Stuctural diversity – resolving Herbig Ae/Be circumstellar Disks at 10-150 AU using PDI

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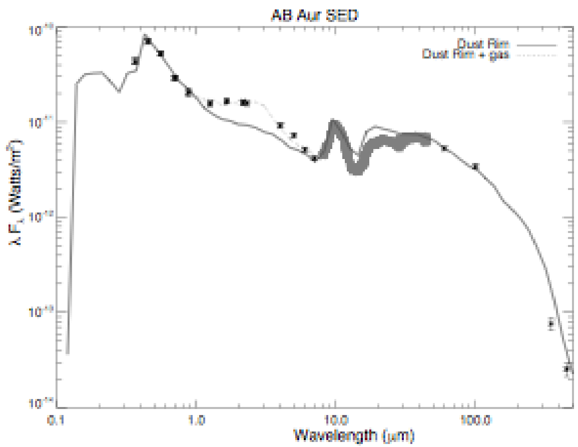
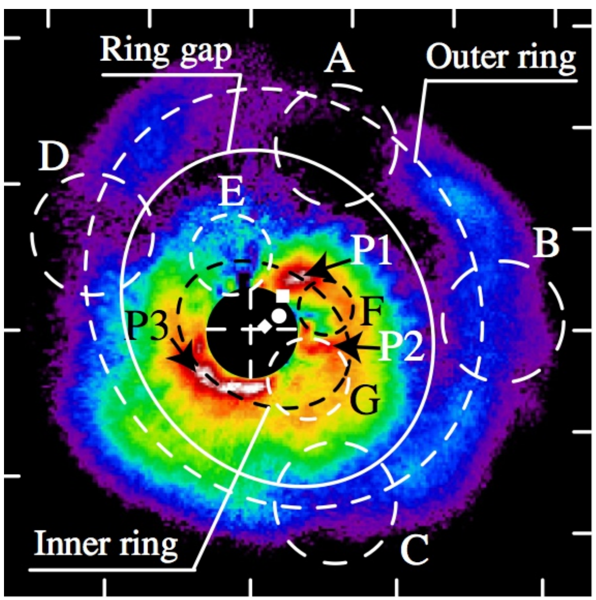
Sascha Quanz, Hans Martin Schmid, Antonio Garufi,
Michael Meyer, Sebastian Wolf and others

Why image protoplanetary disks?



Tannirkulam et al. 2008



Hashimoto et al. 2011

SED can give a lot of information, but is degenerate w.r.t. fine disk structures

Information from scattered light:

- Extent, orientation, inclination, eccentricity, ...
- Sub-structures within the disk
- **Signatures of planet formation**

→ We need resolved, high-resolution images!

We want to do: High-resolution imaging…

Say we want to do 0.1” imaging, then we need a telescope of…

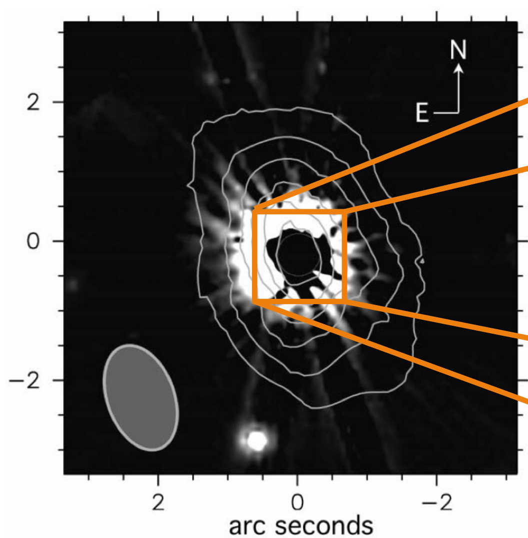
mm / sub-mm	Mid-infrared	Near-IR / VIS
~1mm	~20µm	~1µm
> 2.5km	> 50m	> 2.5m
ALMA	Not possible (wait for E-ELT/TMT/GMT or use interferometry)	VLT, Keck, Hubble Problem: star is very bright

… in the near-IR with small inner working angle

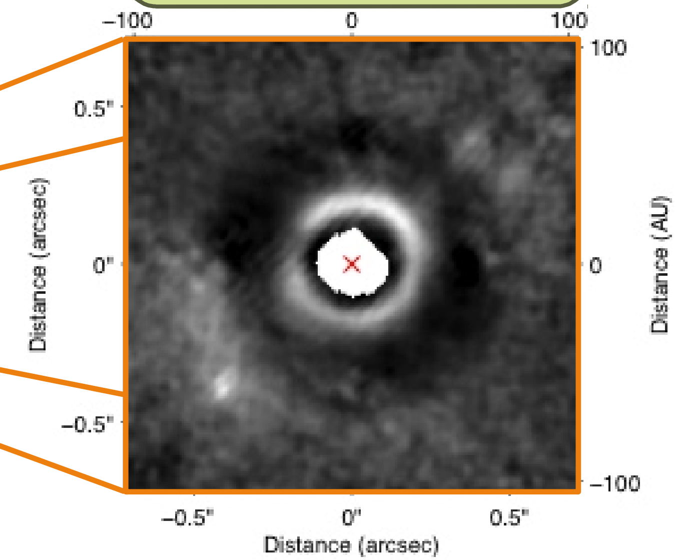
Near-IR / VIS

Coronagraphy
+ PSF subtraction

Polarimetric
differential imaging



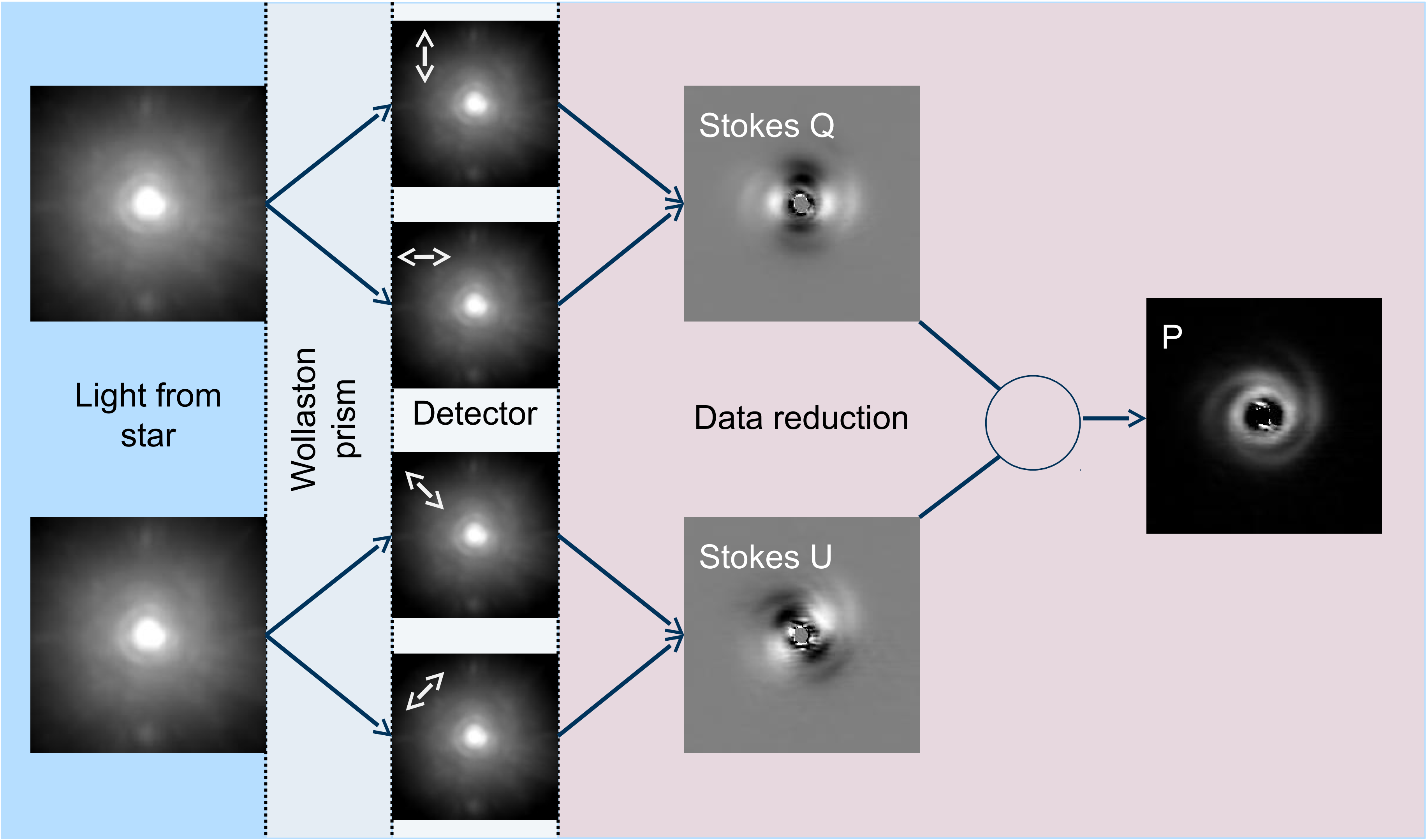
Grady et al. 2007



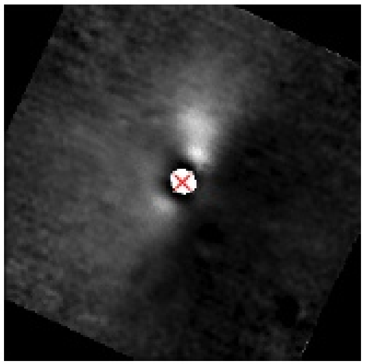
Quanz, Avenhaus et al. 2013

Can probe planet-forming zones (0.1” at 100 pc is 10 AU)

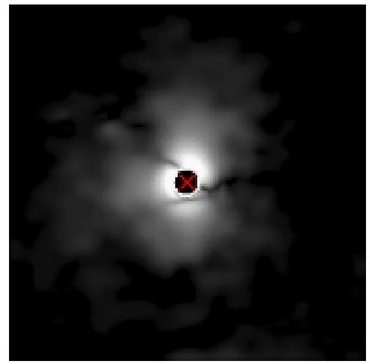
Polarimetric Differential Imaging (PDI) explained



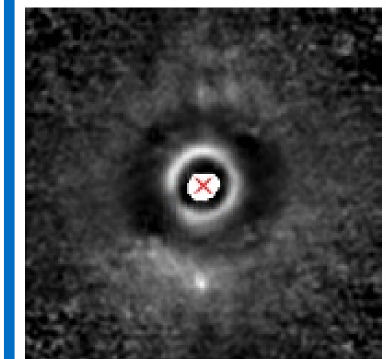
What we see: An overview



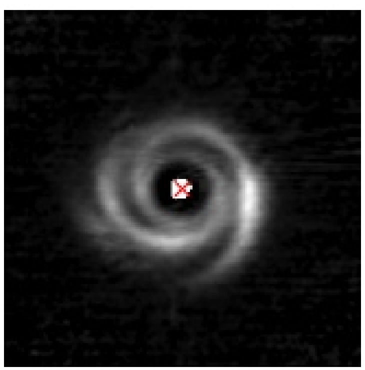
HD100546



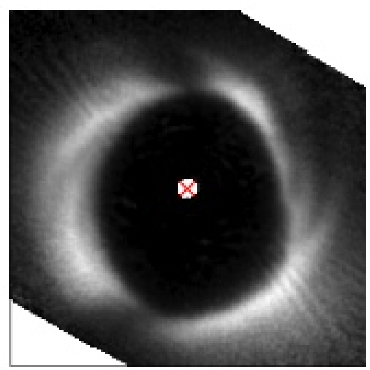
HD97048



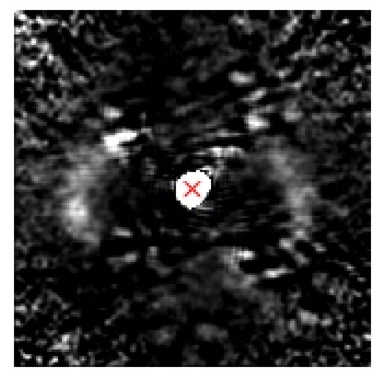
HD169142



SAO206462



HD142527

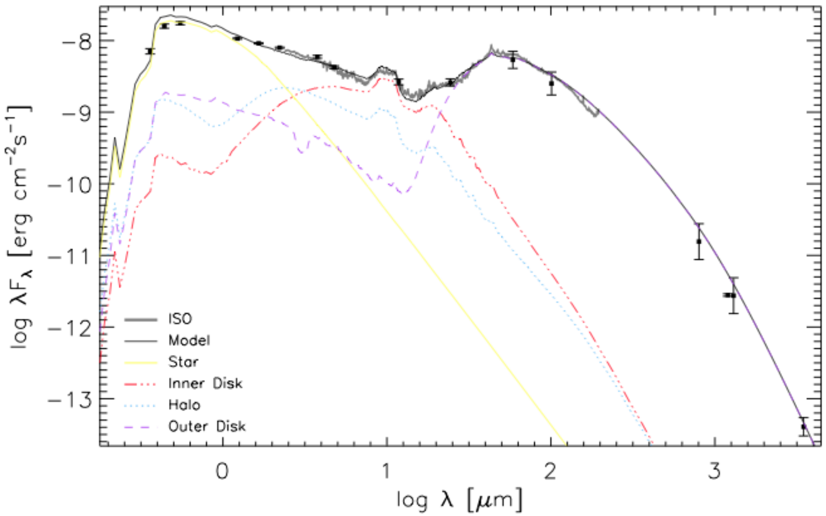


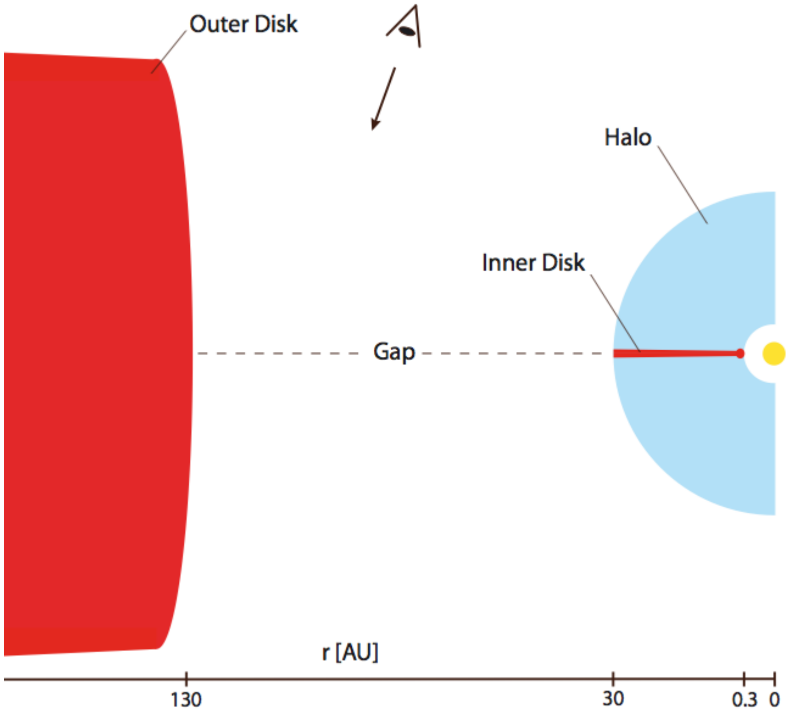
HD163296

HD142527: An intensively studied Herbig star

F6 star of 2-12 Myr at ~145pc

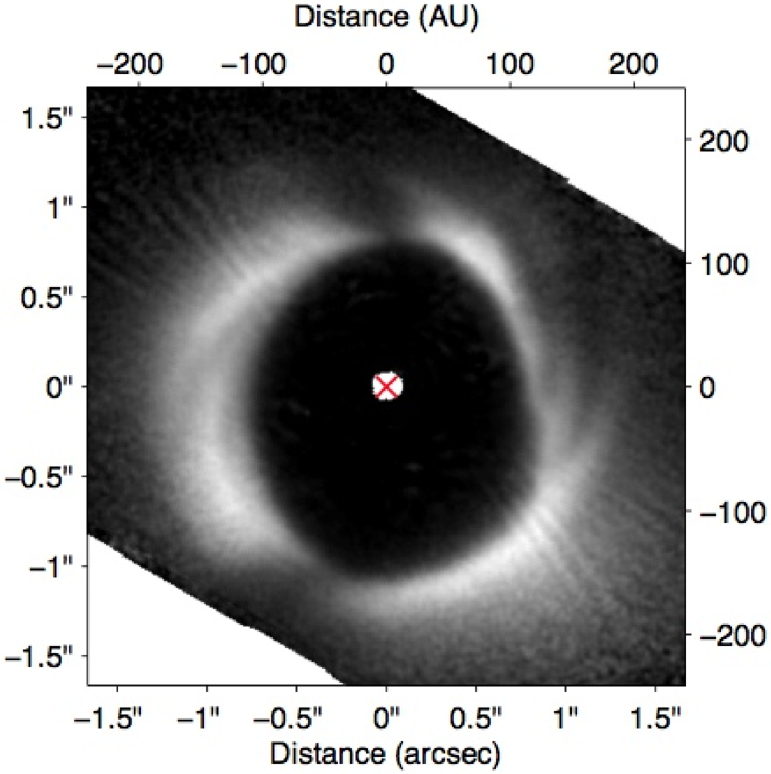
- Outer disk with very large scale height
- Asymmetric inner hole out to ~100-130 AU
- Inner, self-shadowed disk





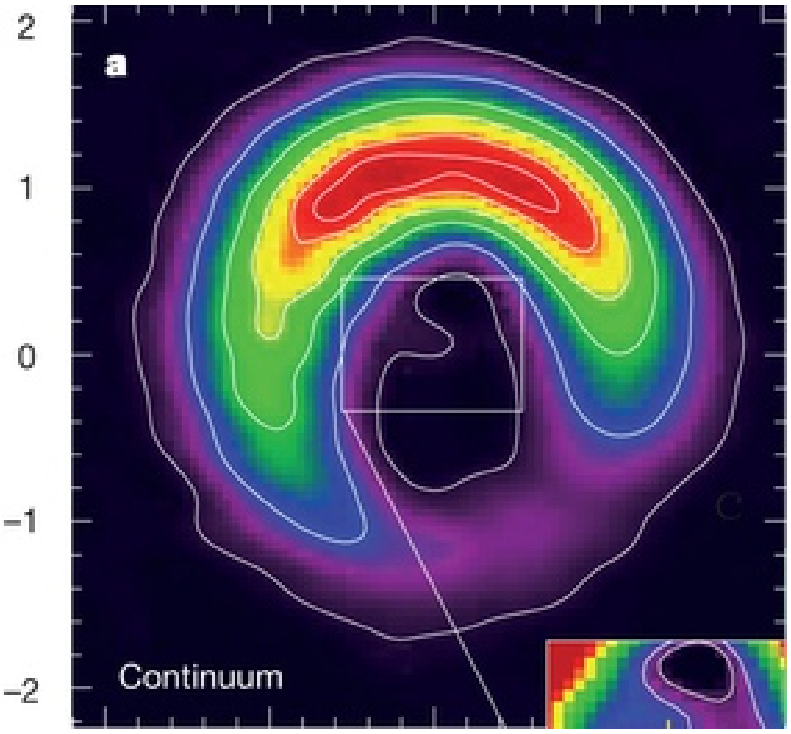
Verhoeff et al. 2011

HD142527: A large inner hole



Ks-band polarized flux (scaled with r^2)

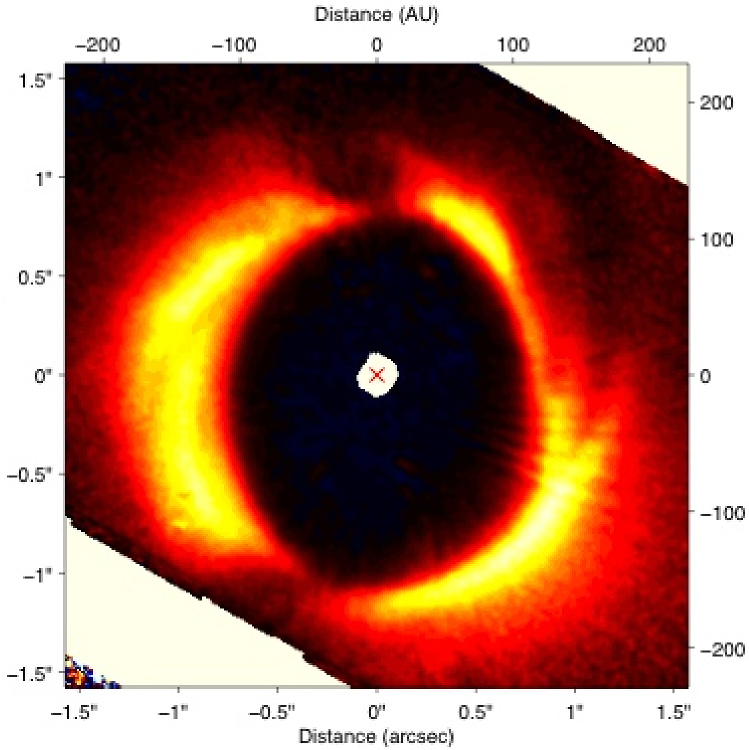
Avenhaus et al. 2013 (in prep.)



Sub-mm continuum emission

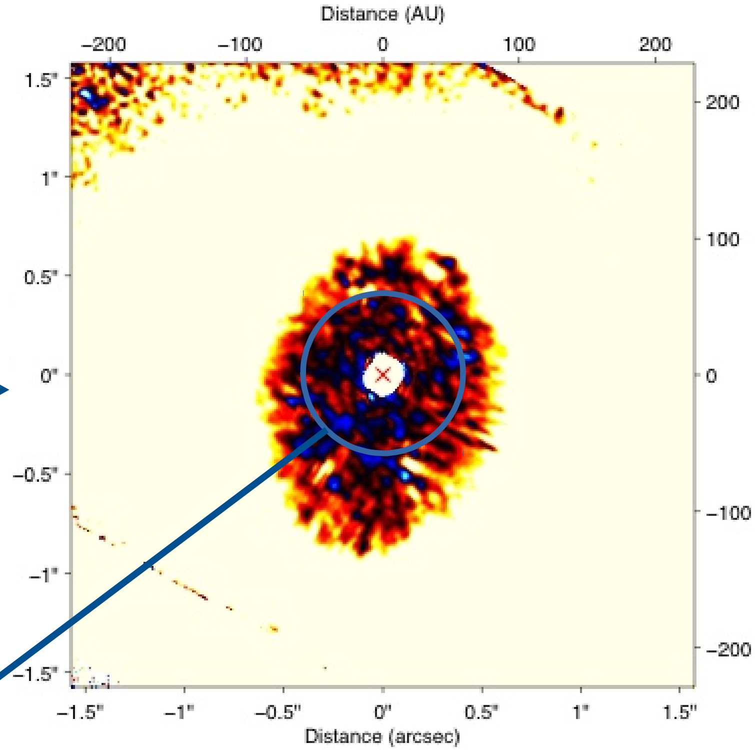
Casassus et al. 2013

HD142527 inner hole: How empty is empty?



Enhance

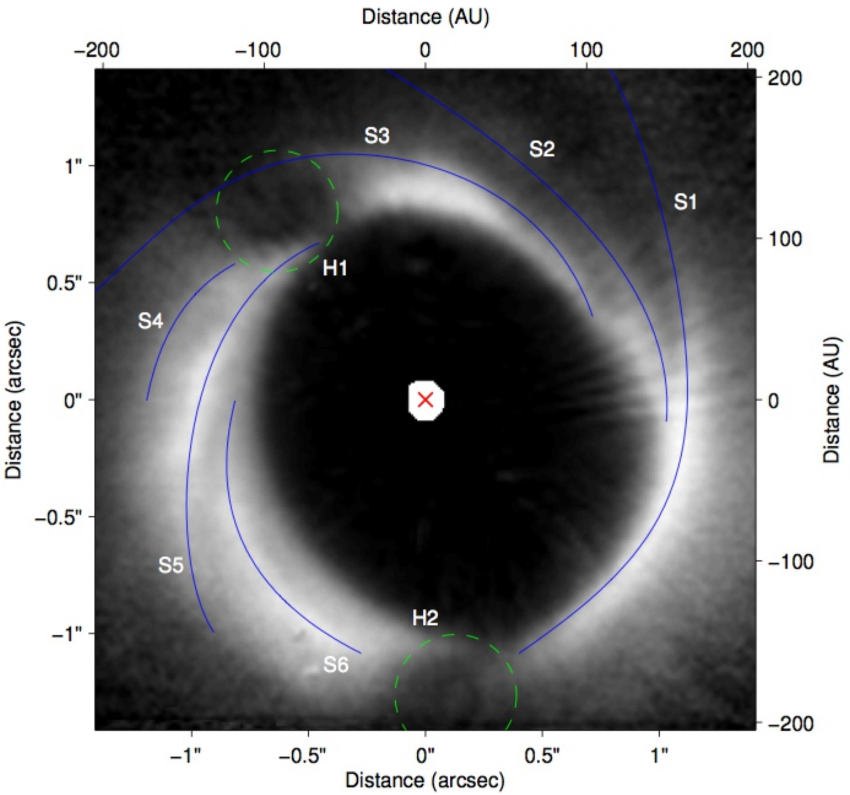
(factor 15)



Weak evidence for dust scattering within the hole, but no “streamers” can be seen (scattering >100x weaker than in outer disk)

→ Too faint? Shadowed by inner disk? No streamers?

HD142527: Sub-structures in the disk



Avenhaus et al. 2013 (in prep.)

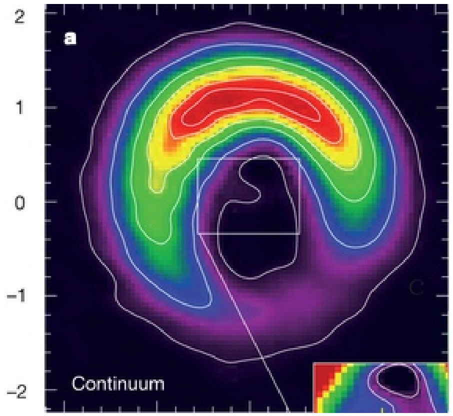
Six spiral arms (at least two of these were known before)

Prominent holes in the disk:

- In northern direction, PA ~0°
- In southeastern direction, PA ~150°

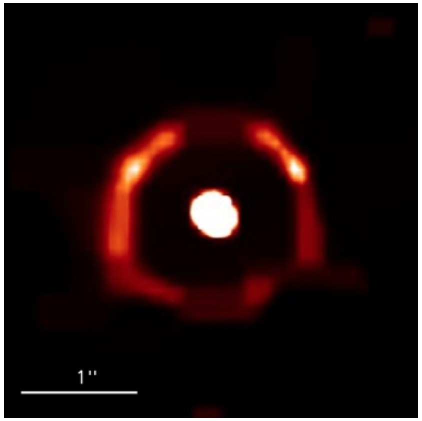
All substructures seen in both H and Ks filters (and we have colors)

HD142527: An asymmetry in the north?



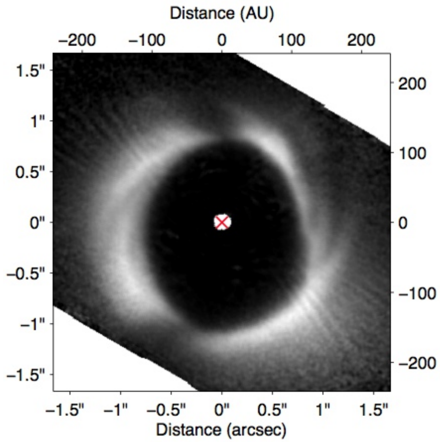
Sub-mm continuum emission

Casassus et al. 2013



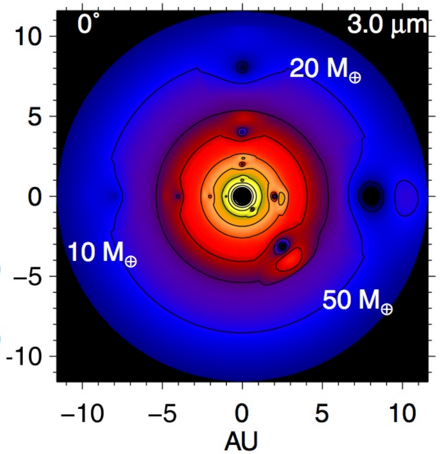
VISIR Q-band 18.7µm (deconvolved)

Verhoeff et al. 2011



Ks-band polarized flux (scaled with r^2)

Avenhaus et al. (in prep.)

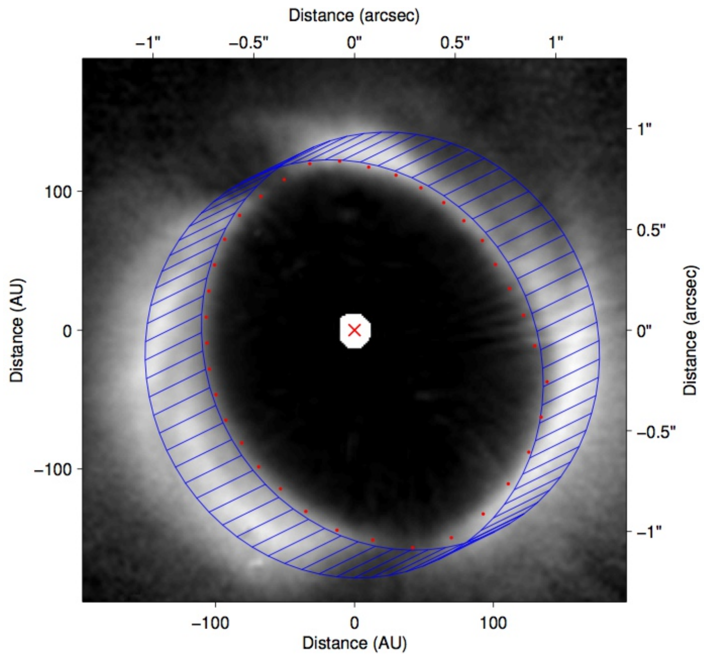


Simulations of planet shadows in disks

Jang-Condell 2009

- Sub-mm continuum is highly asymmetric in northern direction (dust trapping?)
- Verhoeff et al (2011) argue for planet at PA ~0° based on "trojans" seen in mid-IR
- A hole is seen in scattered light in the northern direction
- Planet? Maximum mass a few M_{Jup} based on planet searches (Rameau et al. 2012, Casassus et al. 2013)

HD142527: Estimating disk parameters



Avenhaus et al. 2013 (in prep.)

Well-resolved inner rim allows to fit a phenomenological model for the inner rim

Direct, self-consistent estimates:

- Inclination
- Eccentricity (~0.14)
- Semi-major axis of inner rim
- **Scale height of inner rim (~50 AU)**

But: Inner rim scale height and inclination highly degenerate

HD142527: Conclusions

HD142527 is a very interesting disk:

- Large inner hole, large scale height
- Variety of substructures in outer disk
- Different substructures at different wavelengths

What we learn:

- Only weak evidence for very faint dust scattering in inner hole
- No trace of “streamers”
- No trace of inner disk or halo (likely self-shadowed)
- Disk parameters can be directly estimated

SAO206462 (also known as HD135344B)

~3-12 Myr F4 star at ~140pc

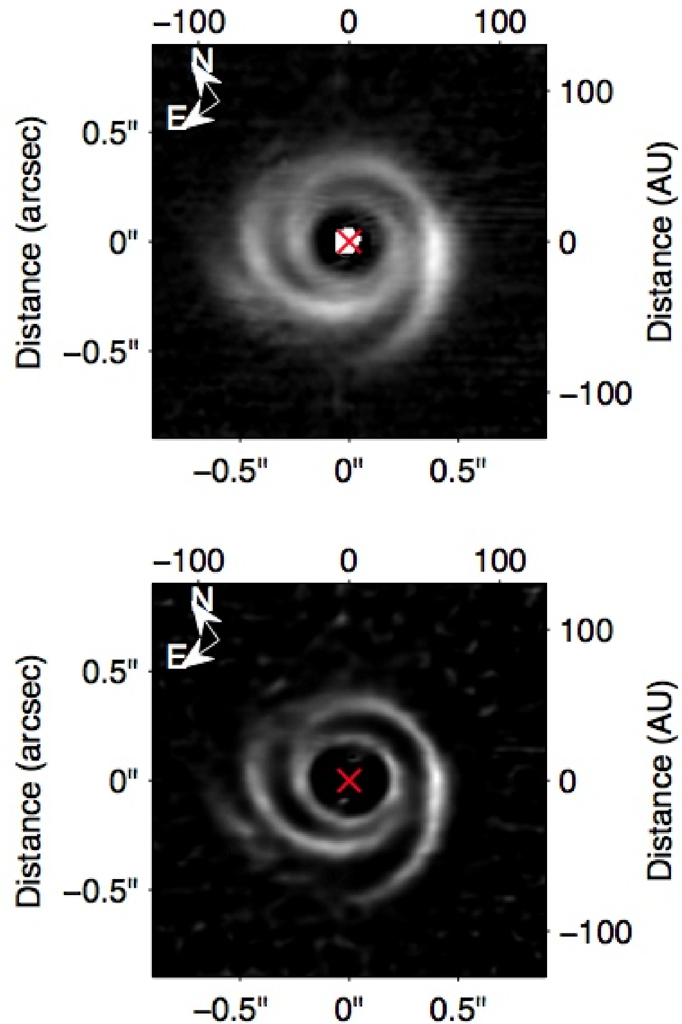
Detections:

- Double-armed spiral structure
- Inner hole inside of ~25 AU
- Inner working angle: 0.07”

Questions to answer:

- Origin of spiral arms? Spiral density waves?
- Origin of gap?
- Structures are on the surface of the disk! (Optically thick)

→ Simulations and further observations (ALMA) required



Garufi, Avenhaus et al. 2013 (in prep.)

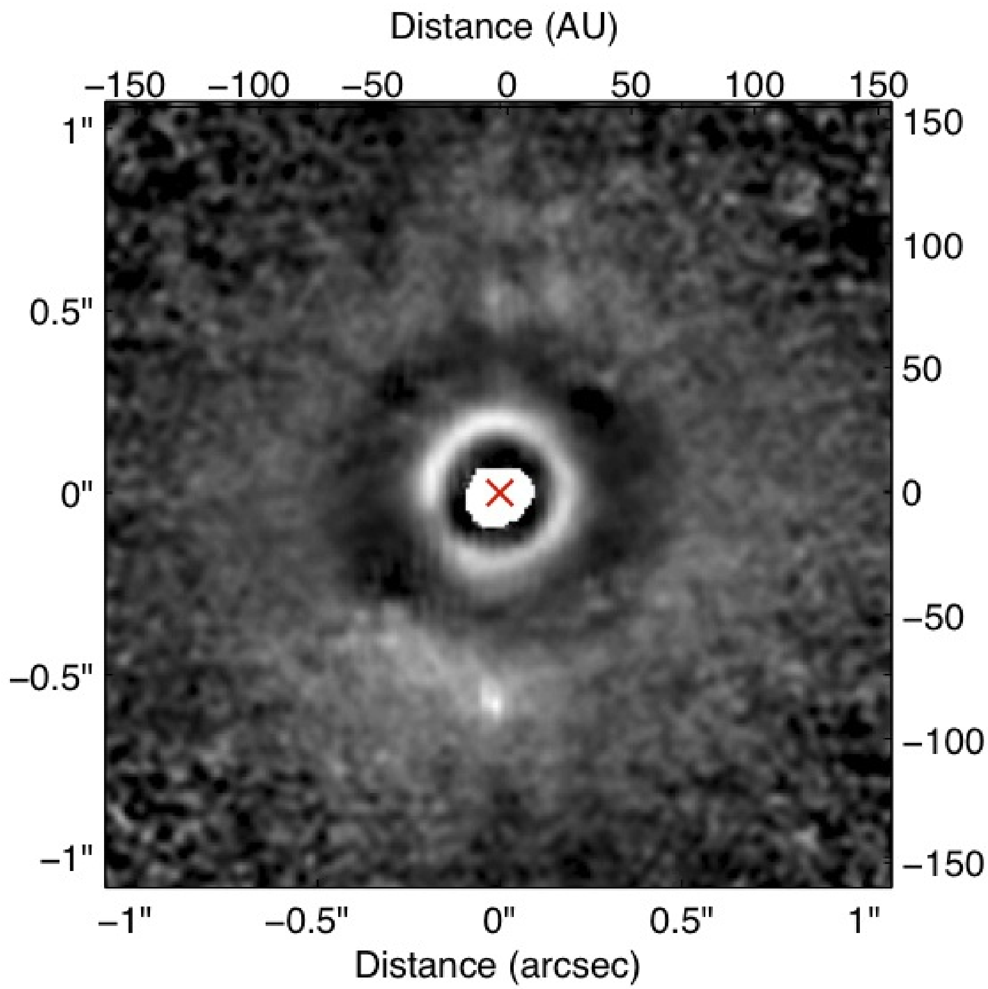
HD169142

A7 star at ~145pc,
~3-12 Myr

Disk features:

- Bright ring at ~25 AU featuring a dip
- Gap at ~30-60 AU
- Outer disk with steep SB profile

What is the origin of the gap?

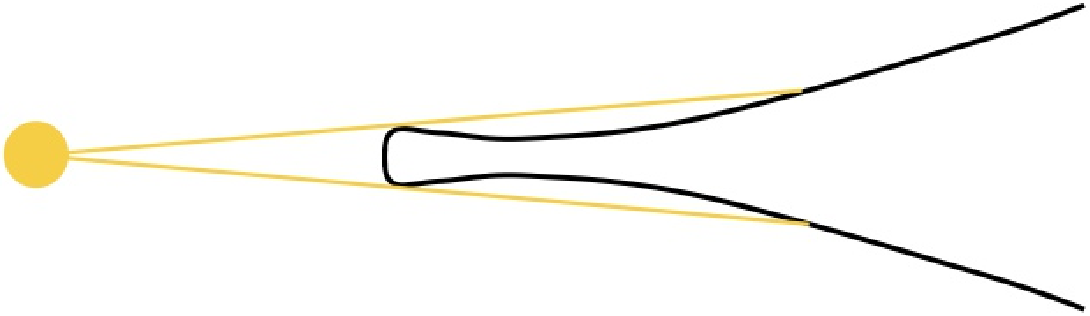


Quanz, Avenhaus et al. 2013

HD169142: What causes the gap?

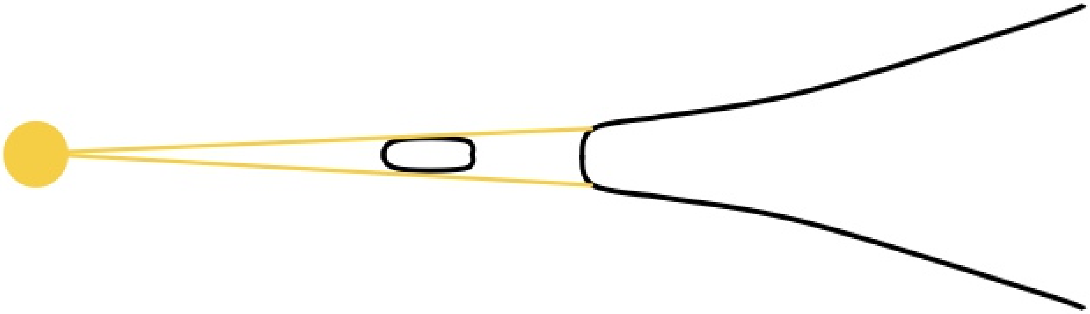
Possibility one:

Puffed up inner rim and disk shadow



Possibility two:

Annular gap in the disk (opened by planet?)



ALMA can answer this question!

PDI: Some thoughts

PDI can give us access to the inner parts of a disk:

- High resolution (short wavelength on big telescope)
- High contrast (uses its own PSF for subtraction)
- Otherwise unreachable inner working angle of ~0.1”
- **Same resolution as ALMA, complimentary information**

But, we have to be aware:

- We are probing scattered light, thus surface of disk (optically thick)
- Polarimetric efficiency variations can mimic structure

Conclusions

To understand planet formation, we need to have imaging that is

- High-resolution (to resolve the structures we are interested in)
- (For scattered light): High-contrast (bright central star)
- Small inner working angle (to probe planet-forming zones)

Few techniques are able to do this:

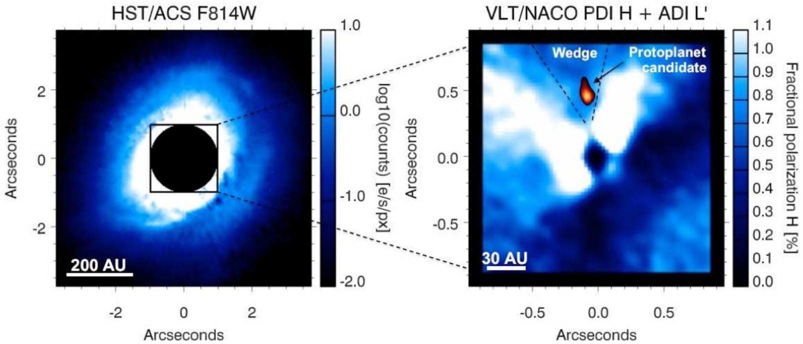
- In (sub)-mm, ALMA is now able to achieve required resolution
- In the mid-IR, we have no telescope big enough
- In scattered light (visible, near-IR), only PDI can get the inner working angle

→ Scattered light and sub-mm observations are complimentary to probe both surface and mid-plane of protoplanetary disks

Future prospects

Visible / near-IR

- Further disk studies and follow-up observations using VLT/NACO
- Higher resolution, better contrast using VLT/SPHERE



Sub-mm / mm

- Find out whether the spirals / rings we see translate to mid-plane structures
- **ALMA at similar resolution (Cycle 2)**

Modelling

- Translate models to scattered-light images using radiative transfer code
- Try to understand the surfaces of disks