A VLTI survey of dusty envelopes 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
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 (**amplitude**) 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
Dust formation

\[ \text{5R} \]

Molecule formation

\[ \text{2R} \]

C-O core, He- H-burning shell

Convective layer

Dynamical atmosphere

Dust-formation zone

Oxygen-rich dust: silicates, Mg-Al, oxides
Carbon-rich dust: amorphous carbon, SiC

Oxygen-rich molecules: H2O, TiO, SiO, ...
Carbon-rich molecules: CN, HCN, C2H2, ...

Circumstellar envelope + wind

H O, OH masers; interaction with ISM

near-IR

mid-IR

far-IR, mm

Courtesy of D. Klotz
Dust formation

Molecule formation

Dynamical atmosphere

Dust-formation zone

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Dynamical atmosphere

Oxygen-rich molecules: H$_2$O, TiO, SiO, ...
Carbon-rich molecules: CN, HCN, C$_2$H$_2$, ...

Convective layer

Dredge-up

C-O core, He- H-burning shell

Thermal pulse

Circumstellar envelope + wind

H$_2$O, OH masers; interaction with ISM

ISM

near-IR

mid-IR

far-IR, mm

MIDI

AMBER + PIONIER
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?
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
VLT(I) Large Program

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MIDI: strategy

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

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

Mass-Loss is between $10^{-9}$ and $10^{-6} \, M_\odot \, \text{yr}^{-1}$
No extreme or infrared objects!
Molecular and dust stratification study (I)

- **R Lep**
  - $C_2H_2 + HCN$
  - SiC

- **TX Psc**
  - $C_2H_2 + HCN$
Molecular and dust stratification study (II)

R Crt

Silicate dust

R Leo
**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)
**Spectroscopic variability**

**YES** spectroscopic variability

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

R Leo

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

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)