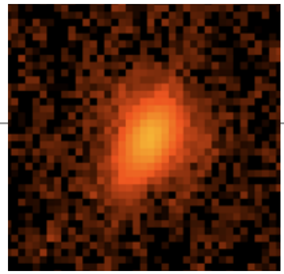
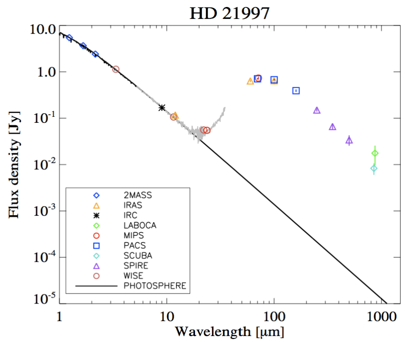
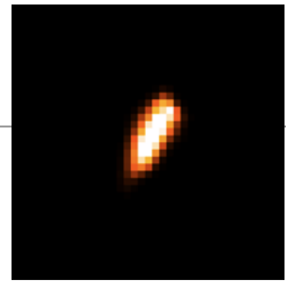
Spatially resolved far-infrared imaging of bright debris disks: studying the disk structure and the stirring mechanism







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Debris disks and their evolution

- After the primordial phase, dust grains of secondary origin form a disk around the star. They are produced by the destruction of circumstellar bodies, thus debris disks signal a planetesimal population in the disk. The structure and dust content of debris disks evolve with time.

- ***Self-stirring scenario***: planetesimal growth starts inside, then proceeds outwards. When protoplanets of ~1000 km are formed, they de-stabilize their vicinity, increasing dust production (Kenyon & Bromley 2008).

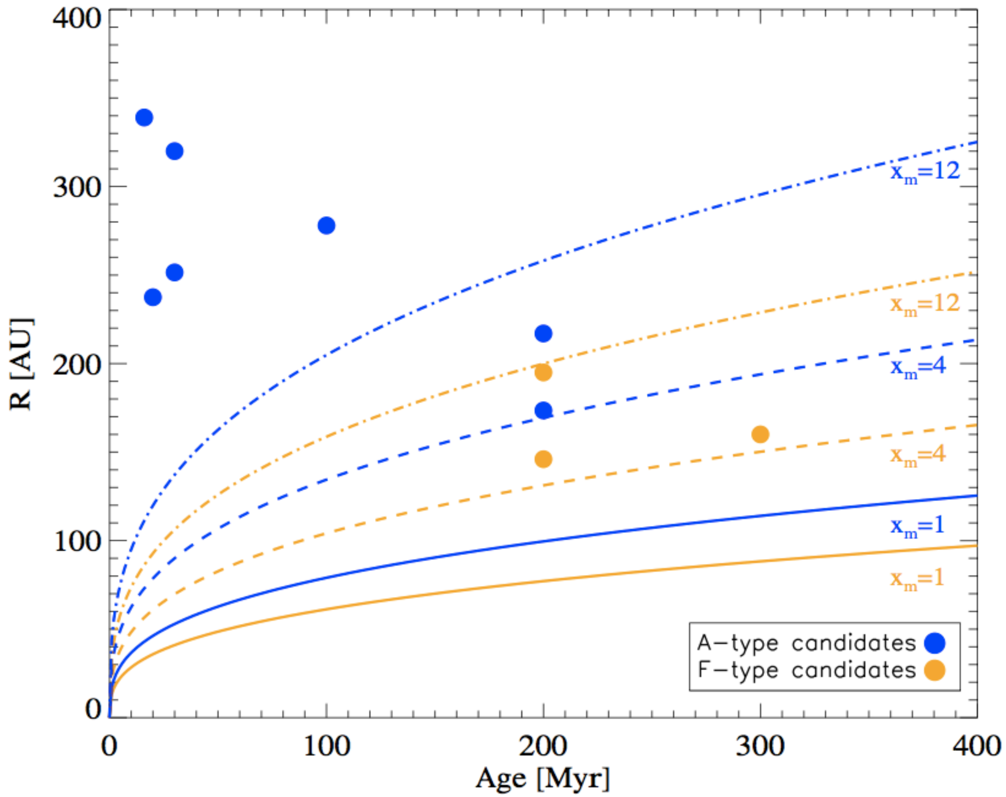
- ***Planetary stirring***: giant planets, formed previously in the primordial disk, or stellar companions can dynamically excite the motion of planetesimals via their secular perturbation (Mustill & Wyatt, 2009).

- ***Close stellar flybys*** can also initiate energetic collisions in a planetesimal disk (Kenyon & Bromley, 2002).

- **Could we decide among these scenarios in a particular debris disk?** It is challenging... Flybys can be identified by tracking stellar trajectories; planets can be detected - but even these detections do not exclude self-stirring.

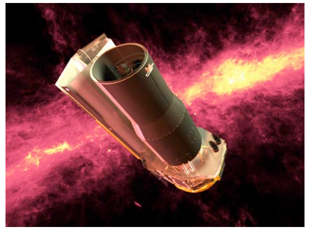
Large debris disks around young stars

- **Theory may help us to exclude self-stirring!**
- Kenyon & Bromley (2008): in the self-stirring scenario debris disks of higher initial mass evolve faster.
- In some cases - e.g. extended disks around young stars - the estimated initial surface density can be suspiciously high (see Mustill & Wyatt, 2009).

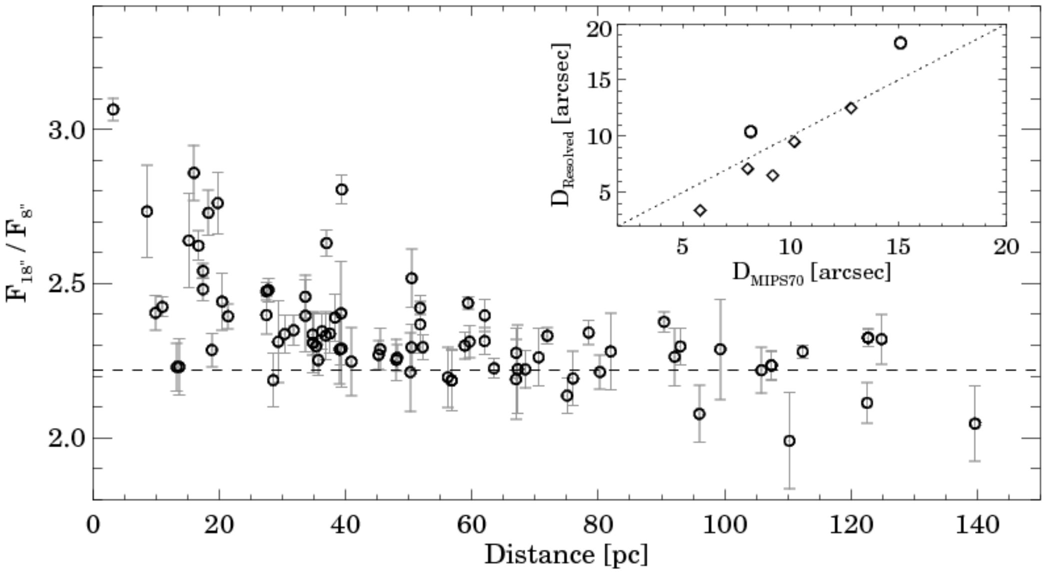


- Observations: there is a subgroup of debris disks around young (10-300 Myr) stars which appear large and cold. **Candidates for planetary stirring/stellar flyby?**
- There are some interesting disks in this subgroup: HR 8799, 49 Ceti,...

Preparatory work based on Spitzer data



- We collected 85 bright debris disks from the Spitzer archive
- We compared their 70 μm image with the MIPS PSF, and identified the (marginally) extended objects.
- Discarded sources reserved in other Herschel programmes (mainly in volume-limited samples, thus our targets are more distant).
- Discarded sources with insufficient wavelength coverage in the SED
- Discarded binaries
- **10 systems were selected for a Herschel-study**



Our Herschel sample

- 7 A-type, 3 F-type stars. Some are well-known sources, but in many cases it is the first claim of being extended in the Spitzer beam.
- HR 8799 was replaced by HD 182681
- Age: 16 - 300 Myr; Distance: 28 - 90 pc
- The estimated initial surface densities are in the range of 4-200 x MMSN!!!

Object ID	Spectral type	Distance [pc]	Age [Myr]	D_{BB} [AU]	D_{MIPS70} [AU/arcsec]
HD 9672*	A1V	59.4	20	170	475.0/8.0
HD 10939*	A1V	62.0	200	330	430.0/7.0
HD 17848	A2V	50.5	100	150	560.0/11.0
HD 21997	A3IV/V	71.9	30	150	500.0/7.0
HD 50571	F7III-IV	33.6	300	130	320.0/9.5
HD 95086*	A8III	90.4	16	400	680.0/7.5
HD 161868*	A0V	31.5	200	120	350.0/11.0
HD 170773	F5V	37.0	200	160	390.0/10.5
HD 182681	A0V	69.9	50	220	–
HD 195627	F1III	27.8	200	130	290.0/10.5
~~*HR 8799**~~	~~A5V~~	~~39.4~~	~~30~~	~~210~~	~~640.0/16.0~~

Objectives of our work

1. **Resolve the dust disks.** According to our preliminary results, all of the proposed disks are expected to be resolved in the 70μm PACS maps, and the largest ones may be resolved at 100/160μm as well.

2. **Characterize their spectral energy distributions.** The observations at >100μm cover the long wavelength side of the peak of the excess emission. Supplementing the Herschel observations with previous mid- and far-IR data, we will have SEDs with an excellent wavelength coverage between 5 and 500μm.

3. **Study the radial and azimuthal distributions of the cold debris.** Utilizing the resolved images and the SED information, we will model the surface brightness profiles of the disks, deduce the properties of the emitting grains (e.g. size distribution), and look for substructures like clumps, warps, and offsets in the disk.

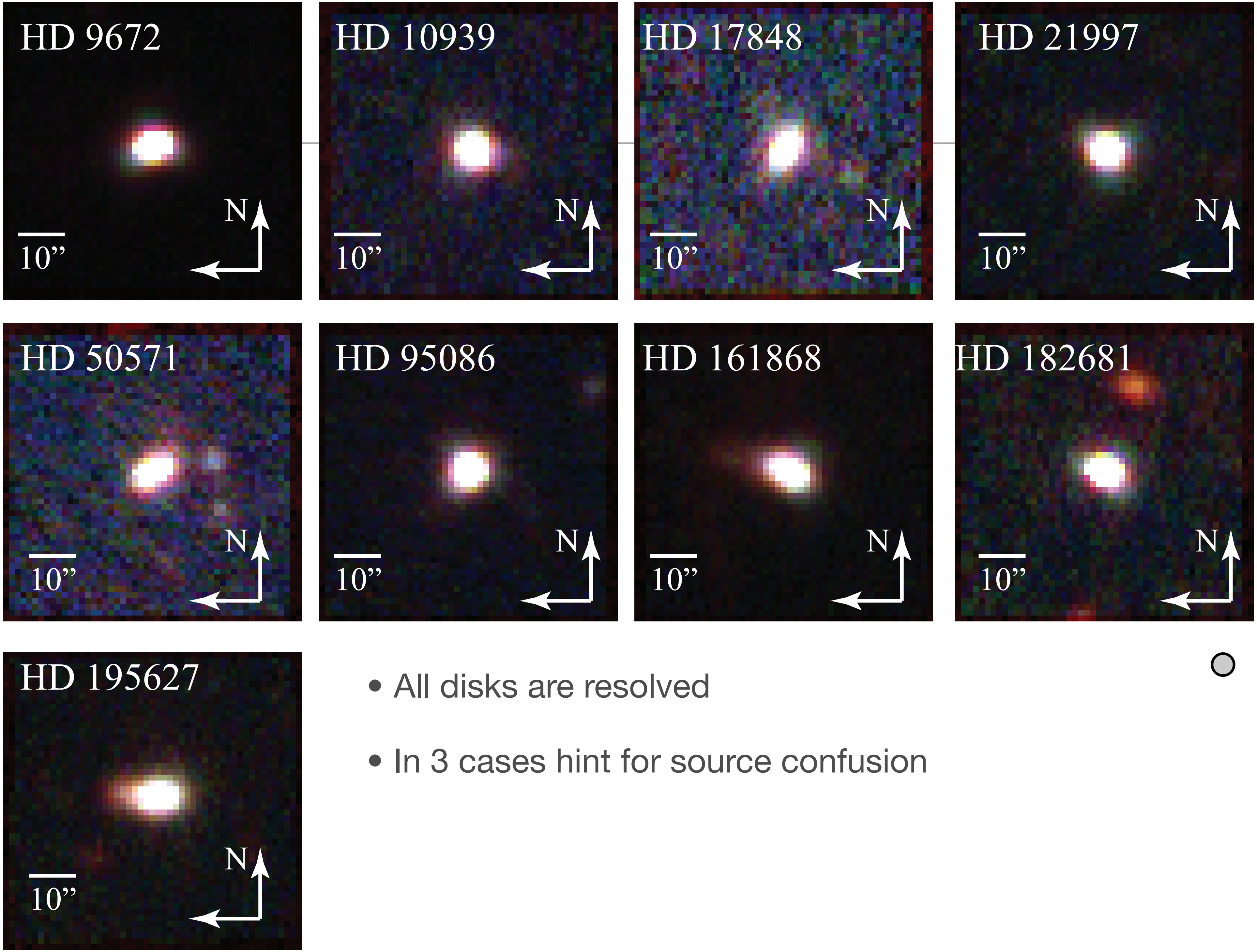
4. **Analyse stirring mechanism in the disks.** Utilizing the new information on the precise location of planetesimal belts we will re-evaluate whether the disk could be self-stirred or not.

Observations & Data reduction

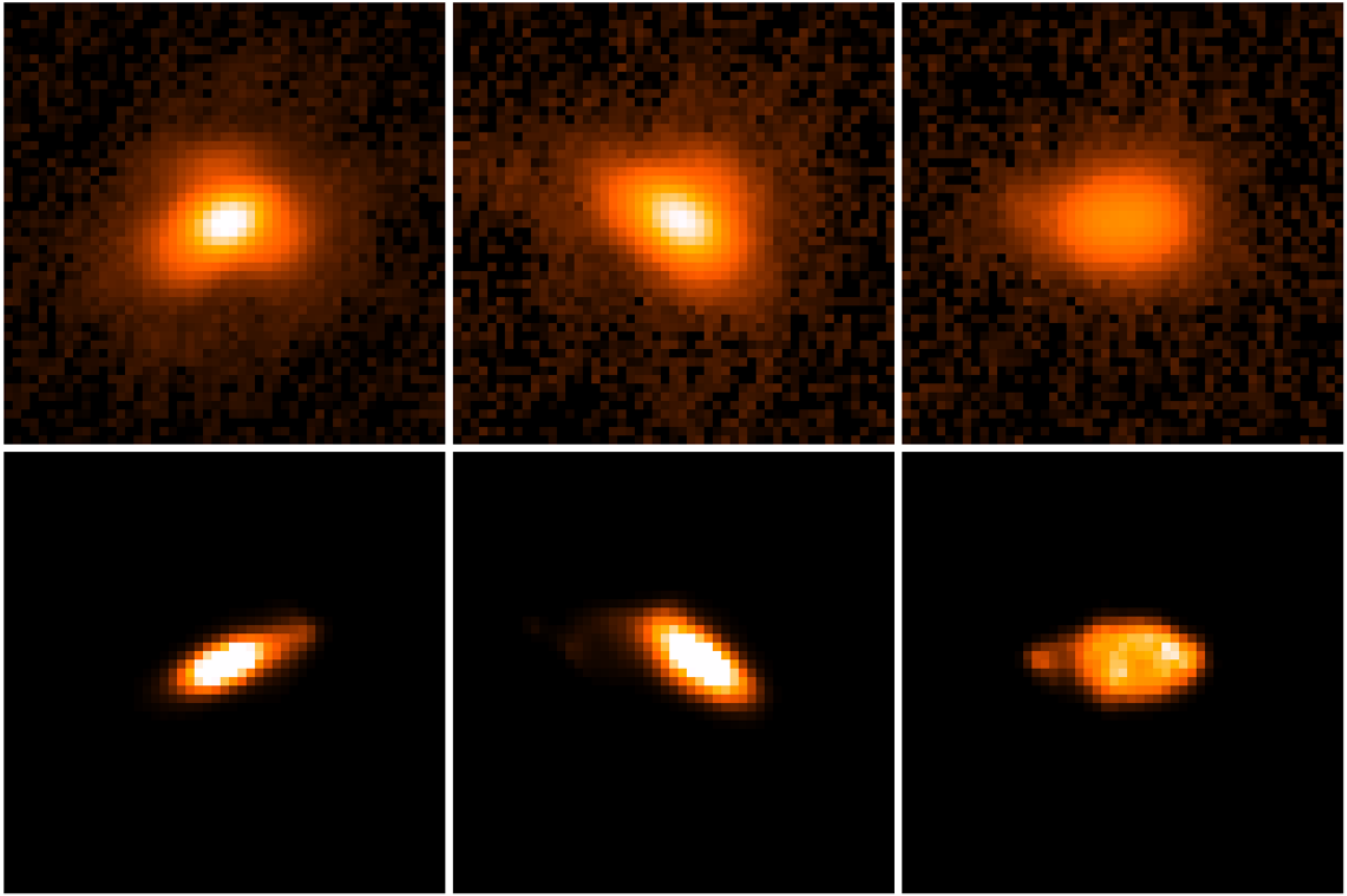
- PACS imaging at 70/100/160 μm in mini-scan map mode, with 2 orientations and 4 repetitions
- The observations are completed recently (HD 170773 only 9 days ago)
- Data processing with HIPE 8.0.3287, from level 0 products.
- Image scales for the final maps are 1.1/1.4/2.1 arcsec per pixel for the 70/100/160 um images, respectively.
- Aperture photometry was performed on individual images
- SPIRE 250/350/500 μm imaging in small map mode, with 2 repetitions
- We have worked on the final Level 2 pipeline processed data.
- Aperture photometry was used.

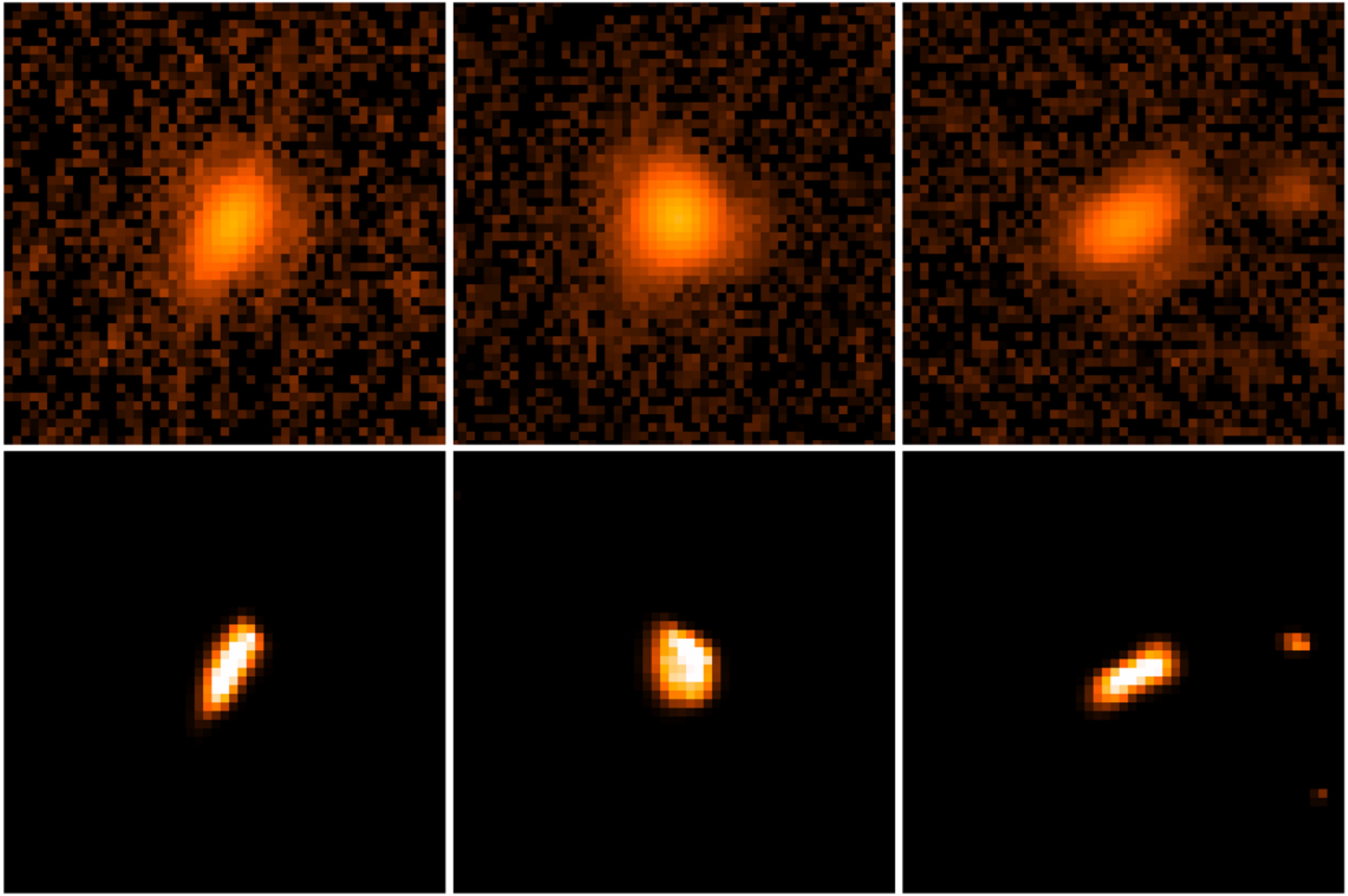
Results: detection statistics

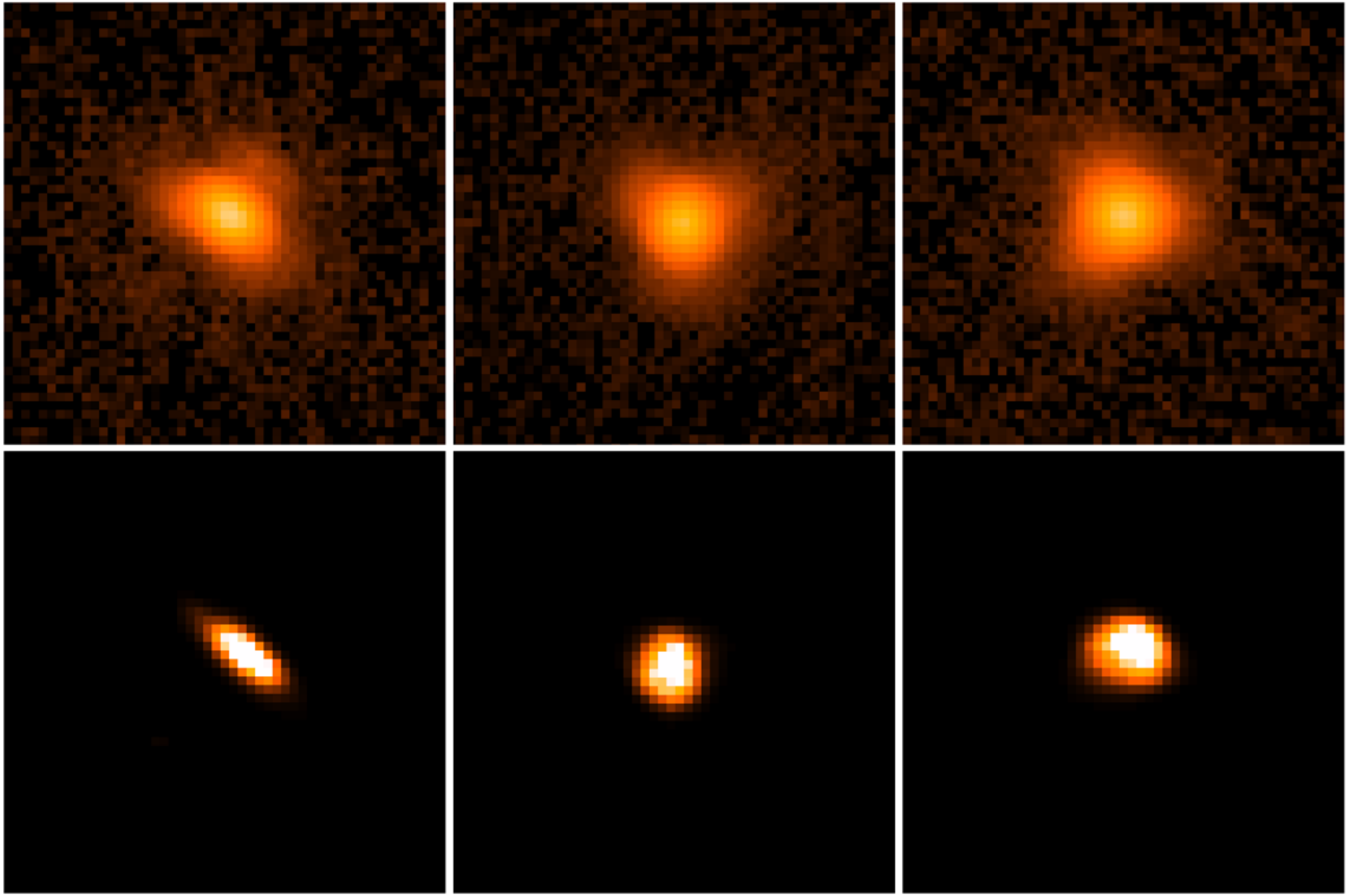
	70 µm	100 µm	160 µm	250 µm	350 µm	500 µm
HD 9672	✓	✓	✓	✓	✓	✓
HD 10939	✓	✓	✓	✓	✓	
HD 17848	✓	✓	✓	✓		
HD 21997	✓	✓	✓	✓	✓	✓
HD 50571	✓	✓	✓	✓	✓	✓
HD 95086	✓	✓	✓	✓	✓	✓
HD 161868	✓	✓	✓	✓	✓	✓
HD 170773	✓	✓	✓	✓	✓	✓
HD 182681	✓	✓	✓	✓	✓	
HD 195627	✓	✓	✓	✓	✓	

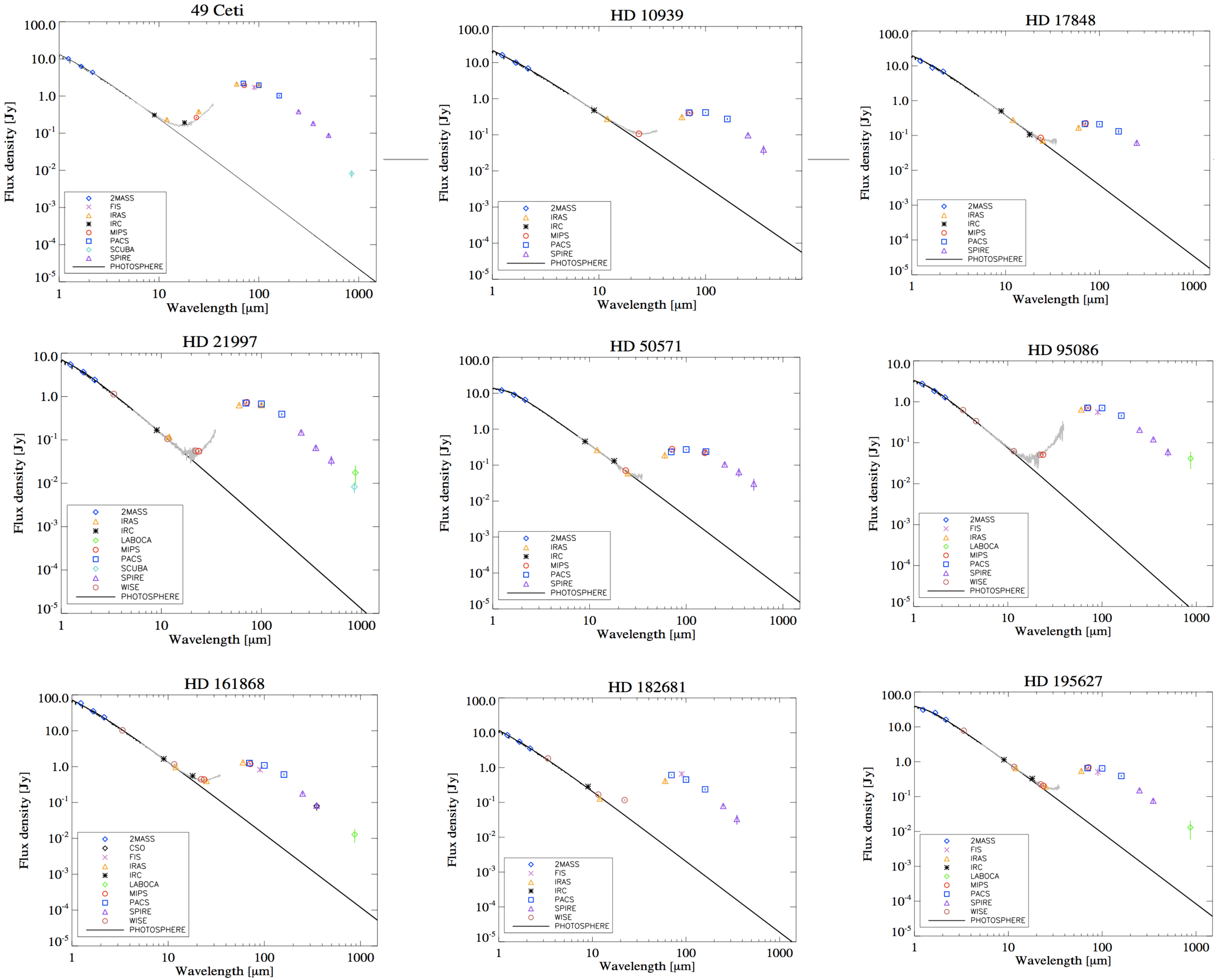


- All disks are resolved
- In 3 cases hint for source confusion






No obvious azimuthal brightness asymmetries are visible.

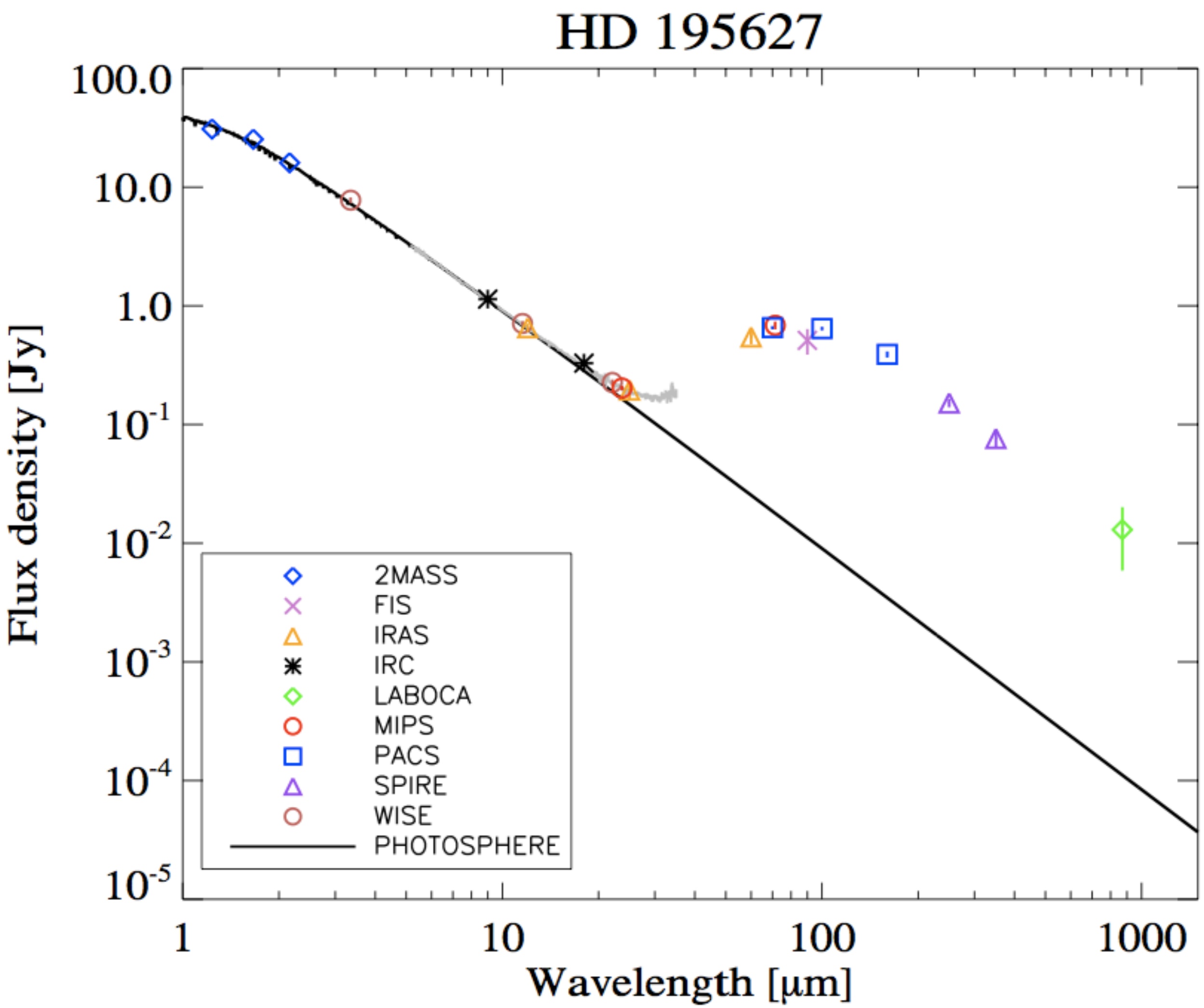

49 Ceti
Flux density [Jy]
Wavelength [µm]
2MASS
FIS
IRAS
IRC
MIPS
PACS
SCUBA
SPIRE
PHOTOSPHERE
HD 10939
Flux density [Jy]
Wavelength [µm]
2MASS
IRAS
IRC
MIPS
PACS
SPIRE
PHOTOSPHERE
HD 17848
Flux density [Jy]
Wavelength [µm]
2MASS
IRAS
IRC
MIPS
PACS
SPIRE
PHOTOSPHERE
HD 21997
Flux density [Jy]
Wavelength [µm]
2MASS
IRAS
IRC
LABOCA
MIPS
PACS
SCUBA
SPIRE
WISE
PHOTOSPHERE
HD 50571
Flux density [Jy]
Wavelength [µm]
2MASS
IRAS
IRC
MIPS
PACS
SPIRE
PHOTOSPHERE
HD 95086
Flux density [Jy]
Wavelength [µm]
2MASS
FIS
IRAS
LABOCA
MIPS
PACS
SPIRE
WISE
PHOTOSPHERE
HD 161868
Flux density [Jy]
Wavelength [µm]
2MASS
CSO
FIS
IRAS
IRC
LABOCA
MIPS
PACS
SPIRE
WISE
PHOTOSPHERE
HD 182681
Flux density [Jy]
Wavelength [µm]
2MASS
FIS
IRAS
IRC
PACS
SPIRE
WISE
PHOTOSPHERE
HD 195627
Flux density [Jy]
Wavelength [µm]
2MASS
FIS
IRAS
IRC
LABOCA
MIPS
PACS
SPIRE
WISE
PHOTOSPHERE

Quadratic deconvolution

- After Gauss 2D fitting we quadratically removed the PSF, and determined disk size, a/b ratio, PA, and inclination. Results:
- Disk major axis FWHM: 5” - 11.9” (290 - 680 AU)
- Inclination: 24º - 67º
- The results are close to the MIPS results (the reliability of the preparatory work is confirmed, but source confusion...)

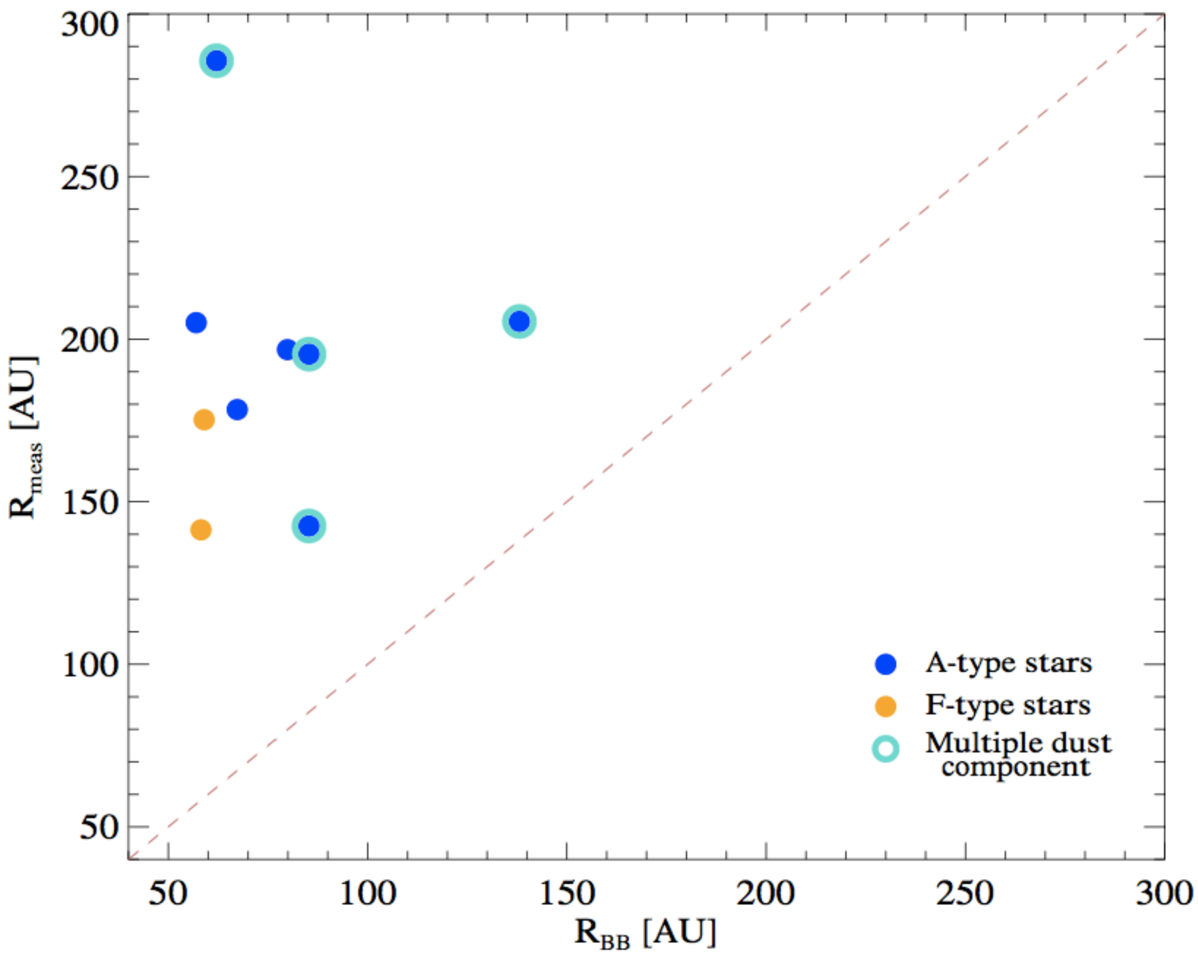
Temperature & beta determination

- The SEDs are fitted with a modified BB function
- T = 49-82 K
- In 4 cases multiple fits
- Beta = 0.26 - 0.76, average value: 0.6 (consistent with Gáspár et al. 2012)
- Gáspár et al. (2012) determined beta for 9 cases where at least 3 submm data points existed; the present programme adds 6 new ones.

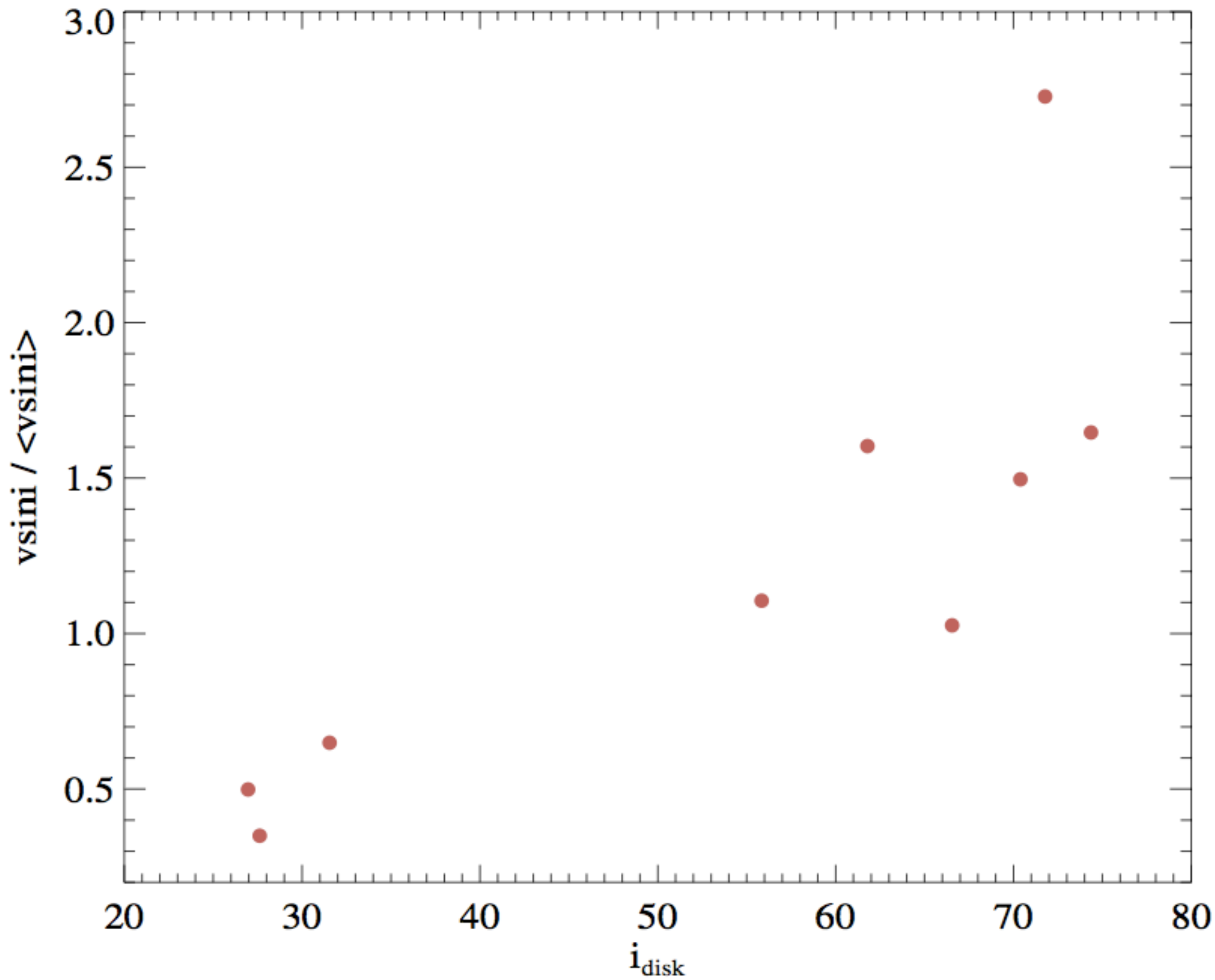


Blackbody vs. Gaussian size

- From the temperature the location of the BB dust is determined.
- All measured disk sizes are larger than the BB diameter.
- (i) a halo of small particles outside the planetesimal belt (blowout)
- (ii) radially extended disk containing small grains

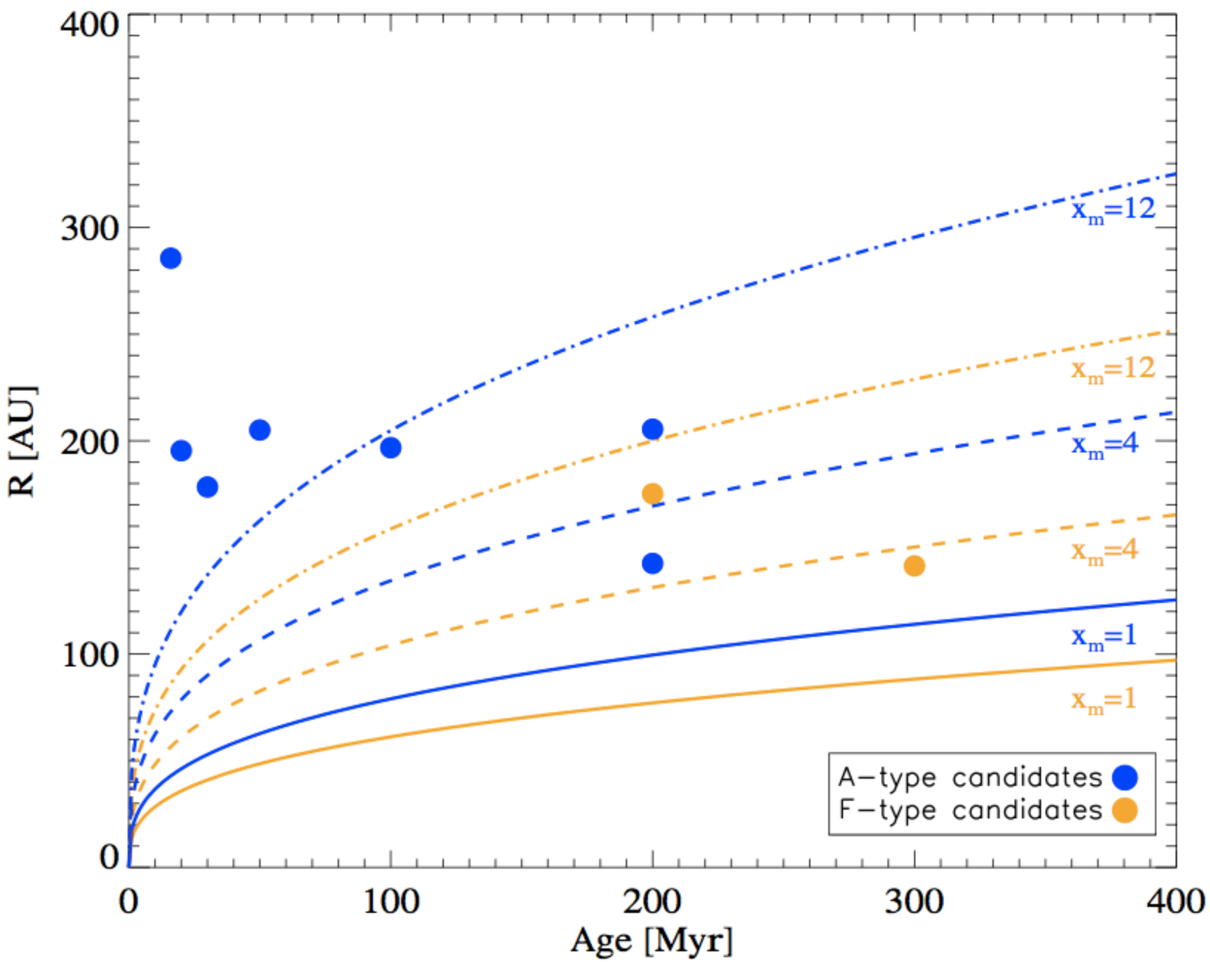


Are the disks in the equatorial plane?



Initial disk mass

- Using the quadratic decomposition sizes, we re-computed the initial surface density values
- Our disks remain “suspicious” for being non self-stirring objects
- HD 17848: early stellar flyby (Deltorn & Kalas 2001)
- **Perhaps the most promising candidate list for planetary stirring and/or stellar flyby**



Next steps

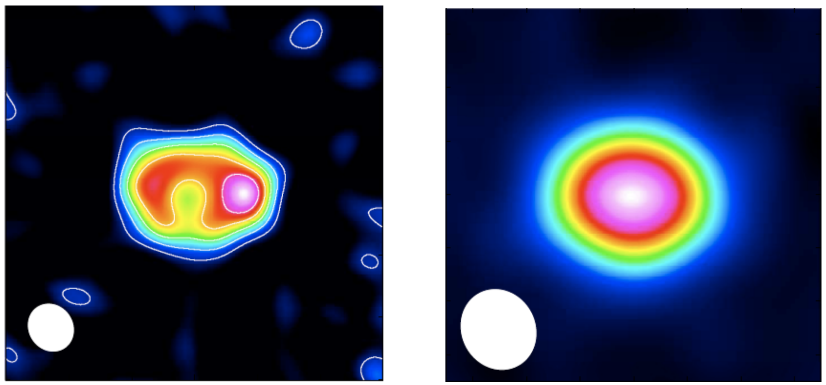
- **Detailed questions:**
  - What is the radial distribution of dust?
  - Where is exactly the planetesimal ring?
  - Are there many small blowout particles outside?
  - What are the disk parameters, what is the $\Sigma(r)$ profil?
  - What is the grain size distribution?
  - Is the size increases with wavelength?

  Try to locate the radius of the brightest region in the disk (this is probably the site of the most collisions): (1) deconvolution; (2) modelling.

- **Modelling with the DEBRA radiative transfer code** (Olofsson et al. 2012): fit the SED ⇨ create image ⇨ compute χ^2

Further observations

- The sample of extended debris disks around young stars is an interesting subgroup, and we continue to investigate them from different aspects.
- Search for molecular gas (CO 3-2, CO 2-1) in 7 out of these 10 stars with APEX: HD 21997 was detected (Moór et al. 2011)
- Some stars are involved in direct planet detection programmes
- PACS spectroscopy survey of 18 such system (Priority 2, PI: Cs. Kiss)
- **ALMA Early Science programme for HD 21997** (PI: Á. Kóspál)



ALMA simulated images