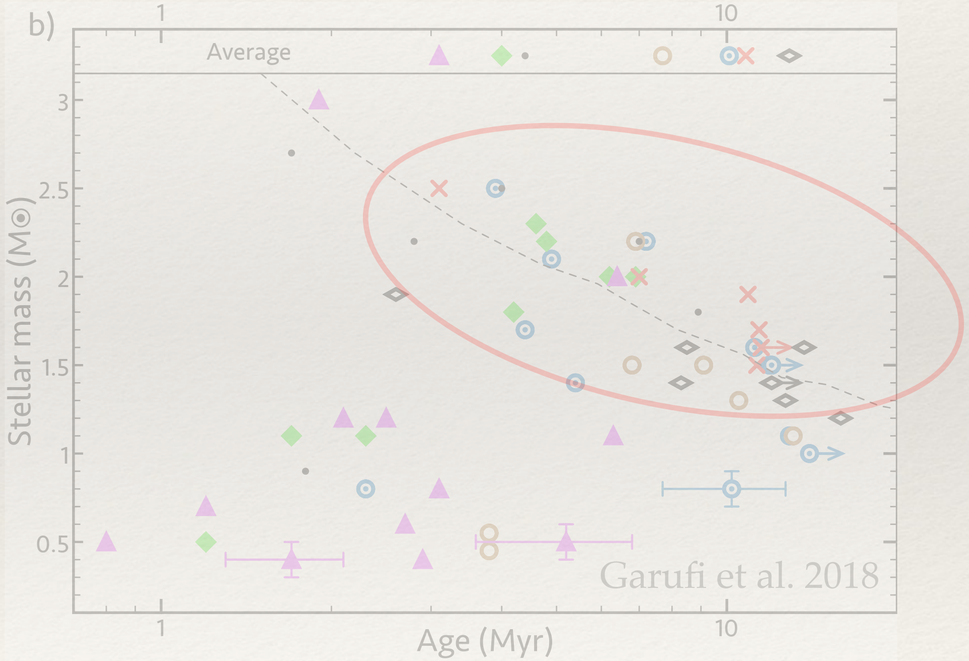
The celebrity: spirals disks (NIR vs mm)



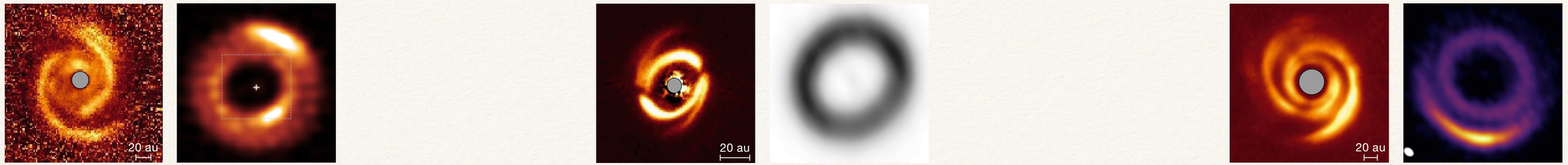
Benisty et al. 2015, 2017, Stolker et al. 2017, Boehler et al. 2018, van der Plas et al. 2019, Cazzoletti et al. 2018

NIR spirals are only seen around Herbig. There is no millimeter counterpart.



NIR-spiral disks are typically old.

The celebrity: spirals disks (NIR vs mm)



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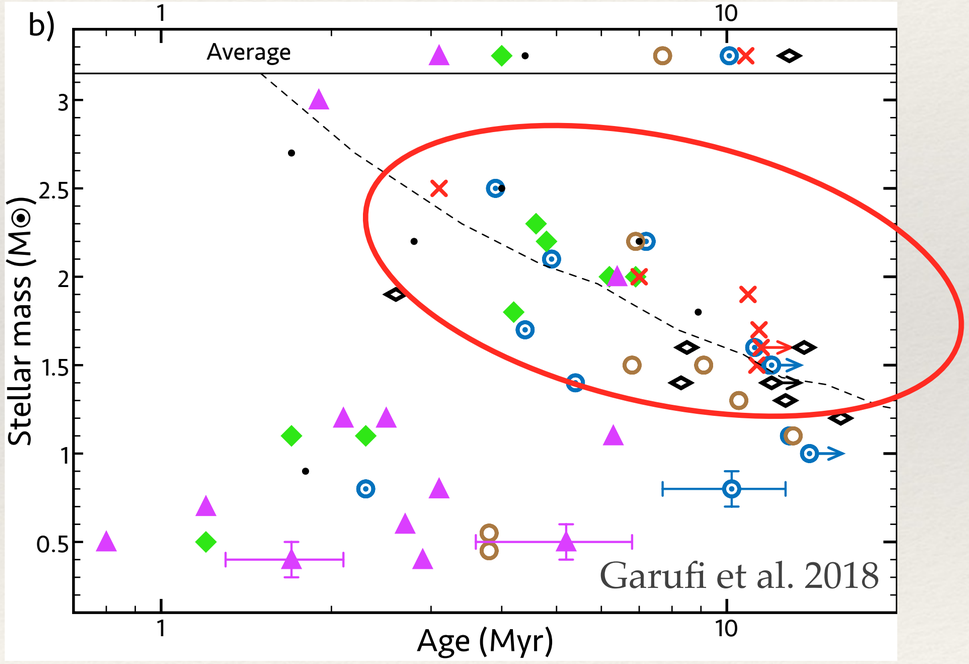

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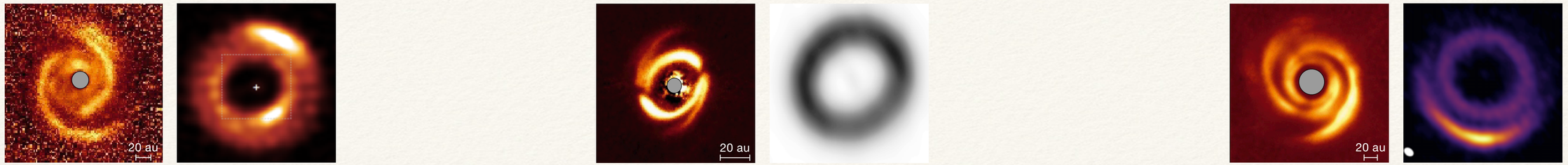

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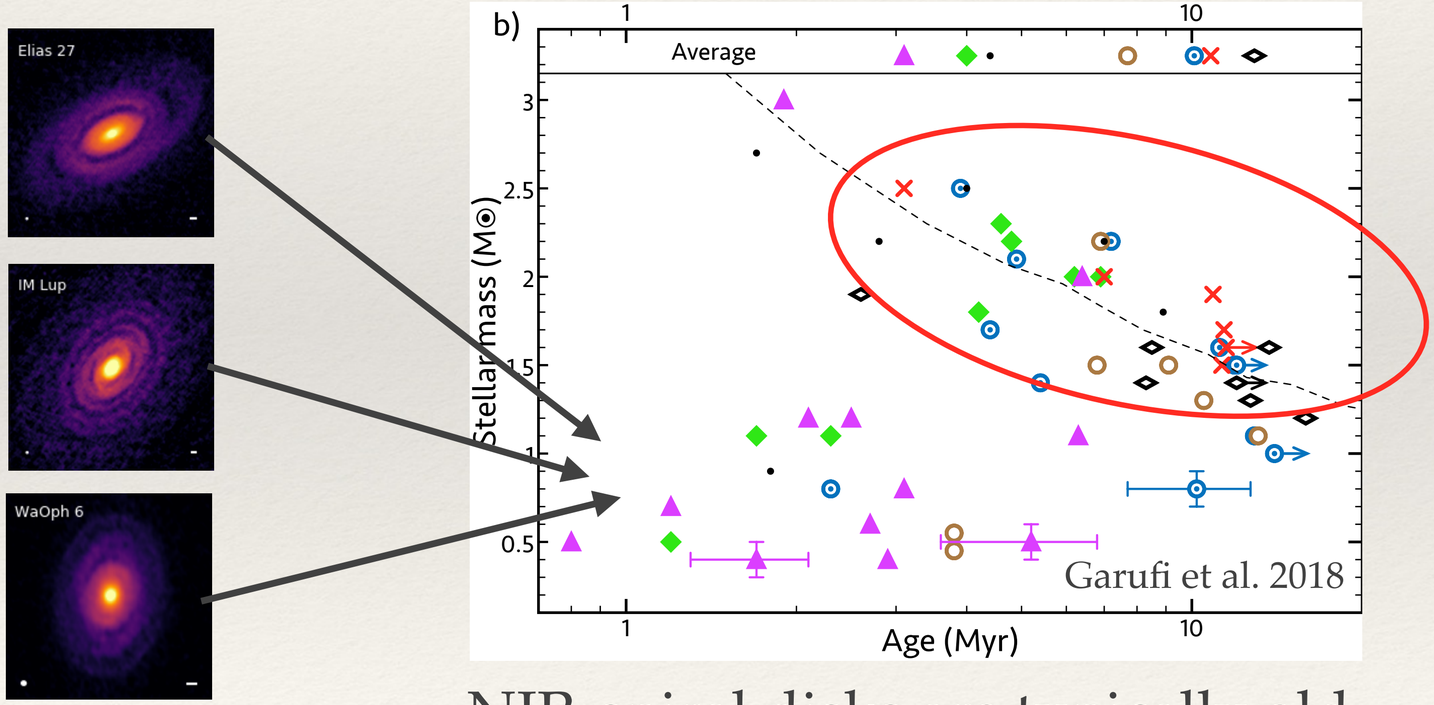
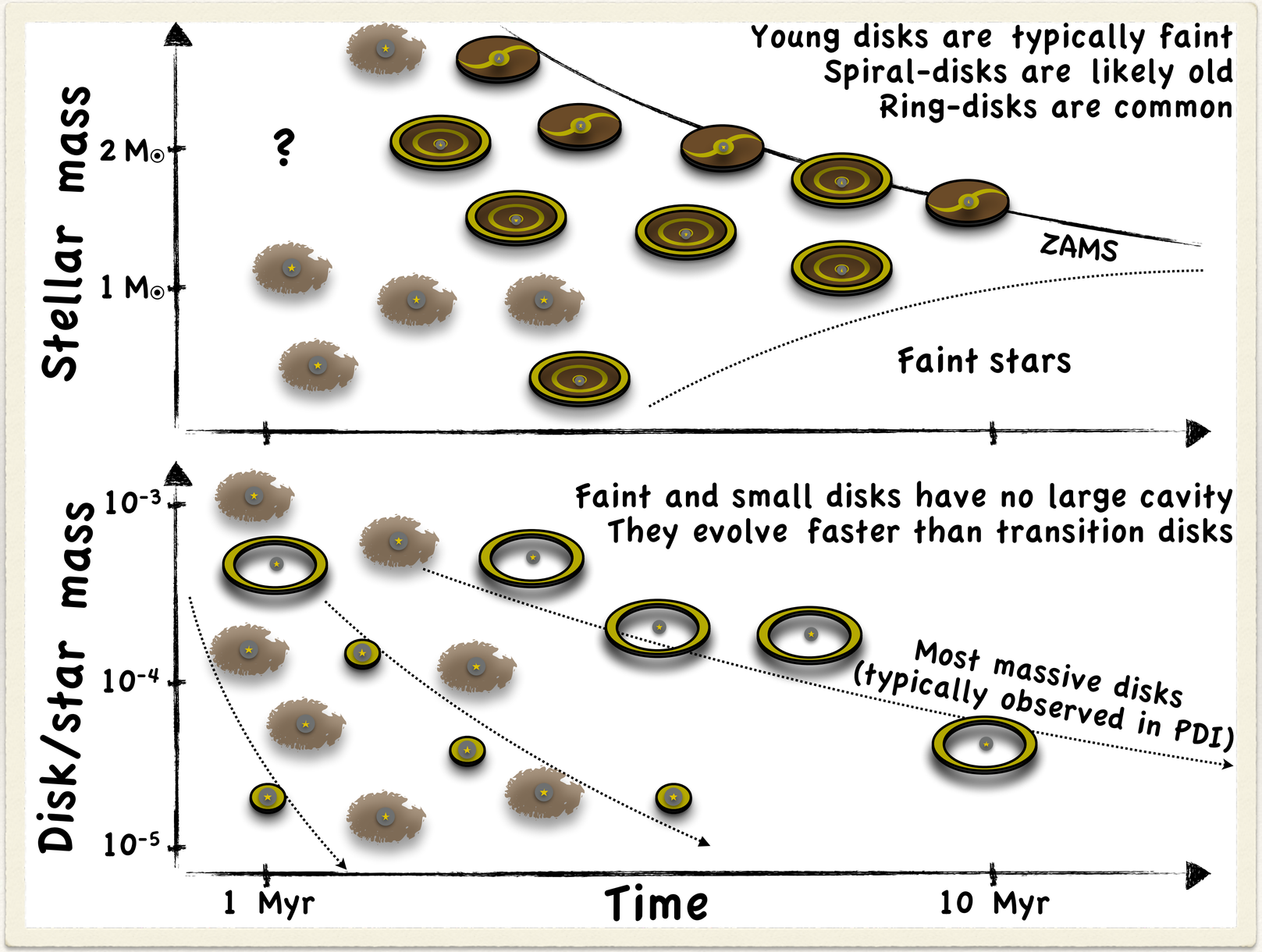


NIR-spiral disks are typically old.

Different origin from the mm-spiral disks, that are young?

Taxonomy in the NIR: summary



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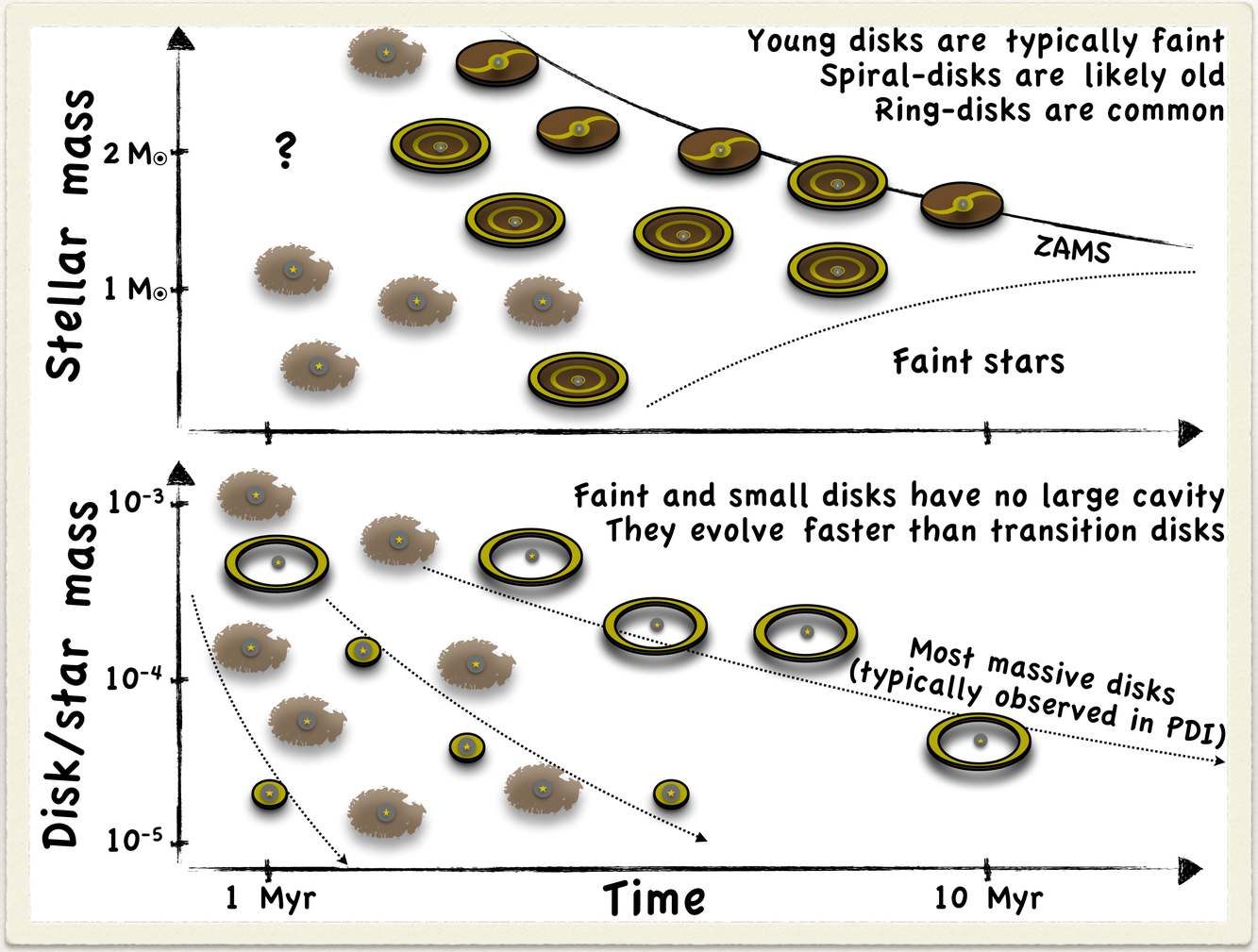
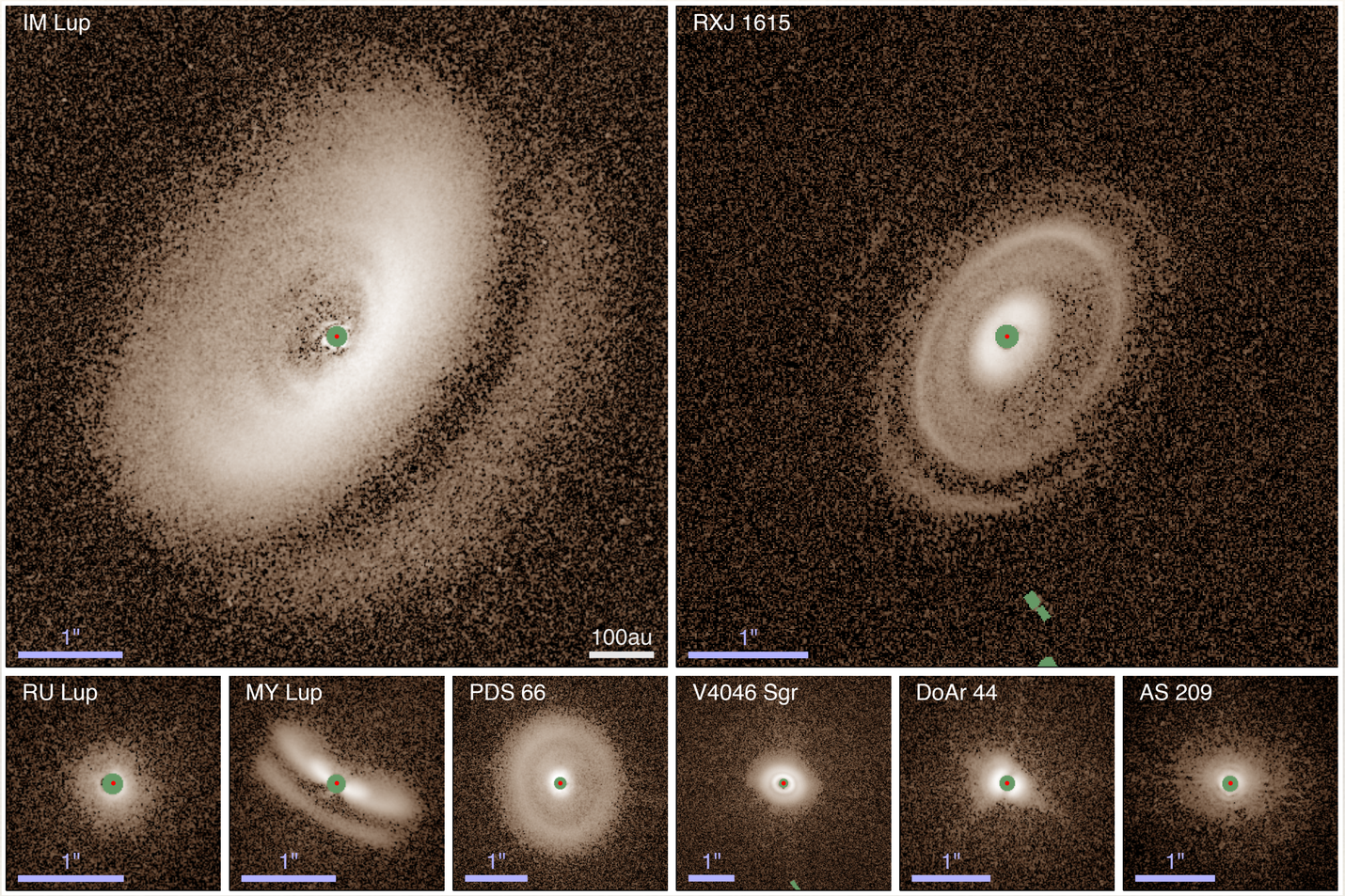
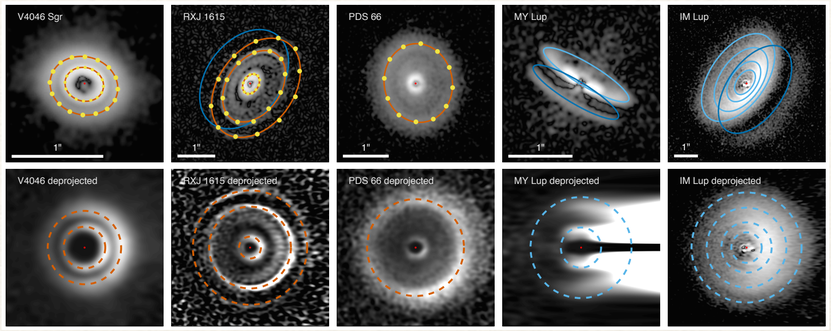
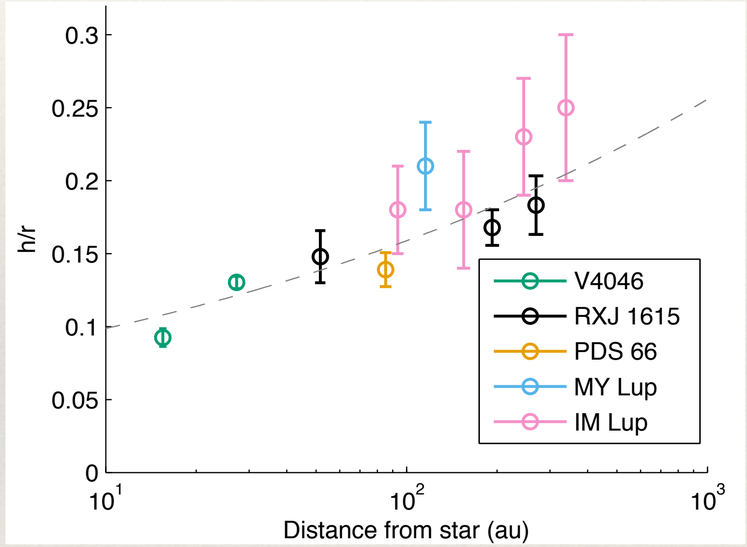


Immediate future: push observations to smaller/fainter disks and to TTSs.
Beyond SPHERE/GTO: **DARTTS** and **DESTINYS**…

DARTTS (Disks around TTSs)



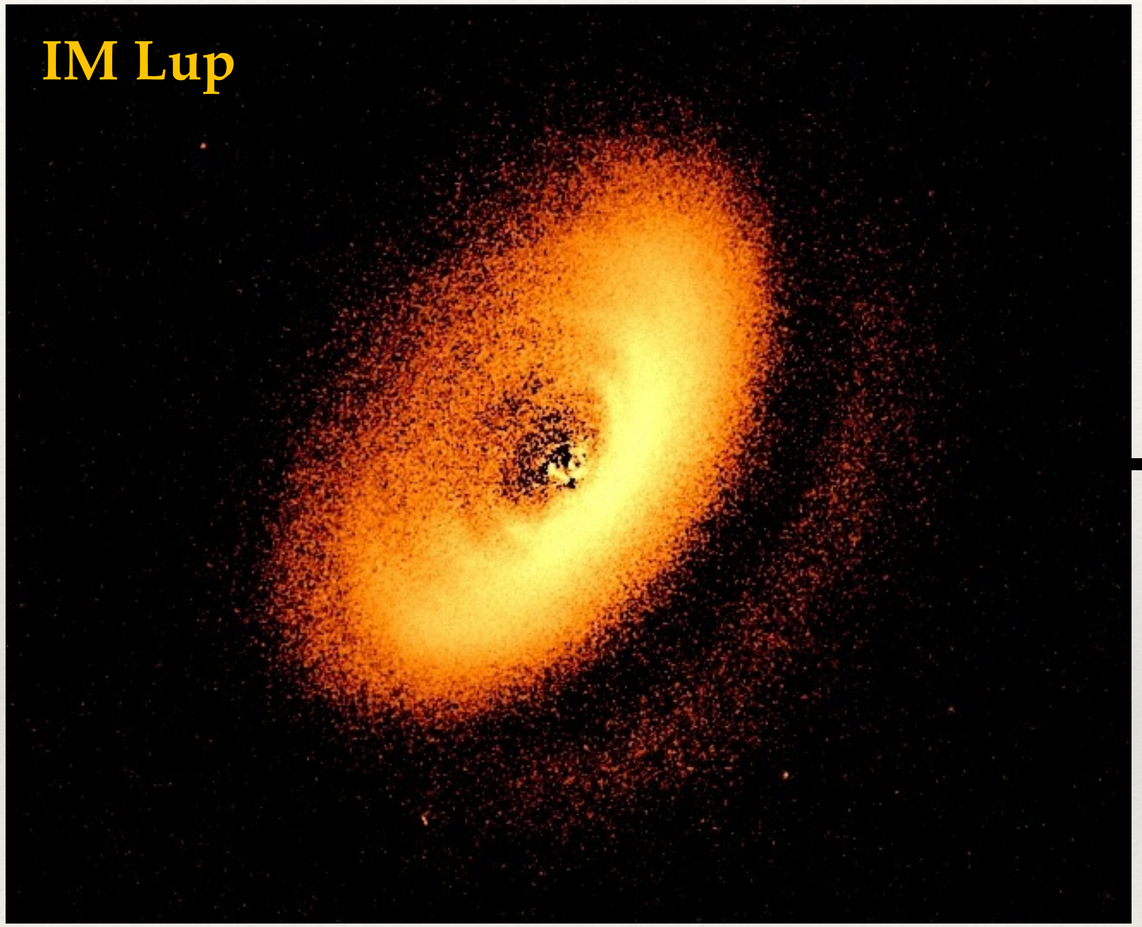




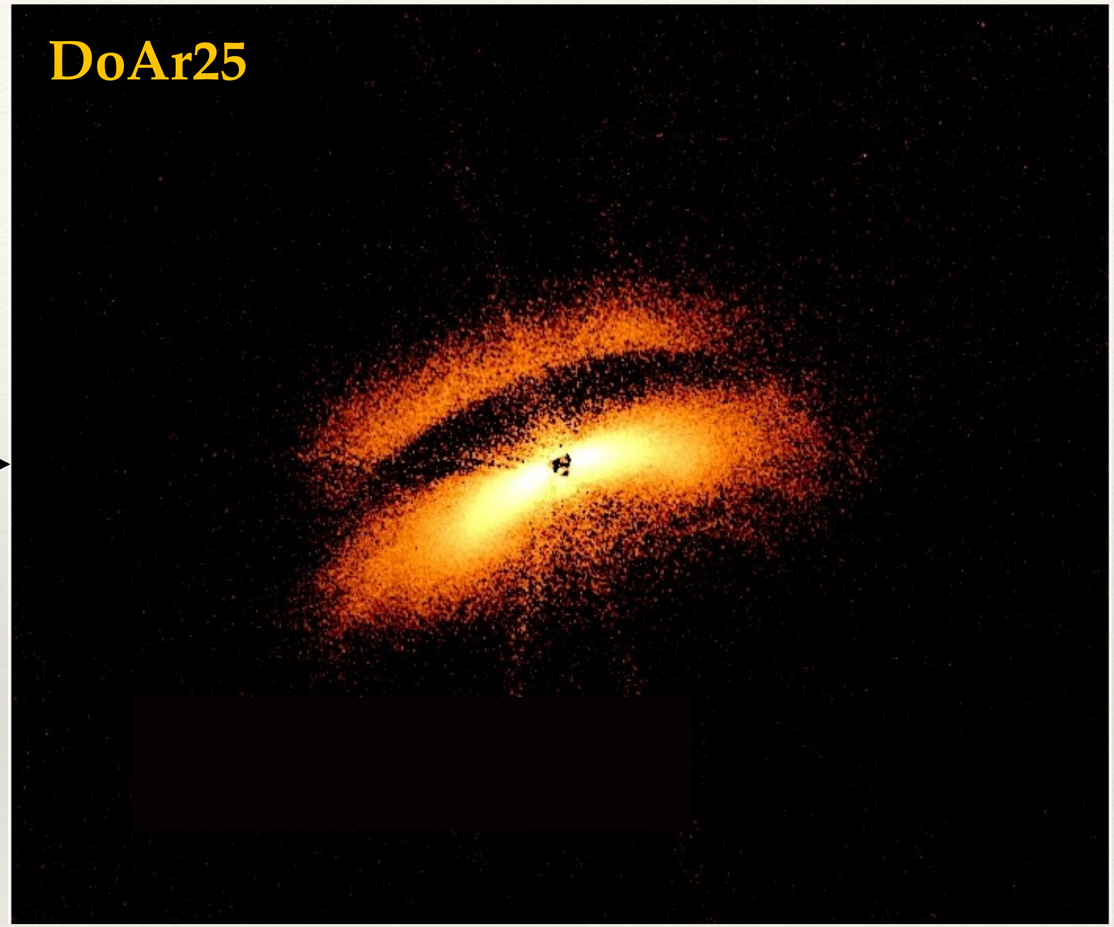
Avenhaus, Quanz, Garufi et al. 2018

Clear sub-structures (but no spiral) in most disks.
General agreement in the scale height (~16 au at r=100 au).

From DARTTS to DARTTS II



Avenhaus et al. 2018



Garufi et al. in prep.

The **second release** of DARTTS datasets cover a larger interval of mm fluxes.

DARTTS II

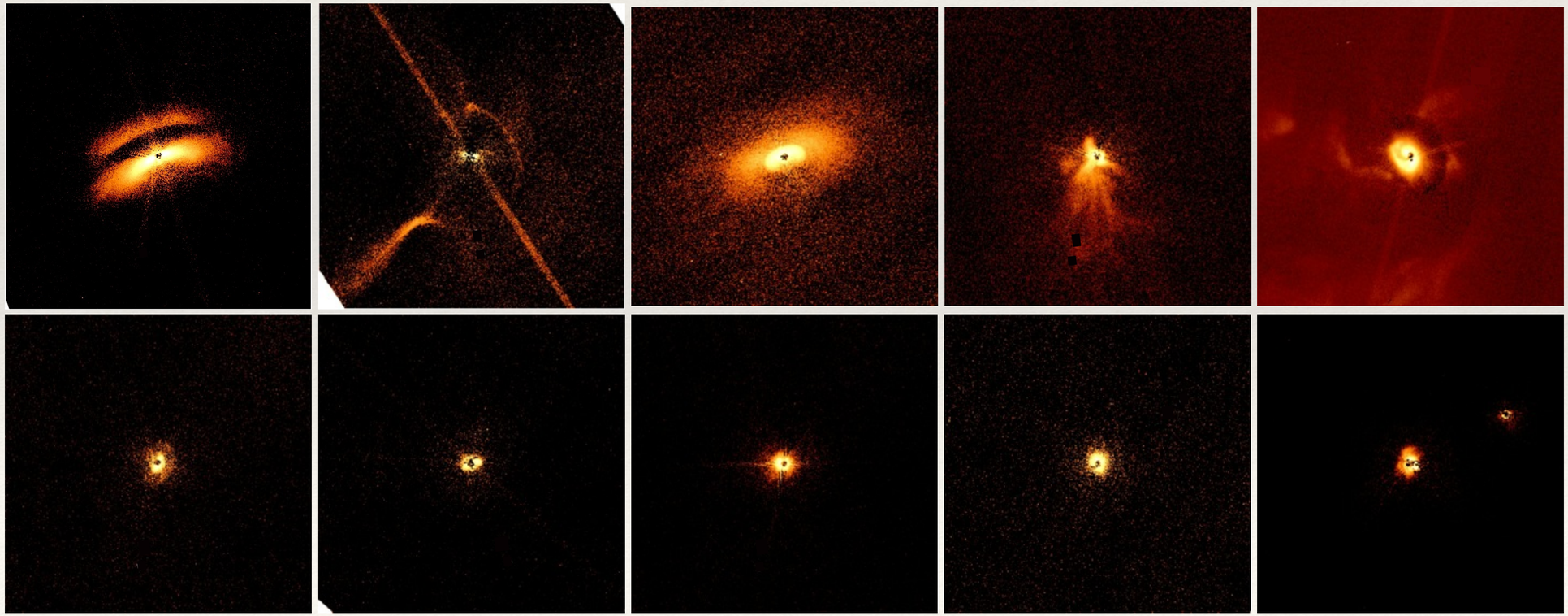
Work in progress

PDI observations of 21 TTSs.

8 additional mm-bright + 13 mm-**faint** sources.

10 Upper Sco, 5 Ophiuchus, 4 Lupus, 2 Chamaeleon.

10 clear detections vs 11 (probable) non-detections.

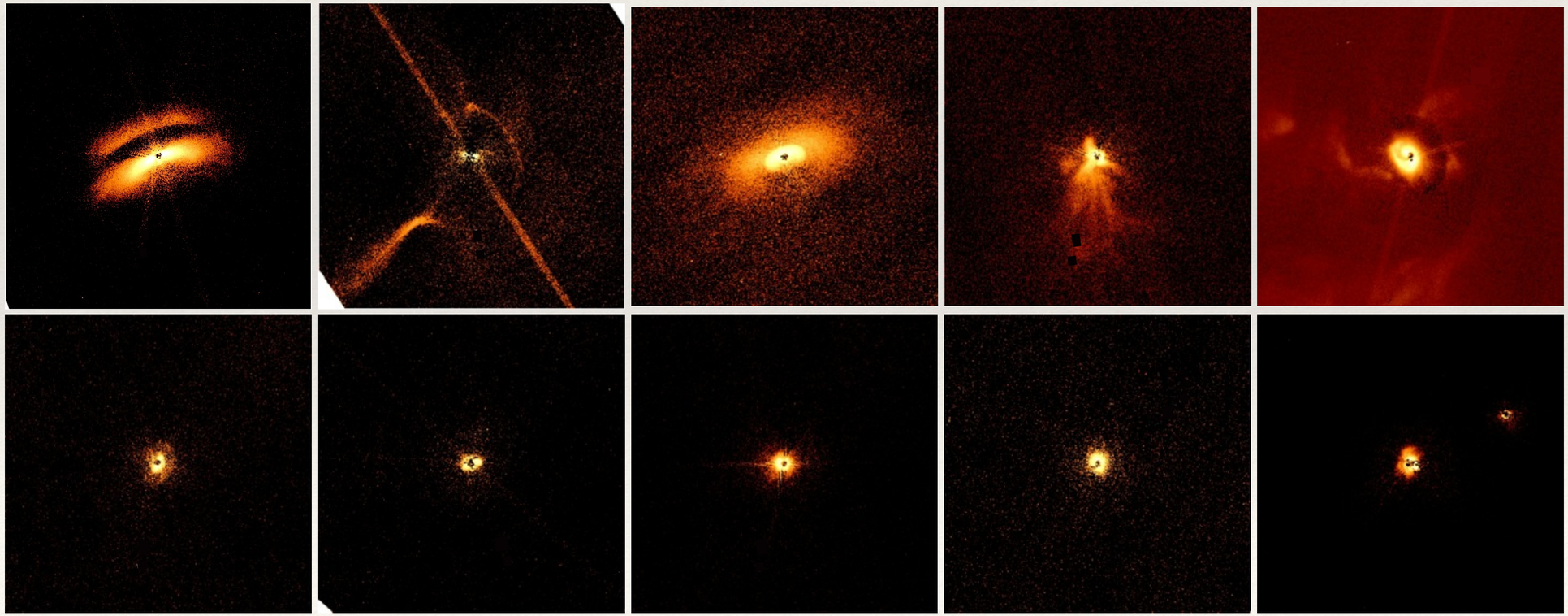


DARTTS II

Work in progress

Some disk sub-structures are visible, but yet no clear **spirals**…

Many disks appear in strong interaction with the medium
(these are - contrary to the past - young sources in SFRs)

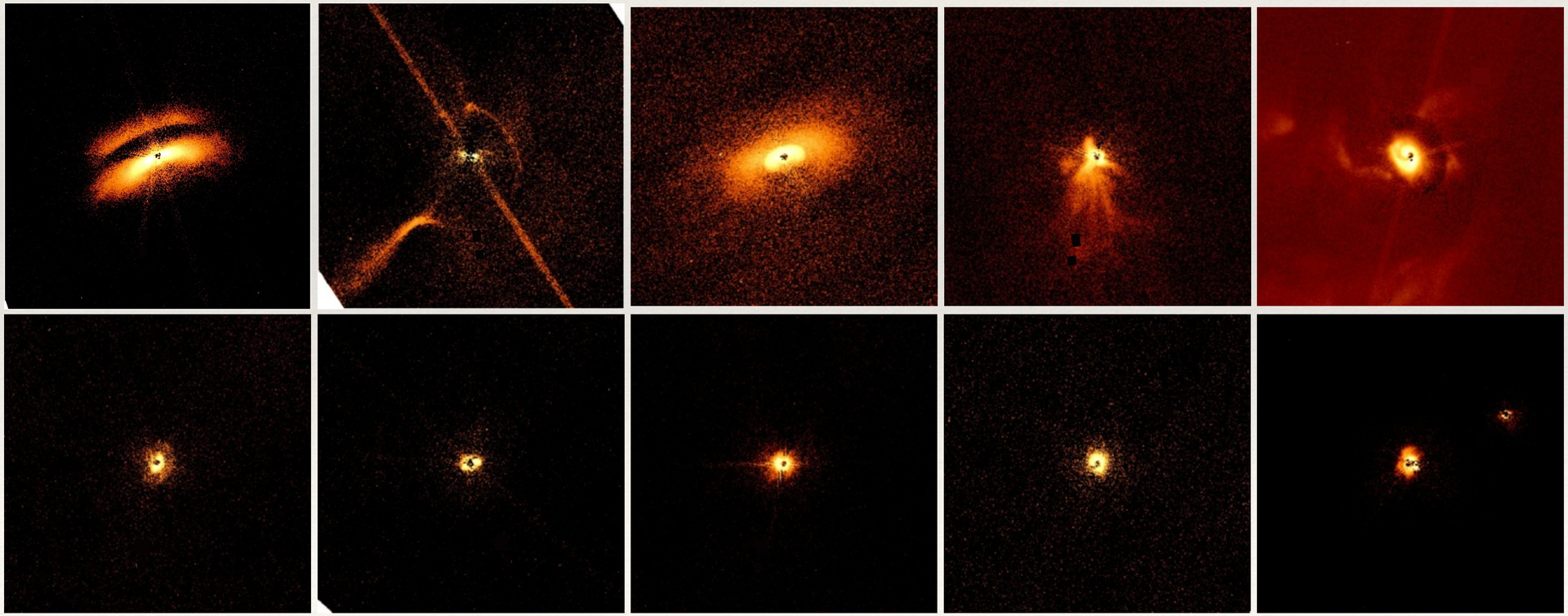


DARTTS II

Work in progress

8/11 non-detections have an outer stellar **companion**.
Truncated disks smaller than the coronagraph (~10 au)?

However, the *projected* distance of companions is
on average 100 au (30 - 270 au)…

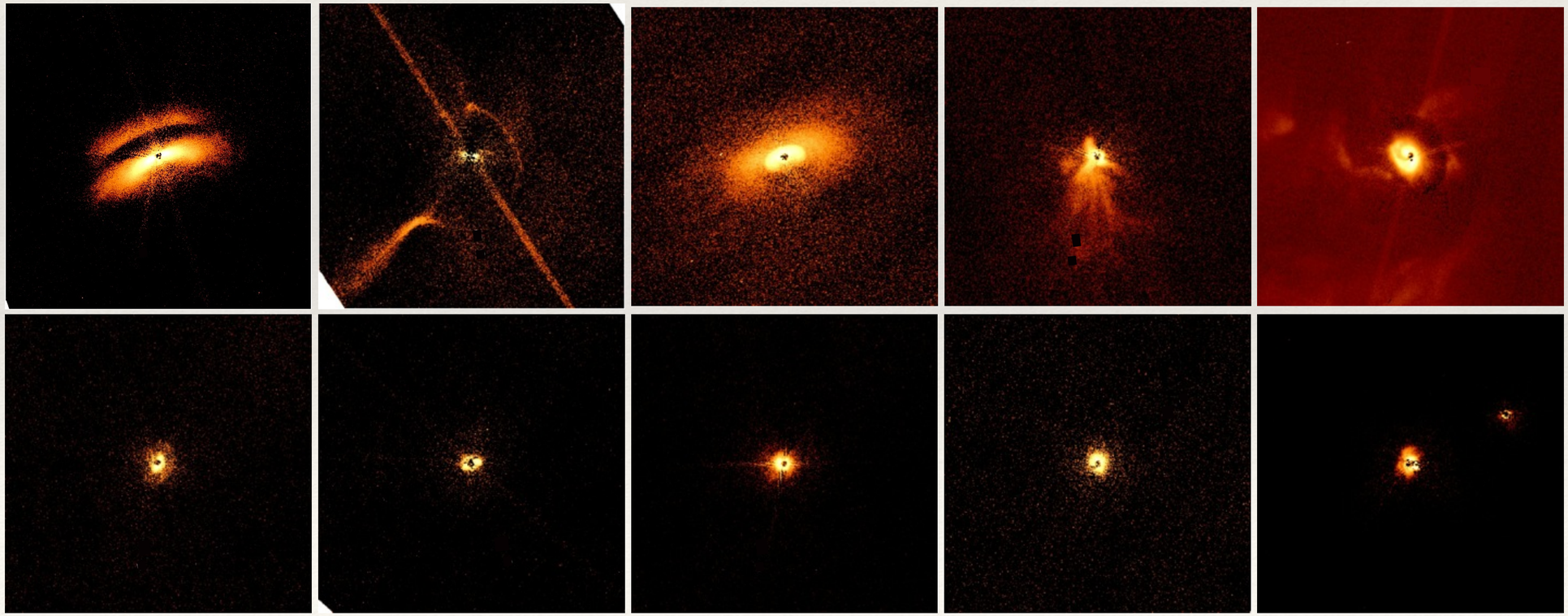


DARTTS II

Work in progress

The lowest-**mass** disk (ever) detected in PDI is $M_{dust} \sim 4\ M_{\oplus}$

In e.g. Lupus, ~45% of disks is below this threshold.
But future observations (e.g., DESTINYS) will be planned accordingly…



Open questions

What planetary systems are born from a **10 au**-large disk?

How early are disk **cavities** and other sub-structures formed?

Do **spirals** in the NIR (old) and in the millimeter (young) have different origin?