Evolution of protoplanetary disks from their taxonomy in scattered light

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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](http://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 $\sim\frac{2}{3}$ of the PDI sample.
(To be compared to the 10% from photometric surveys.)
Disk cavity

Facts #1 and #2:

Very high occurrence: resolved in ~\(\frac{2}{3}\) of the sample.
(To be compared to the 10% from photometric surveys.)

Cavities explain the Meeus observational dichotomy

**Group I** vs **Group II**

![Graph 1](image1)

- **High FIR**
- **Large MIR slope**

![Graph 2](image2)

- **Low FIR**
- **Small MIR slope**
Disk cavity

Cavities explain the Meeus observational dichotomy

Group I vs Group II

Increasing MIR slope

Disk brightness

→ Polarized light contrast ($\cdot 10^{-3}$)

→ $F(30 \mu m) / F(13.5 \mu m)$
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 $\sim\frac{2}{3}$ 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.
Fact #3:
We have more observational biases. Primarily, massive disks around old stars have been observed.
Disk cavity

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

Garufi et al. 2018 (also Villenave et al. in prep.)
Fact #3:

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

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).
Within the disk cavity

Fact #4:

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

\[
\begin{align*}
F_{\text{NIR}} \% & \quad R_{\text{CO}} \text{ (au)} \\
\uparrow & \quad \uparrow \\
\text{Amount of hot reprocessed light} & \quad \text{Origin of CO emission}
\end{align*}
\]

Banzatti et al. 2018
Another observational dichotomy is among the transition disks (Group I).

**Fact #4:**

The datasets combined in this work show a linked behavior in the multi-dimensional parameter space, as illustrated in the four panels of Figure 3. Linked behavior between the datasets is observed in the sub-NIR cavities, no/small cavities, high-NIR cavities, and low-NIR cavities. The red curve shows a parametric model of the decrease of F(NIR) vs R$_{\text{CO}}$ (au), which probe the presence or absence of dust cavities detected by mm-wave imaging, sensitivity to the type of CO excitation, and gas kinematics in protoplanetary disks.
Another observational dichotomy is among the transition disks (Group I). Within the disk cavity

Fact #4:

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 $\rightarrow$ Increased accretion/ejection events.
Jet wiggling $\rightarrow$ 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.
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.
Fact #6:
Spirals are detected in \(~10\%\) of Herbig stars. Never detected in TTSs. 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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Possibly, spirals are “late” structures. We do not observe late TTSs.

Garufi et al. 2018
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.
Spirals & Shadows

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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.

But what about the relative azimuthal asymmetries in the mm?

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)