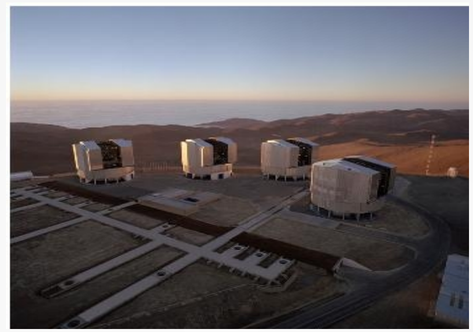
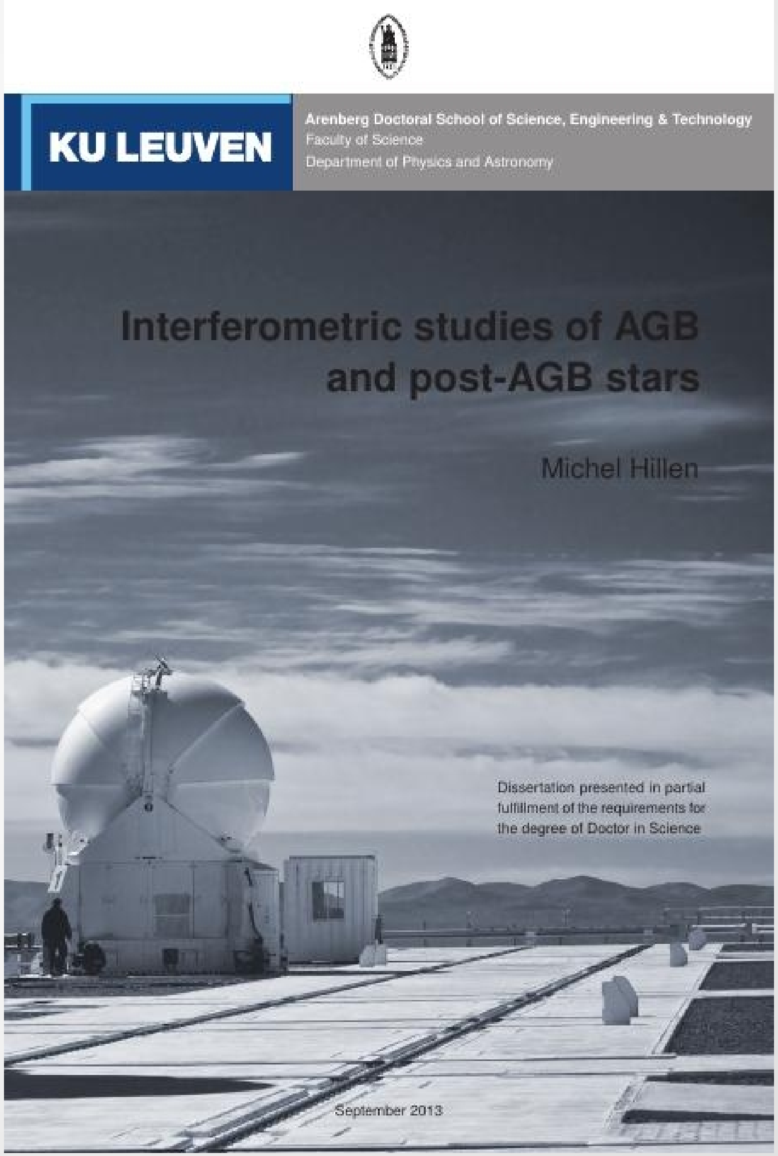
An N band interferometric survey of the disks around post-AGB binary stars



Michel Hillen, post-doc, Instituut voor Sterrenkunde, KU Leuven

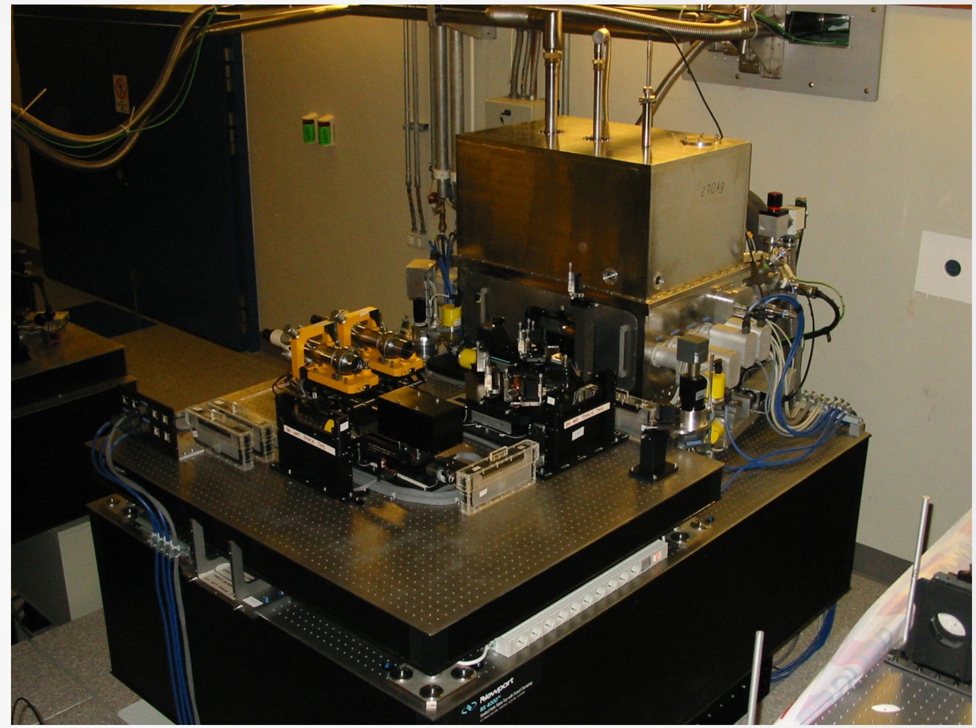
J. Menu, R. Manick, J. Debosscher, T. Verhoelst, D. Kamath, H. Van Winckel

My memories of Olivier



MIDI: Olivier's baby

- First 2nd generation instrument at VLTI
- 2T combiner at 10 µm
- Decommissioned in March



- Olivier published 10 first-author papers with 'MIDI' in the abstract, including
  - a review about the instrument and its data reduction
  - some of the first observations taken with the instrument
  - observations of Be stars, OH/IR stars, PNe, Eta Carinae, Novae

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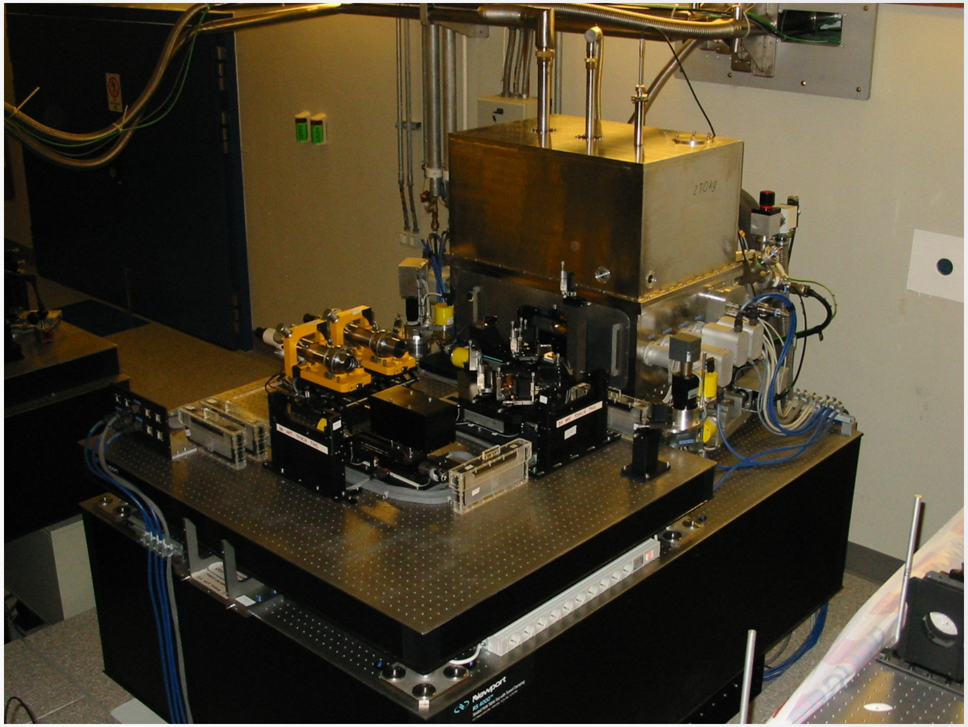
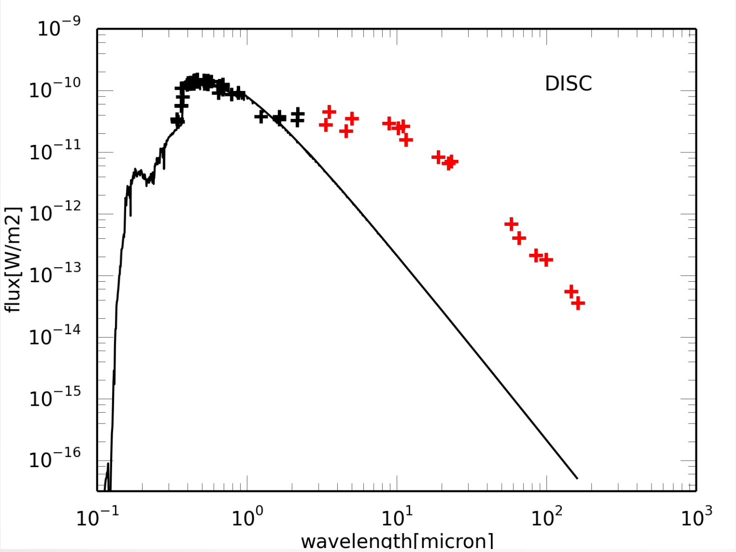
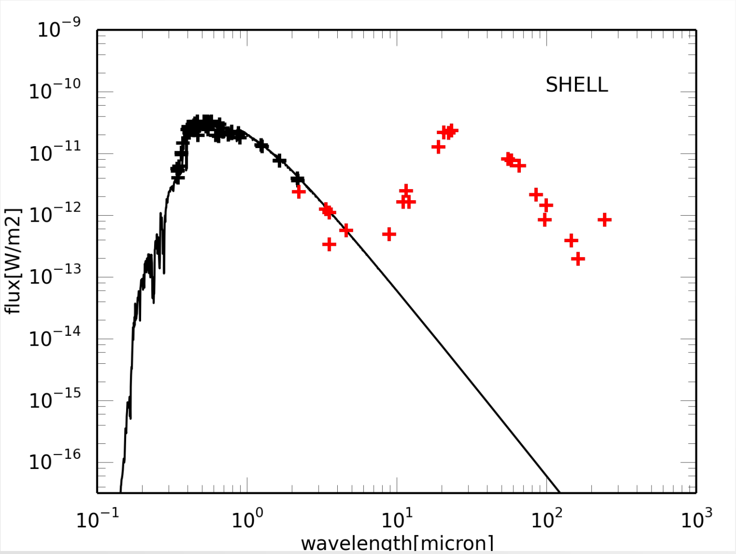


Disks were a central theme in these works!

One class of 'evolved star disks' that Olivier did not touch are the ones around post-AGB stars!

Optically bright post-AGB/RGB stars





(Gezer et al., in prep.)

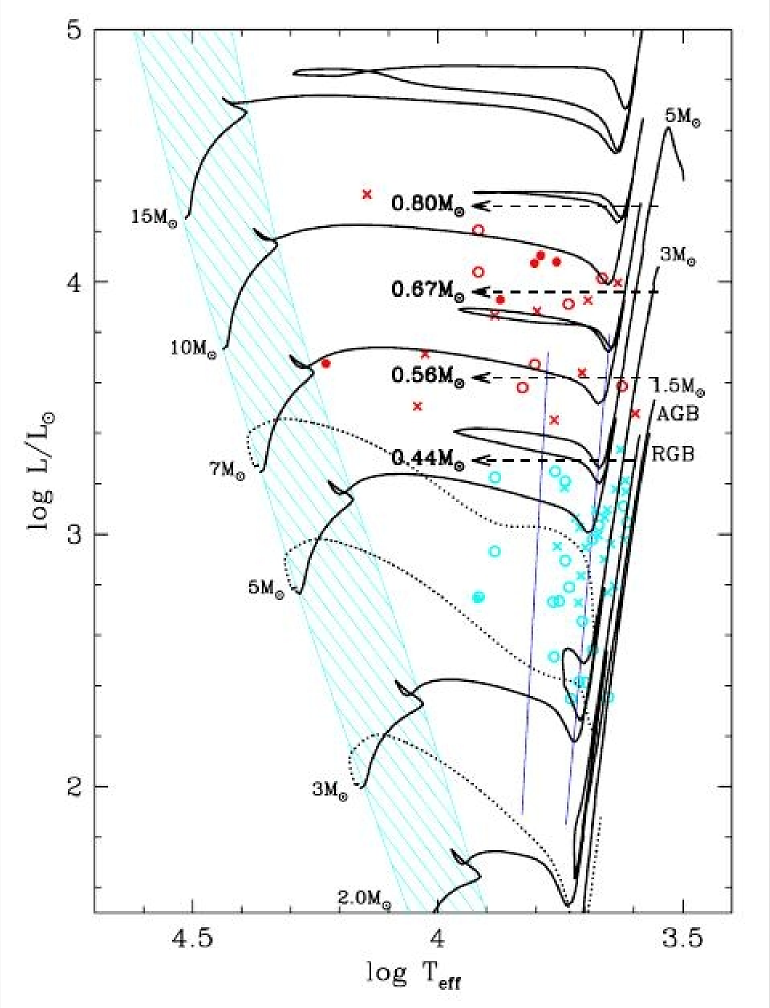
F,G,K spectral types

See talks of

Van Winckel

Kamath

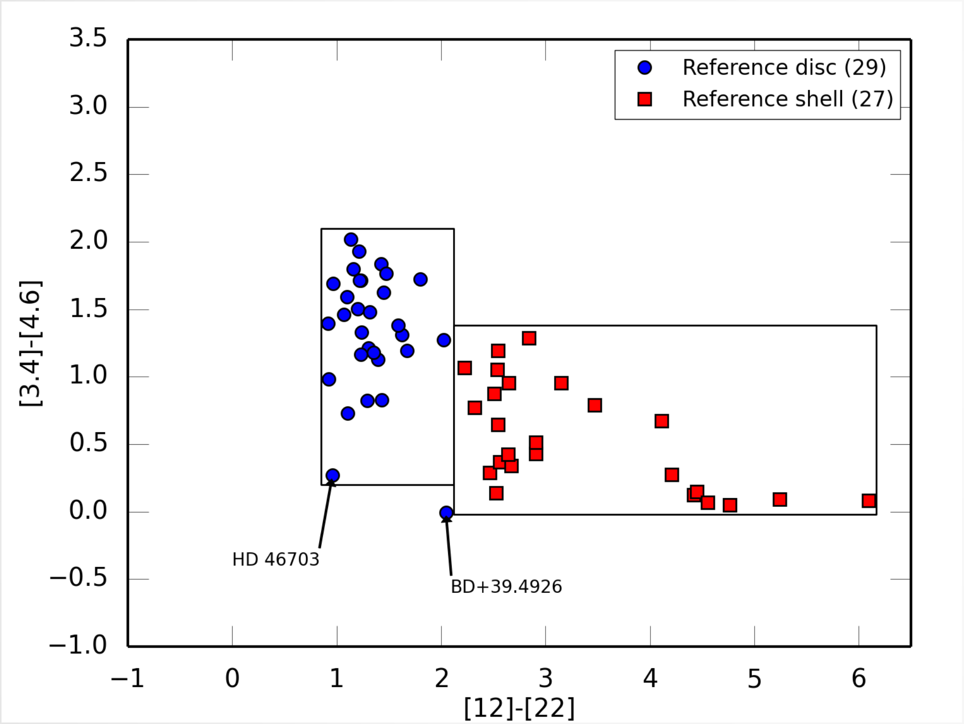
Vos



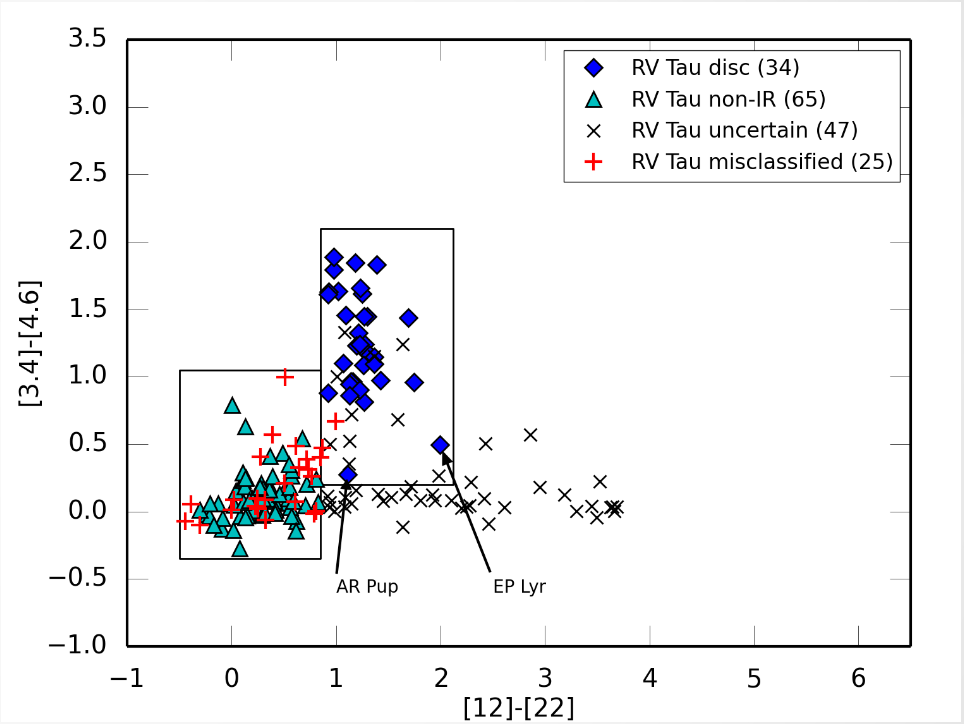
(Kamath et al., 2014)

The WISE view of post-AGB stars: color-color diagrams

Gezer et al., subm.



Reference sample

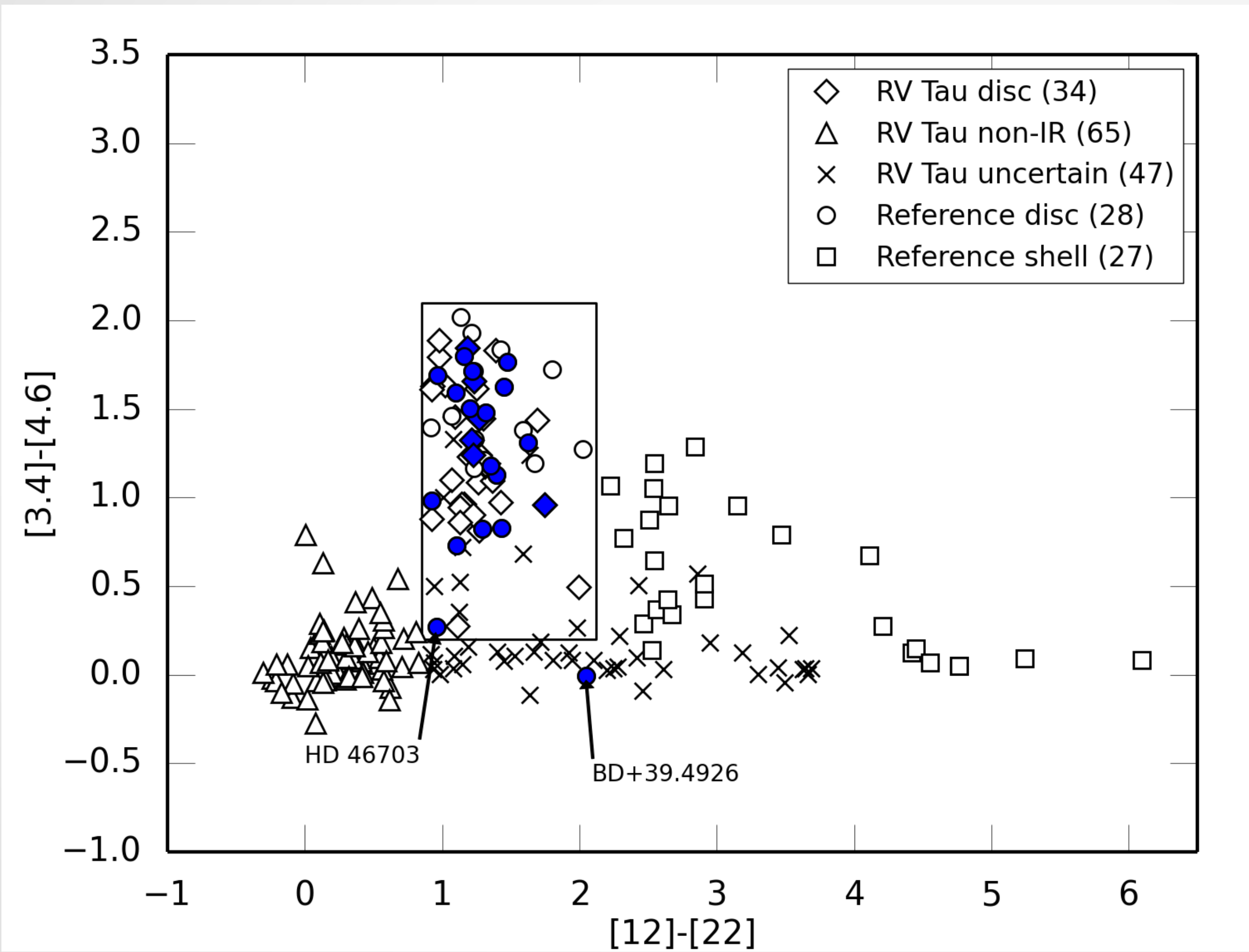


RV Tauri sample
(from the GCVS)

Disks: binaries (P_{orb} ~100-3000 d)
Shells: single stars? -> see poster B. Hrivnak

Type II Cepheids with P_{puls}>20 d
--> L and T_{eff} = post-AGB star

Disk – binary connection



Total Galactic *disk sample*: ~100 sources

Our MIDI sample:
18 sources spread over the *disk box,* including reference as well as RV Tauri objects

All confirmed binaries!

Gezer et al., subm.

Aims/Questions

The **disk nature** of the circumstellar material around post-AGB binaries is now **well established**, but we don't understand

- the formation of the disk (binary interaction!)

  (N. Soker's GEE scenario may be relevant here)

- the evolution of the disk (and its influence on the binary!)

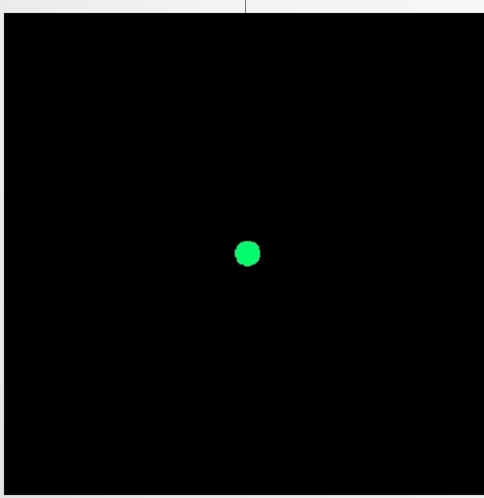
  (search for progeny etc., see long binaries in PNe)

The MIDI sample

IRAS	name	α_{2000} [h m s]	δ_{2000} [° ′ ″]	Spectral Type	P_{binary} [days]	
04440+2605	RV Tau	04 47 06.7	+26 10 45.6	K3pv	1180 ± 15	
07008+1050	HD 52961	07 03 39.6	+10 46 13.1	F6I	1297 ± 7	Deroo et al. 2006
07284-0940	U Mon	07 30 47.5	−09 46 36.8	K0IIb	~ 2600	
08011-3627	AR Pup	08 03 01.6	−36 35 47.9	F0I	1250 ± 300	
08544-4431		08 56 14.2	−44 43 10.7	F3	508 ± 2	Deroo et al. 2007
09256-6324	IW Car	09 26 53.3	−63 37 48.9	A4Ib/II	~ 1440	
10158-2844	HR 4049	10 18 07.6	−28 59 31.2		434 ± 1	Acke et al. 2013
10174-5704		10 19 16.9	−57 19 26.0	G8Iab	323 ± 50	
10456-5712	HD 93662	10 47 38.4	−57 28 02.7	K5	572 ± 6	
12185-4856	SX Cen	12 21 12.6	−49 12 41.1	G3V	592 ± 13	Deroo et al. 2006
12222-4652	HD 108015	12 24 53.5	−47 09 07.5v	F4Ib/II	914 ± 4	
15469-5311		15 50 43.8	−53 20 43.3	F3	390 ± 1	
17038-4815		17 07 36.6	−48 19 08.6	G2p	~ 1400	
17243-4348	LR Sco	17 27 53.6	−43 50 46.3	G2	~ 475	
17534+2603	89 Her	17 55 25.2	+26 03 00.0	F3	288 ± 1	Hillen et al. 2014
18281+2149	AC Her	18 30 16.2	+21 52 00.6	F2Iep	1194 ± 6	Hillen et al. 2015
19125+0343		19 15 01.2	+03 48 42.7	F2	520 ± 2	
22327-1731	HD 213985	22 35 27.5	−17 15 26.9	A0III	258.6 ± 0.3	

Studies of individual objects

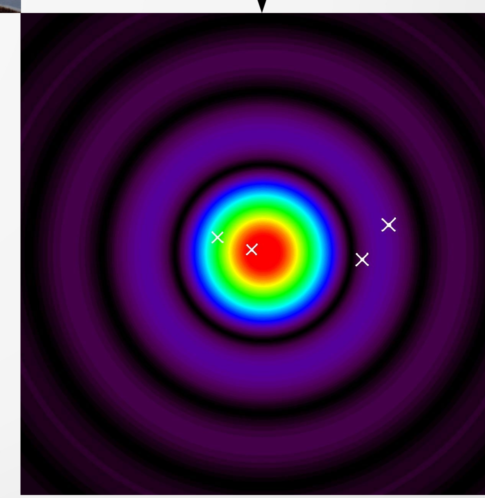
Basics of interferometry



$I(\alpha,\beta)$

$$V(u,v) = FT(I(\alpha,\beta))$$

B_{hor} / λ B_{ver} / λ



Direct inversion ("imaging") usually not feasible due to limited uv-filling.

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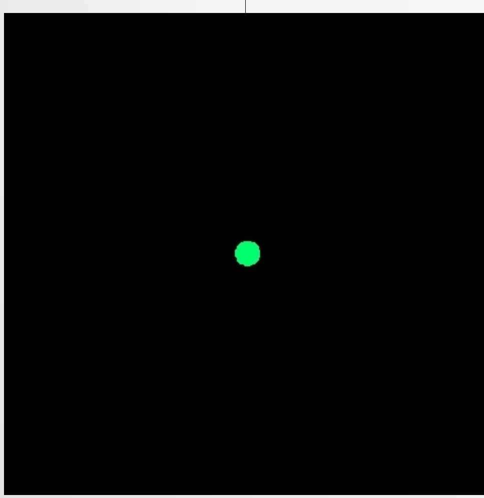

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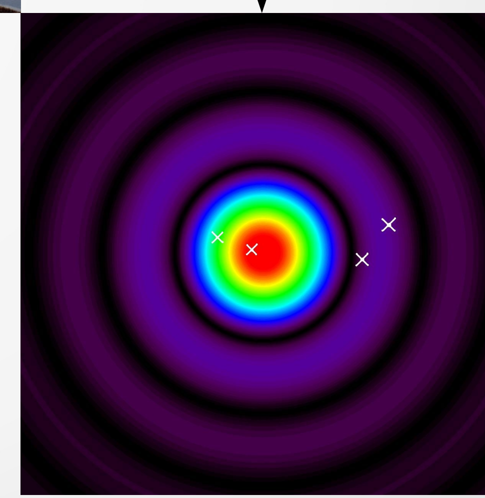
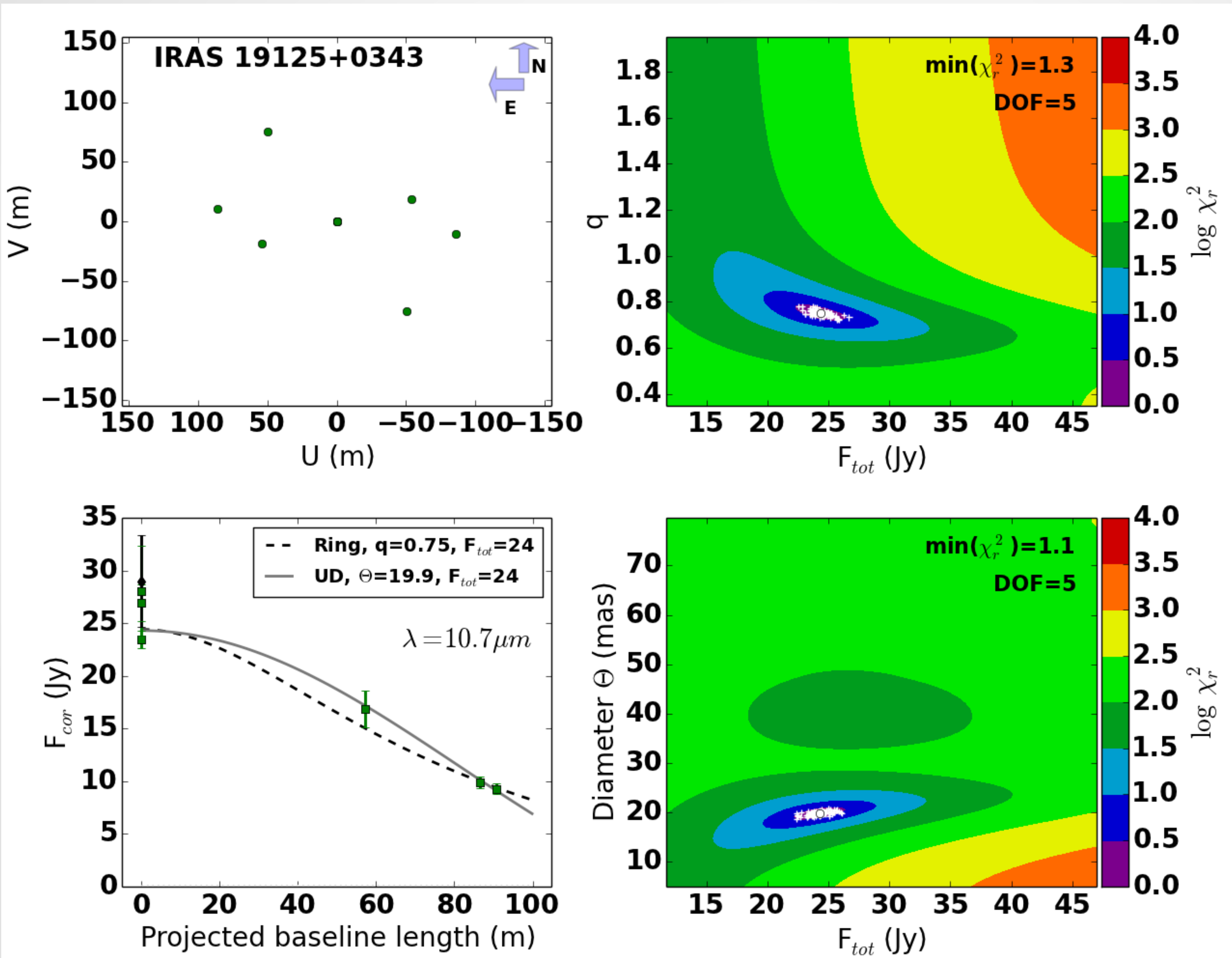


Direct inversion (“imaging”) usually not feasible due to limited uv-filling.

→ for a nice example, come to EWASS, Tenerife or STEPS, Garching

Fit results



Ring model

2- parameter fit: F_{tot} and q, which translates into hlr

Uniform disk model

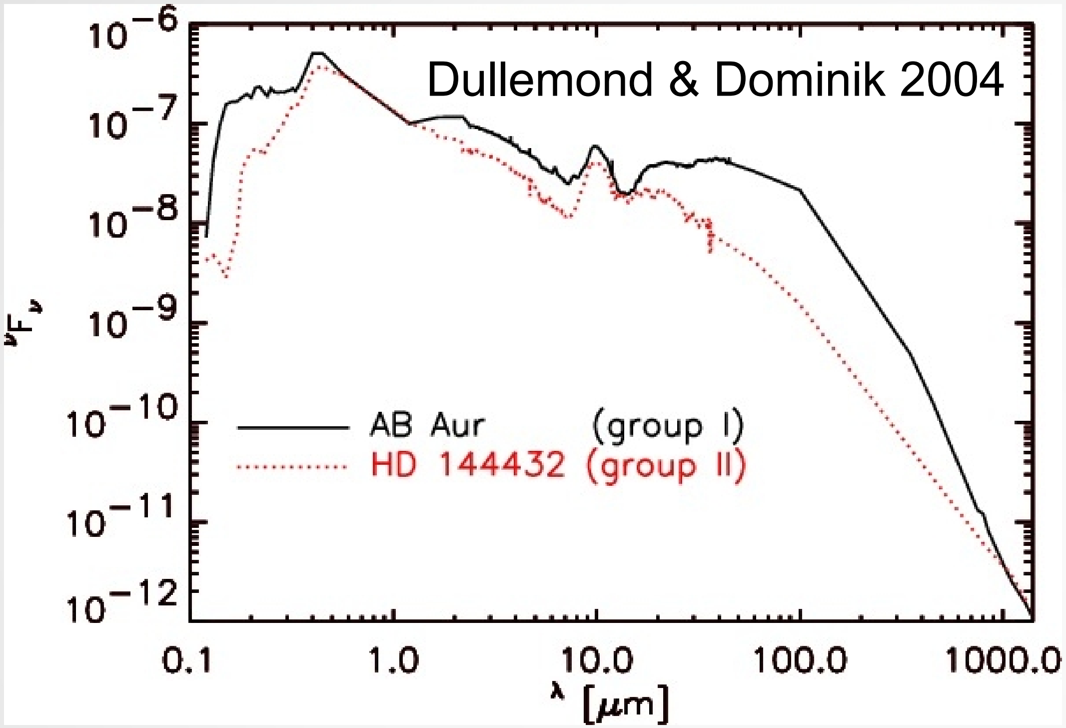
2-parameter fit: F_{tot} and Θ

Let's look at the bigger picture...

...and compare with another sample of disks, recently studied in exactly the same way: Herbig Ae/Be stars.

Remember: the underlying physics is the same and we're after diagnostic signs of evolution!

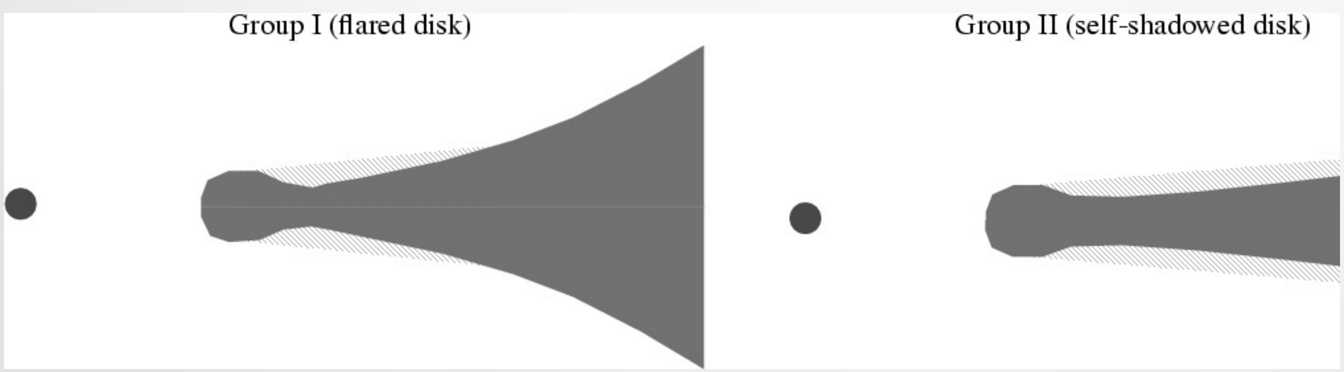
Herbig protoplanetary disks: the classical picture



Group I <-> Group II

Interpreted in terms of disk shape/surface

Flaring <-> Flat

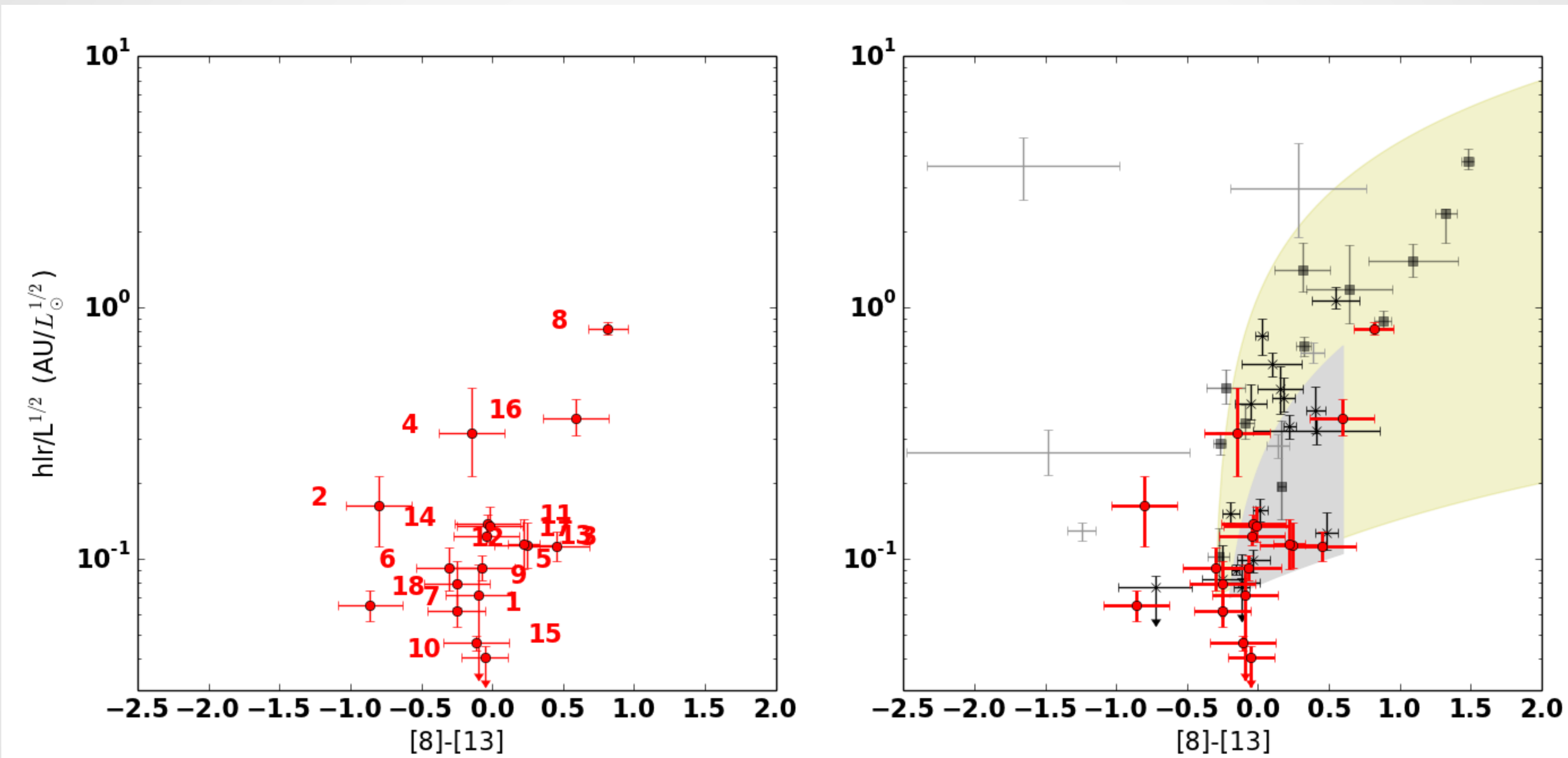


Remark:
1) Inner radius = dust sublimation radius
2) Concept of 'shadowing' controversial

(see Dullemond & Monnier, ARA&A, 2010)

Sample results: size-color diagram

Herbig results from Menu et al. (submitted)



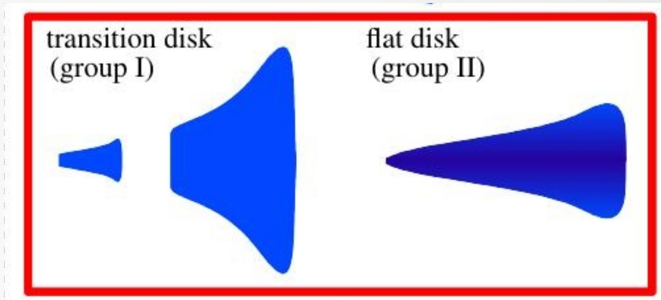
Distance-independent size!

Shaded zones: Monte Carlo RT models

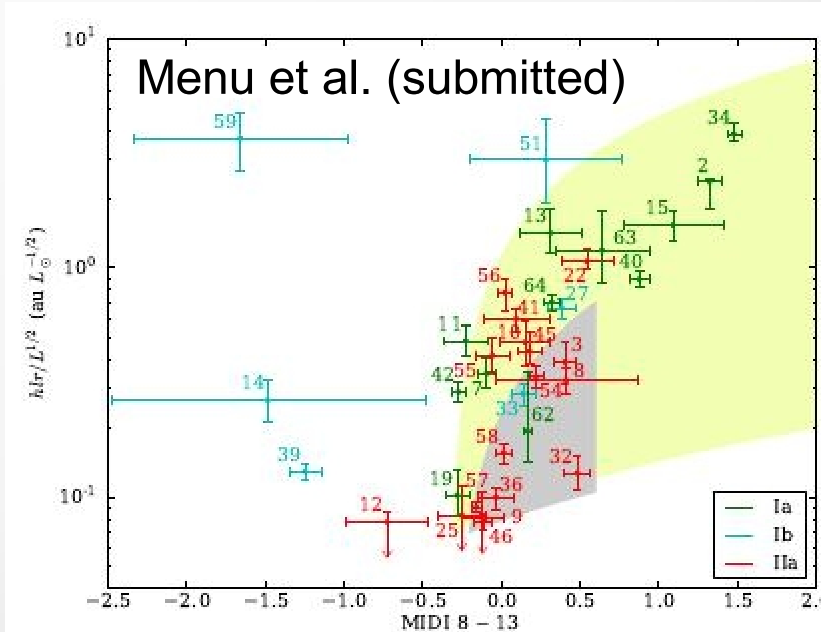
Red: post-AGB
Black squares: group Ia Herbig Ae disks
Black crosses: group II Herbig Ae disks
Grey: group Ib Herbig Ae disks

Herbig protoplanetary disks (revisited)

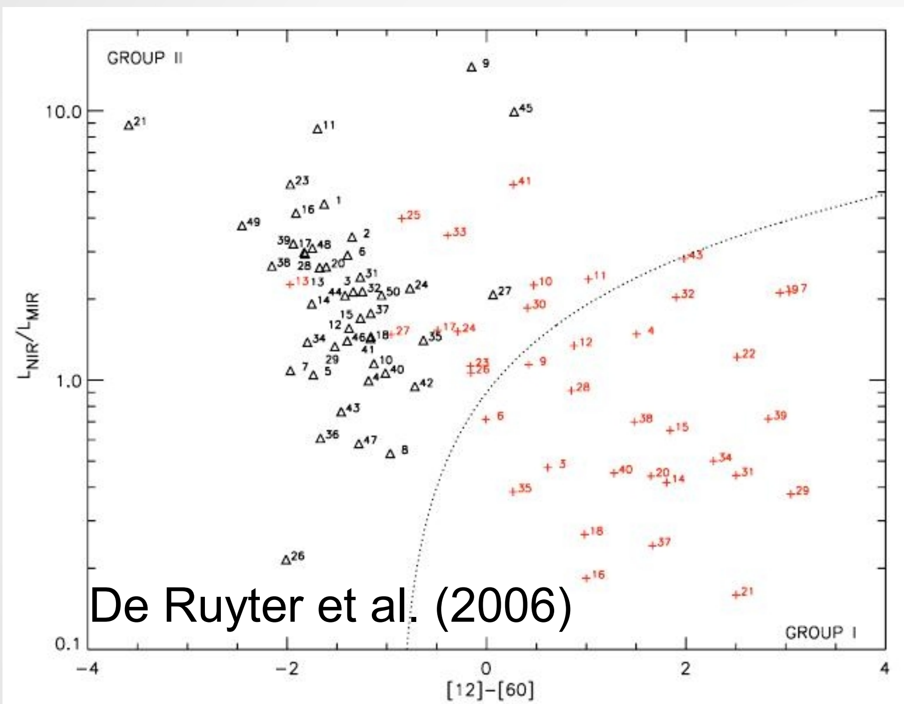
- Which underlying physical process(es) cause(s) the dichotomy in structure?
- Evolution?
- Recent observations show a connection between group I classification and the presence of disk gaps (Maaskant et al. 2013, 2014, 2015).
- The MIDI color-size diagram confirms this:
  - the **yellow** zone denotes the region populated by **RT models with gaps**, while models with inner radii at the **sublimation radius** are in the **grey** zone!
  - (Most) Ia sources must have gaps! IIa sources may be continuous or have gaps.
- Group Ib objects have non-thermal emission from PAHs.



Maaskant et al. (2013)



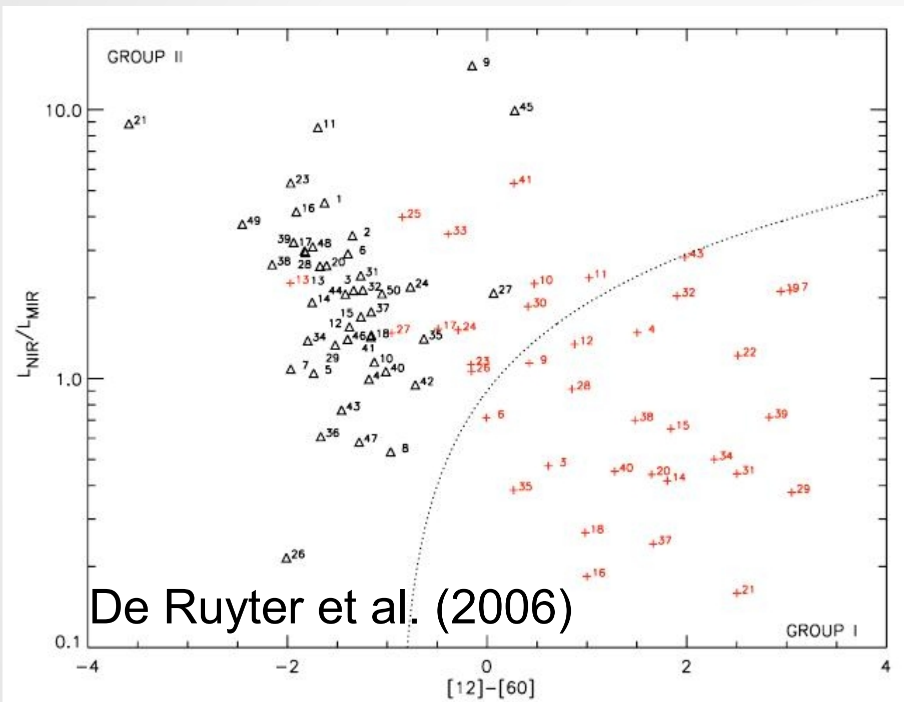
Post-AGB vs. Herbig disks

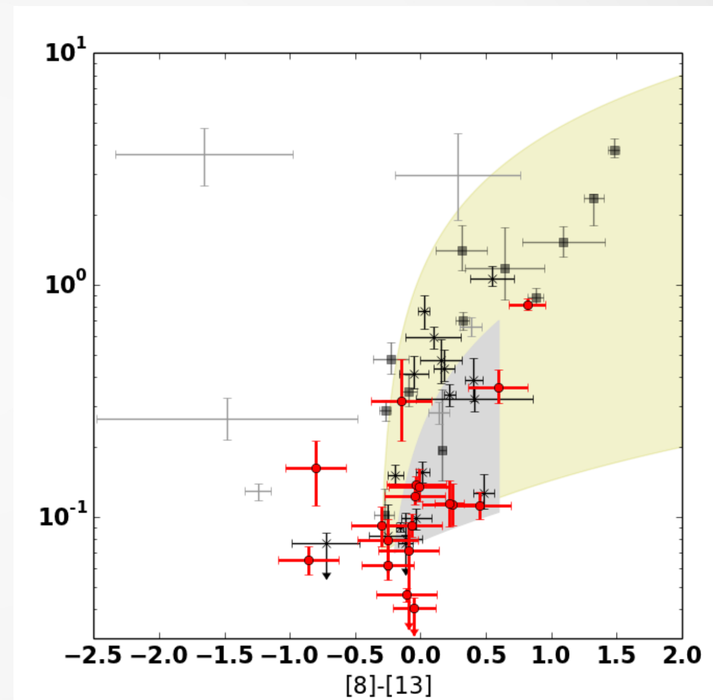


De Ruyter et al. (2006)

“Photometrically” post-AGB disks belong to group II (but not exactly the same).

Post-AGB vs. Herbig disks



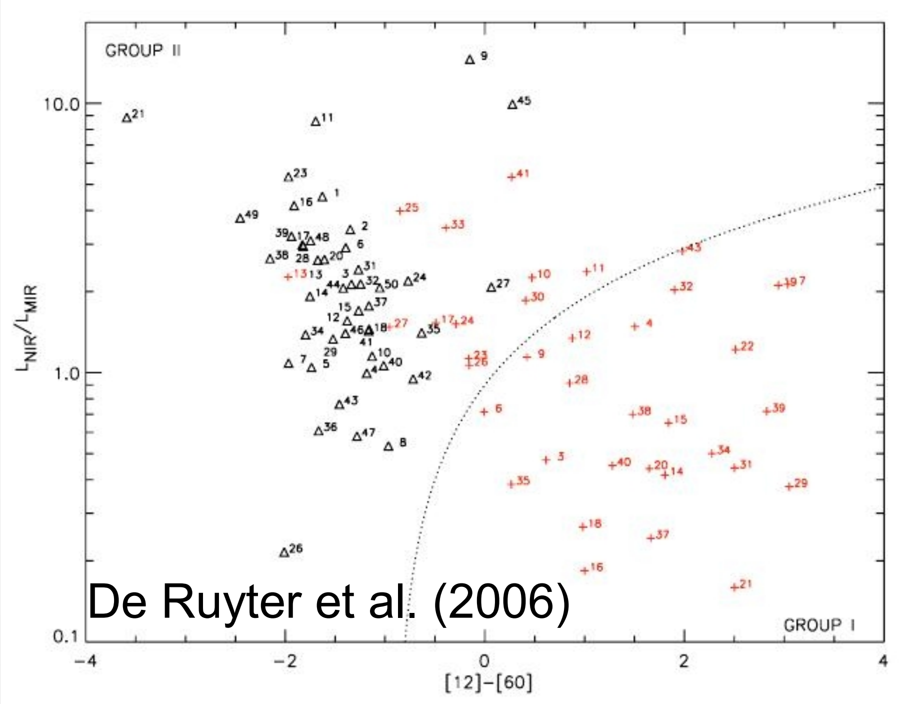


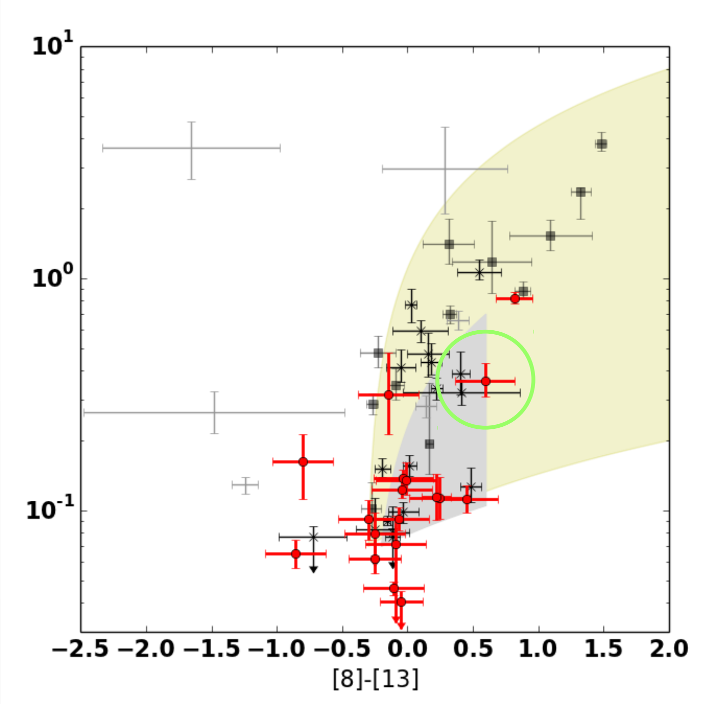
"Photometrically" post-AGB disks belong to group II (but not exactly the same).

"Interferometrically" they also belong to group II (and not exactly the same).

Post-AGB vs. Herbig disks

Still to be done: compute models in a post-AGB context!





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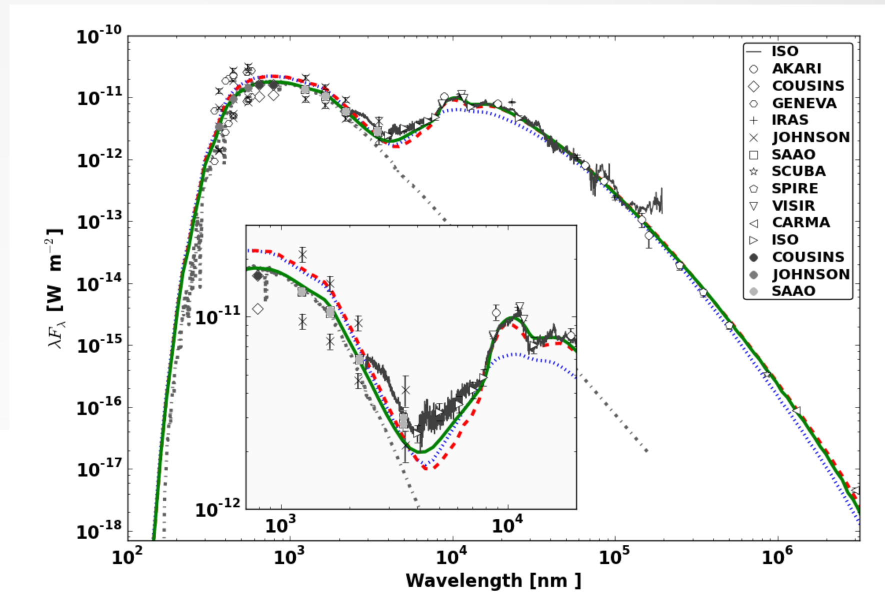
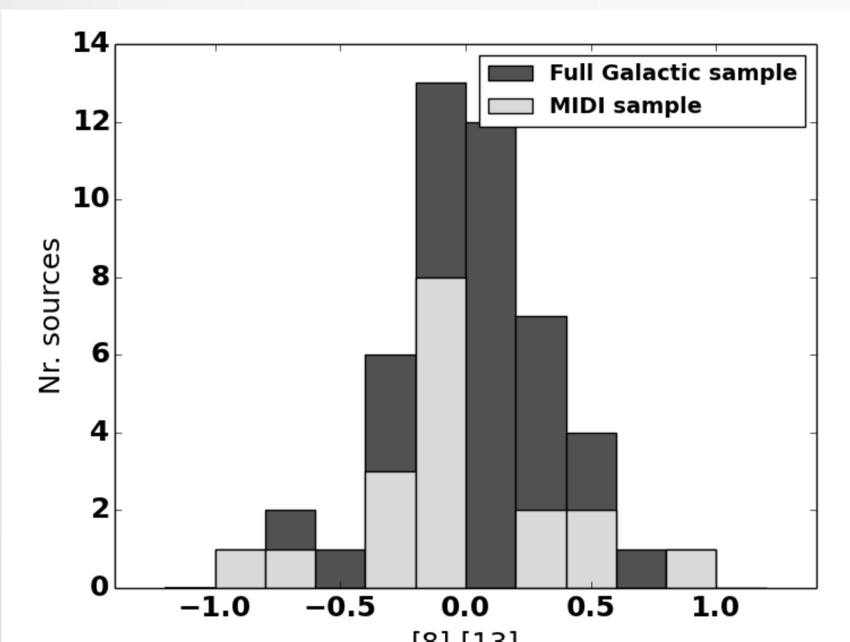
Outliers and biases?

AC Her: inner disk radius ~10 times dust sublimation radius! (Hillen et al. 2015)





Galactic sample from de Ruyter et al. (2006)

Conclusions

- RV Tauri stars separate well in the WISE color-color diagram, just like the post-AGB reference sample. --> in total ~100 disk sources identified
- Mid-IR interferometric sample studies provide unique insights about the structure and evolution of disks. We studied **~20% of the known post-AGB disk population** in the Galaxy with MIDI.
- Post-AGB “disk sources” (i.e. as identified from their SEDs) are indeed **spatially compact** in the mid-IR, consistent with inner radii at the dust sublimation radius (with a few exceptions, like AC Her).
- Post-AGB disks probably **evolve differently than Herbig Ae** disks, given that they are all “group II” objects.
- Future work should focus more on objects just outside the *disk box* to distinguish between shells, evolved disks and genuine non-IR sources!

To end with a quote

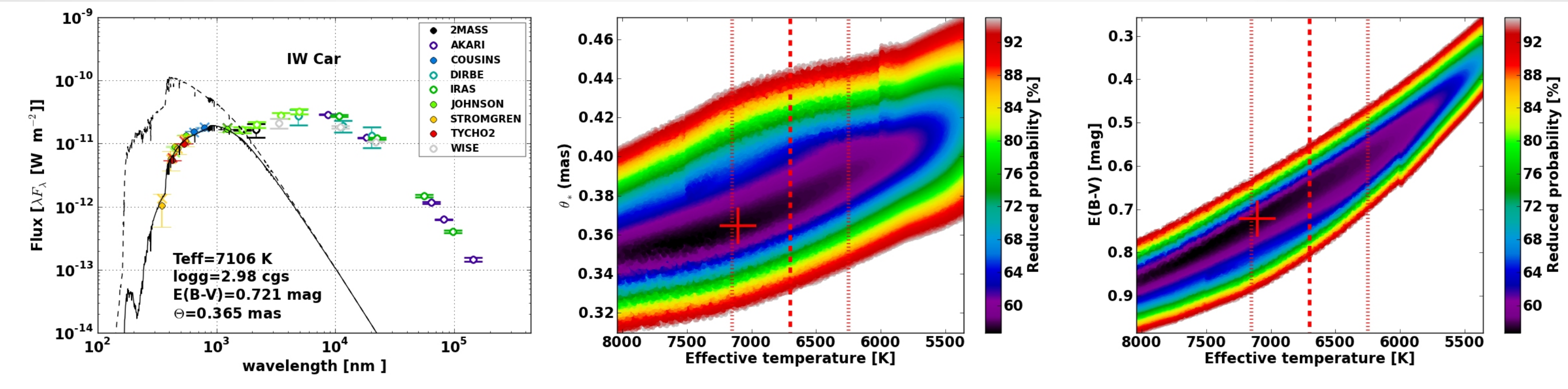
“My personal opinion is that the discovery of a stratified disk with proved Keplerian kinematics is directly connected to the influence of a companion, albeit the few exceptions presented above, namely the Young Stellar Objects or the critical velocity rotating massive sources such as Be stars. This hypothesis must be confirmed by further observations.”

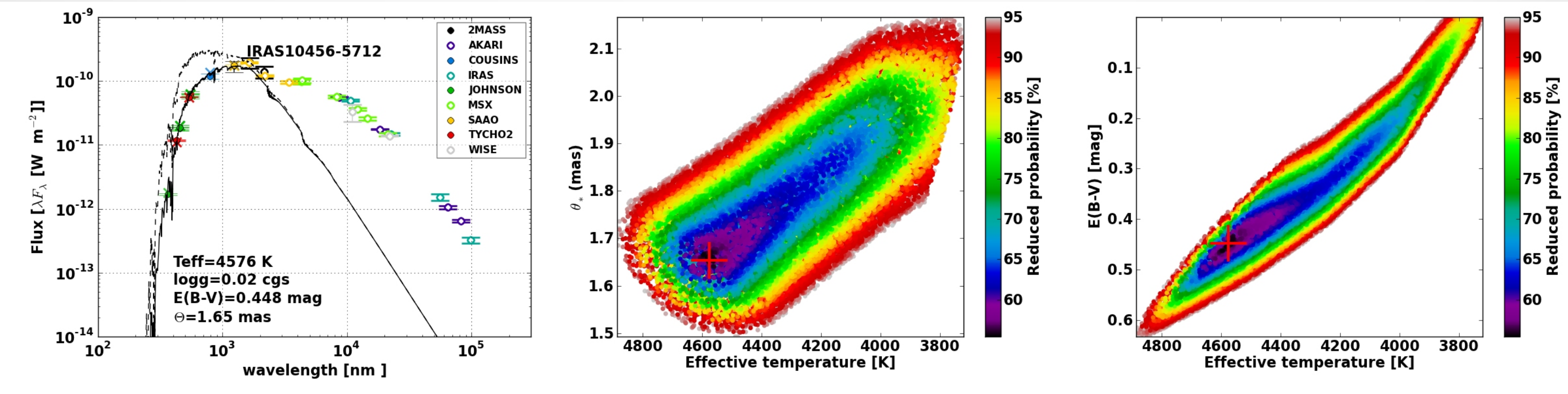
O. Chesneau
(Chapter 10 of Lecture Notes in Physics Vol 857, 2013)

The end

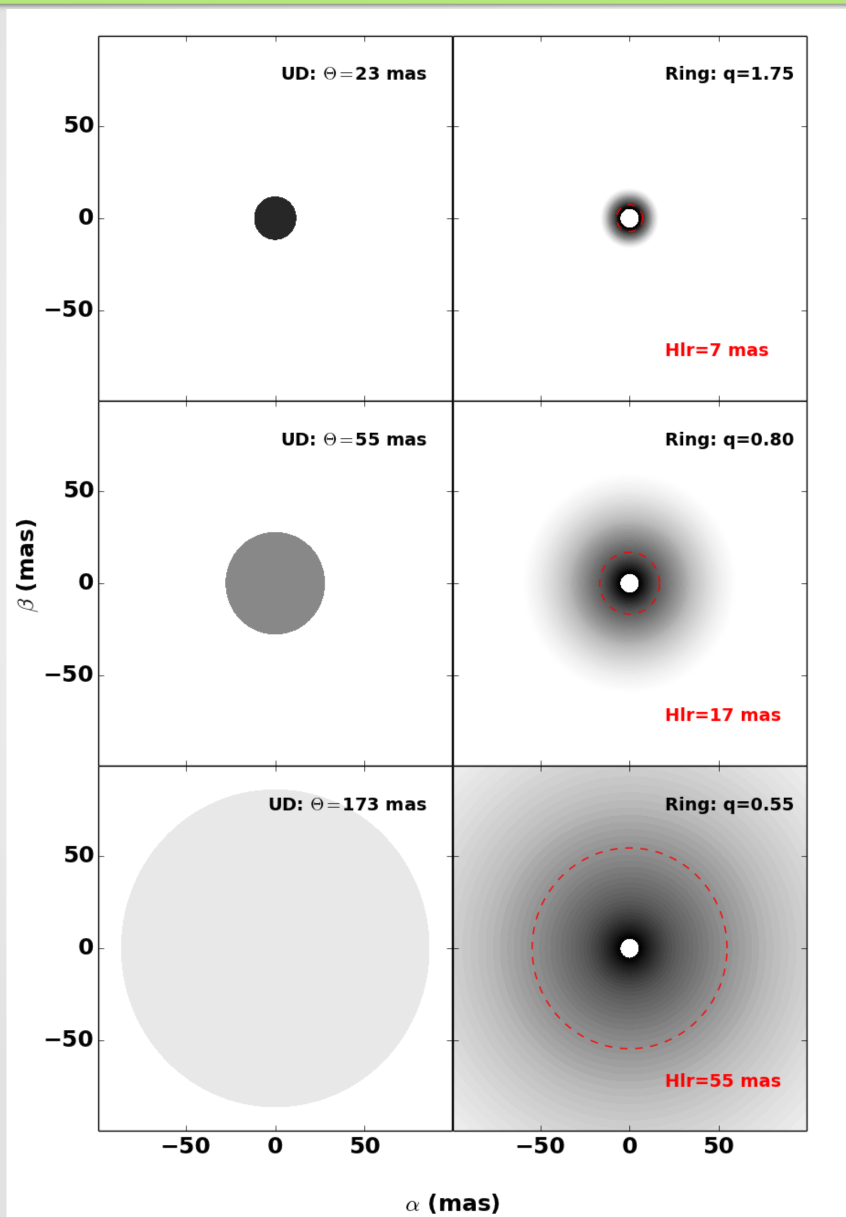
Thank you for your attention!

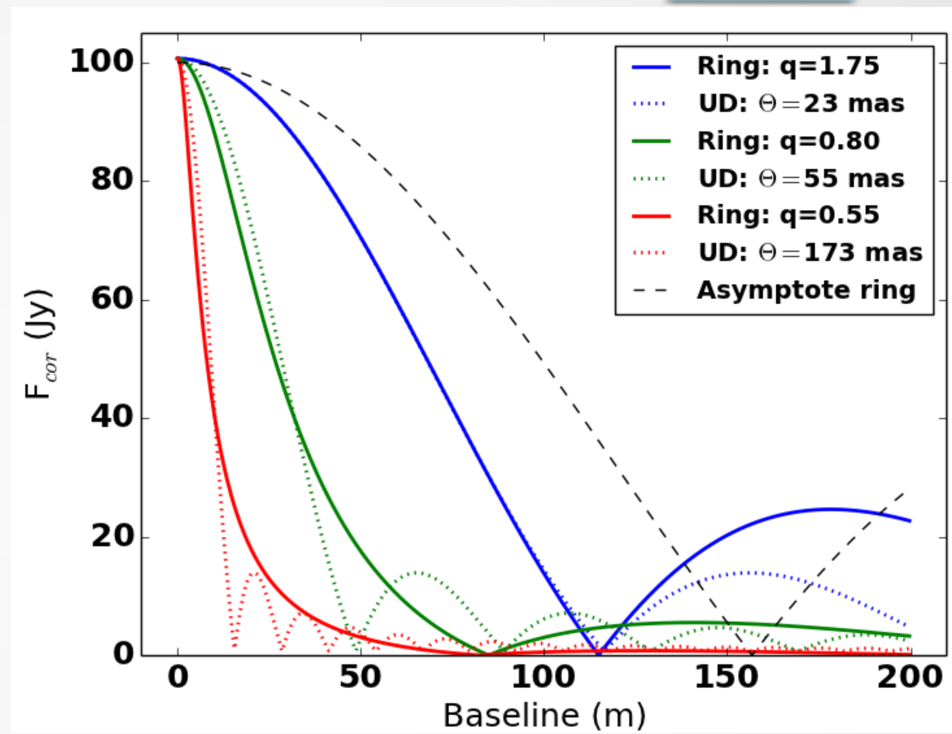
Stellar parameters: optical spectroscopy + SED fitting





Model fitting of MIDI data





$$I_\nu(\rho) = \tau B_\nu(T(\rho)) \quad \text{for} \quad \rho_{\rm sub} < \rho < \rho_{\rm out}$$

$$T(\rho) = T_{\rm sub}\left(\frac{\rho}{\rho_{\rm sub}}\right)^{-q} \qquad \rho_{\rm sub} = \frac{\theta_\star}{2}\left(\frac{T_{\rm eff}}{T_{\rm sub}}\right)^2$$

Hlr = half-light radius

Teff: optical spectra θ_*:SED fit