Herschel, VLT(I), and the mass-loss geometry of AGB stars

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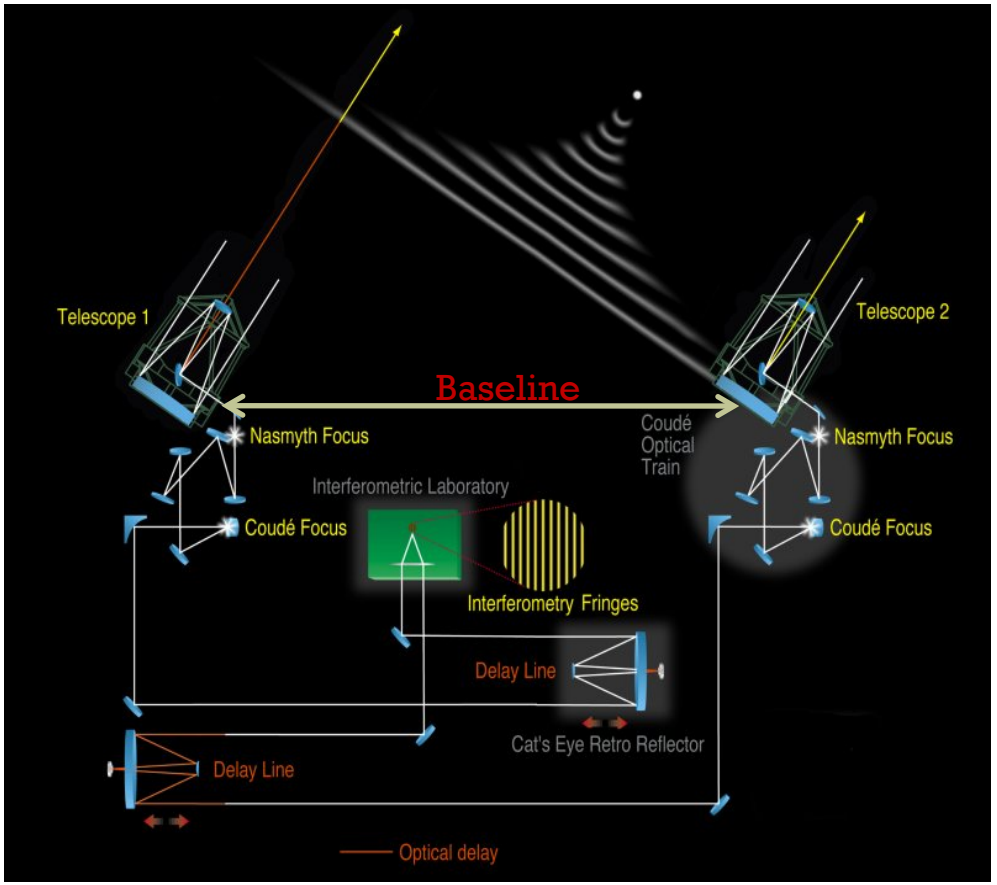
Outline

- 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

Principles of interferometry

Not a single dish, but light combined from different apertures

- **Gain**: high angular resolution
- **Cost**: sensitivity



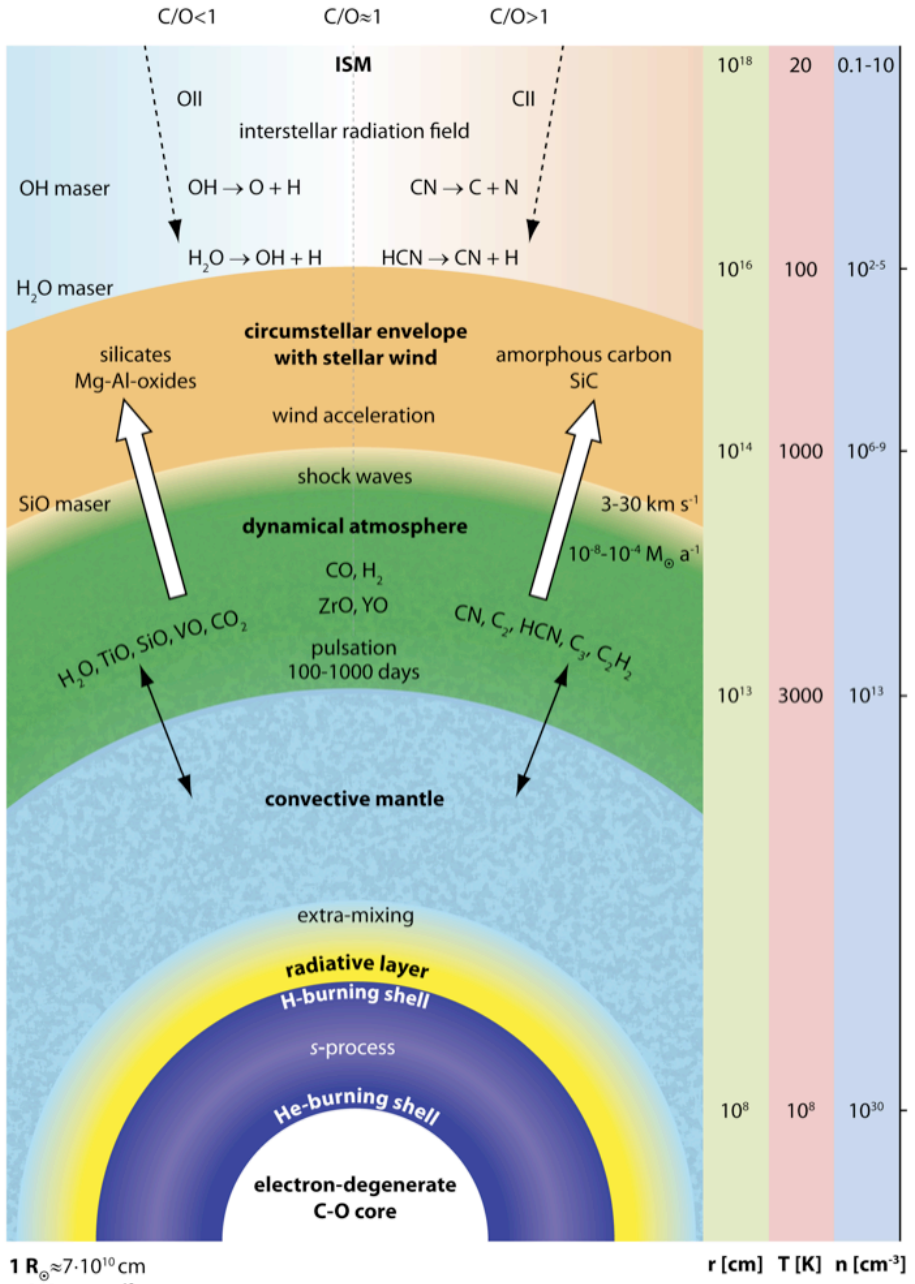
credit image: www.eso.org

What do we measure?

We observe FRINGES and we measure a complex quantity called VISIBILITY

- Fringe visibility is the contrast between fringes.
  - **Size of the object**
- Fringe phase related to the location of fringes.
  - **Symmetry of the object**

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



AGB stars

AGB stars are low-intermediate mass stars at the late evolutionary stage:

The future of our Sun!

They lose mass through stellar wind:

Building blocks of the next generation of stars, planets… life.

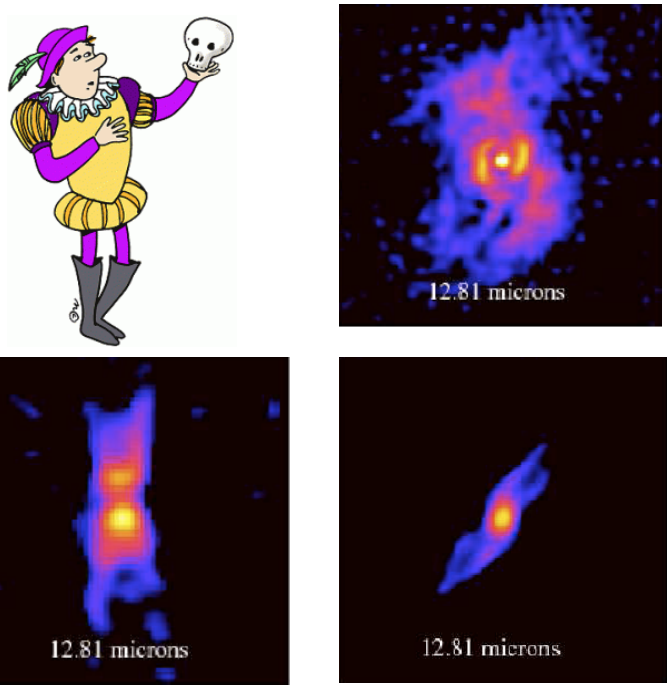
1. Very bright in the infrared
2. Very extended atmosphere

Ideal targets for interferometry

The geometry of the mass-loss process

- Many Post-AGB stars show departure from spherical symmetry

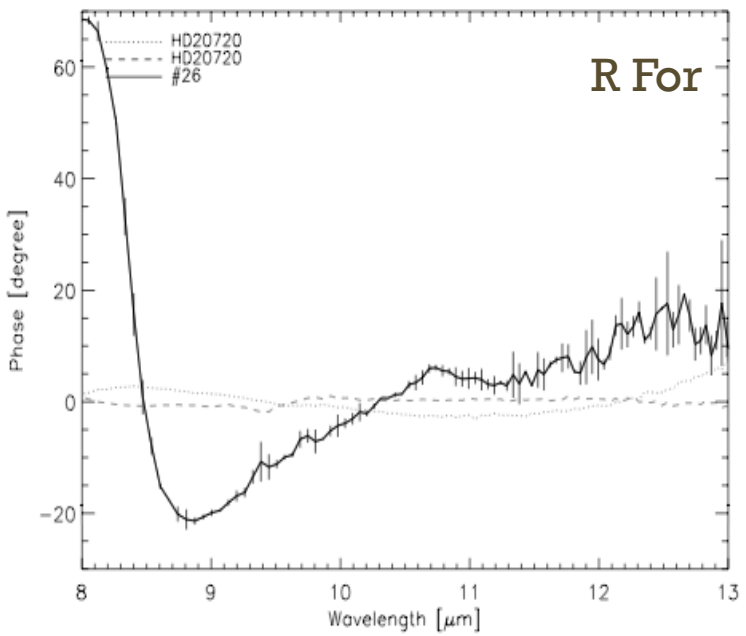
- Asymmetries should develop in the previous stage but on the AGB the picture remains uncertain.



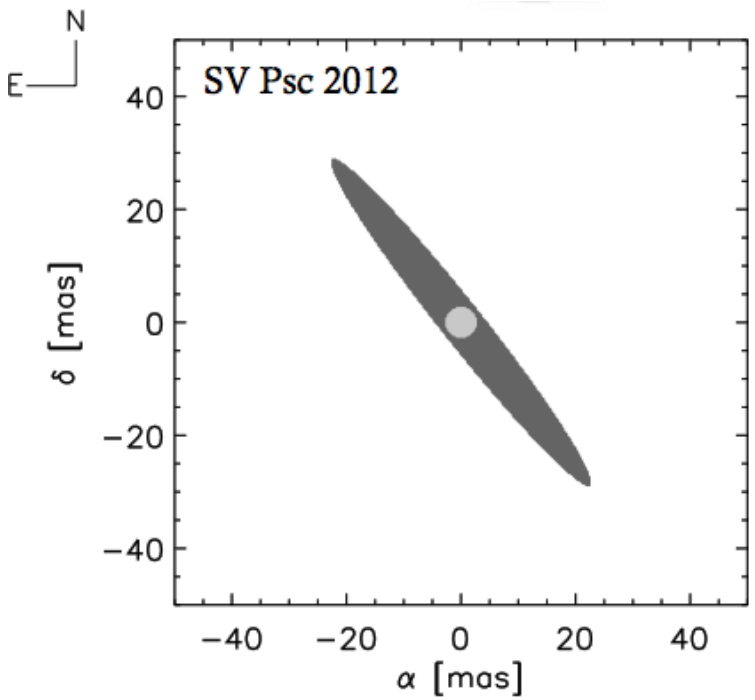
Lagadec et al., 2011

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)

Herschel and MESS

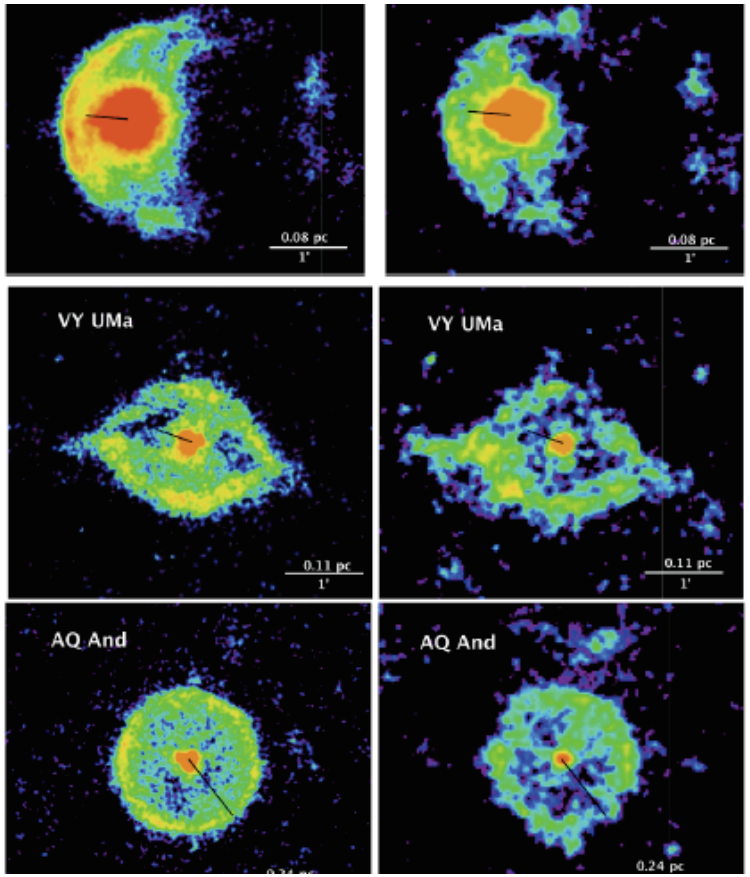
MESS (Mass-loss of Evolved StarS; Groenewegen et al. 2011) program maps the outer envelope of evolved stars. Imaged with PACS at 70 and 160 μm

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

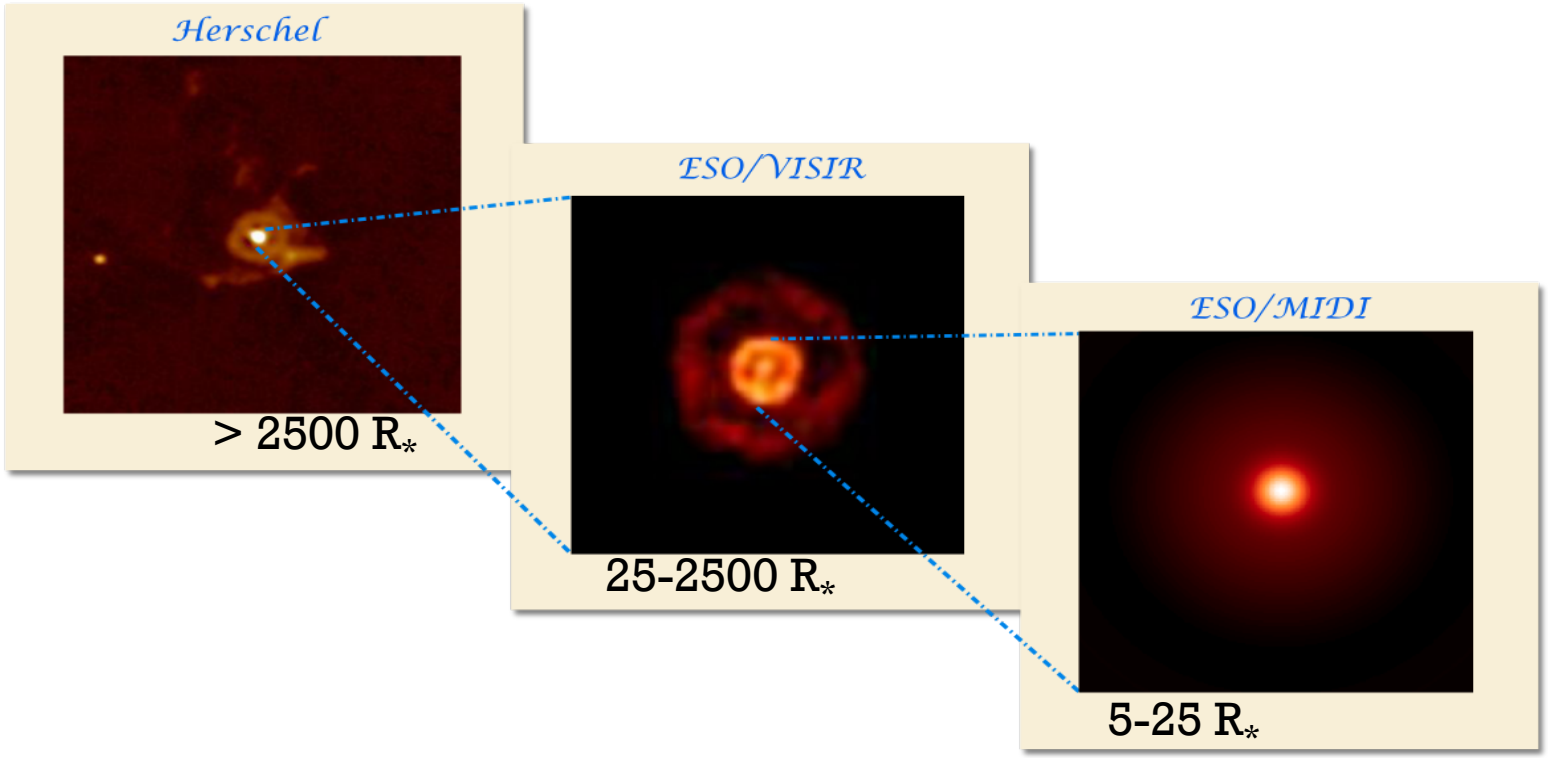
Detached shells; bow shocks;

eye-like shapes detected…

(Cox et al., 2012 & references therein)



A joint venture in the red



Basic Questions

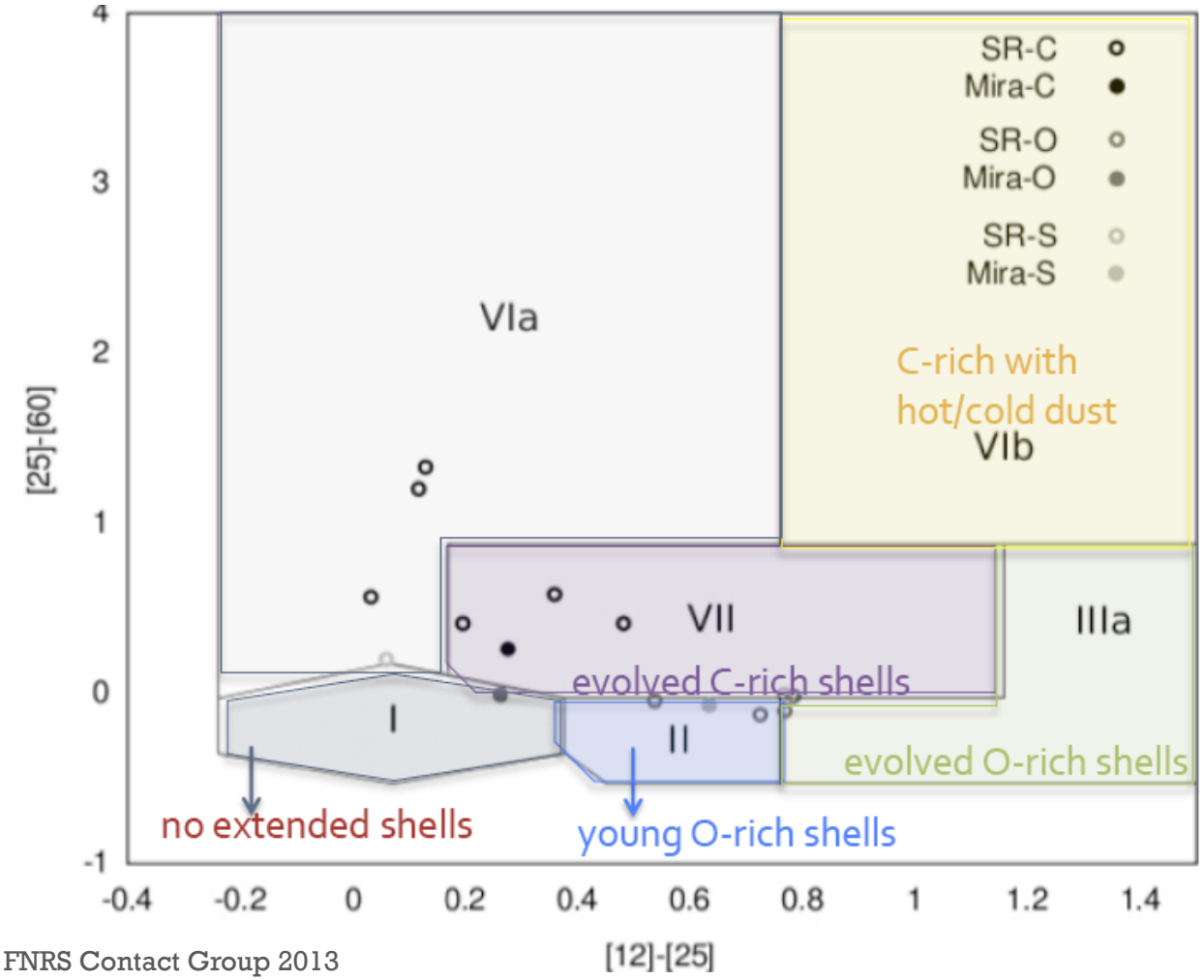
- Is the dusty mass-loss process episodic?
- At which height in the atmosphere can asymmetries develop?
- How does this change with the evolutionary phase of the star?

VLT(I) Large Program

Accepted January 2011
(PI: Paladini)

- 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

IRAS color-color diagram



Status report

Interferometric data:

- VLTI observations carried out between April 2011 and May 2012, only one month more than expected. Very efficient!
- 80% of the data have good quality.
- All the archive data reduced
- Modelling started

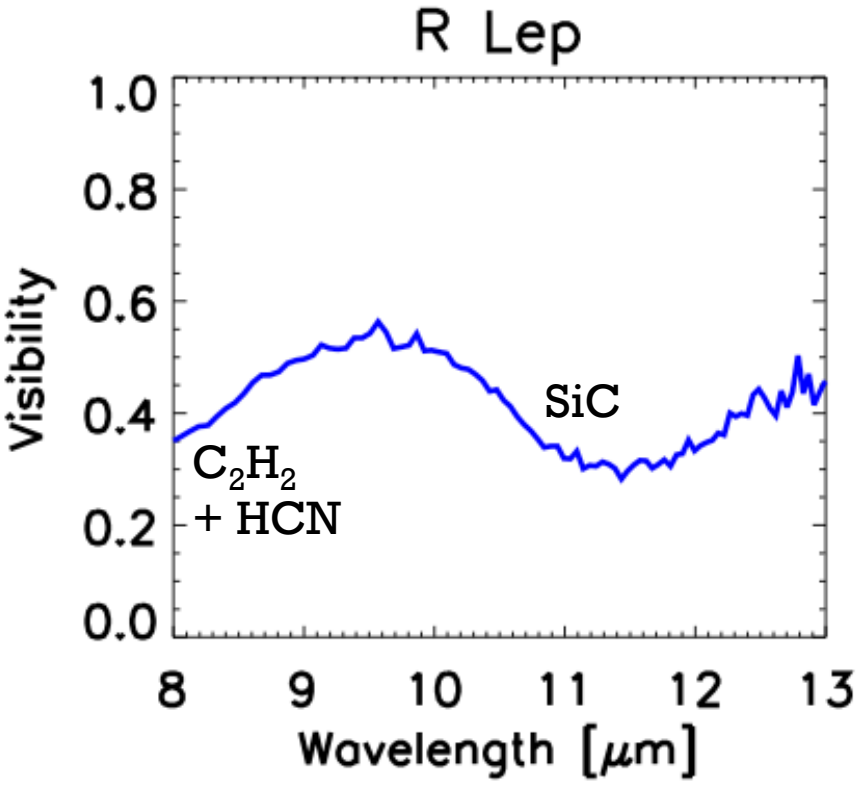
Imaging: not very lucky with the weather…

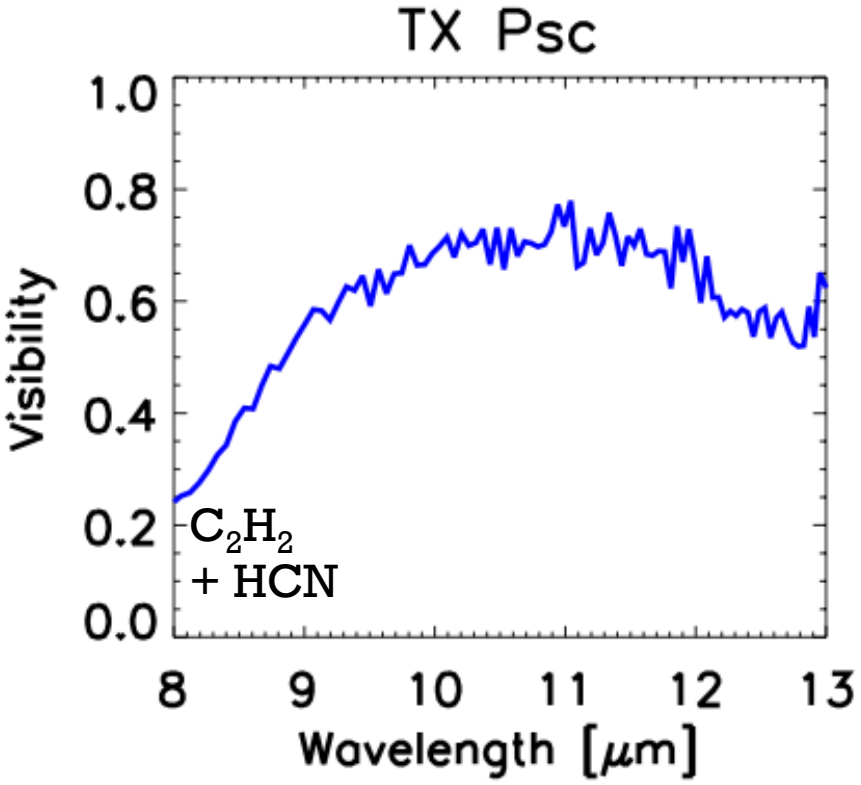
- We will apply again for VISIR data
- Exploring other possibilities

MIDI paper in progress

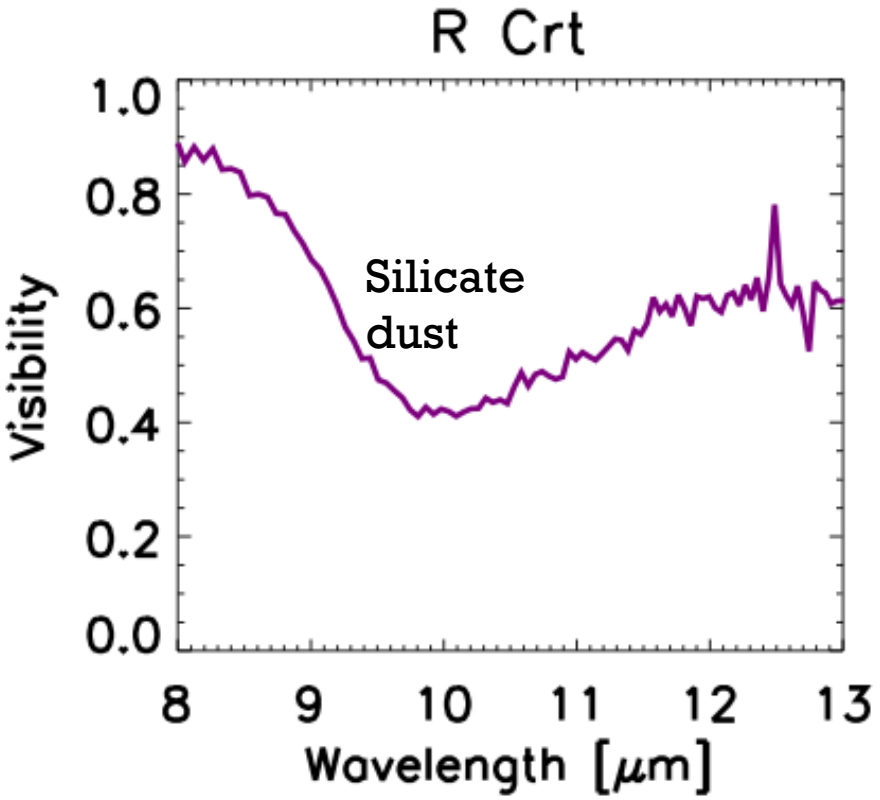
- Description of the program
- Data analysis
- Visibility morphology (different dust species)
- Geometry (GEM-FIND, Klotz et al. 2012)
- Connections with Herschel morphology

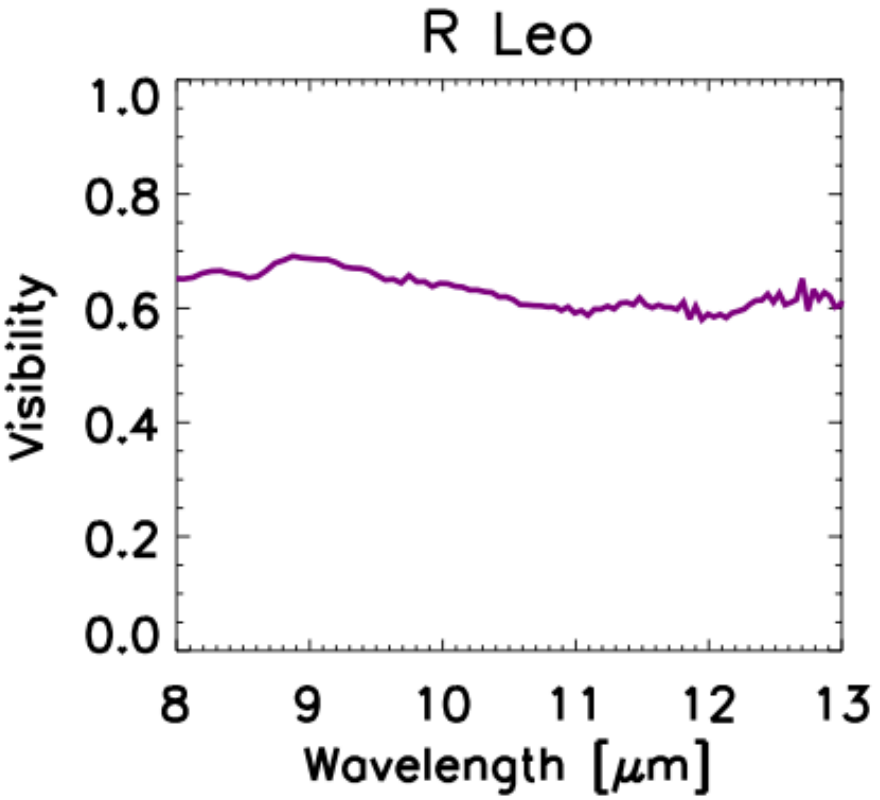
Molecular and dust stratification study



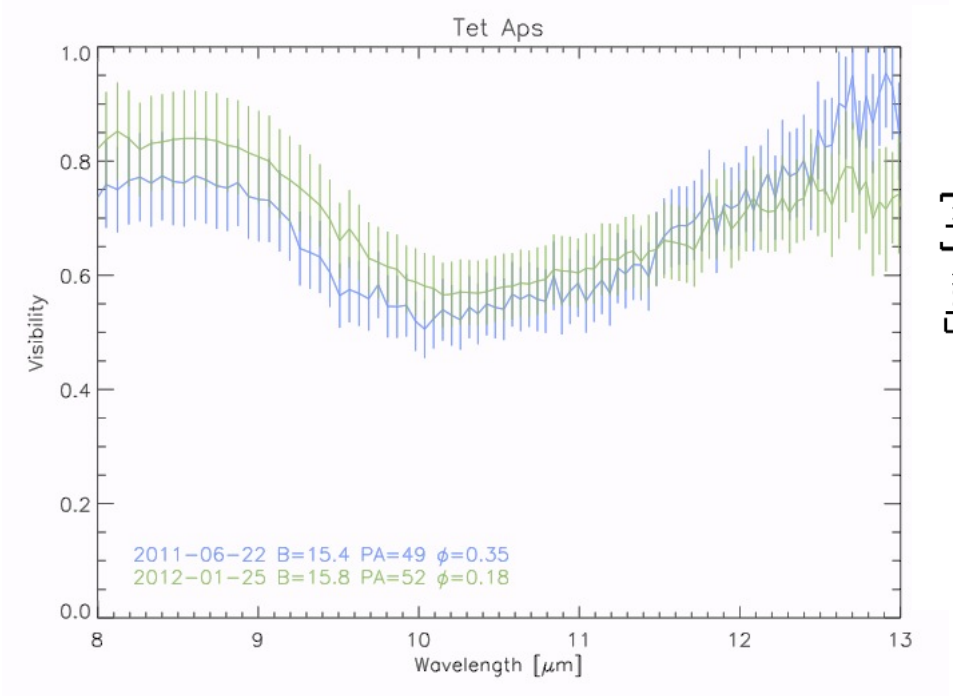


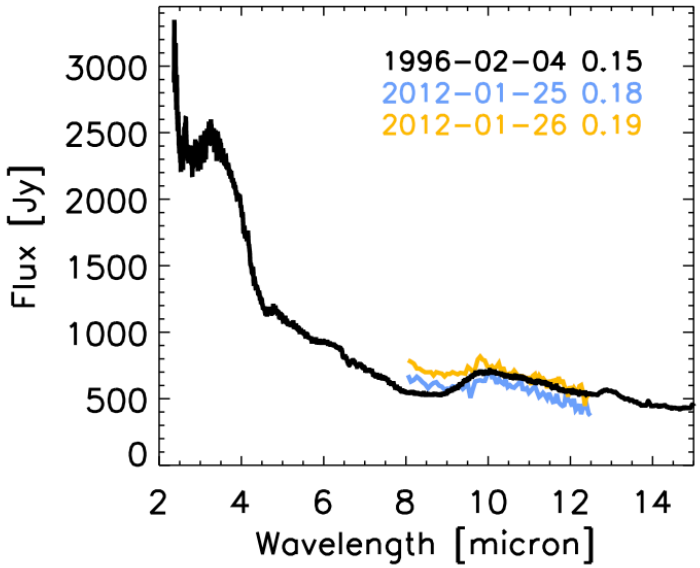
Molecular and dust stratification study



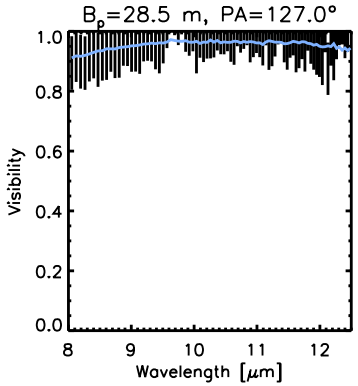


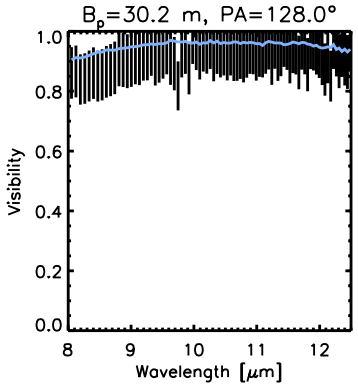
Interferometric and spectroscopic variability

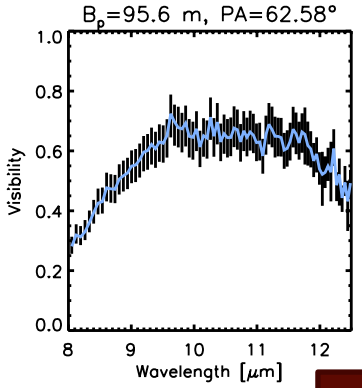


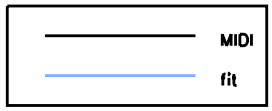


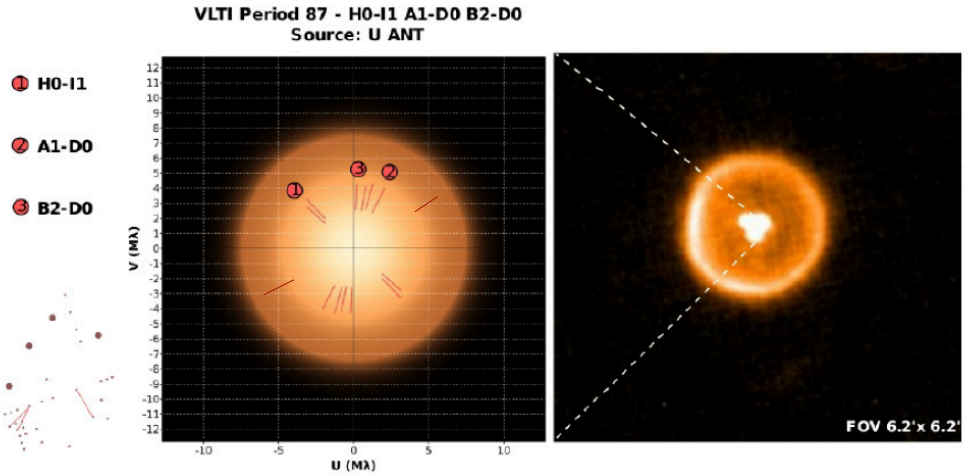
Geometry: U Ant











Spherical environment.
Diameter derived: 20 mas

Near-IR diameter: 10 mas
N-band diameter expected:
30-40 mas (Danchi et al. 1994)

Same trend for many objects: smaller than expected.
Possible implications on dust formation theory…

Ongoing work & to do list

The key for understanding the mass-loss process is the synergy between instruments (and techniques). The MESS sample gives us an incredible opportunity!

My role:

- Look at the very inner circumstellar environment (2-10 stellar radii) with interferometry
- Modelling with geometric models and later on with model atmospheres

While waiting for VISIR:

- Collaboration with the MESS team for dedicated papers
  - The case of π^1 Gru (Mayer et al. 2013 in prep.): AMBER+MIDI geometric modelling
- Near-IR data collected (AMBER+NACO) for the most interesting "Herschel" stars
- Preparation for a VLTI imaging campaign
- Preparing the ground for comparison with 3D modelling (see K. Braun talk later today)

Thank you!