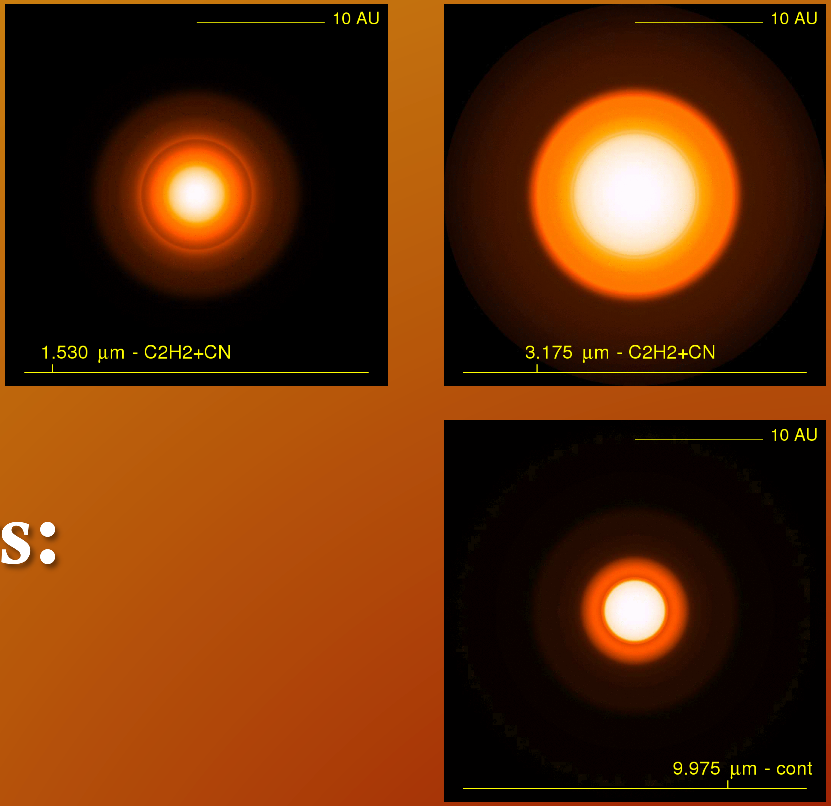

Observations of AGB stars: Atmosphere morphology

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Outline

- *Setting the stage:* Asymptotic Giant Branch (AGB) stars
- *Why?* The importance of AGB stars
- *What?* The geometry of the atmosphere
  - Near the stellar surface: visibilities & phase
  - Near the stellar surface: imaging
  - What's next?
  - Dust forming zone: visibilities & phase
  - What's next?
- Lessons to learn

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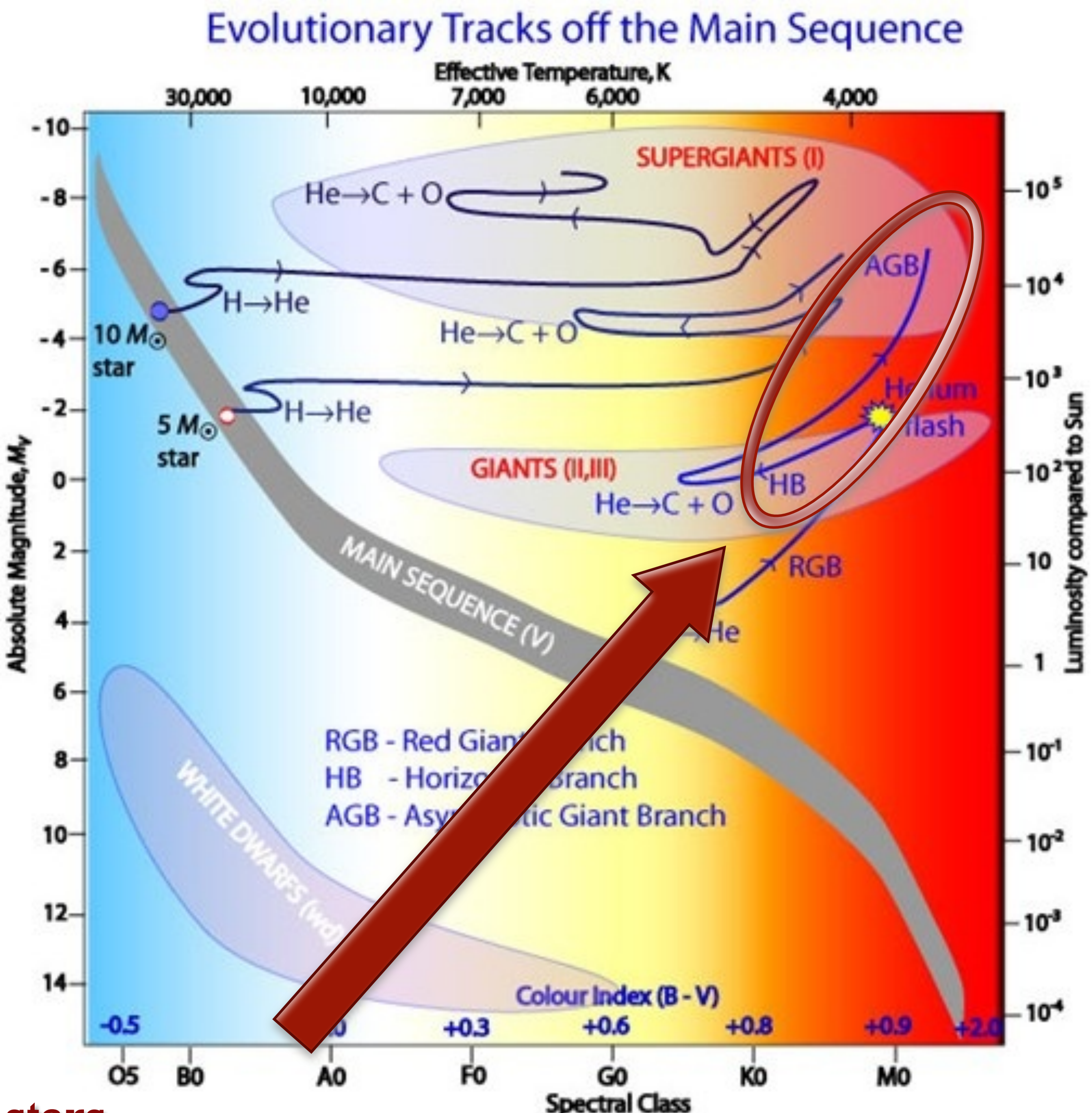
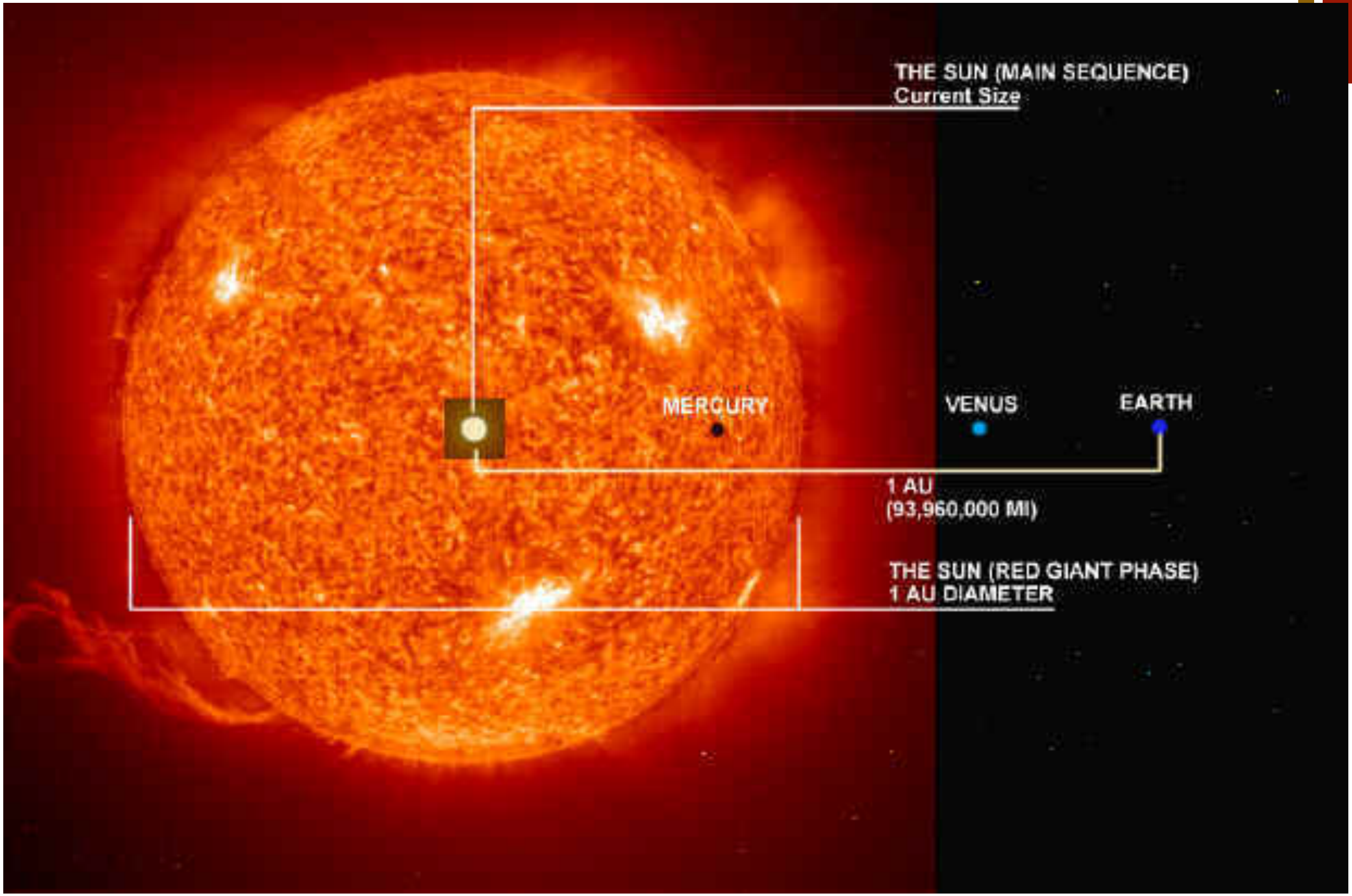


1-8 solar mass stars
Evolve on the
Asymptotic Giant Branch (AGB)

credit: http://outreach.atnf.csiro.au/

AGB stars = the future of our Sun



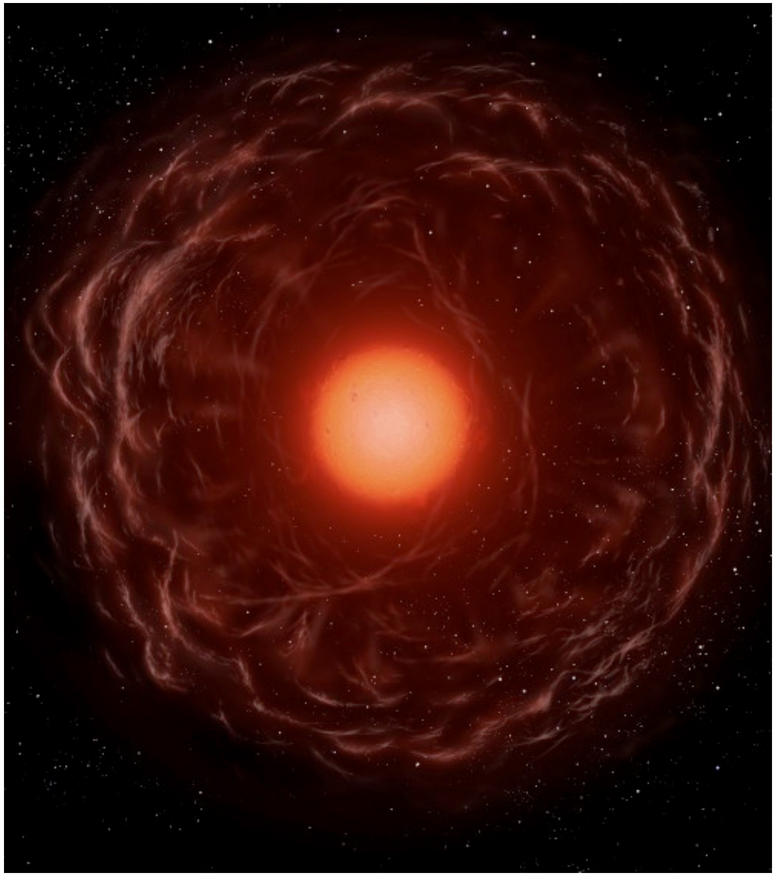
AGB stars = the future of our Sun

Why AGB stars?

- Nucleosynthesis
- Mass-loss through stellar wind

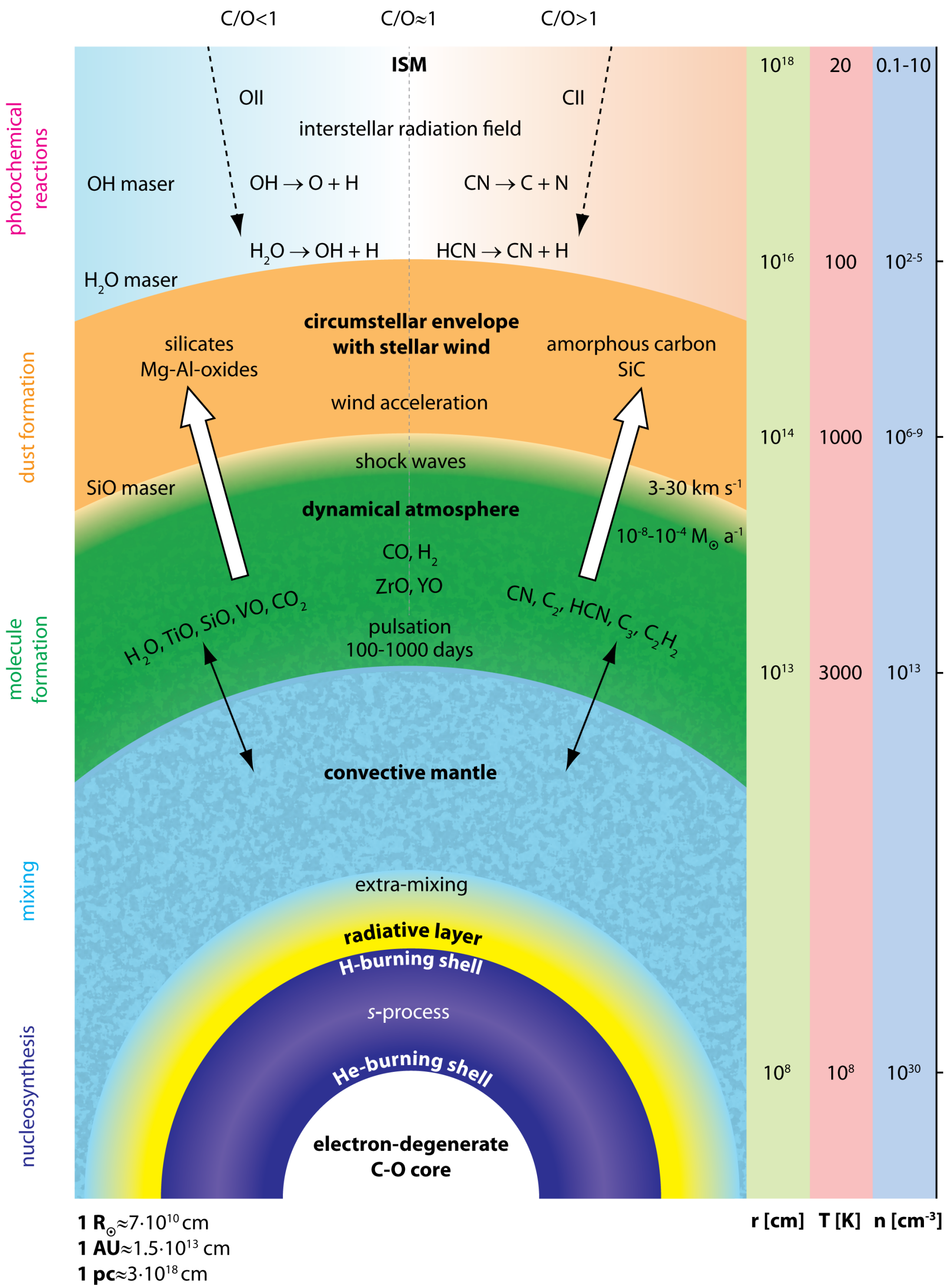
Chemical enrichment pf galaxies

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



Artistic impression of a Red Giant

Schematic view of an AGB star



AGB stars

- $1 < M < 8\ M_\odot$
- $R = 300\ R_\odot$
- $L = 5{,}000 – 10{,}000\ L_\odot$
- T_{eff}=2,600 – 3,500 K
- Very bright in the IR
  - ~1 mag in nearIR
  - >40 Jy in the midIR

Ideal targets for interferometry!

Mass-Loss mechanism

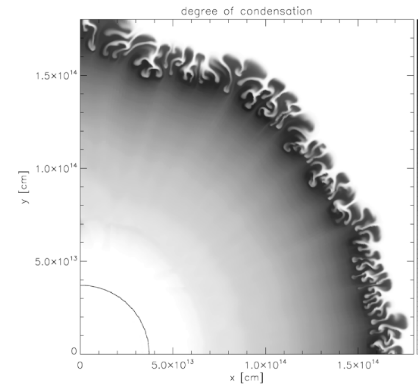
- Carbon-rich AGB stars
  - Radiative pressure on dust grains
  - Gas & dust accelerated away from the star
  - Models can reproduce observations (talks & exercises next week)

- Oxygen-rich AGB stars
  - Dust grains have to be close (iron-free) and have enough absorption cross-section in near-IR (iron-rich) (Woitke 2006)
  - Scattering cross-section of forsterite particles high enough to drive the wind for micron-sized particles (Hoefner 2008, Bladh 2013)

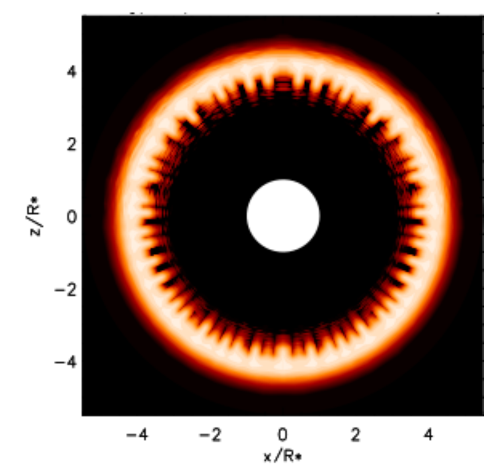
+ Physical mechanisms (I)

- Pulsation induce shock-waves
  - Dust shells formation
  - Length scale ~ few stellar radii
- Drift instabilities
  - System switches between high/low mass-loss state
  - Shell structures
  - Length scale ~ few 100 stellar radii
- Radiative instabilities
  - Dust clouds
  - Cool dust structures are surrounded

  by warmer gases



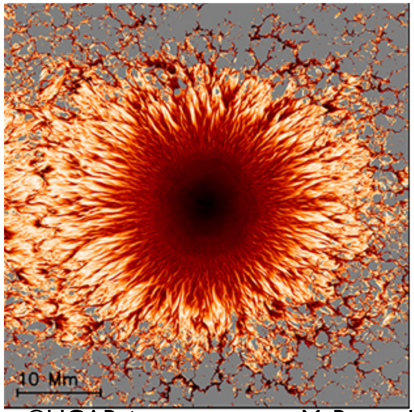
Woitke 2006



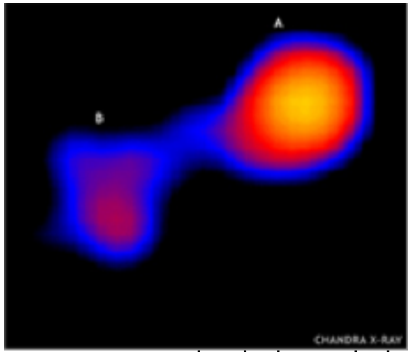
Woitke & Niccollini 2004

Physical mechanism (II)

- Magnetic activity = formation of magnetic spots
  - Locally facilitates dust formation
  - Possible cause for deviation from spherical outflows
- Rotation = more dust on equatorial plane
  - Increase density scale height in the equatorial plane
  - Dust formation more efficient
- Binarity = companion transfers angular momentum
  - Influence of rotation on dust distribution
  - System may capture lost mass in circum-binary disc



©UCAR, image courtesy M. Rempel


chandra.harvard.edu

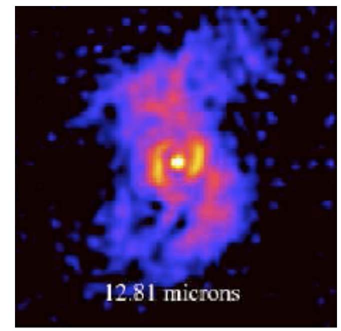
To be or not to be asymmetric?

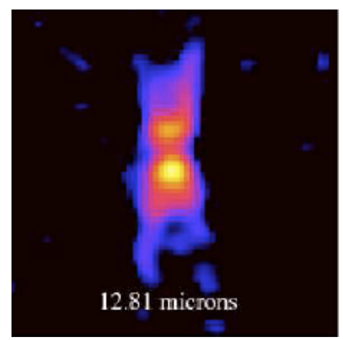
Many Post-AGB stars show departure from spherical symmetry

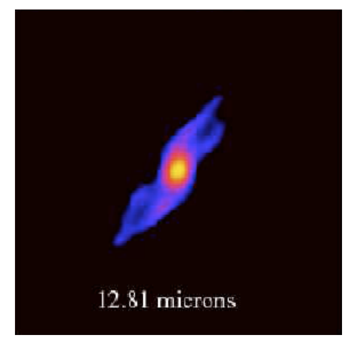
Asymmetries should develop in the previous stage: the AGB

Few AGB stars show departure from spherical symmetry

Multi-wavelength observations contradict each other.







Lagadec et al., 2011

Where are the asymmetries?

Asymmetries are there but in the past:

- Poor instrument sensitivity
- No coordinated (multi-wavelength) programs
- Not enough angular resolution
- (partially consequence) no suitable models

Picture still puzzling, no answer for basics questions like:

- 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?

Zoo of stellar morphologies

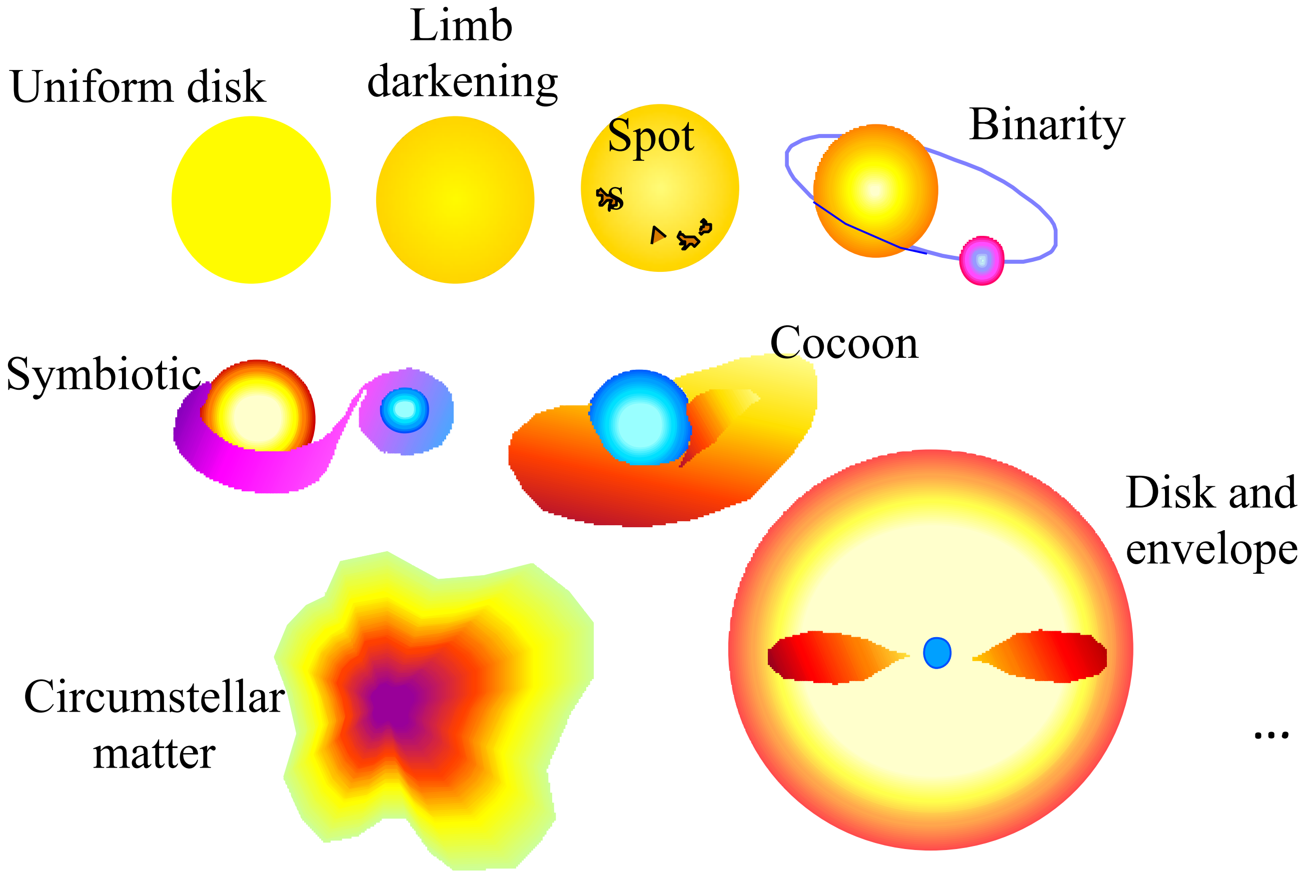


Figure courtesy: S. Sacuto

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Close to the stellar surface

Departure from spherical symmetry detected at small spatial scales (1-5 stellar radii)

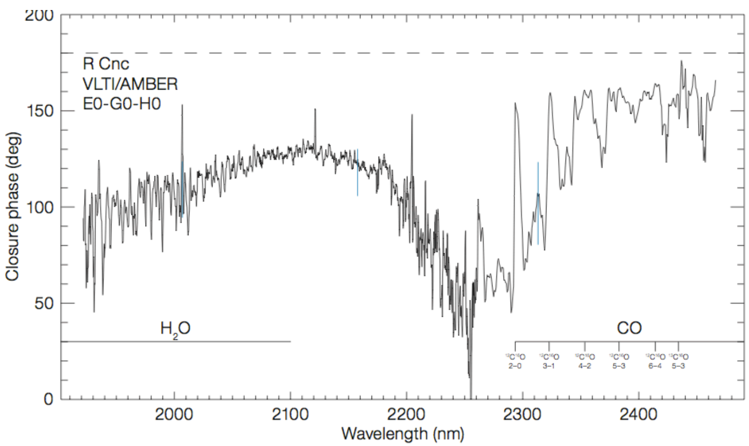
- Lunar Occultation (Richichi et al. 1995; Meyer et al. 1995)
- Optical interferometry
  - Ragland 2006:"only" 29% AGB stars asymmetric. Probably because of broad band (small asymmetries average out) and too low spatial frequencies for some objects.
  - van Belle et al. (2013): evidence of asymmetries for many C-stars (surface inhomogeneities or effect of stellar rotation)
  - Cruzalebes et al. (2013, subm.) found closure phase signatures with AMBER for many AGB stars (surface inhomogeneities)

…

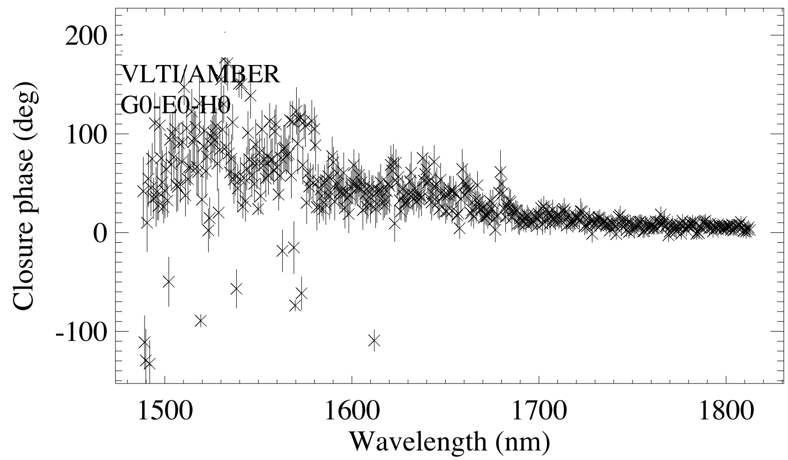
Many works are in broad band or with low resolution.
Still no clear answer on what process is behind the asymmetries.

The power of (spectral) resolution

Wittkowski et al. 2011



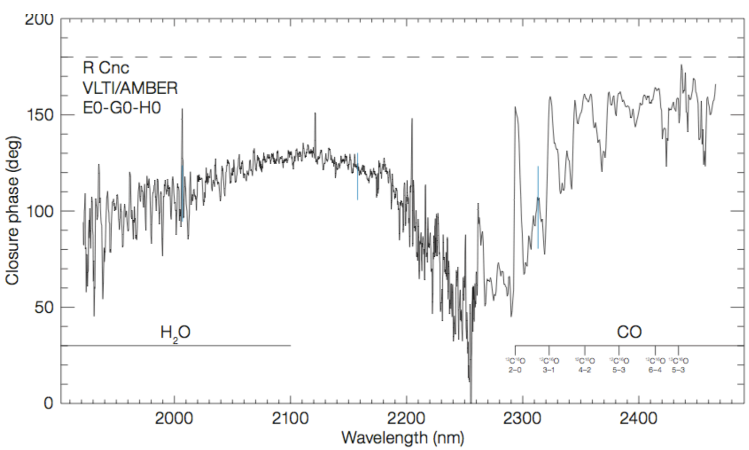
Paladini et al. (prep.)



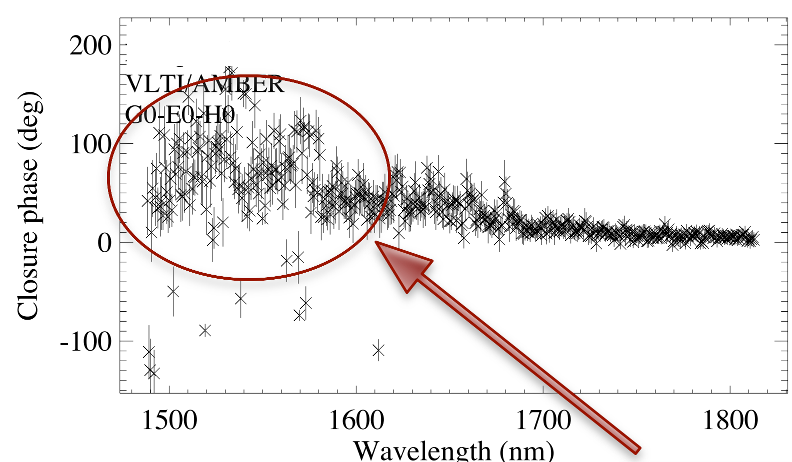
Asymmetries can be associated to specific spectral features!
Will shed light on non-LTE processes of molecular formation

The power of (spectral) resolution

Wittkowski et al. 2011



Paladini et al. (prep.)



Implications on dust formation theory

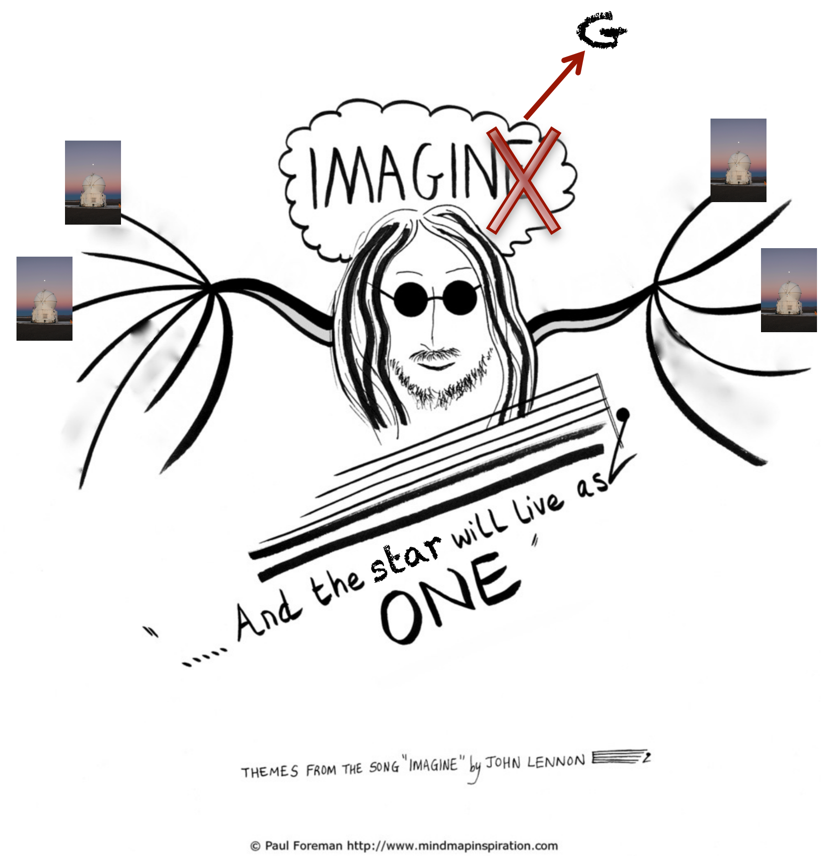
Asymmetries can be associated to specific spectral features!

Will shed light on non-LTE processes of molecular formation

Imaging: things to be aware of

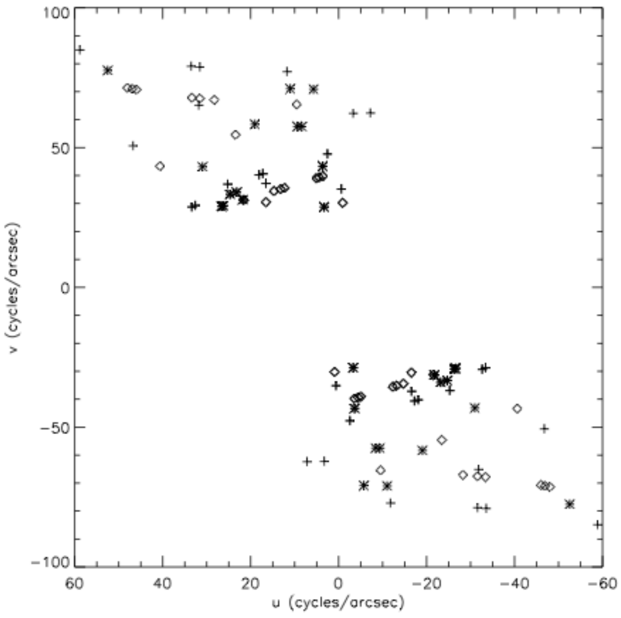
Not an easy task. Why?

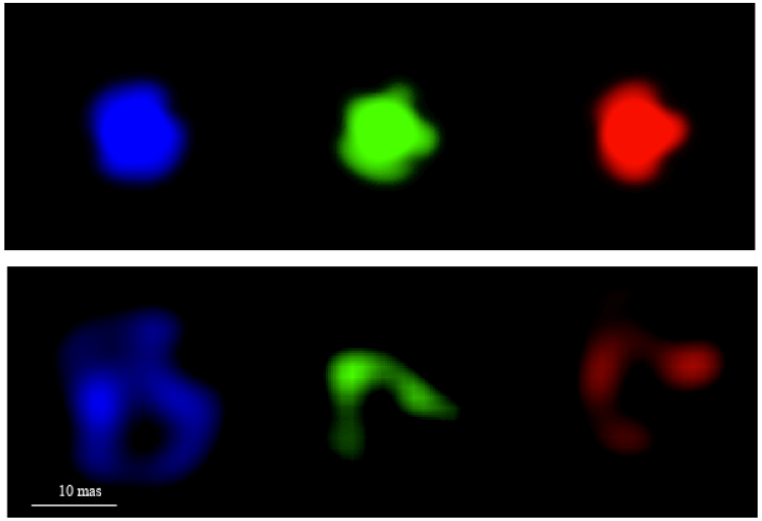
- Very extended objects bright sources means very low visibilities
- Good uv-coverage needed
- Different wavelength cannot be combined
- Stars are variable: need to have all configurations in a short time
- Image reconstruction algorithms & multi-wavelength



The power of imaging (I)

R Aqr reconstructed in 3 channels 1.51, 1.64 and 1.78μm with IOTA (Ragland 2008)

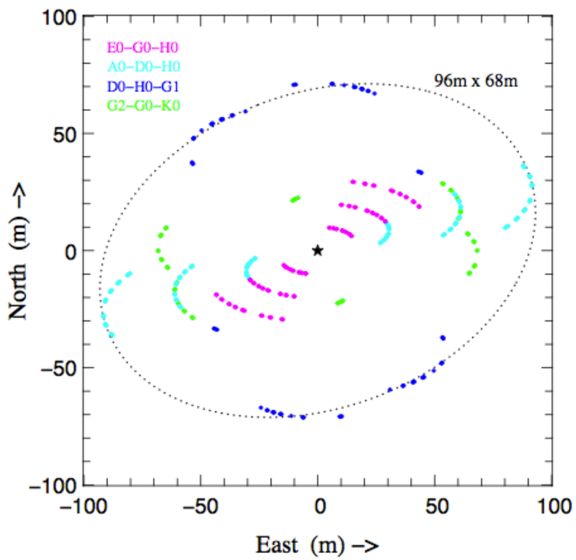


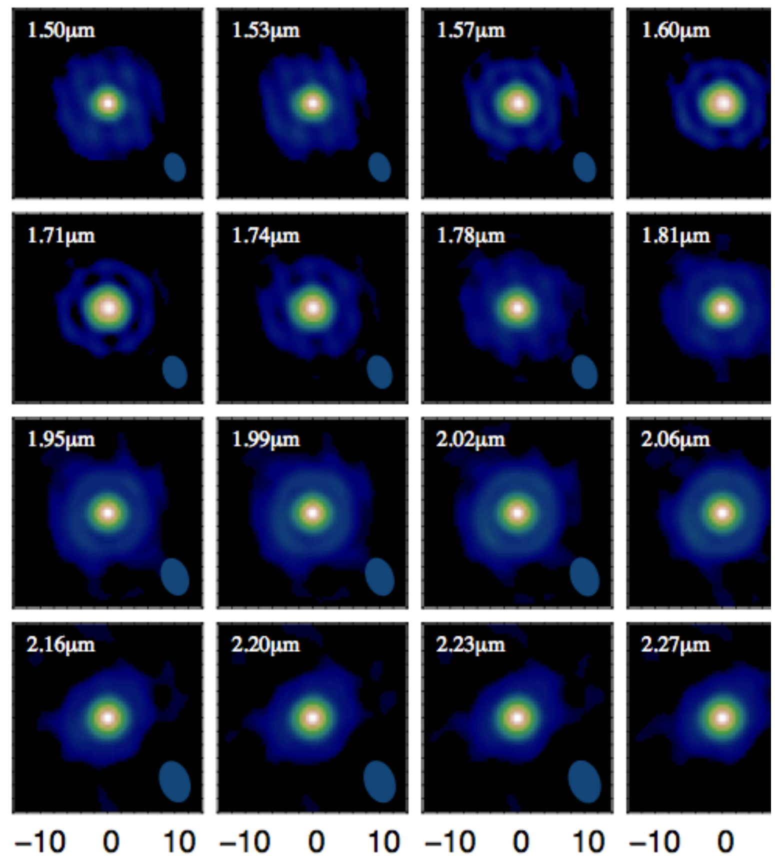


Strong asymmetric structures in the H_2O molecular layer

The power of imaging (II)

T Lep imaged with AMBER
(Le Bouquin et al. 2009)

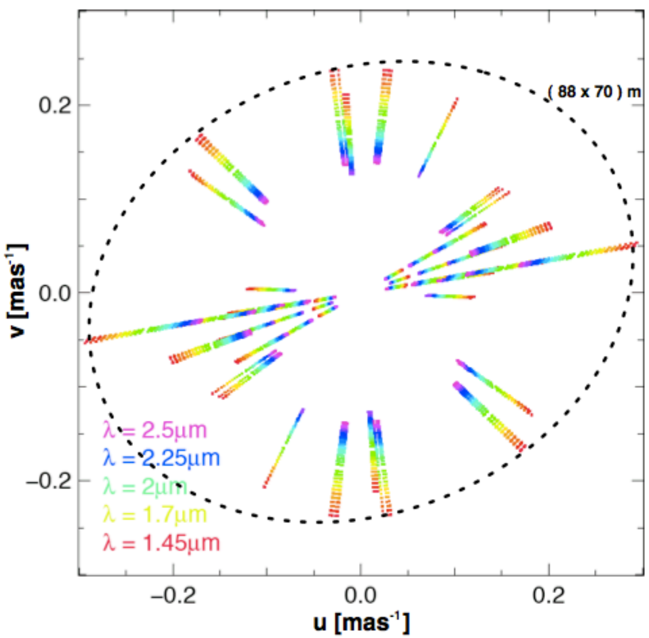


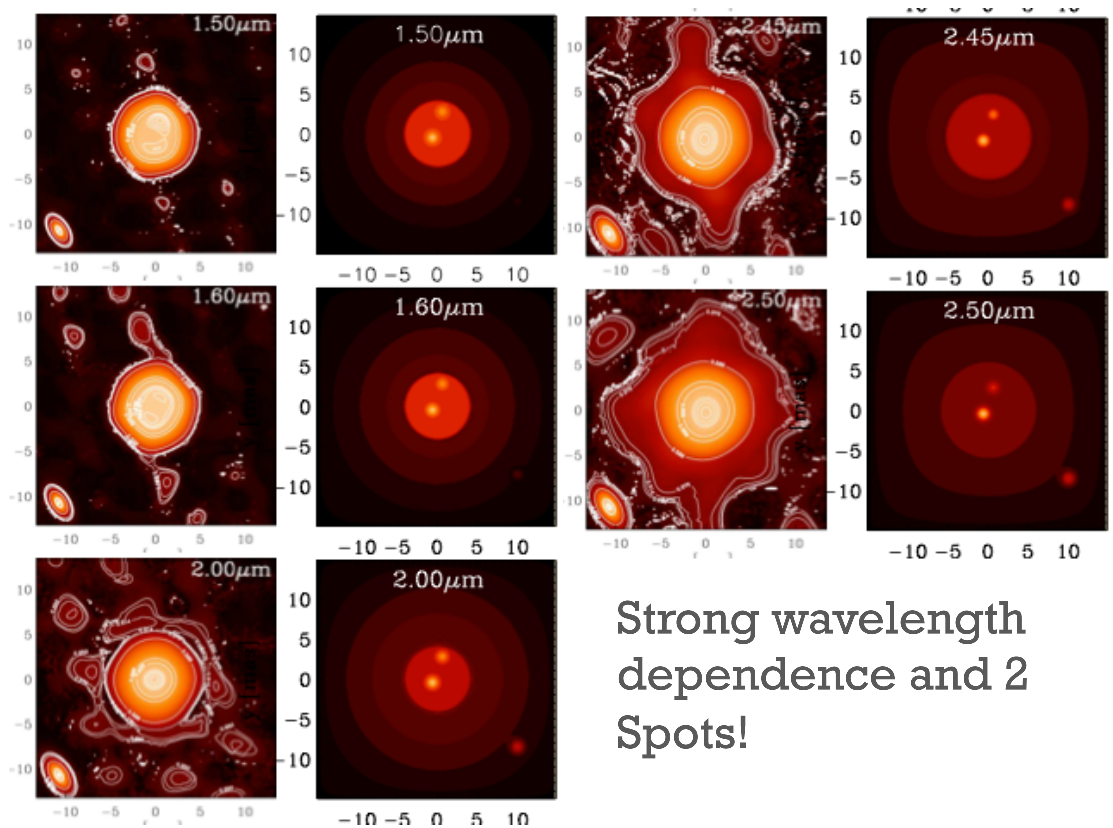


Unveil a "onion-like" shape
(molecular shells)

The power of imaging (III)

VX Sgr imaged with AMBER (Chiavassa et al. 2009)

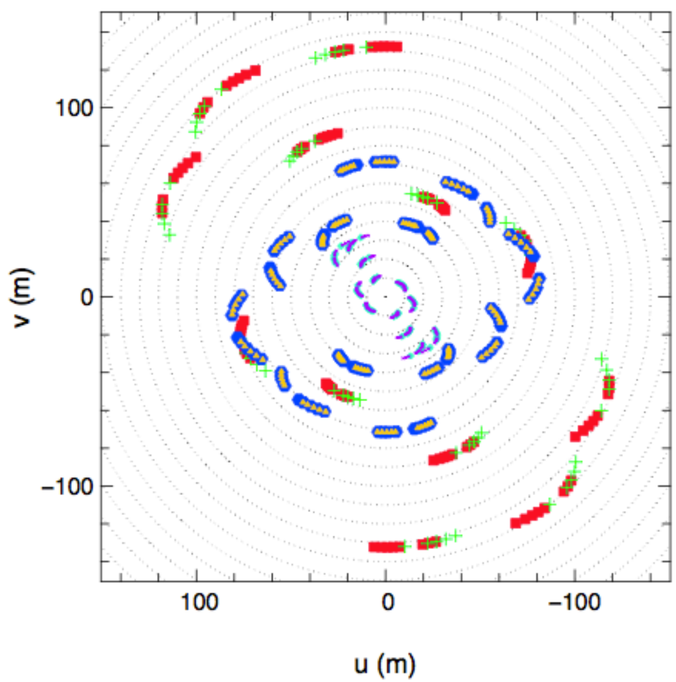


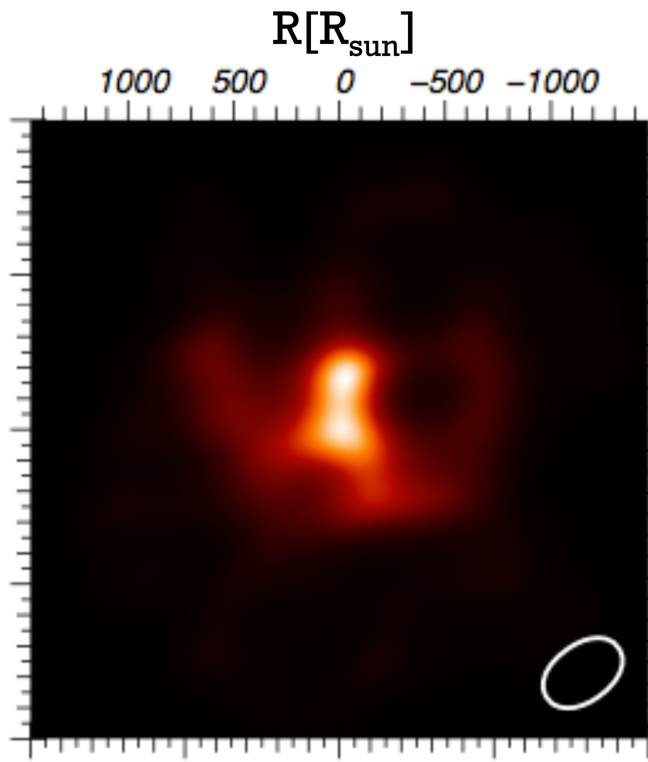


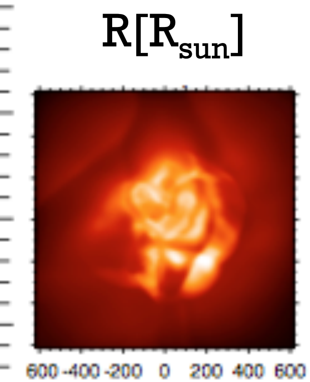
Strong wavelength dependence and 2 Spots!

The power of imaging (IV)

PIONIER image of a Mira carbon star (H-band, 3 spectral channels, only 1.59 m shown, Paladini et al. prep.)







Freytag & Hoefner (2008)

Different features @ different spectral channels. Probably spotty surface, more pronounced at 1.59 micron.

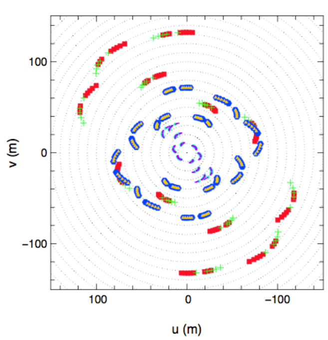
Second generation instruments (I)

Imagine…

spectral resolution

+

4 telescopes



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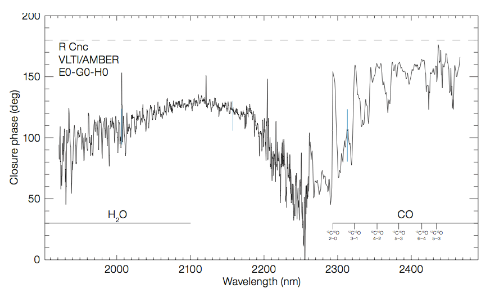
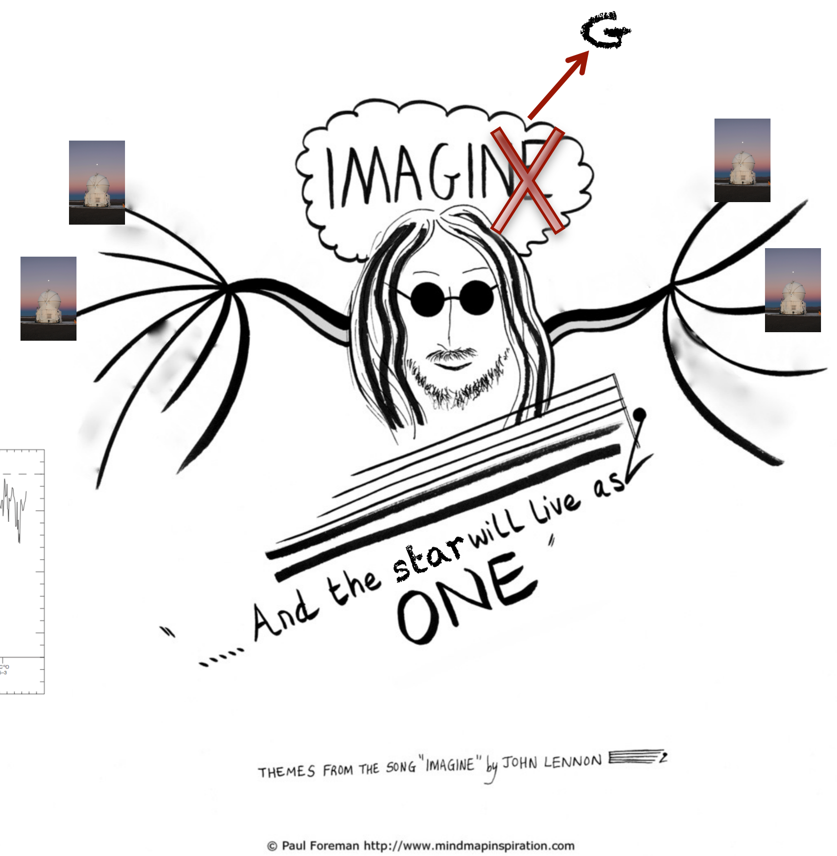
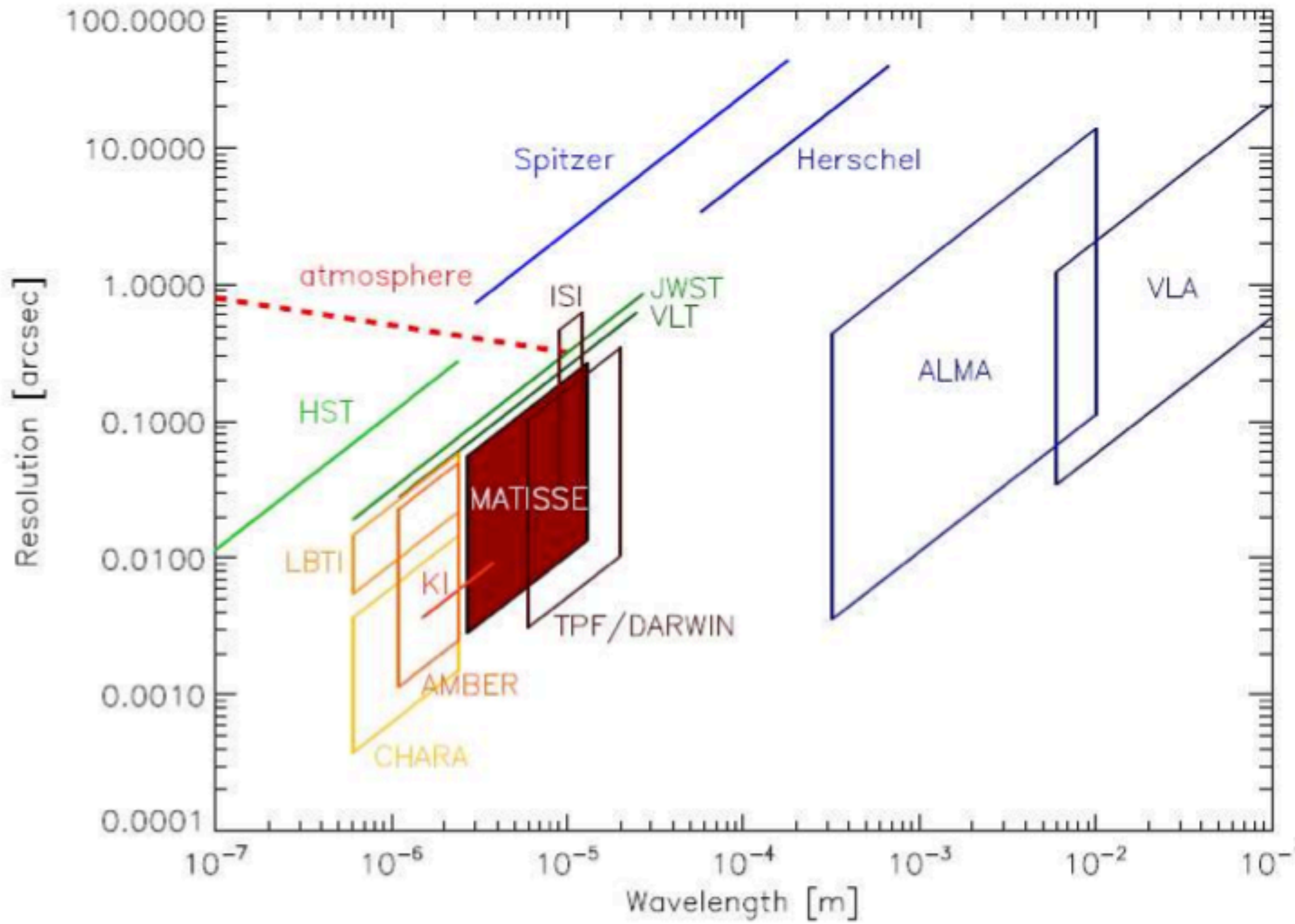




What will you do with GRAVITY?

Current wavelength GAP



Lopez et al. 2008

AMBER stops at 2.4 microns and MIDI starts at 8 microns… waiting for MATISSE

Asymmetries in the mid infrared

Outside the photosphere, in the molecular and dust formation zone. Until '90 mass-loss considered constant outflow. Using interferometry:

- Danchi (1994) reported episodic dust formation @ 3-5 stellar radii
- Tabete (2006): asymmetries in 6 AGB stars. R Aqr asymmetry due to presence of binary

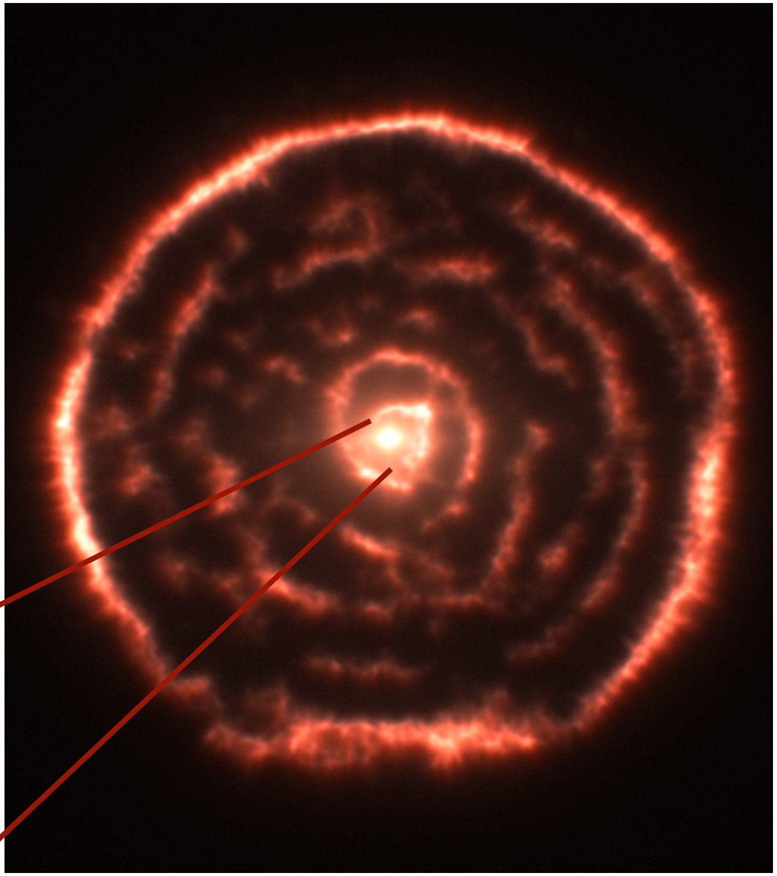
…

Spirals? Discs?

Many studies on IRC+10216 (Weigelt et al. 1998; Tuthill et al. 2000; Leão et al. 2006; Chandler et al. 2007) report asymmetries due to dust clumps

Do the clumps follow a random distribution? or a preferential one (disc, spiral)?

Still an open question for imaging campaign



Maercker et al., 2012

+
Asymmetries with MIDI

EWS (talk/exercise last Tuesday!) extracts differential phase from MIDI data.

Non zero differential phase means asymmetric object

BUT

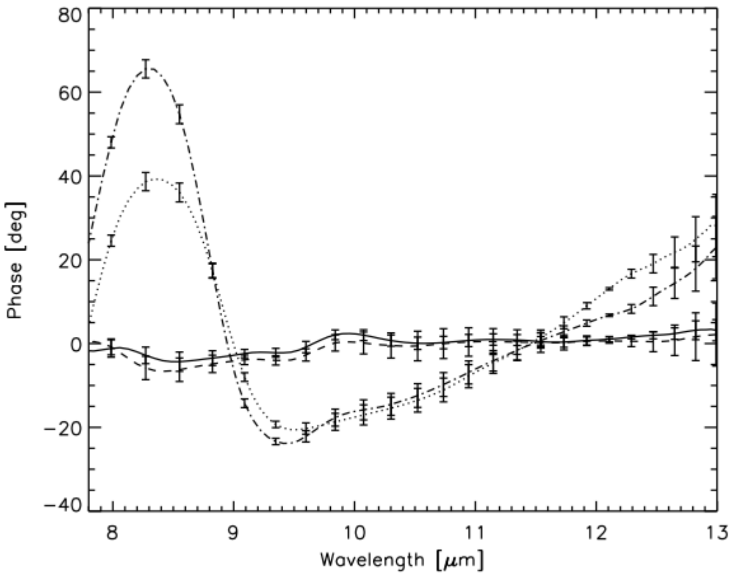
only very few detections.

Differential Phase (I)

Deroo et al. (2007) observed differential phase for a J-type carbon AGB star.

J-type stars believed to be result of a merge.

Asymmetry interpreted as presence of circumbinary disc.



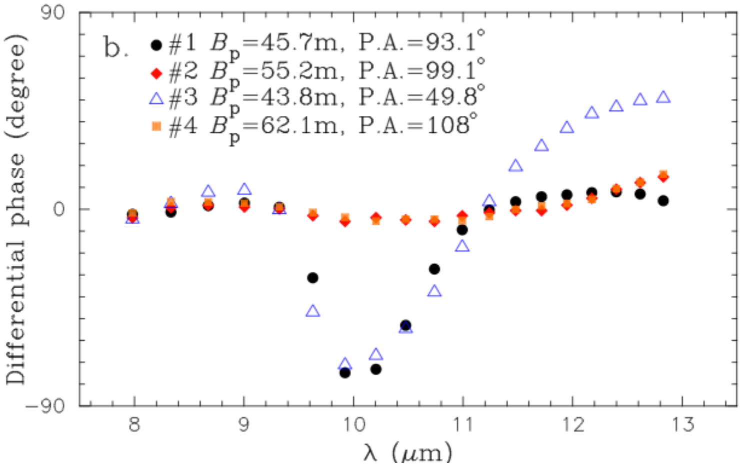
Differential Phase (II)

Ohnaka et al. (2008): another J-type AGB star showing non zero differential phase.

Asymmetry interpreted as presence of circum-companion disc.

Questions

- Are this differential phases common only among J-type AGB stars?
- Are they the signature of a binary?



Note: the differential phase jump is Different from previous star.
Dust chemistry!

Differential Phase (III)

Paladini et al. (2012): differential phase detected for a carbon Mira. "Normal" object, well studied, no signatures of binaries so far…

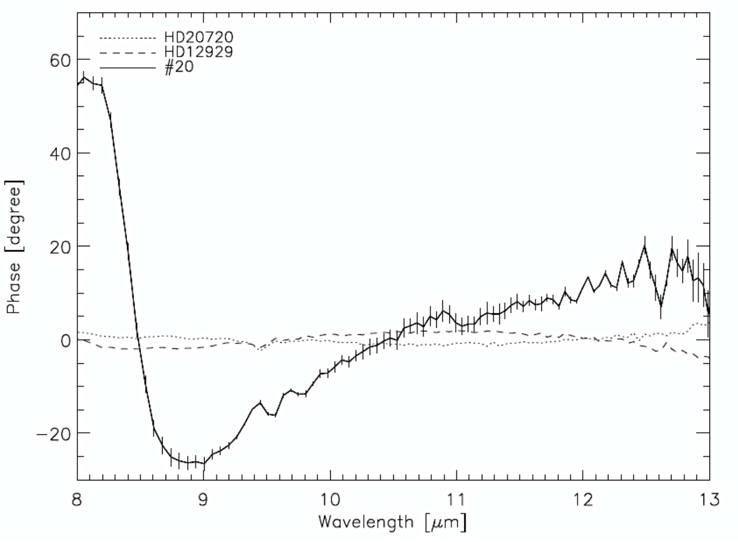
The signature is very similar to the one of Deroo's star

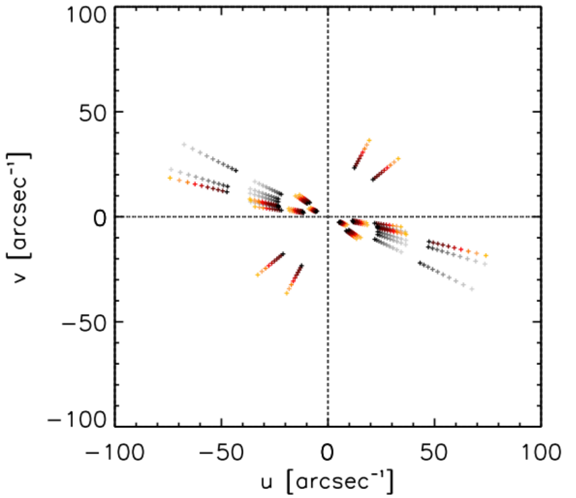
Interpretations:

- Signature of a dust clump
- Dust clump enshrouding a sub-stellar companion

How do we distinguish?

Be careful! Non unique interpretation because of limited uv-coverage.



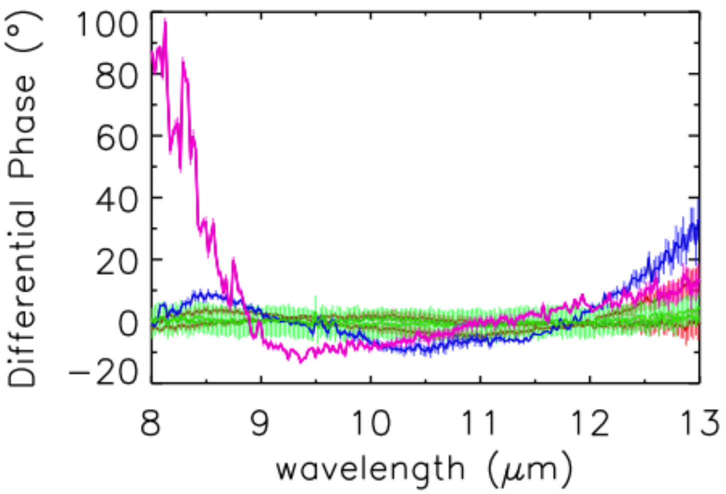


Differential Phase (IV)

Sacuto et al. (2013): another differential phase for a "normal" AGB star.

Same interpretation as previous cases.

Are all the AGB binaries? Or we are looking at something else?

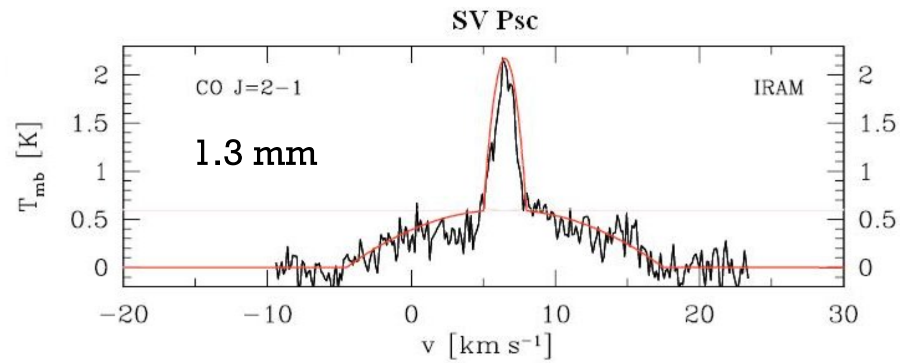


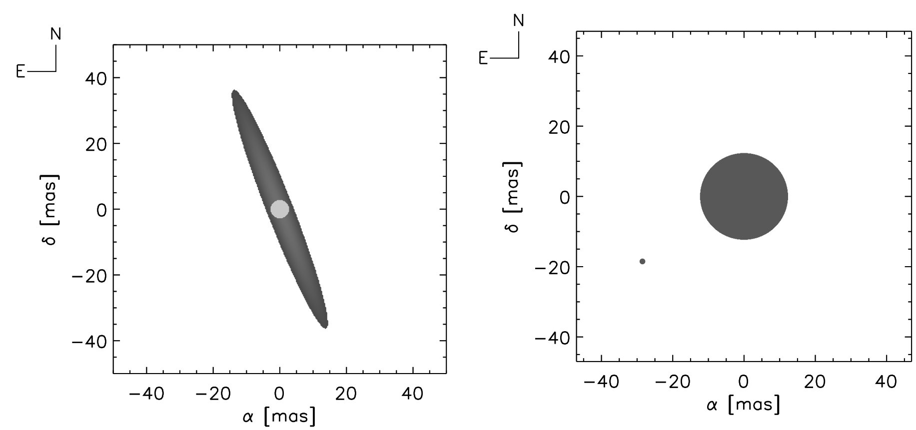
Discs and binaries

Klotz et al. (2012)

- Double-velocity component (Kerschbaum & Olofsson 1999)
- narrow feature (1.5 kms^{-1}) centered on broader (9.5 kms^{-1})
- only visible in small number of stars (< 10)
- 4 scenarios
- MIDI excludes 2 scenarios: binary & disc are the scenarios left

Winters et al. 2003





Where are the other asymmetries?

- Very few works report asymmetries, although they are expected. Where are the dust clumps?
- Ohnaka et al. 2005; Wittkowski et al. 2007; Sacuto et al. 2011; Zhao-Geisler et al. 2011, 2012; Karovicova et al. 2011 did not observe any asymmetric structure
- MIDI observes between 5-100 stellar radii, the range is the right one but…
  - Minimum angular resolution is 20 mas. Is it possible that clumps are smaller?
  - uv-coverage is limited by 2 telescope configuration, difficult to disentangle between various geometries
  - More probable to find asymmetries at high spatial frequencies (i.e. long baselines configurations)

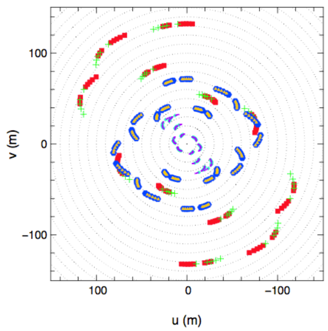
Second generation instruments (II)

Imagine…

spectral resolution

+

4 telescopes



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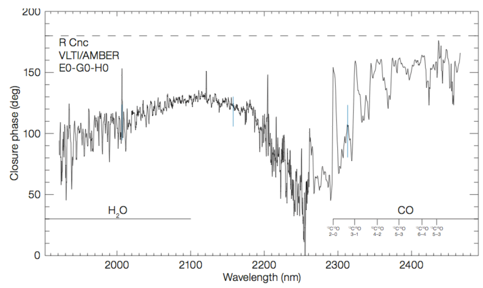
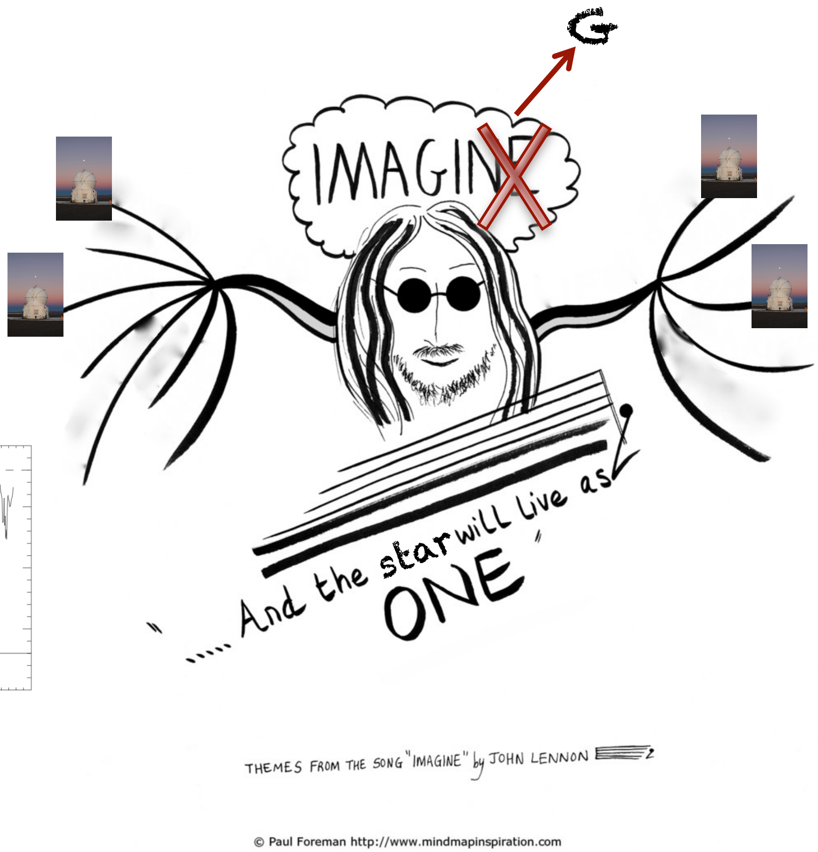




What will you do with MATISSE?

"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 ...

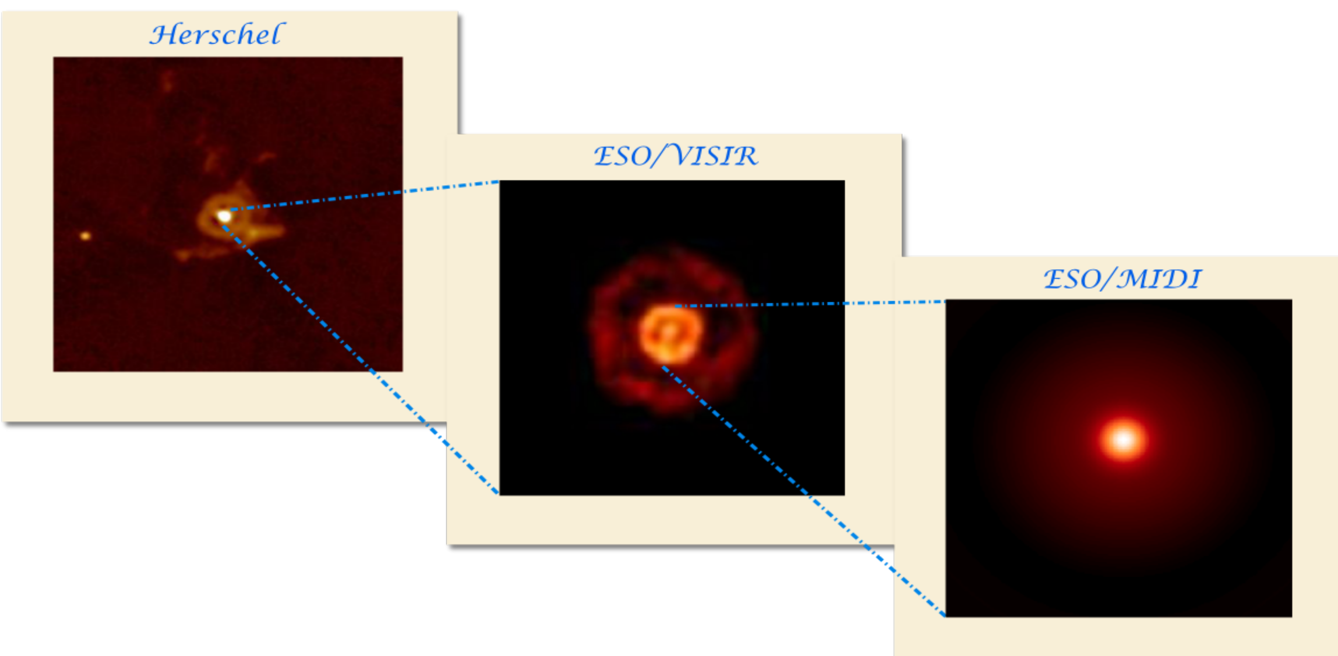
One should push forward to organise such a large coordinated program."

(Foy, 1990)

Coordinated works on a statistical sample

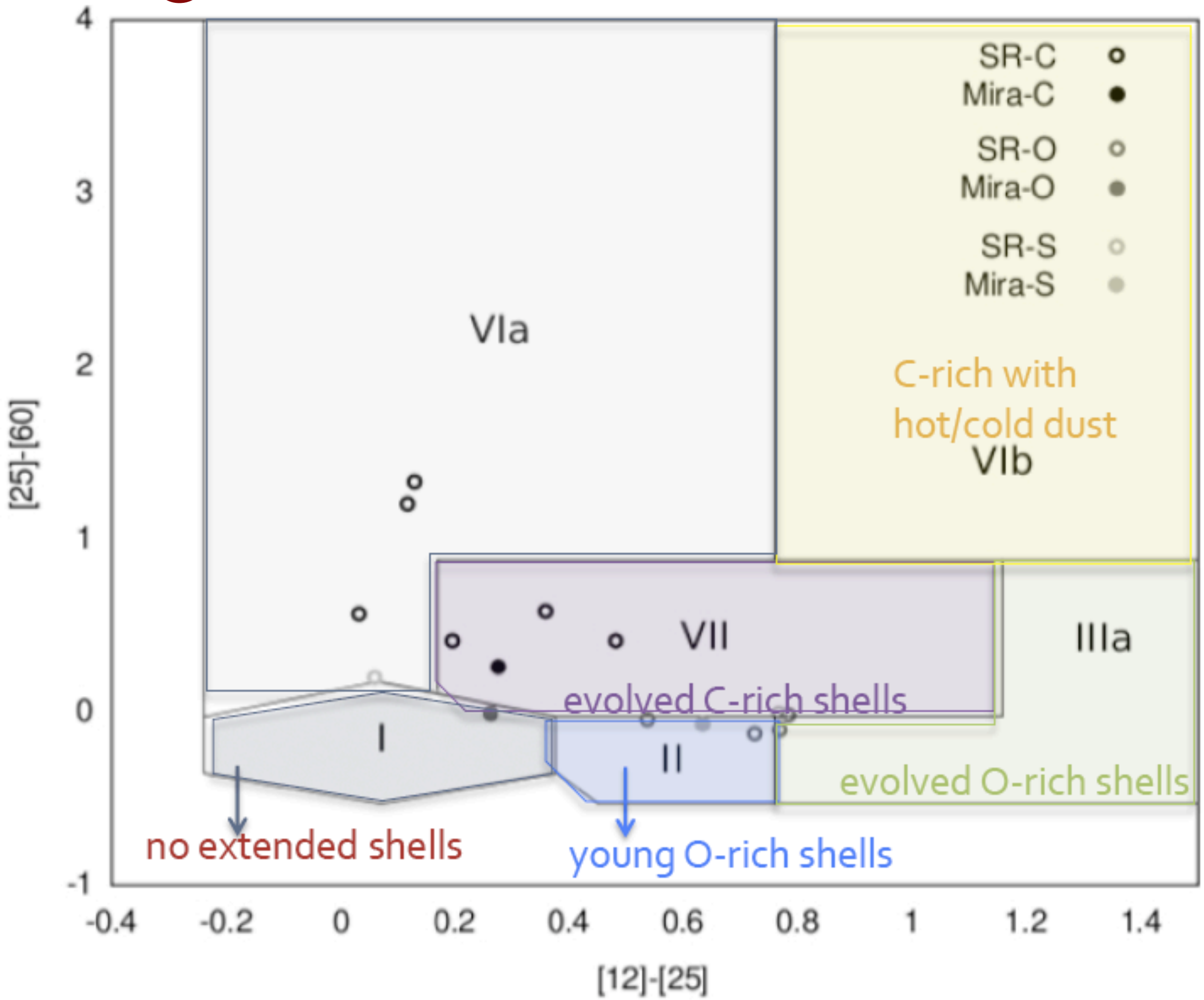
To understand properly the physics of the environment of AGB stars, coordinated works on large samples of stars are needed.

Multi-wavelength + multi-techniques



Paladini et al. prep.

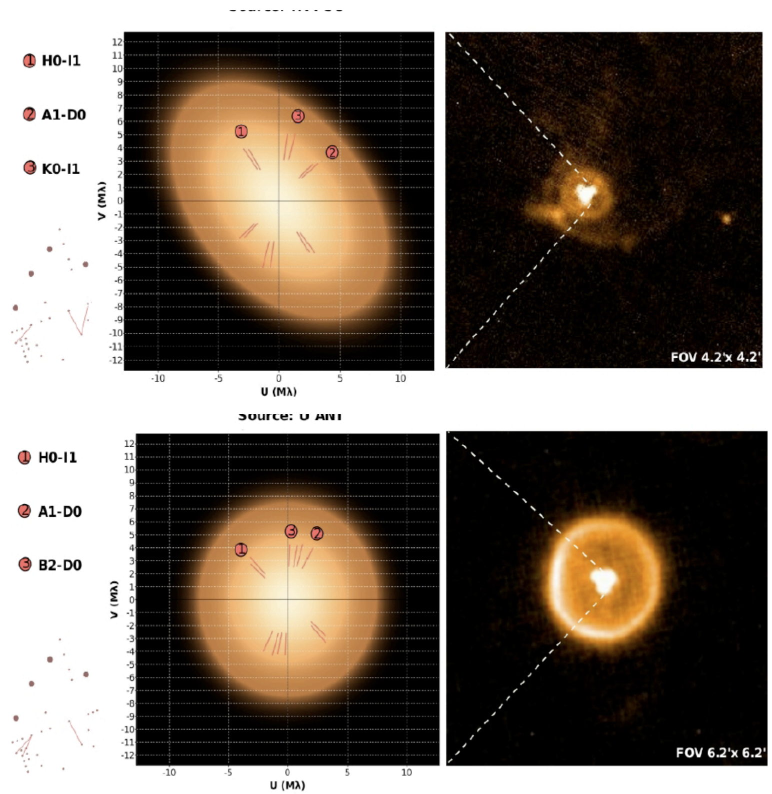
The AGB sample in the IRAS color-color diagram



Preliminary results from MIDI large program

Paladini et al., prep.

- Very few differential phases
- No interferometric variability
- Spectroscopic variability
- Dust probably forms closer than what we thought
- Detached shell of dust



Jorissen et al., 2011

Kerschbaum et al., 2010

Lessons to learn

- AGB stars are perfect targets for interferometry, but very challenging for imaging programs
  - uv-coverage
  - Multi-wavelength image reconstruction
  - observations to be taken in a short time (variability!)
- Plenty of physics to investigate!
  - mass-loss
  - variability
  - dust formation
  - geometry of the environment at different scales
- Not primary targets for second generation instruments, but a lot can be done.

Start thinking!

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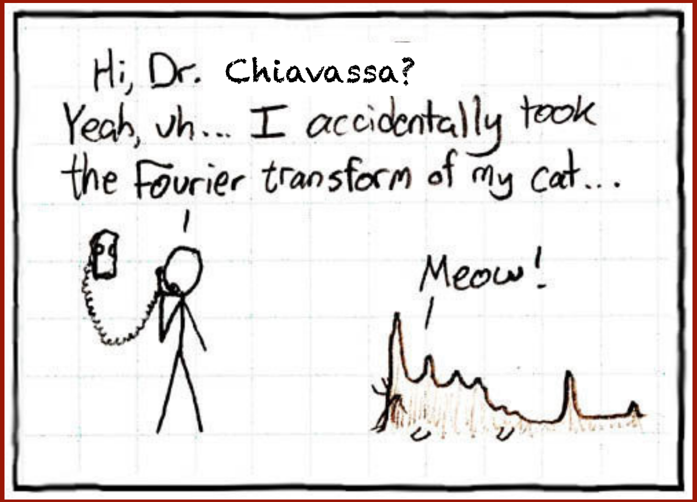
Thank you!



http://xkcd.com