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

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J. Menu, R. Manick, J. Debosscher, T. Verhoelst, D. Kamath, H. Van Winckel
My memories of Olivier
MIDI: Olivier's baby

- First 2\textsuperscript{nd} 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

F,G,K spectral types

See talks of
Van Winckel
Kamath
Vos

(Gezer et al., in prep.)

(Kamath et al., 2014)
The WISE view of post-AGB stars: color-color diagrams

Gezer et al., subm.

Reference sample

Disks: binaries ($P_{\text{orb}} \sim 100$-$3000$ d)
Shells: single stars? $\rightarrow$ see poster B. Hrivnak

RV Tauri sample
(from the GCVS)

Type II Cepheids with $P_{\text{puls}} > 20$ d
$\rightarrow$ L and $T_{\text{eff}} = \text{post-AGB star}$
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.
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  | $\alpha_{2000}$ [h m s] | $\delta_{2000}$ [$^\circ$ ' '] | Spectral Type | $P_{\text{binary}}$ [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               |
| 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 | IW Car | 08 56 14.2               | -44 43 10.7                   | F3           | 508 ± 2                |
| 09256-6324 | HR 4049 | 09 26 53.3               | -63 37 48.9                   | A4Ib/II      | ~ 1440                 |
| 10158-2844 |        | 10 18 07.6               | -28 59 31.2                   | G8IIab       | 323 ± 50               |
| 10174-5704 |        | 10 19 16.9               | -57 19 26.0                   | K5           | 572 ± 6                |
| 10456-5712 | HD 93662 | 10 47 38.4               | -57 28 02.7                   | G3V          | 592 ± 13               |
| 12185-4856 | SX Cen | 12 21 12.6               | -49 12 41.1                   | G4           | 434 ± 1                |
| 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                |
| 18281+2149 | AC Her | 18 30 16.2               | +21 52 00.6                   | F2Iep        | 1194 ± 6               |
| 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            |

Deroo et al. 2006
Deroo et al. 2007
Acke et al. 2013
Deroo et al. 2006
Hillen et al. 2014
Hillen et al. 2015

Studies of individual objects
Basics of interferometry

\[ V(u,v) = \text{FT}(I(\alpha, \beta)) \]

Direct inversion ("imaging") usually not feasible due to limited uv-filling.
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$$V(u,v) = \text{FT}(I(\alpha,\beta))$$

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: $F_{\text{tot}}$ and $q$, which translates into hlr

**Uniform disk model**

2-parameter fit: $F_{\text{tot}}$ and $\Theta$
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

Interpreted in terms of disk shape/surface

Group I <-> Group II

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!

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

Shaded zones: Monte Carlo RT models
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.
“Photometrically” post-AGB disks belong to group II (but not exactly the same).
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“Interferometrically” they also belong to group II (and not exactly the same).

De Ruyter et al. (2006)
Post-AGB vs. Herbig disks

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De Ruyter et al. (2006)

Still to be done: compute models in a post-AGB context!
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!
“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)
Thank you for your attention!
Stellar parameters: optical spectroscopy + SED fitting
Model fitting of MIDI data

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

\[ T(\rho) = T_{\text{sub}} \left( \frac{\rho}{\rho_{\text{sub}}} \right)^{-q} \quad \rho_{\text{sub}} = \frac{\theta_*}{2} \left( \frac{T_{\text{eff}}}{T_{\text{sub}}} \right)^2 \]

Hlr = half-light radius

Teff: optical spectra \quad \theta_*: SED fit