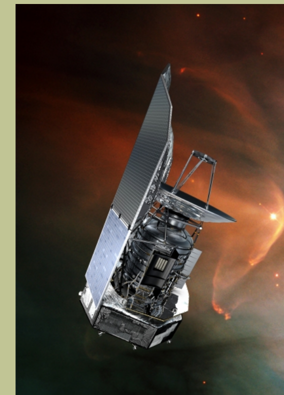
A VLTI survey of dusty envelopes of AGB stars



Claudia Paladini

CoIs: Klotz D., Sacuto S., Lagadec E., Verhoelst T., Hron J., Groenewegen M.A.T., Jorissen A., Kerschbaum F., Richichi A., Wittkowski M., Olofsson H.

Outline

- Interferometry in a nut-shell
- Set the stage: Asymptotic Giant Branch (AGB) stars
- Towards the Large Program: the geometry of the mass-loss process
- Large Program presentation
  - Observations
  - Molecular/dust stratification study
  - Spectroscopic and interferometric variability
  - Geometric Fitting
- Ongoing projects and followup

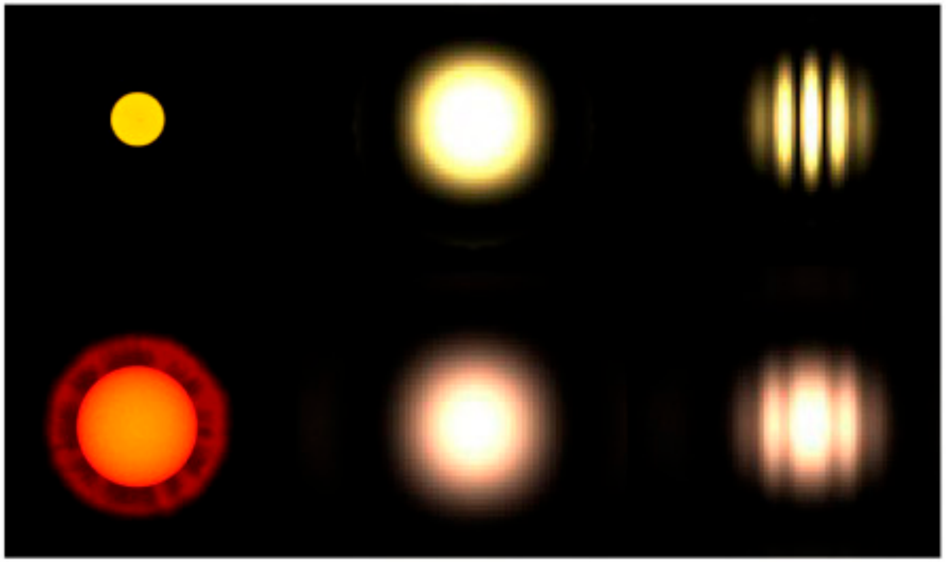
What do we measure?

Not a single dish, but light combined from different apertures

- **Gain**: angular resolution

We observe FRINGES and we measure a complex quantity called VISIBILITY

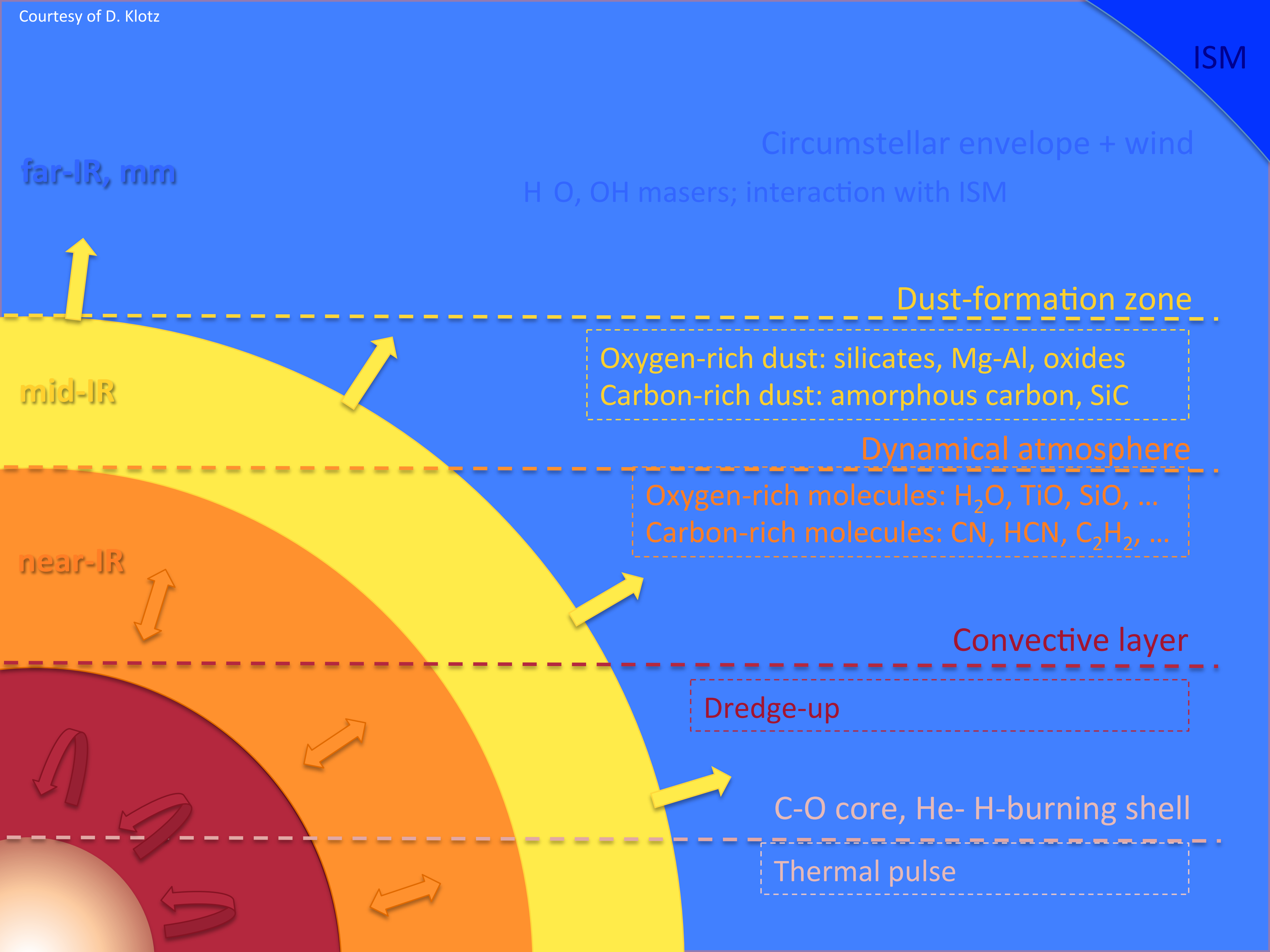
- Fringe visibility (<u>amplitude</u>) is the contrast between fringes.
  - **Size of the object**
- Fringe <u>phase</u> related to the location of fringes.
  - **Symmetry of the object**



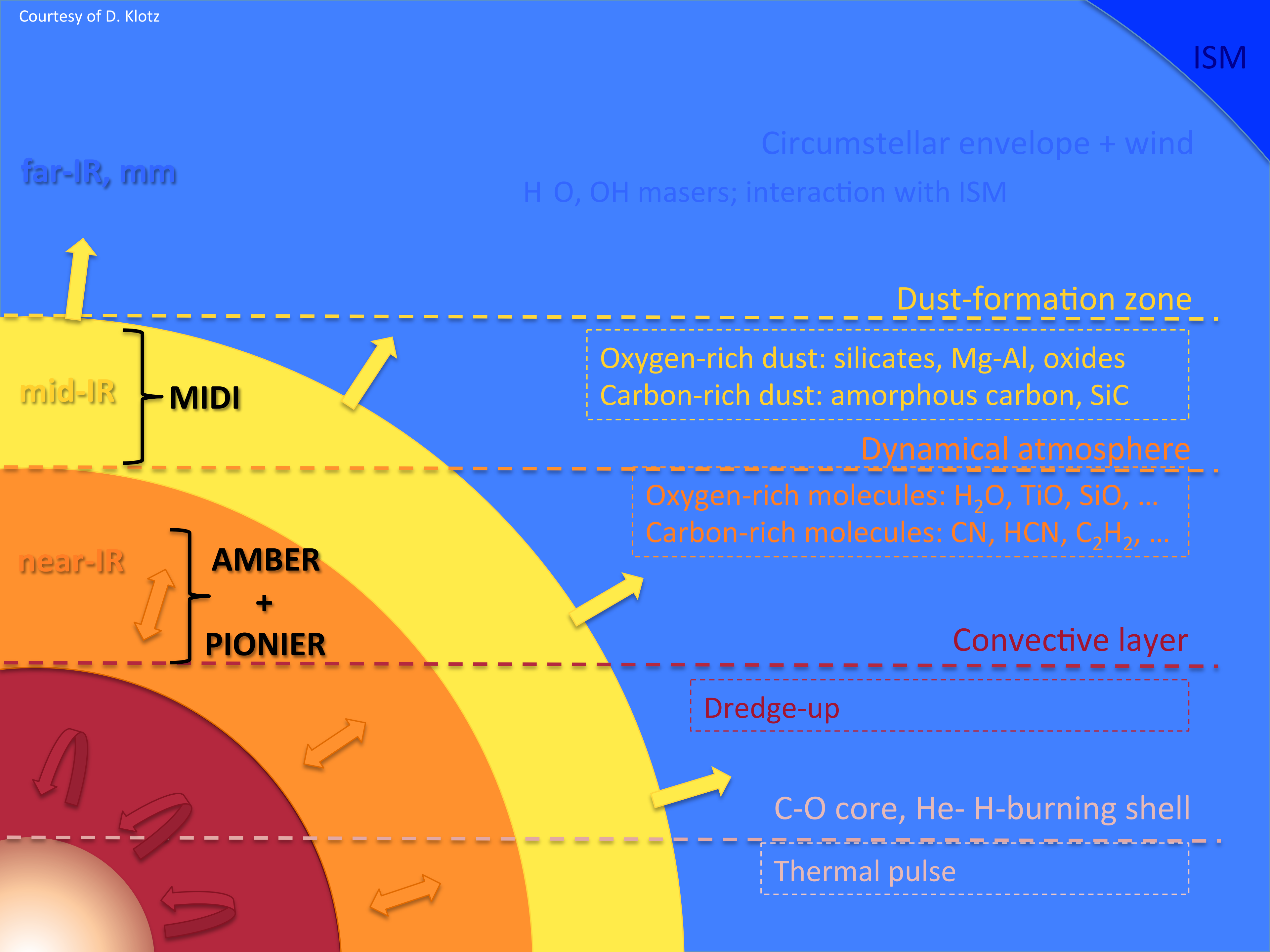
Interferometric Fringes from Star with Different Angular Diameters (Simulation)

ESO PR Photo 10d/01 (18 March 2001)

left: "real star"
center: star observed by single dish
right: star observed by interferometer



Courtesy of D. Klotz

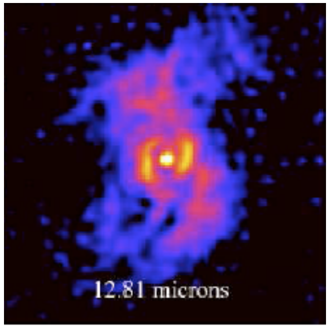


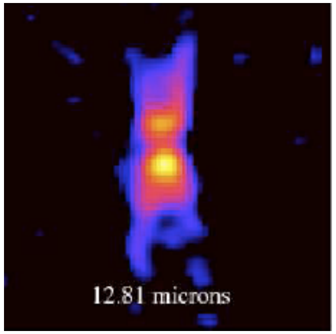
Courtesy of D. Klotz
ISM
Circumstellar envelope + wind
far-IR, mm
H O, OH masers; interaction with ISM
Dust-formation zone
mid-IR
MIDI
Oxygen-rich dust: silicates, Mg-Al, oxides
Carbon-rich dust: amorphous carbon, SiC
Dynamical atmosphere
Oxygen-rich molecules: H_2O, TiO, SiO, …
Carbon-rich molecules: CN, HCN, C_2H_2, …
near-IR
AMBER
+
PIONIER
Convective layer
Dredge-up
C-O core, He- H-burning shell
Thermal pulse

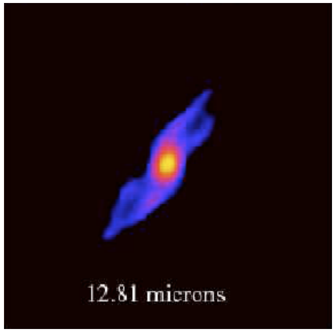
The geometry of the mass-loss process

- Many Post-AGB stars show departure from spherical symmetry

- Asymmetries should develop in the previous stage but on the AGB the picture remains uncertain.



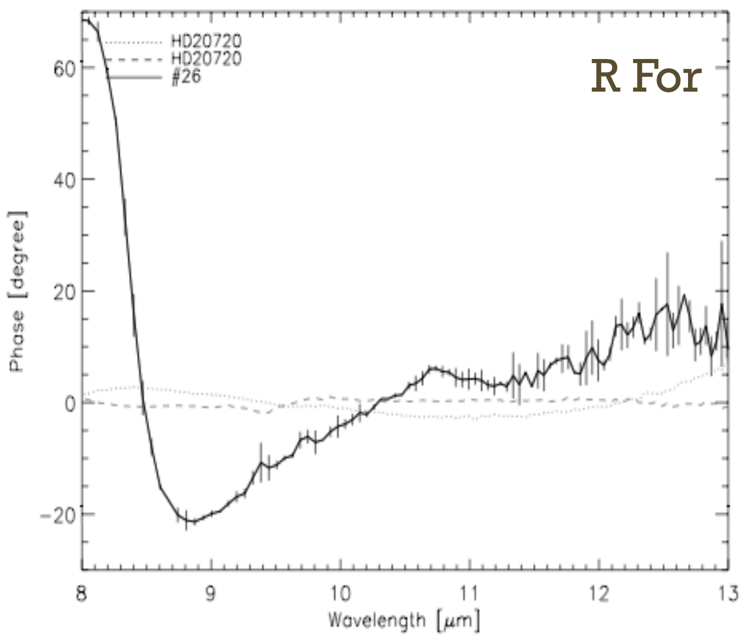




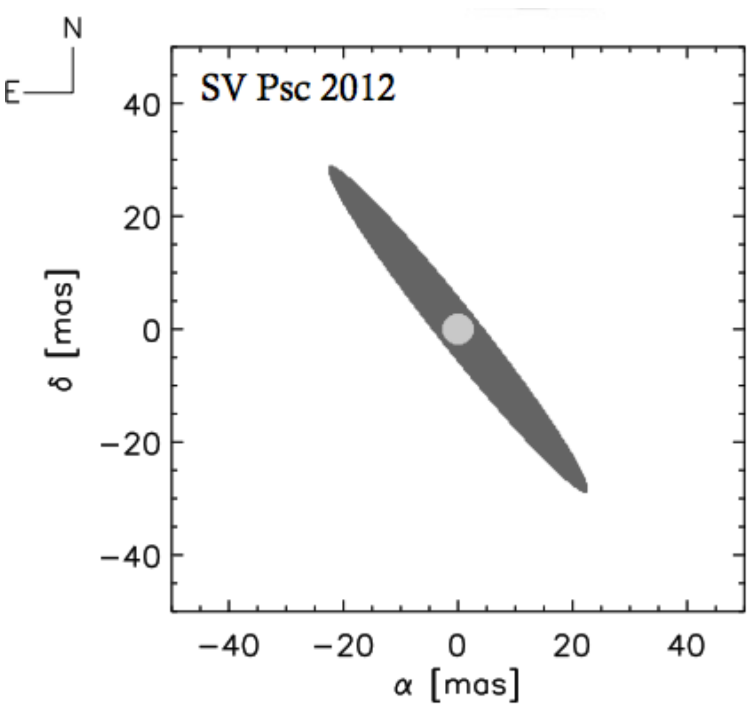
Lagadec et al., 2011
(all the other talks during this conference)

Geometry of the inner dusty region

Paladini et al. 2012: asymmetries in the dusty environment of Mira variables



Klotz et al. 2012: elongation in the environment of semi-regular variables



Other works on the geometry: Deroo et al. (2007); Ohnaka et al. (2008); Sacuto et al. (2013); talks of Ohnaka, talk of Lykou.

"One should expect significant progress from a large coordinated program for frequent observations

i) of a few selected objects,
ii) over a few light cycles, and
iii) based on as many as possible techniques from UV to radio wavelengths ...

One should push forward to organize such a large coordinated program."

(Foy, 1990)

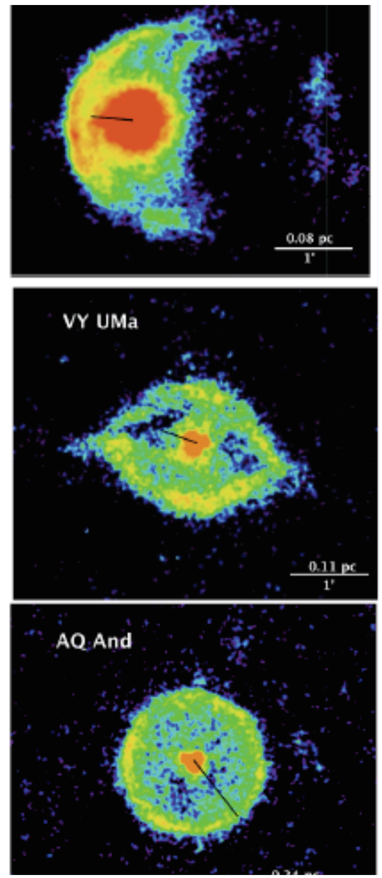
Herschel and MESS

MESS (Mass-loss of Evolved StarS; Groenewegen et al. 2011) program maps the outer envelope of evolved stars. Imaged with PACS at 70 and 160 μm

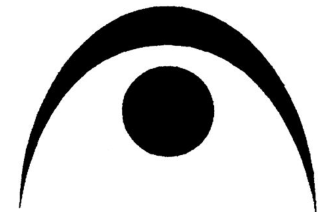
- 32 O-rich AGB stars and Red Super Giants (RSGs)
- 9 S-type AGB stars
- 37 C-type AGB stars
- 2 post-RSGs

Detached shells; bow shocks; eye-like shapes detected…

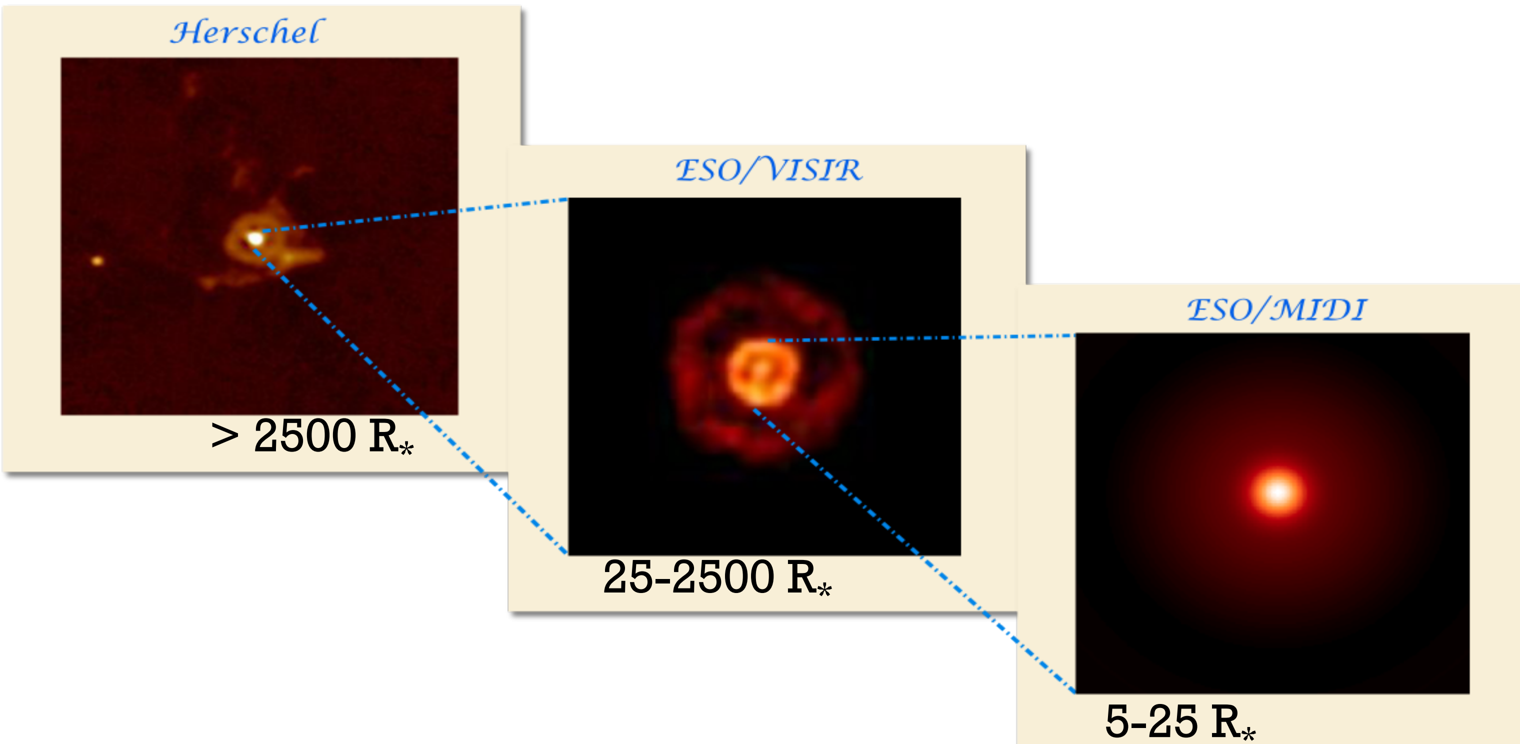
(Talk from A. Mayer on Monday)



(Cox et al., 2012)



A joint venture in the red



What is the Large Program idea?

- Ground-space-synergy
- Study different layers in the star
- Study geometry of CSE
- To answer the following questions
  - Is the mass loss an episodic process?
  - Where do asymmetries develop?
  - How do asymmetries change with evolutionary stage?
  - Can we find the asymmetries seen with Herschel also with MIDI?

VLT(I) Large Program

Accepted January 2011
(PI: Paladini), paper in prep.

- 15 targets (M-, S-, C-type AGB stars; different variability classes)
- ~ 140 hours of MIDI + VISIR time over 2 periods
- 2 observations x 3 triangular configurations with VLTI/MIDI (N-band interferometry)
- *N*+*Q* band observations (imaging) with VISIR

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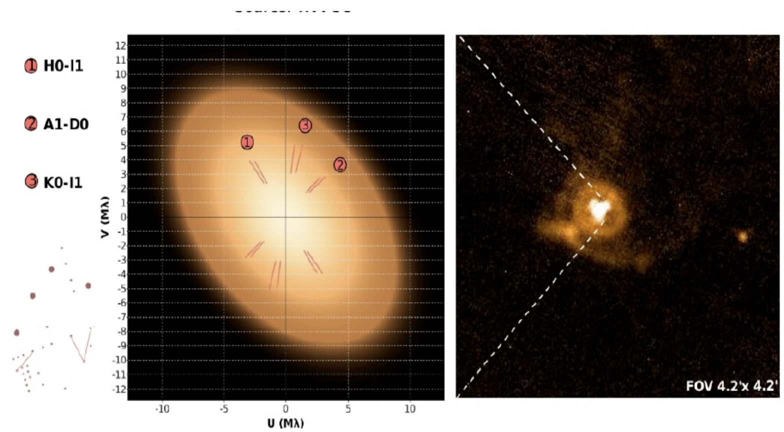
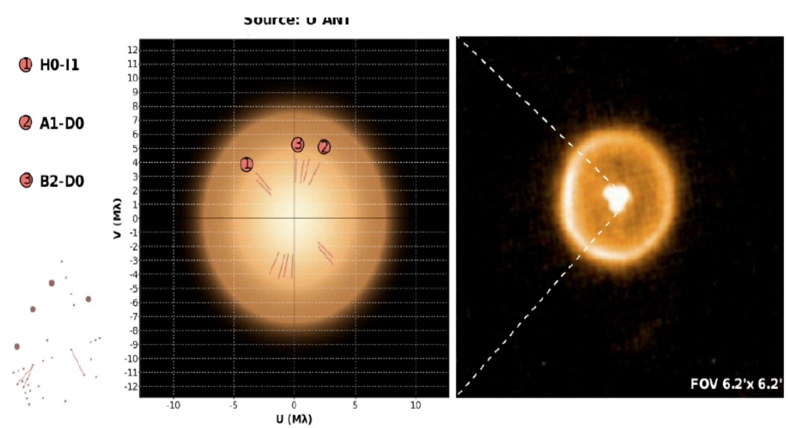
+ MIDI: strategy

- Target with asymmetry: Herschel observations and MIDI preliminary modeling (ASPRO2) of TX Psc.



Jorissen et al., 2011

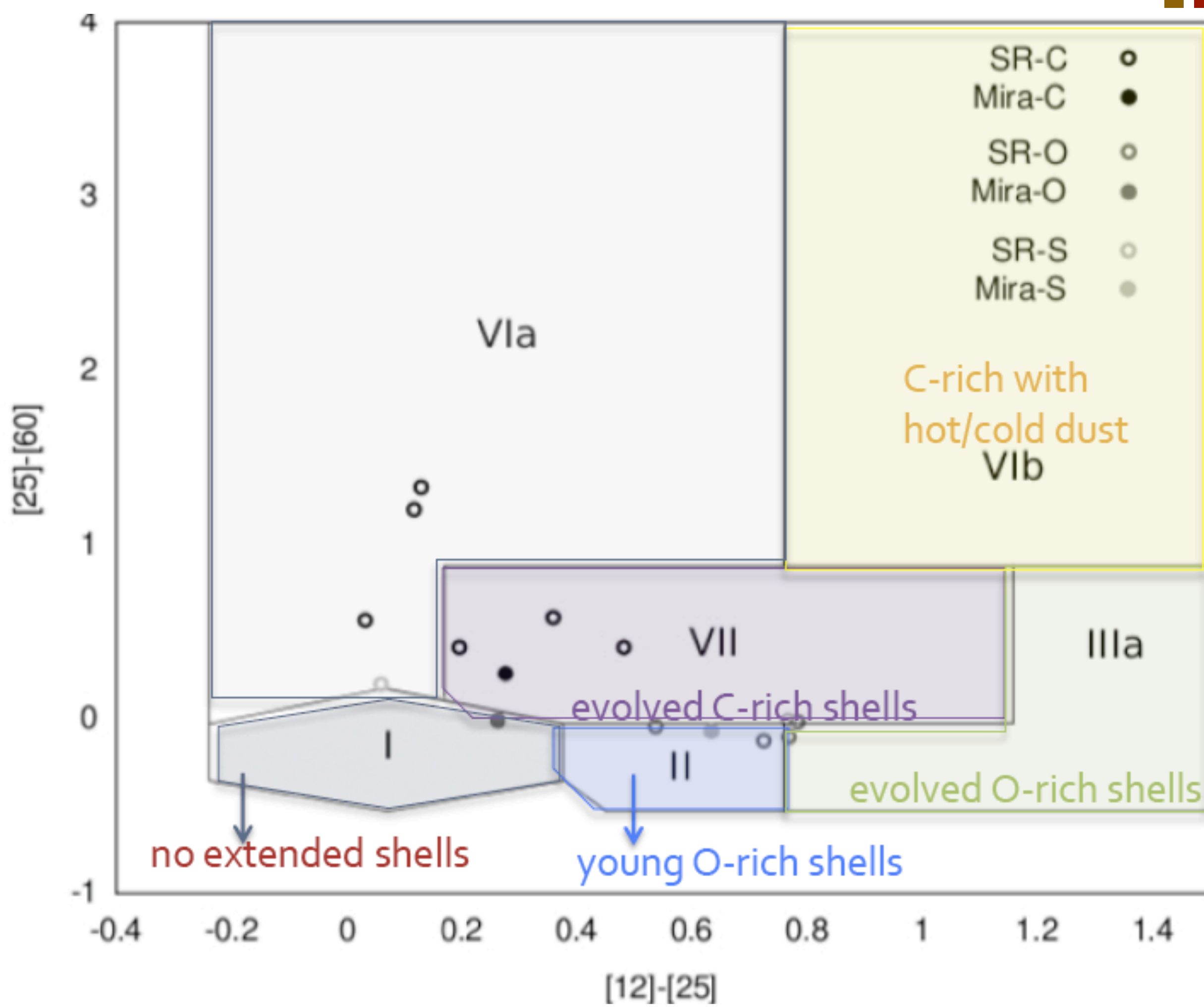
- Symmetric target: Herschel observations of U Ant and MIDI modeling (ASPRO2).



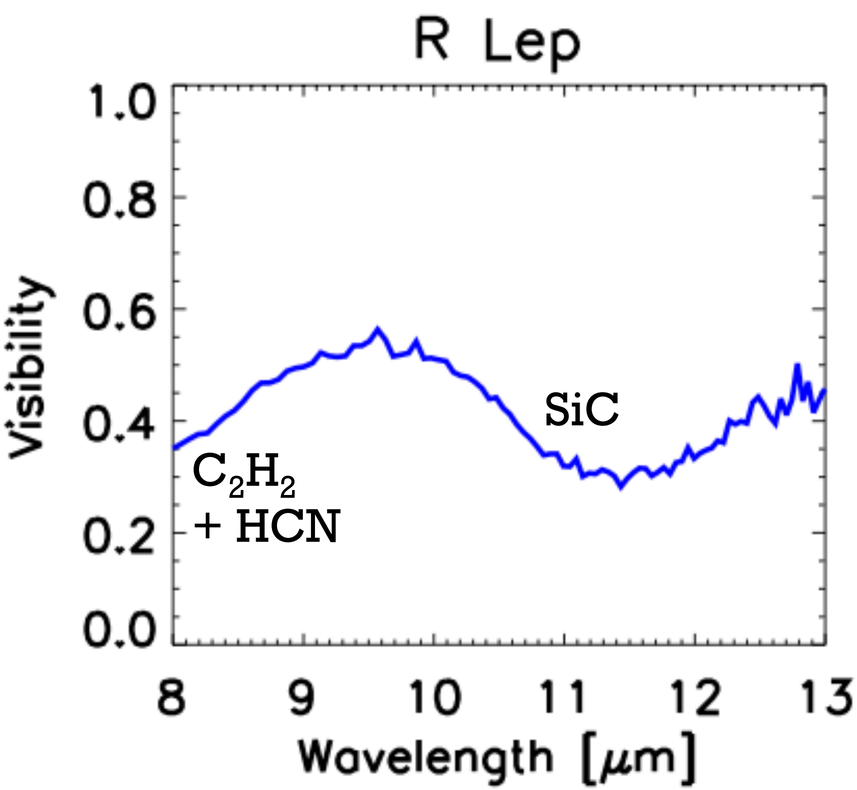
Kerschbaum et al., 2010

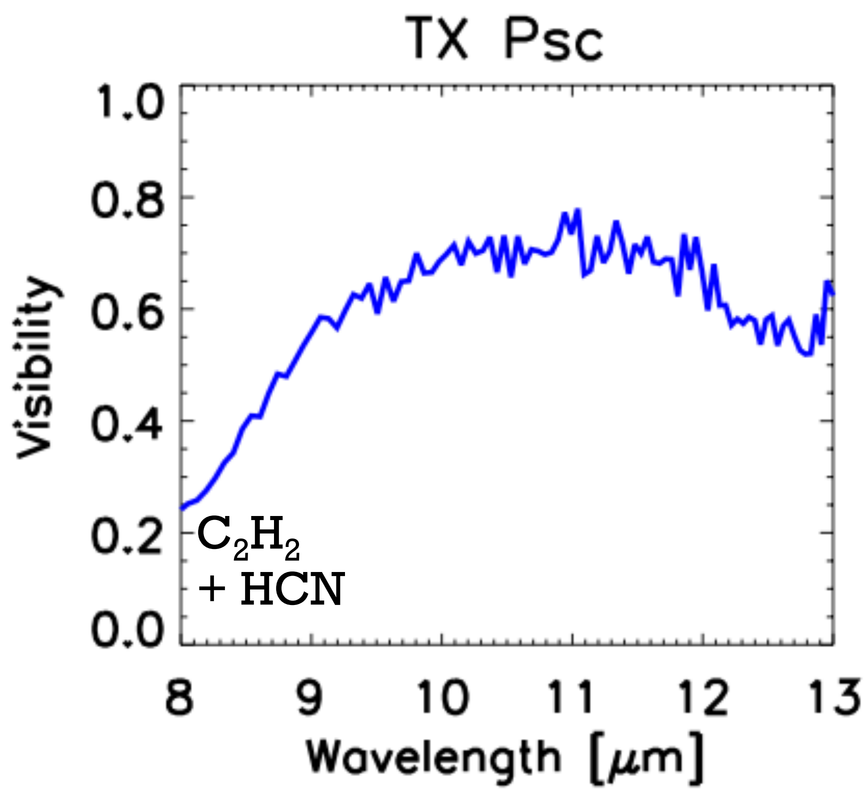
IRAS color-color diagram

Mass-Loss is between 10^{-9} and 10^{-6} $M_{\odot}yr^{-1}$
No extreme or infrared objects!

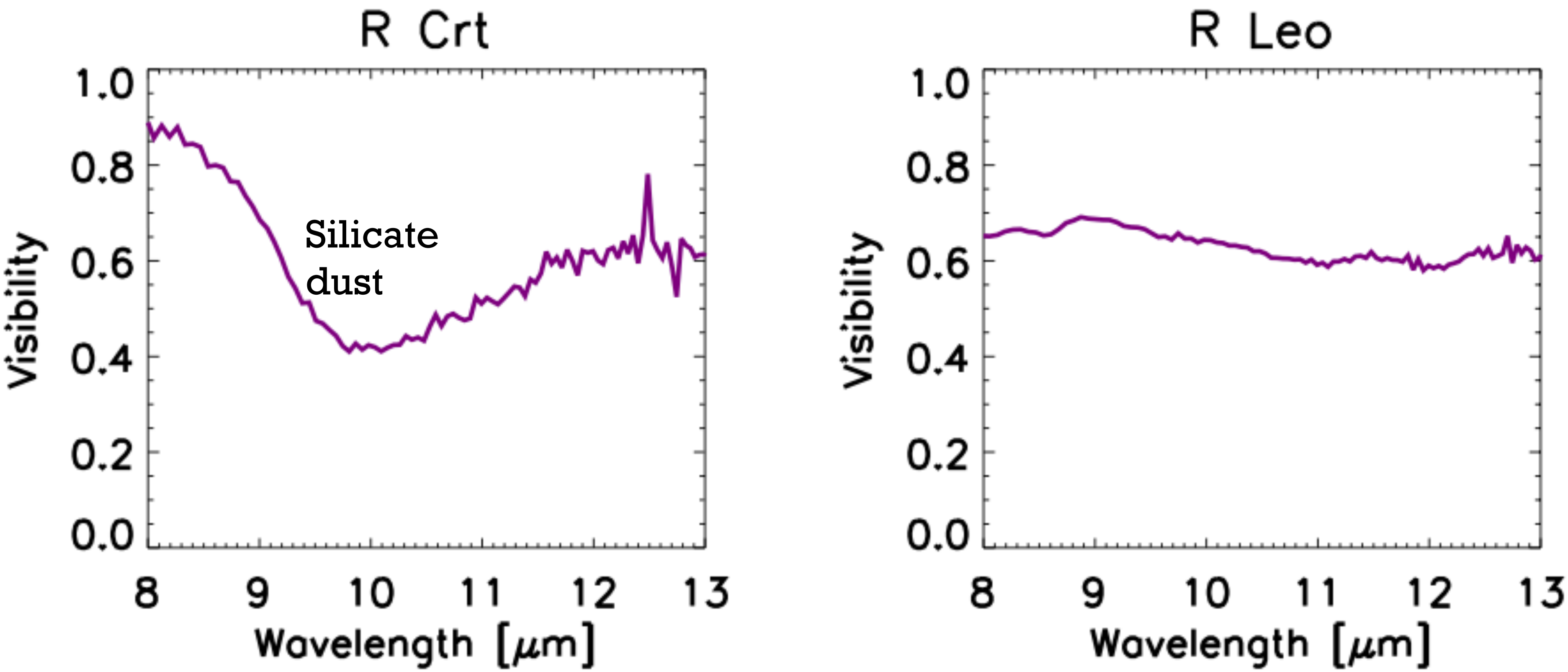


Molecular and dust stratification study (I)





Molecular and dust stratification study (II)



+ Interferometric variability

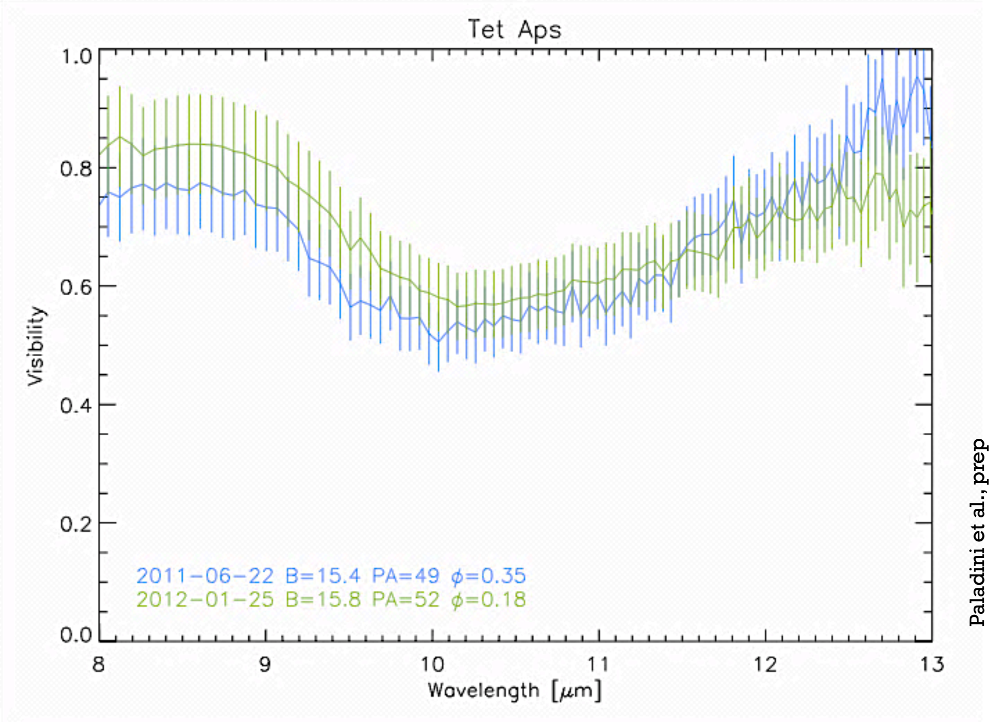
NO interferometric variability

Why?

- Size of the structures involved?
- MIDI errors too big?

BUT…
Ohnaka et al. (2007) found interferometric variability for a C-rich star

- Chemistry? (not many data available to check variability for carbon stars)



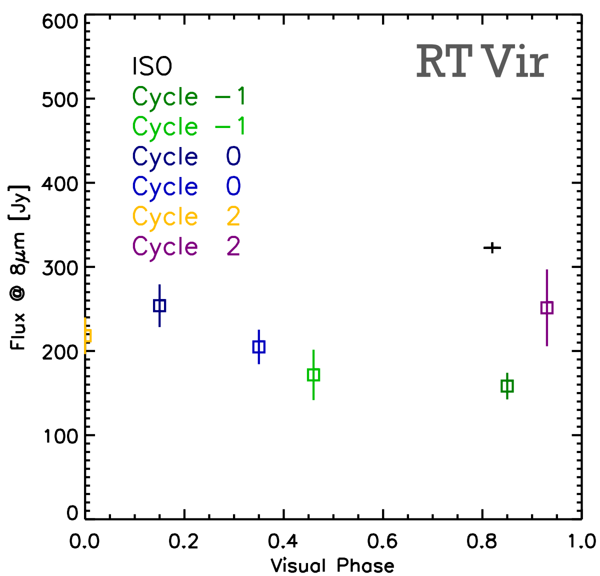
Paladini et al., prep

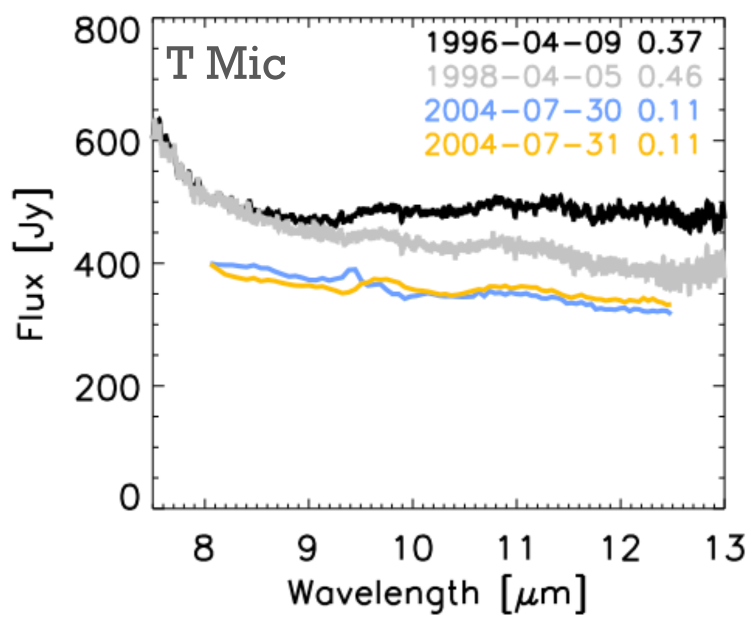
+

Spectroscopic variability

YES spectroscopic variability

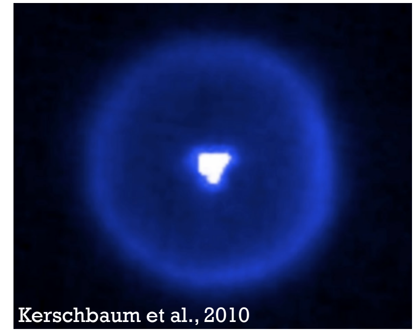
- Might be intra-cycle or cycle-to-cycle.
- FOV





Paladini et al., prep

The detached shells



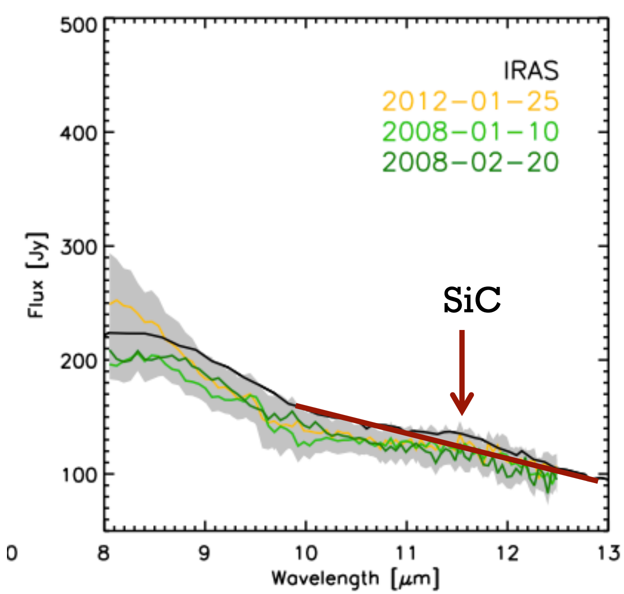
U Ant:

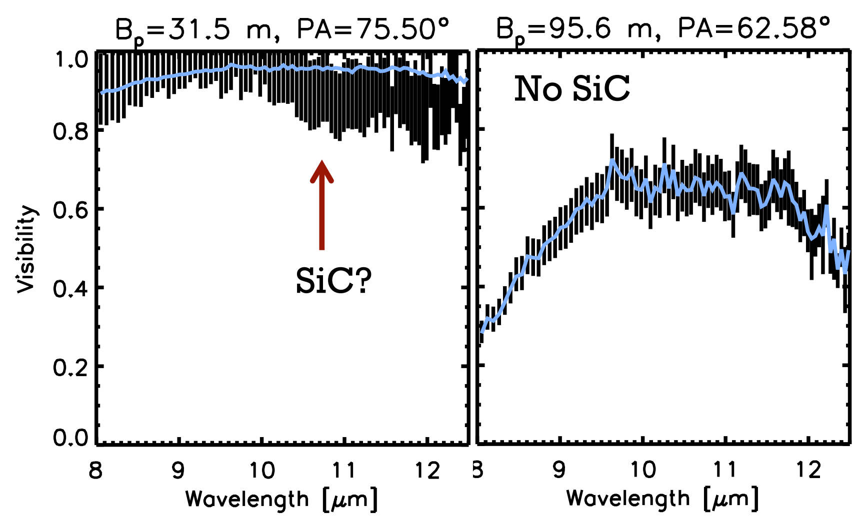
- No strong departure from spherical symmetry.

- Diameter derived: 20 mas
- Near-IR diameter: 10 mas

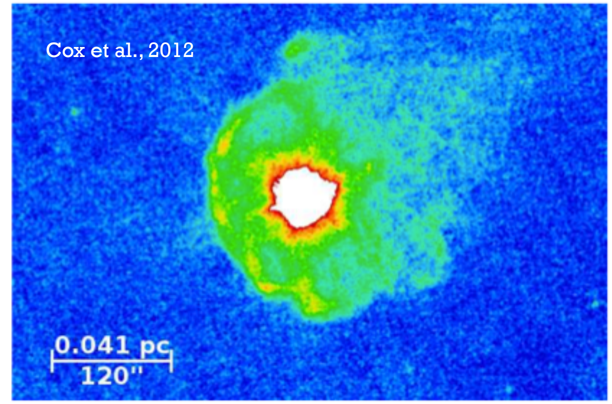
- No SiC in the visibility
- Maybe a signature at 10 stellar radii.

2 (out of 4) detached shells show the same.
Connection to mass-loss history?
Where does SiC form?
Under investigation…



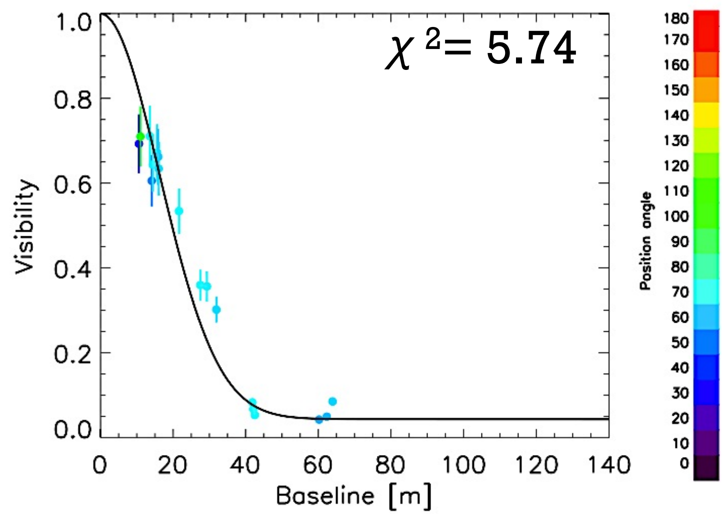


Weird cases



R Leo

- Not possible to fit with "simple" geometric models.
- Spectroscopic variability
- Phase signature (i.e. asymmetries)



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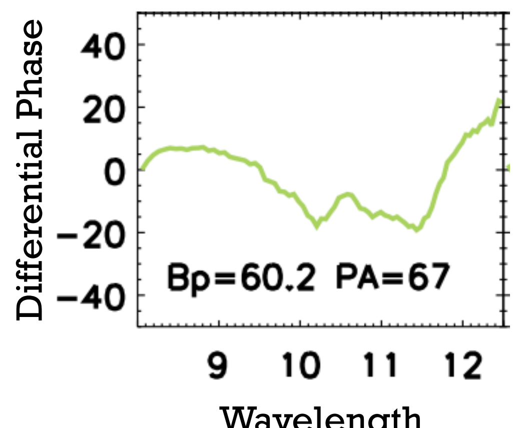


Paladini et al., prep

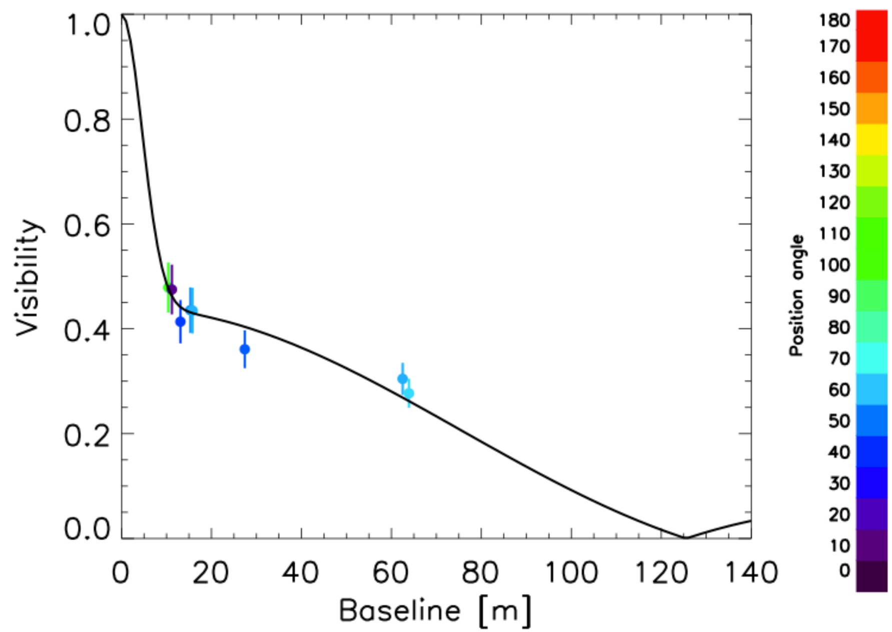
Another asymmetric case: RT Vir (Sacuto et al., 2013)

Geometry

Most of the objects fitted with 1 or 2 spherical component. No disks.

Why?

- Visibility error bars too big? Klotz et al. 2012b showed 15% error is enough to distinguish elliptical-spherical object.
- Asymmetries due to clump show up at low visibilities. Not probed for all the stars.



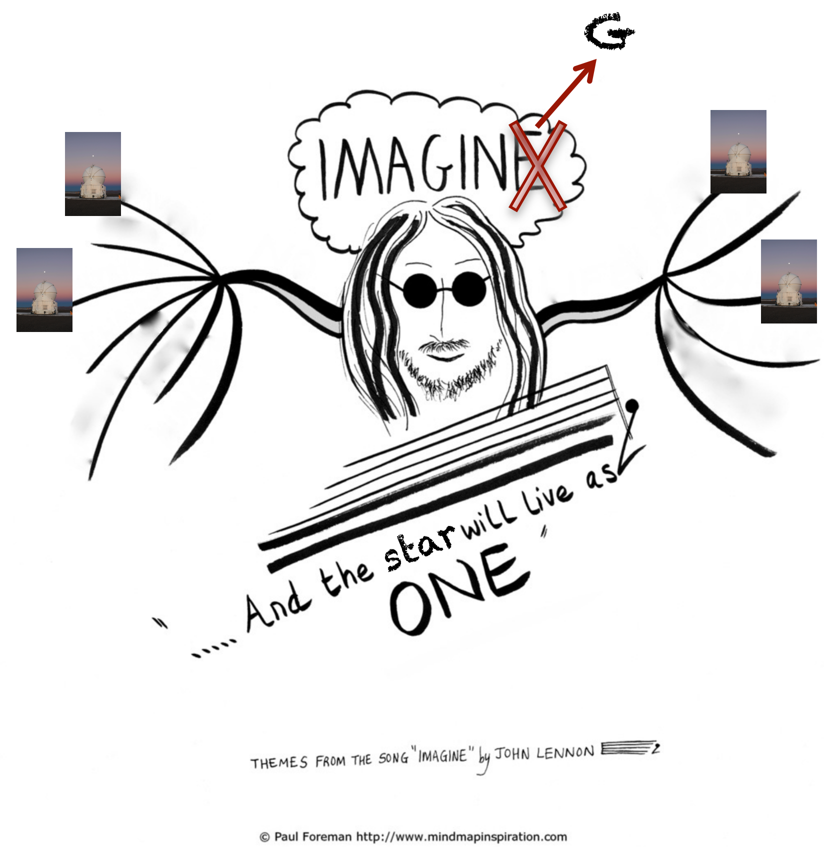
The environment is very likely clumpy

Conclusions

- Is the mass loss an episodic process?
  - Yes it is, and MIDI can observe this: see detached shells, and spectroscopic variability.
- Where do asymmetries develop?
  - Asymmetries do develop in the inner parts but beside exceptional cases we expect/observe only small asymmetric structures (clumps). No disks.
- How do asymmetries change with evolutionary stage?
  - More evolved stars are more dusty and (probably) show more clumpy environment.
- Can we find the asymmetries seen with Herschel also with MIDI?
  - Not in the "fermata" case where asymmetries originate by ISM interaction. The ISM interaction does not perturb the MIDI range.
  - Rings, Irregular, Eye shapes need to be imaged with optical interferometry.

Outlook

- Detailed model atmosphere analysis ongoing
- Preparation for a VLTI imaging campaign with second generation VLTI/ MATISSE
- Preparing the ground for comparison with 3D modelling



PIONIER science meeting & VLTI Community day

January 13-16th 2014 (Grenoble, France)