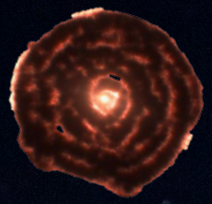
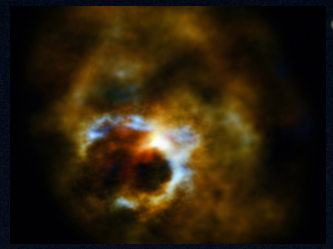
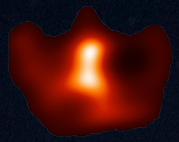






Surface Features with VLTI

Claudia Paladini

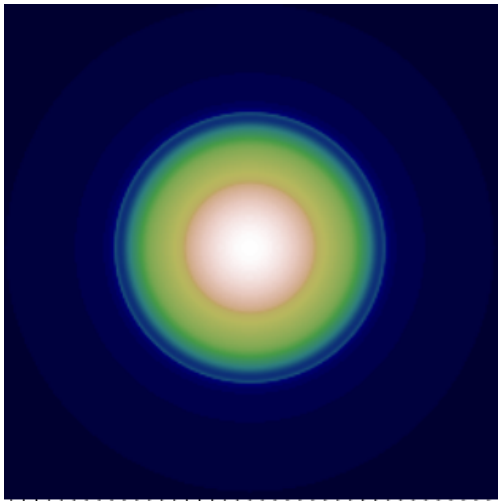
ULB UNIVERSITÉ LIBRE DE BRUXELLES

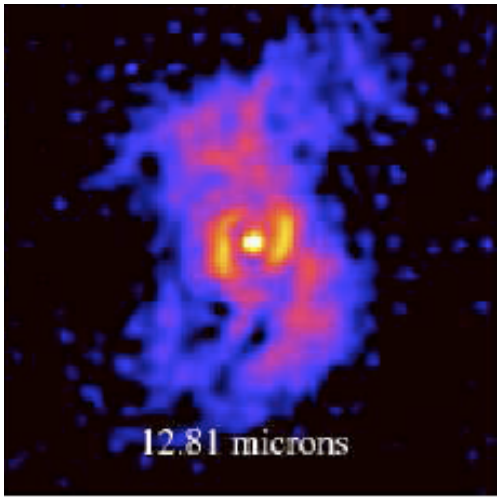
fnrs FREEDOM TO RESEARCH

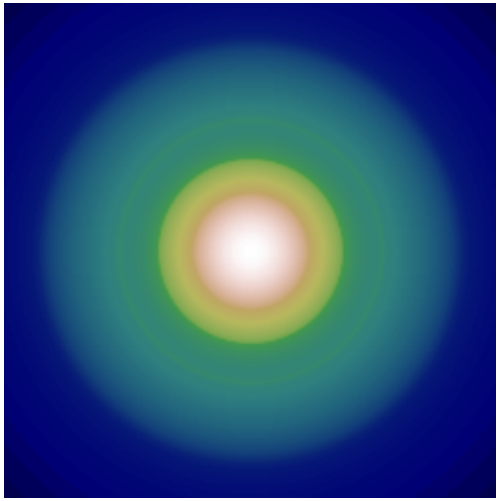
Old concept

AGB are round

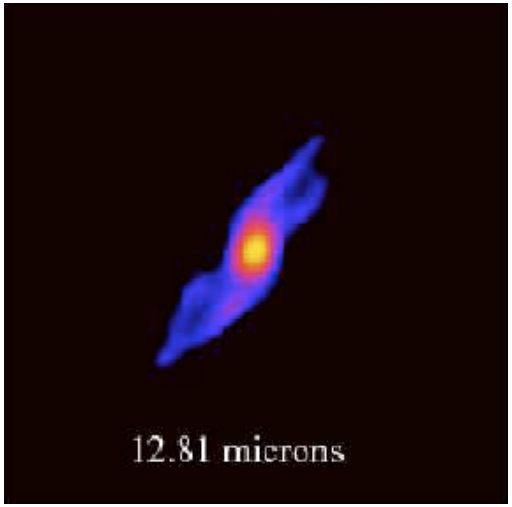
Post-AGB, planetary nebulae are not





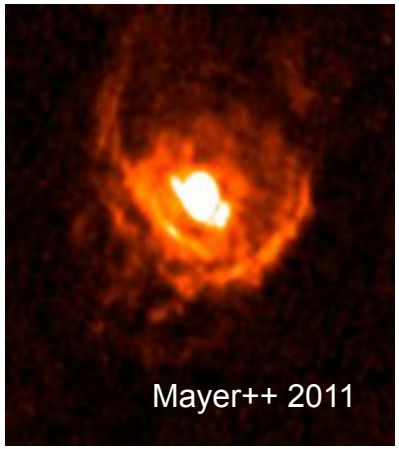


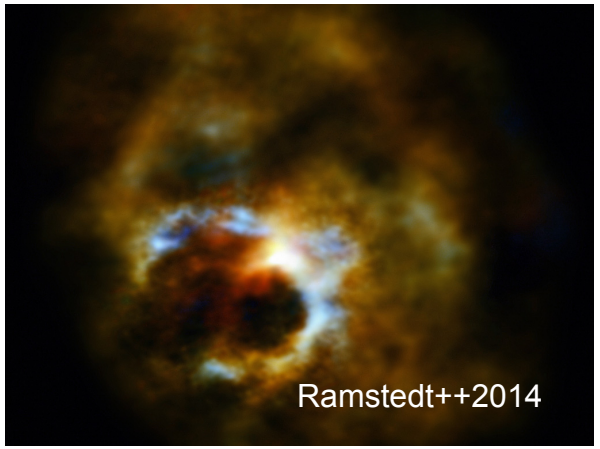
1D models Höfner 2003

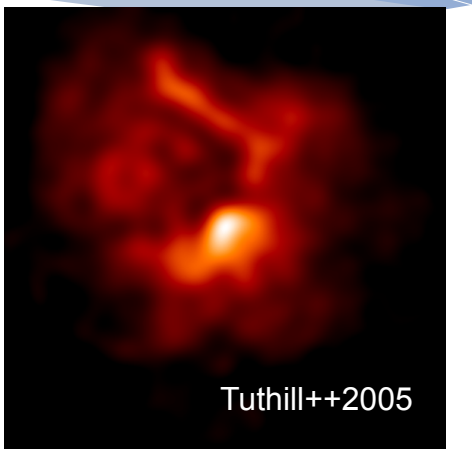


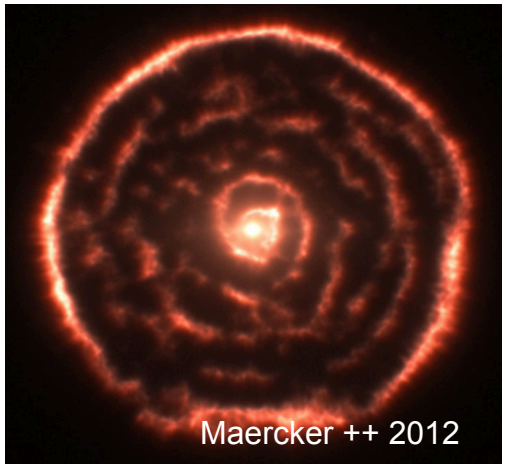
Lagadec et al., 2011

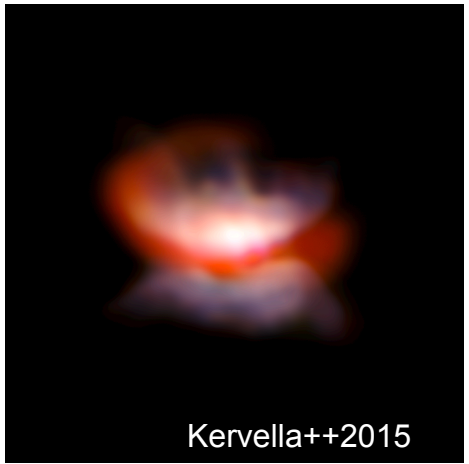
New observations

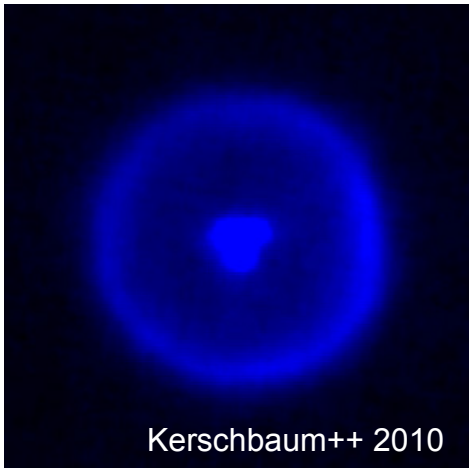






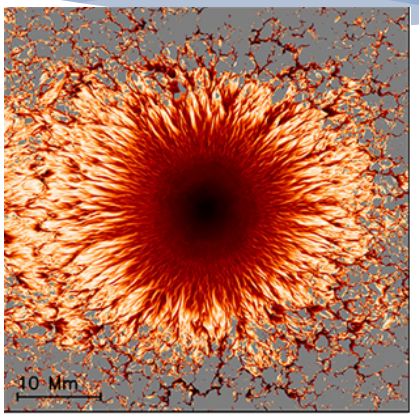




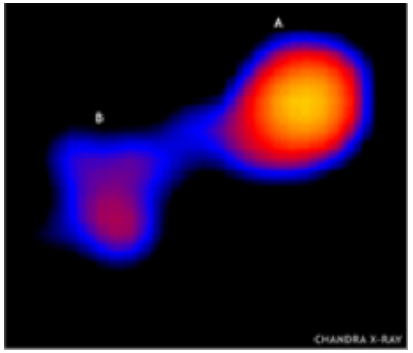


What does it shape the circumstellar envelope?

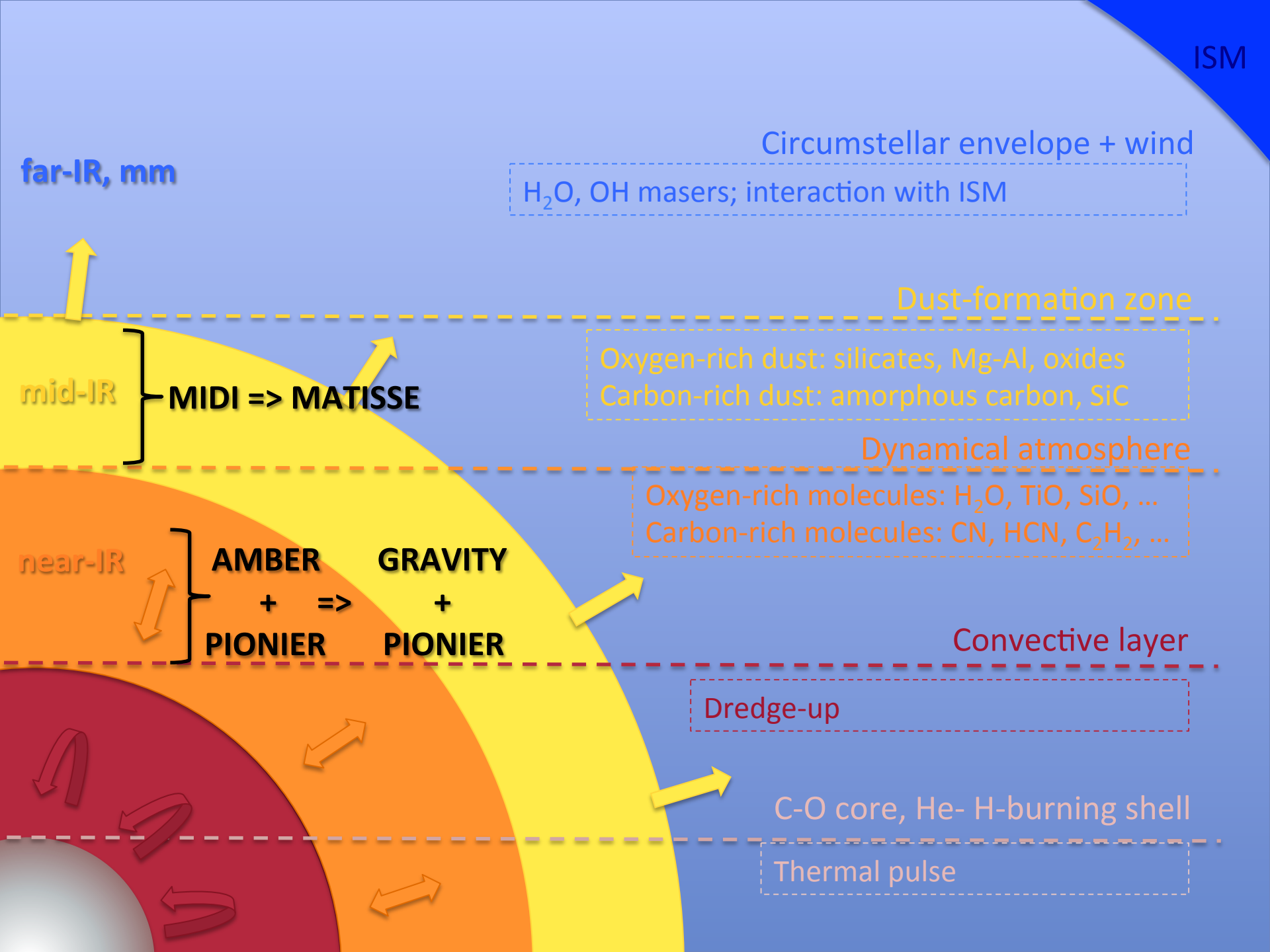
* Convection
* Magnetic activity
* Rotation
  - Increase density scale height in the equatorial plane
* Binarity = companion transfers angular momentum
  - Influence of rotation on dust distribution
  - System may capture lost mass in circum-binary disc



©UCAR, image courtesy M. Rempel



chandra.harvard.edu


ISM
Circumstellar envelope + wind
far-IR, mm
H_2O, OH masers; interaction with ISM
Dust-formation zone
mid-IR
MIDI => MATISSE
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 => GRAVITY + PIONIER
Convective layer
Dredge-up
C-O core, He- H-burning shell
Thermal pulse

Literature

Lunar Occultation (Richichi et al. 1995; Meyer et al. 1995), aperture masking, speckle, optical interferometry

* Departure from spherical symmetry detected at 1-5 stellar radii
* Ragland 2006:"only" 29% AGB stars asymmetric

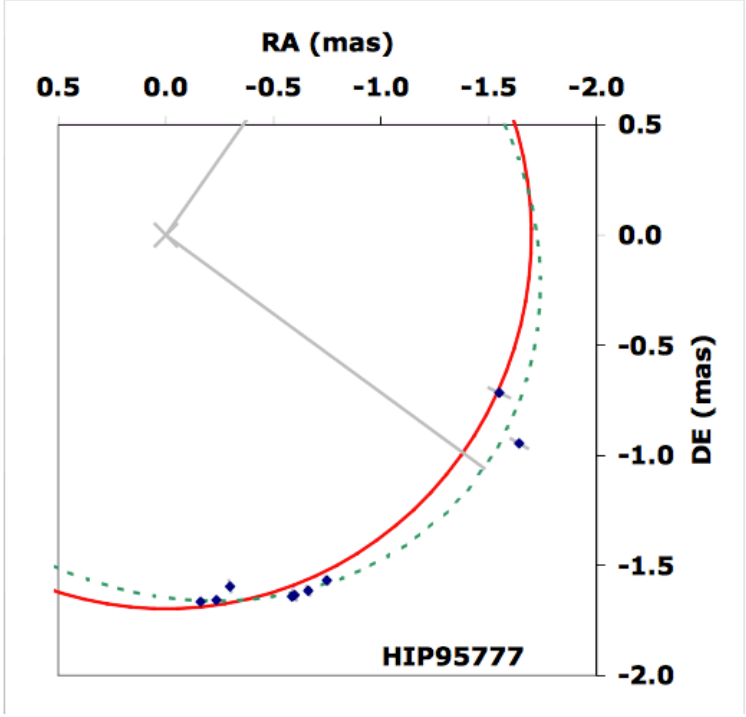
Many works are in *broad band or with low resolution*.
Still no clear answer on what process is causing those asymmetries!

Rotation?

van Belle et al. (2013) studied a sample of C-stars by means of model atmospheres and geometric models

evidence of asymmetries for many C-stars

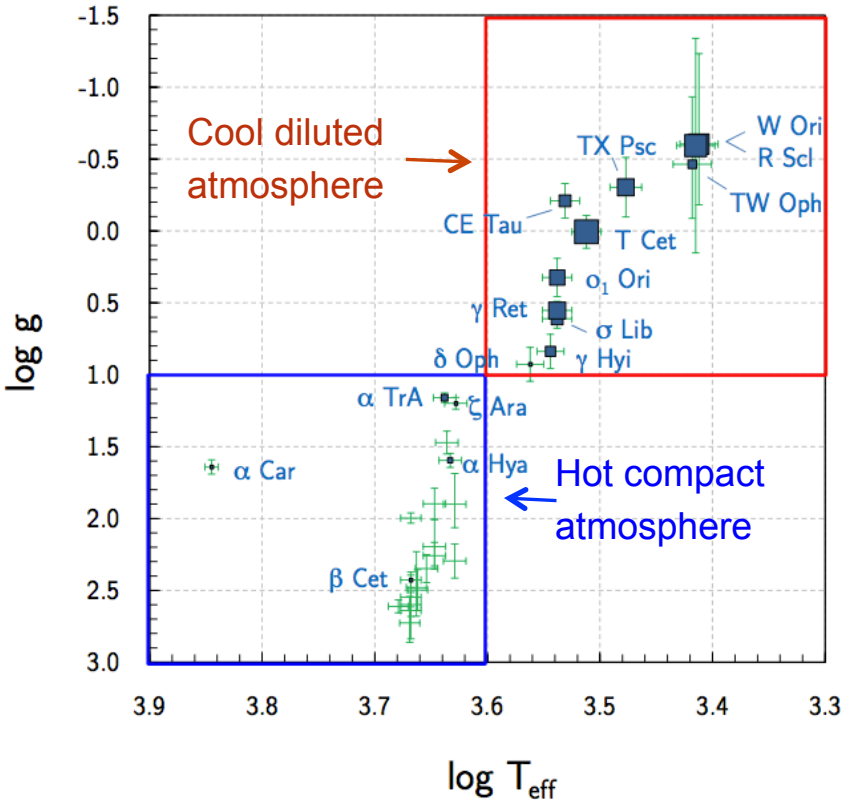
* surface inhomogeneities or effect of stellar rotation?



Convection (I)

Cruzalebes et al. (2014) found closure phase signatures with VLTI/AMBER for many AGB

* Asymmetry increase following the sequence K giants -> RSG -> AGB

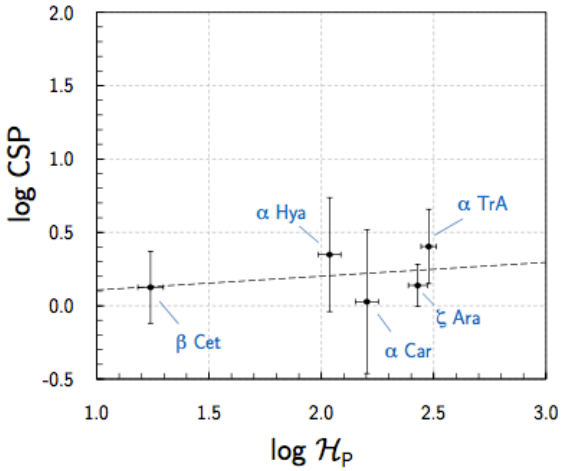


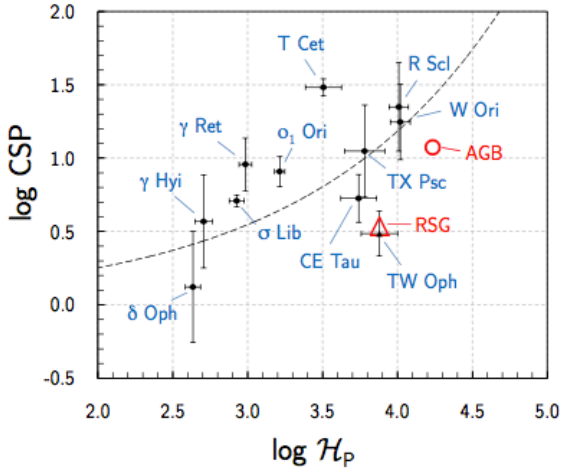
Convection (II)

Cruzalebes et al. (2014)
Asymmetries increase with H_P parameter

Agreement with photocentric motion relation predicted by 3D-RHD simulations (Chiavassa et al. 2011)

$$H_p \sim \frac{T_{\rm eff}}{g}$$



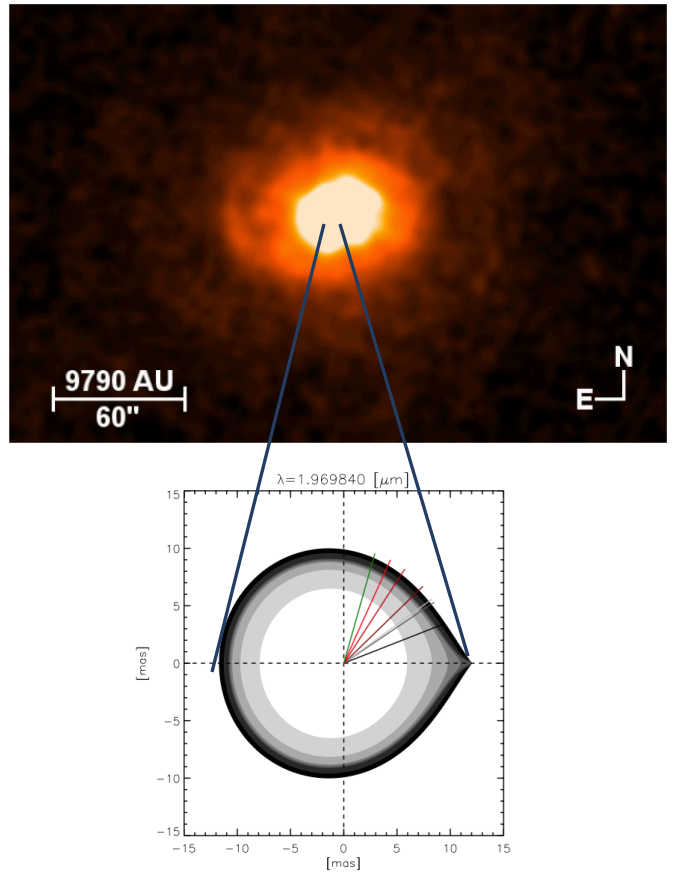


The effect of binarity

Mayer et al. (2014)

Herschel/PACS + Hipparcos + VLTI/AMBER data S-type AGB

* Literature +Hipparcos +AMBER suggest presence of close binary



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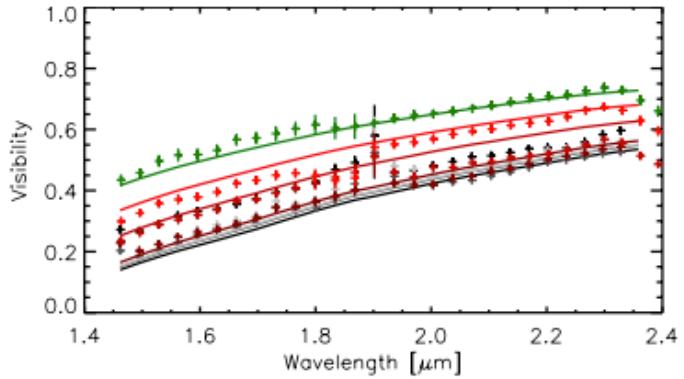
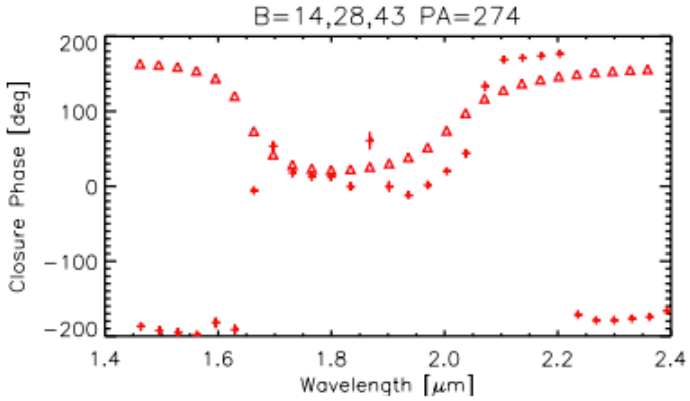
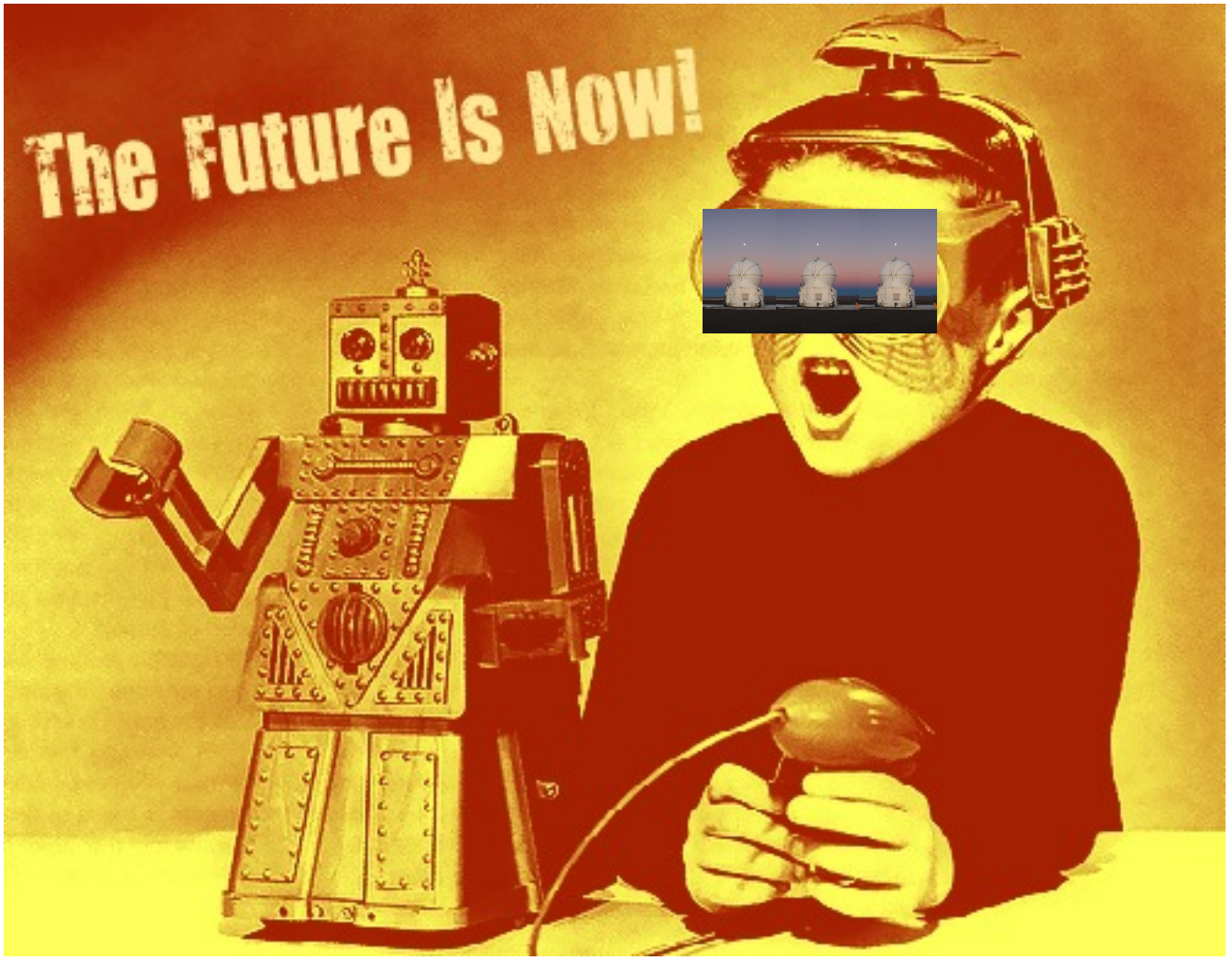




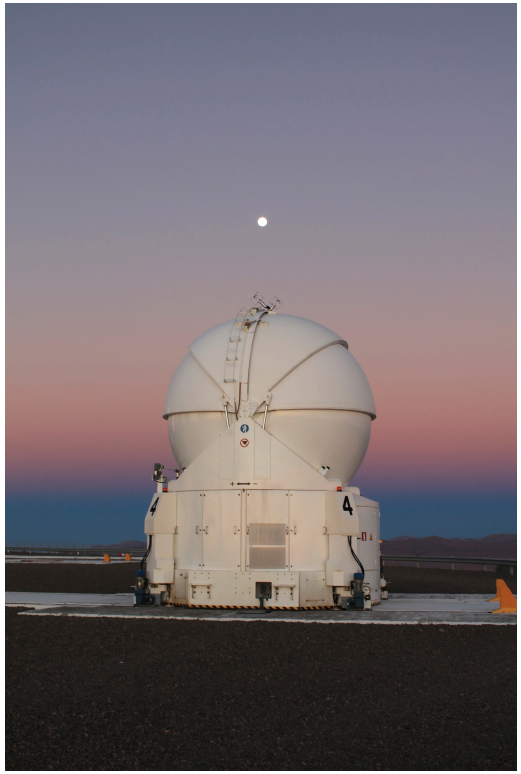
Imaging!



Imaging of Giants things to be aware of

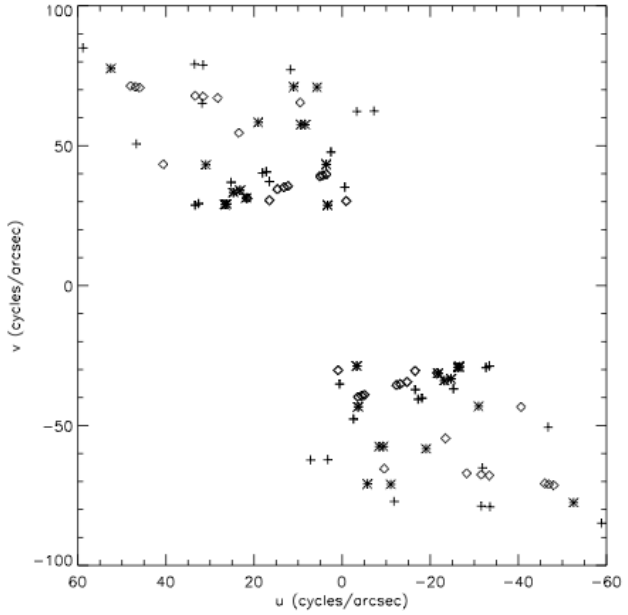
Not an easy task. Why?

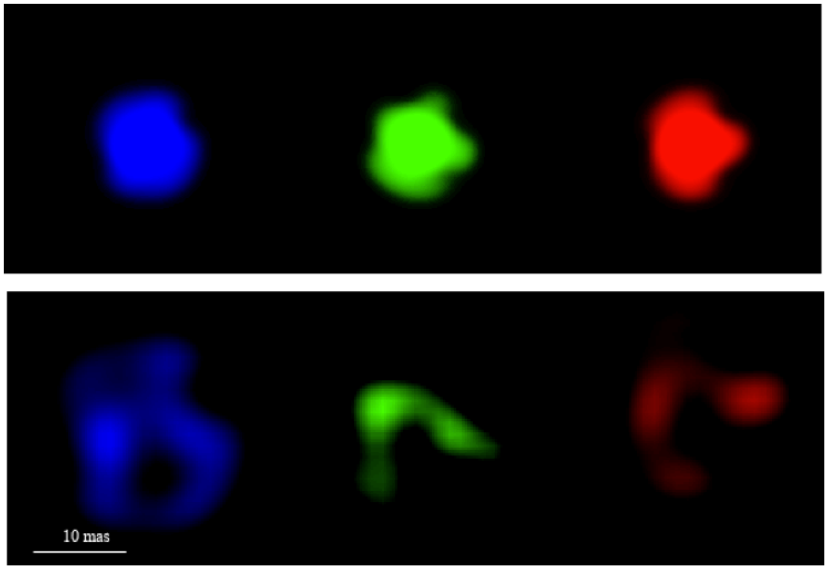
* Very extended objects bright sources means very low visibilities
* Good uv-coverage needed
* Different wavelength cannot be combined
* Image reconstruction algorithms & multi-wavelength
* Stars are variable: need to have all configurations in a short time



Asymmetric shells

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

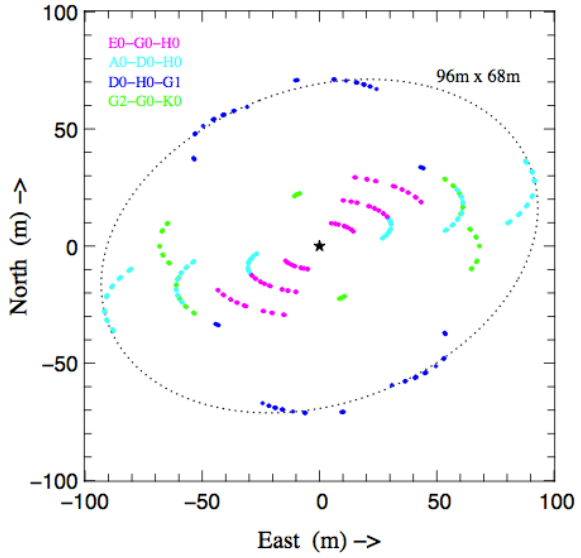




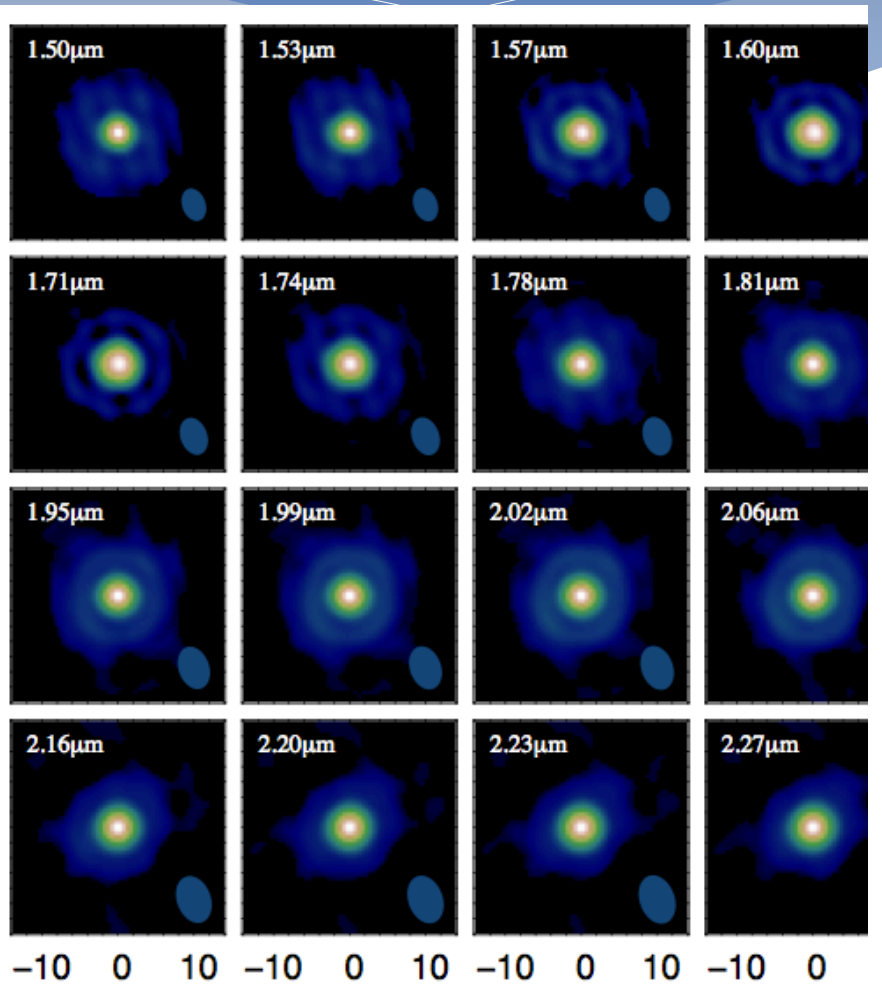
Strong asymmetric structures in the H_2O molecular layer

Molecular shells

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

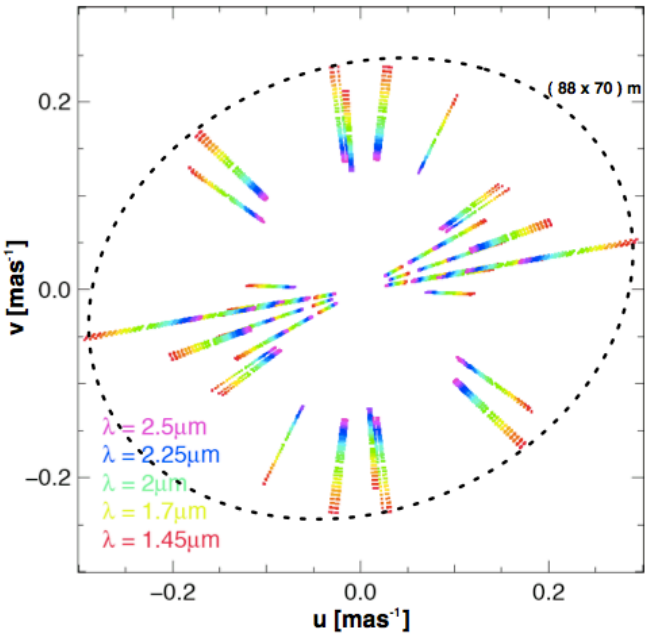


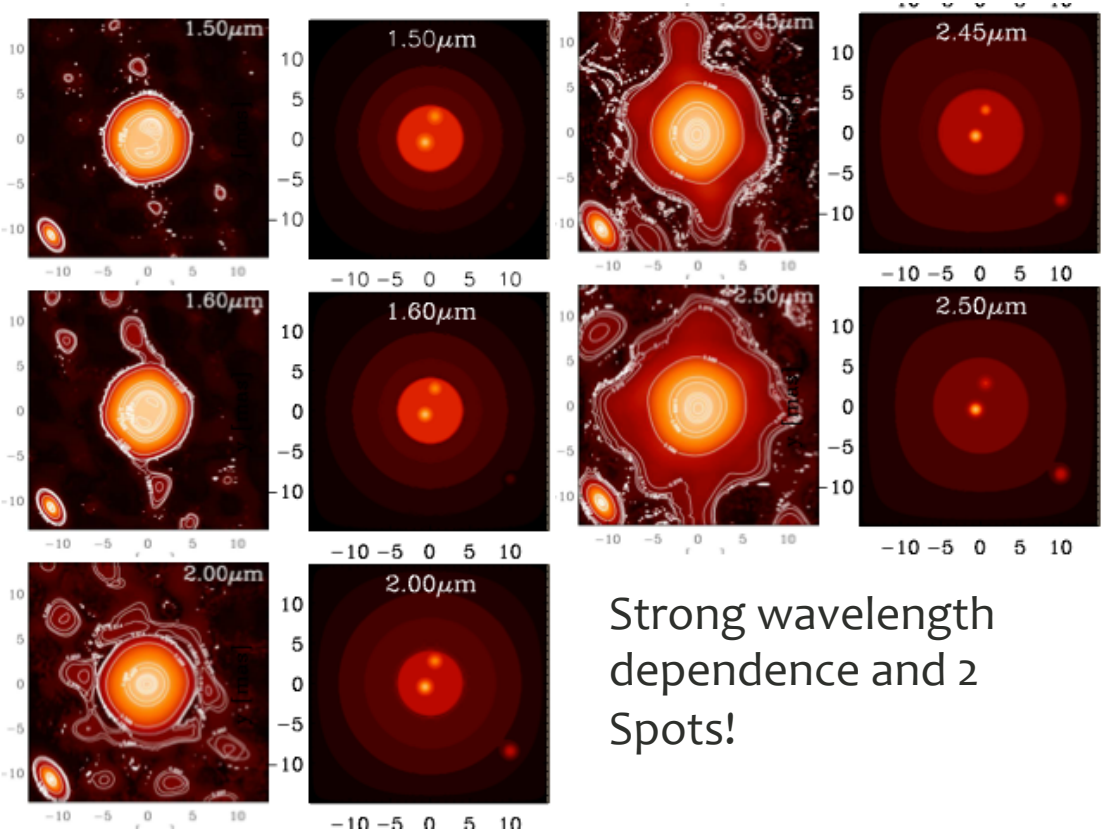
Unveil a "onion-like" shape (molecular shells)



Spots!

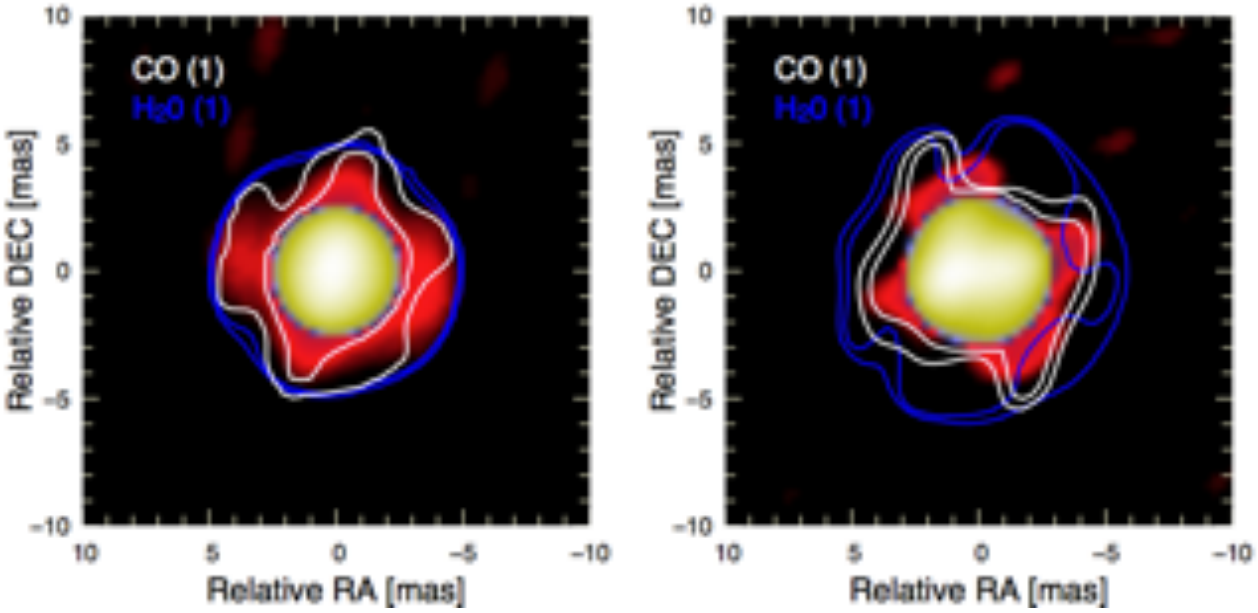
VX Sgr imaged with AMBER (Chiavassa et al. 2009)





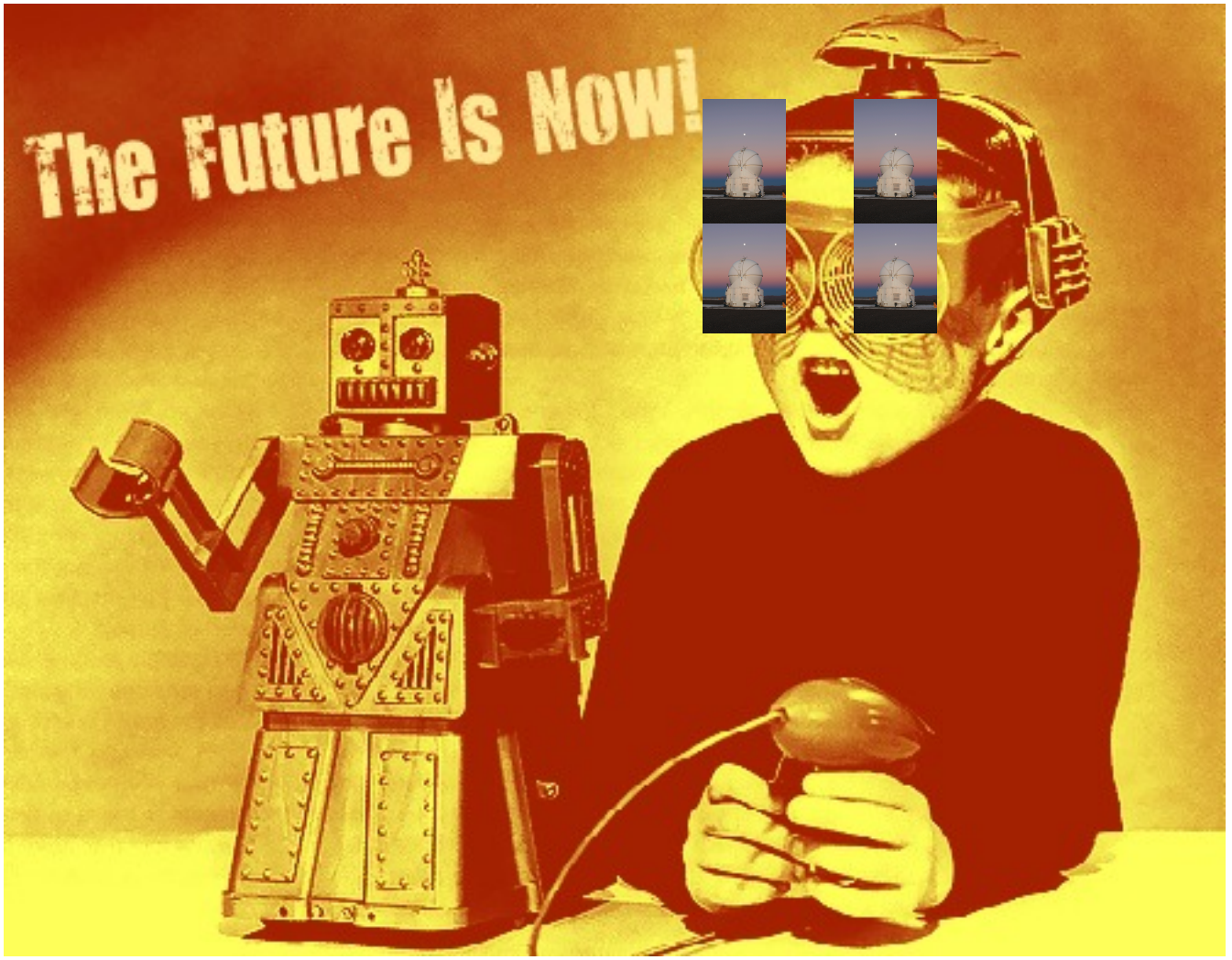
Strong wavelength dependence and 2 Spots!

Variability

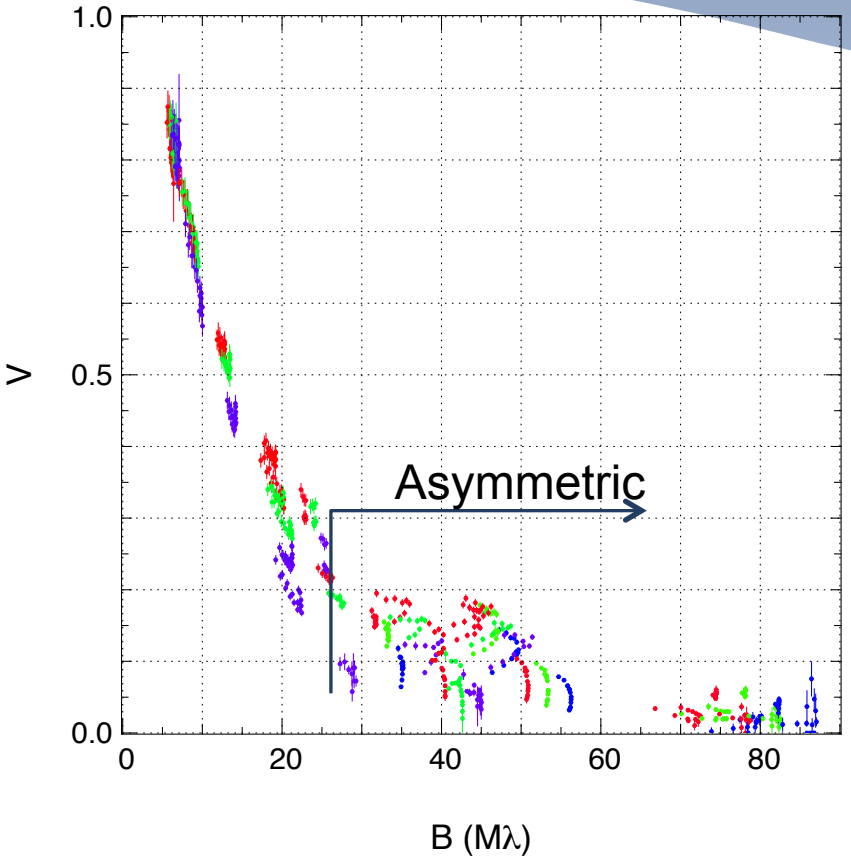


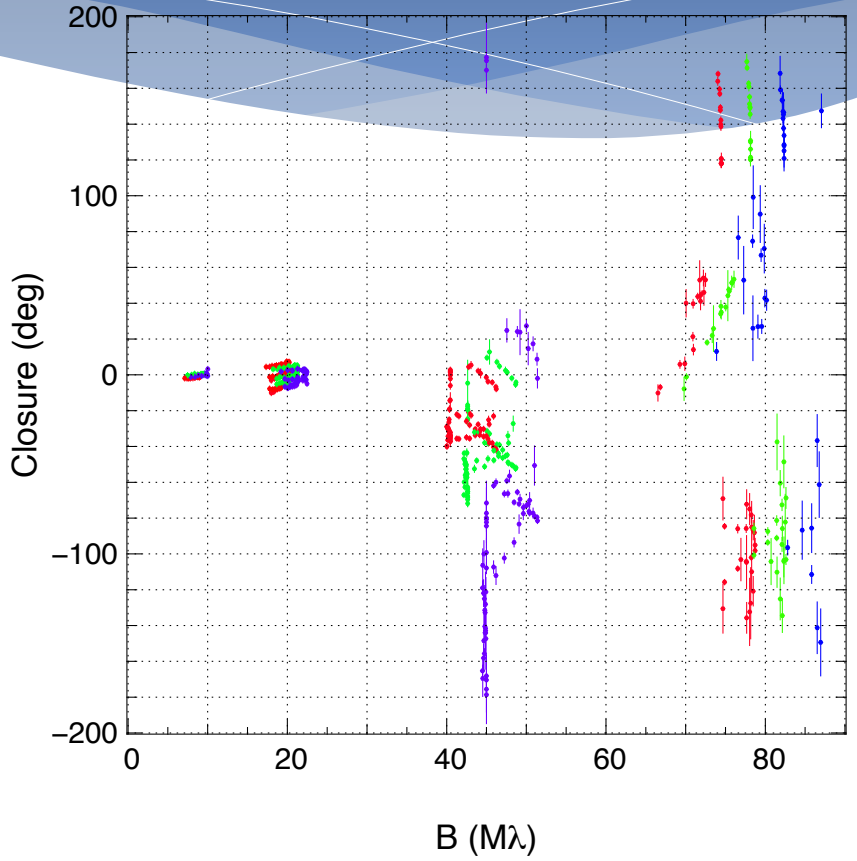
Haubois et al. (2015 accepted)
VLTI/AMBER, low resolution data (R~30)
Variability of the shell of a Mira over pulsation period

Imaging with VLTI PIONIER!



VLTI PIONIER data of C-rich Mira

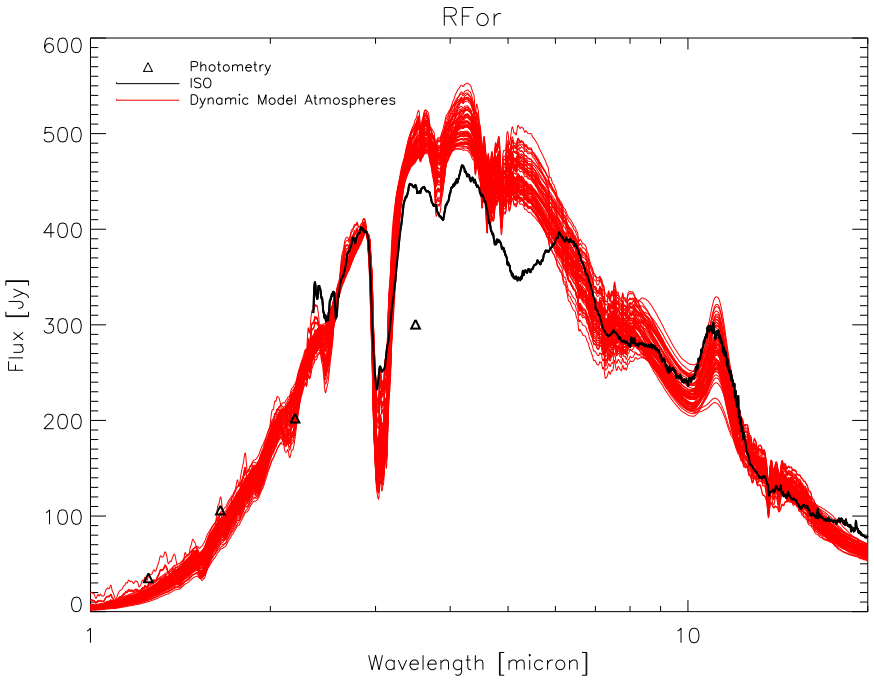


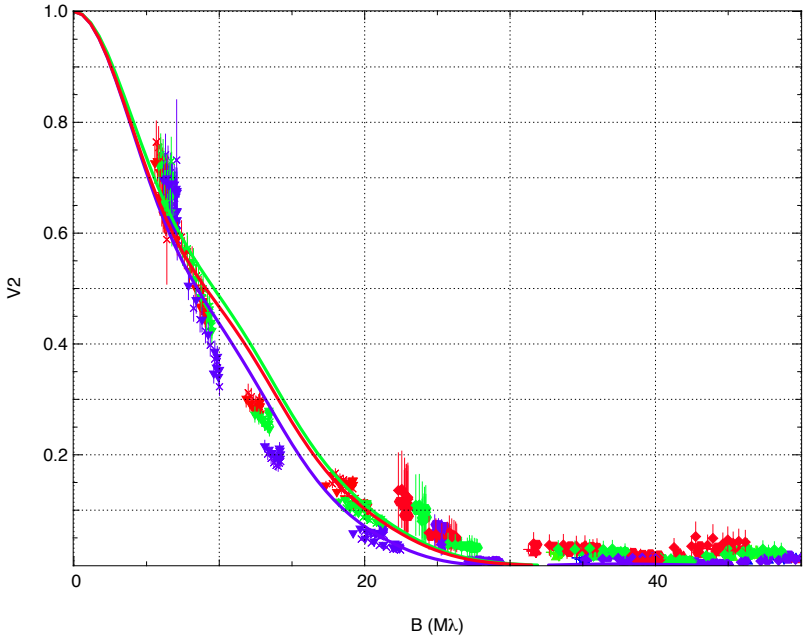


3-half nights within 2 weeks with 3 quadruplets!

Paladini et al., prep.

Modelling the data





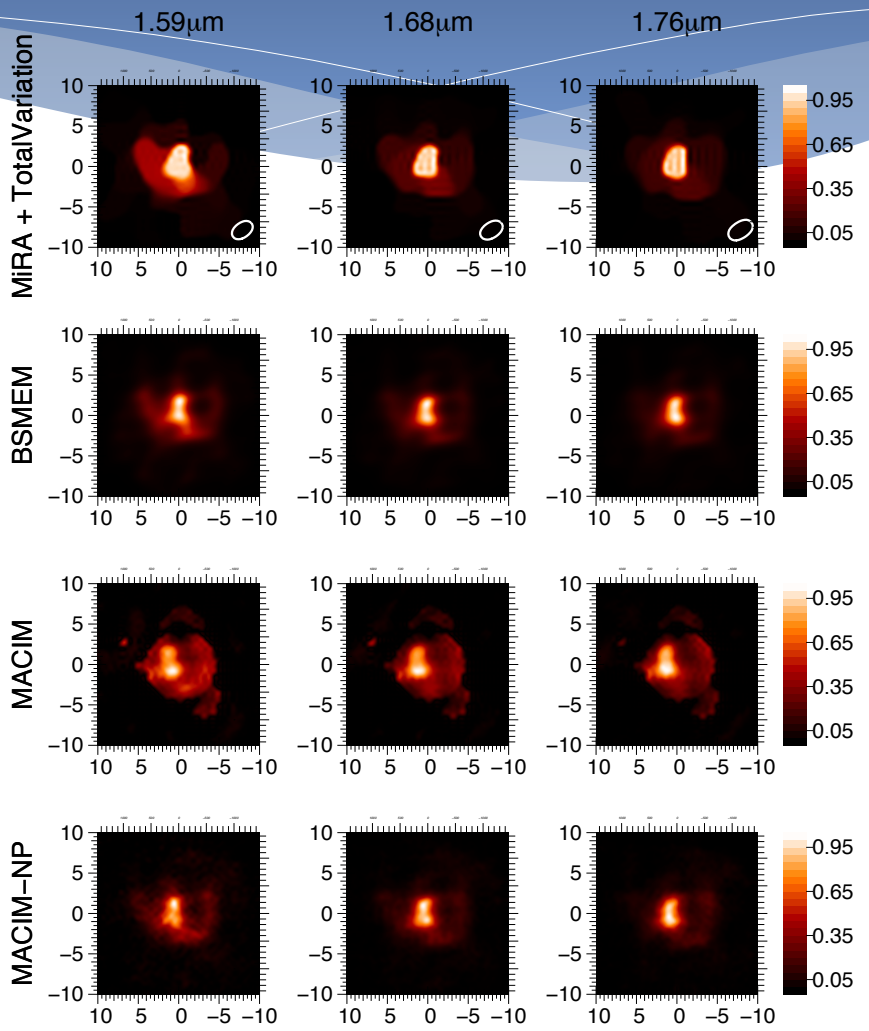
1D dynamic model atmospheres (Höfner et al. 2003, Mattsson et al. 2010)

Image reconstruction (our internal beauty contest)

Blind reconstruction with different tools.

What we trust:

* Elongated structure + diffuse environment
* FWHM of the elongated structure ~2-4 mas
* Extended bright "arc" in the first channel



Preliminary interpretation

* Image compatible with models from Freytag & Höfner 2008

* Where is the star?

(Vassiliadis & Wood 1993)

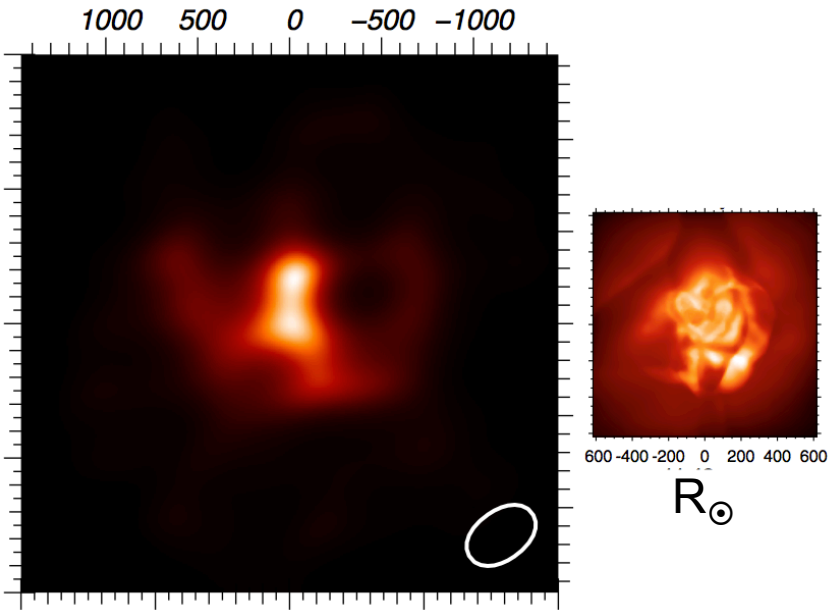
LogP=-2.07+1.94LogR-0.9logM

  * Radius~700$R_\odot$ => 3 $M_\odot$
  * Radius~360$R_\odot$ => 0.4 $M_\odot$

Be aware of uncertainties..

Is there a disc in front of the object?

=> Other spatial scales + time series



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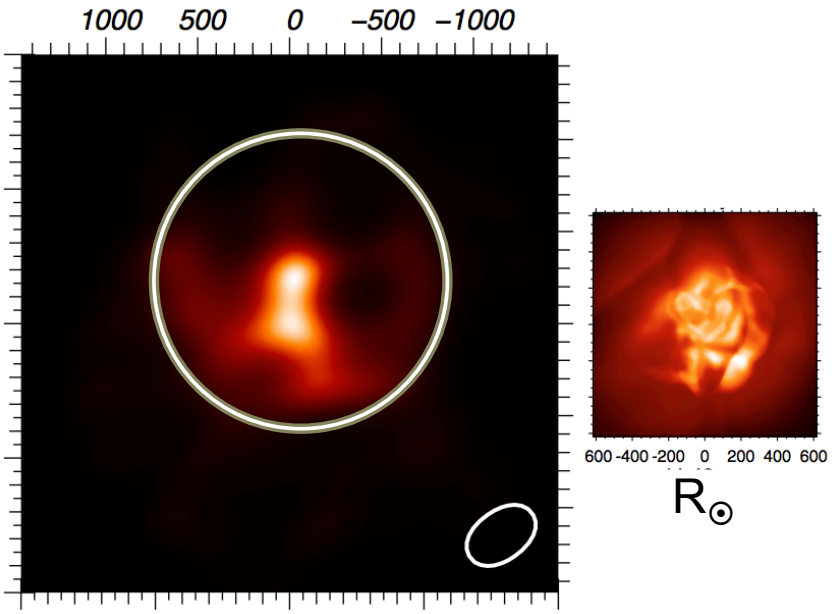
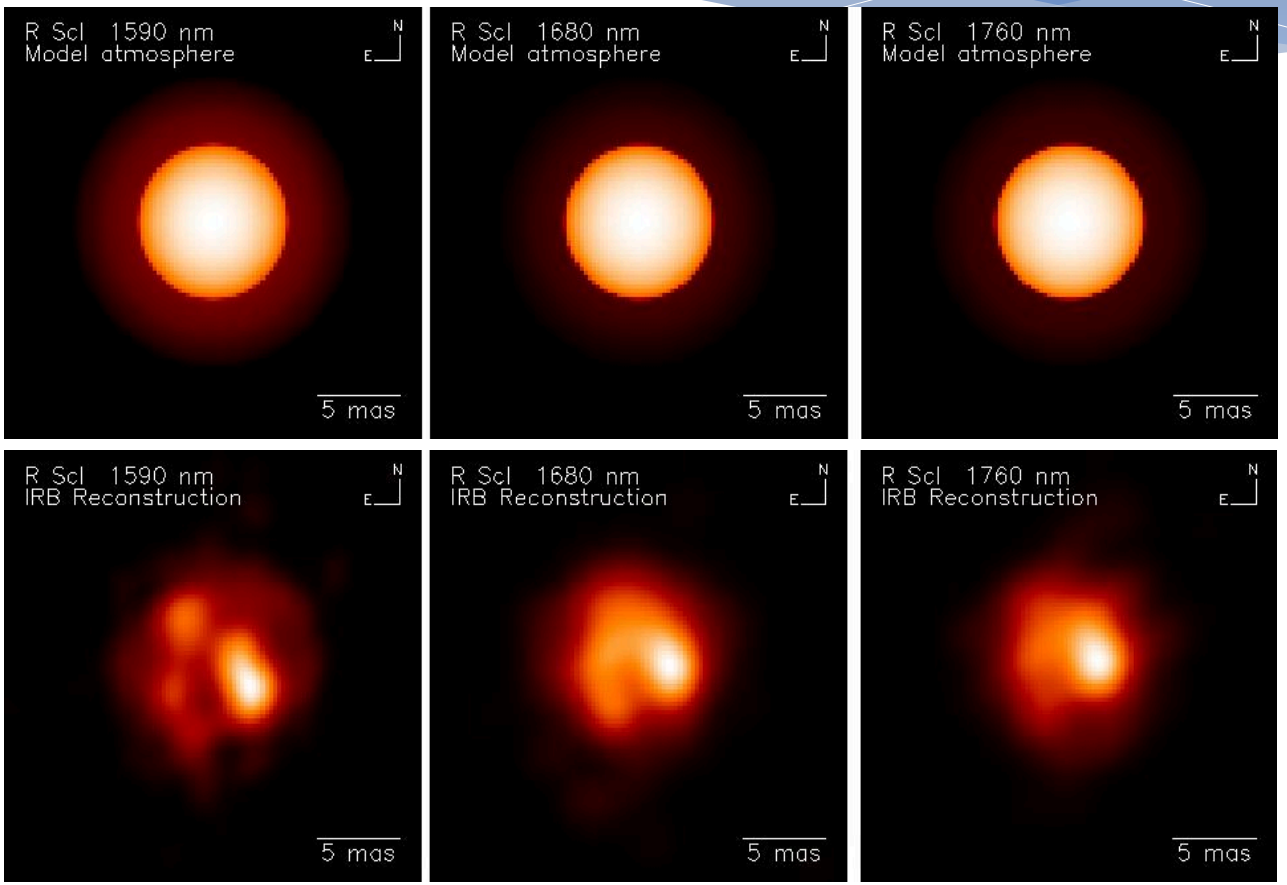
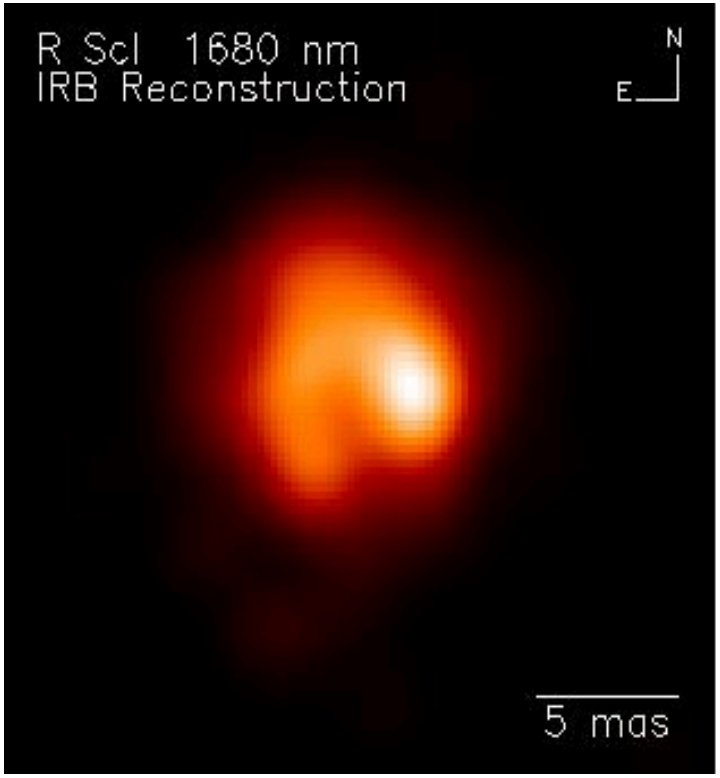


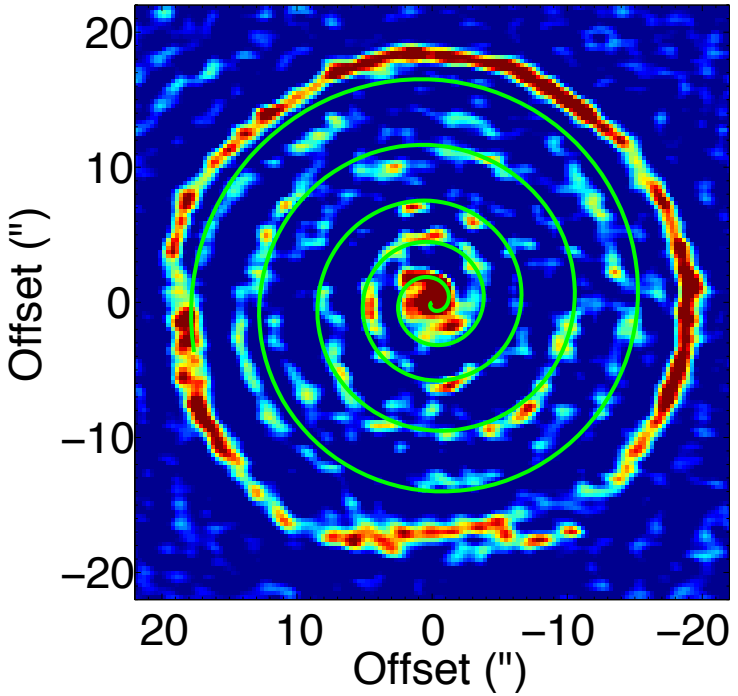
VLTI/PIONIER image of R Scl



Wittkowski et al., in prep

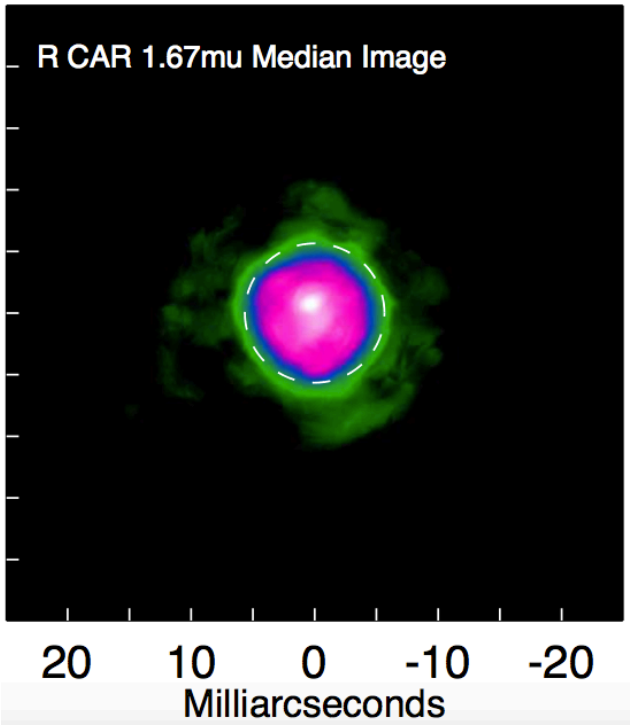
VLTI/PIONIER image of R Scl



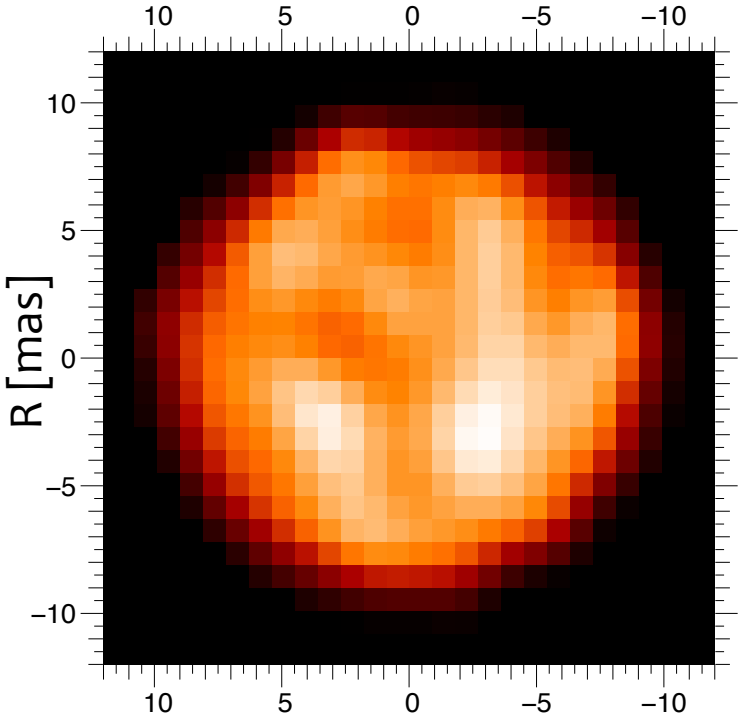


- Dominant (mass-loosing?) spot on the surface of R Scl.
- Spiral structure consistent with large spiral, or simply a random convective morphology?

Even more surface structures



Monnier et al. 2014



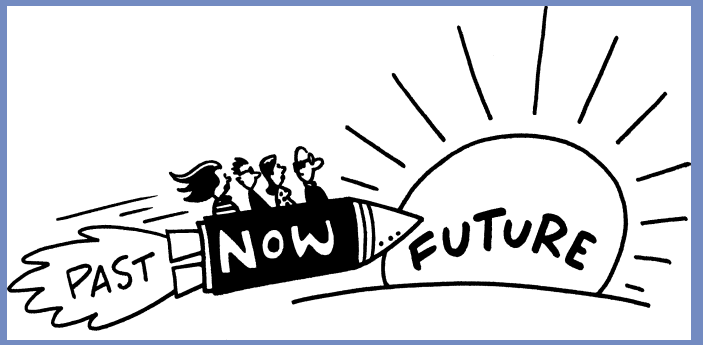
Paladini, Mayer et al. prep.

Take home messages

* Optical interferometry is the way to go to study the surface and inner circumstellar environment of giant stars
* New images show patterns due to the effect of convection => can be used to constrain the theory!
* Potential to detect binaries & to constrain their orbit
* Need of 3D models

The future is not *now*.

The future is *next*, and it is created by the decisions you make and the actions you take now.

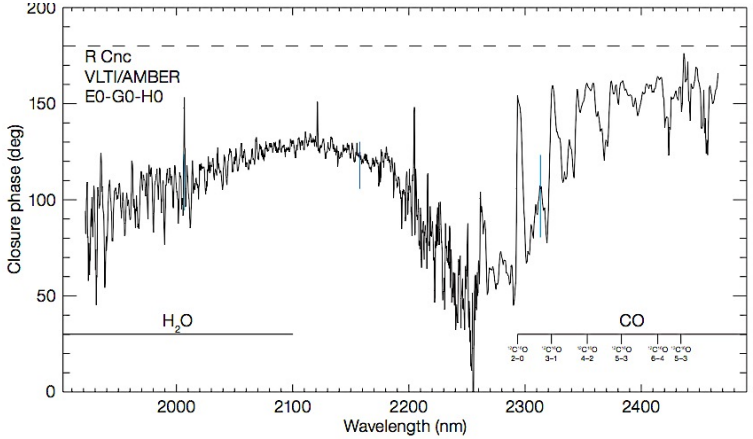


What's next for you?

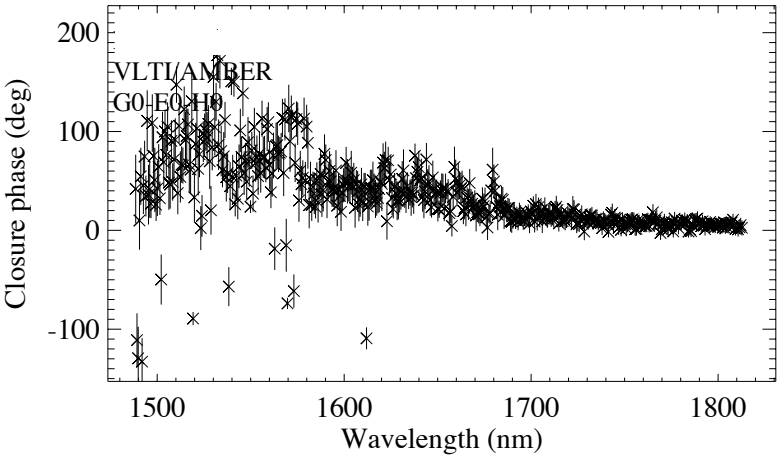
- Spectral resolution
- Time series (constrain the dynamic)
- Different spatial scales
- Polarization?

The power of (spectral) resolution

Wittkowski et al. 2011



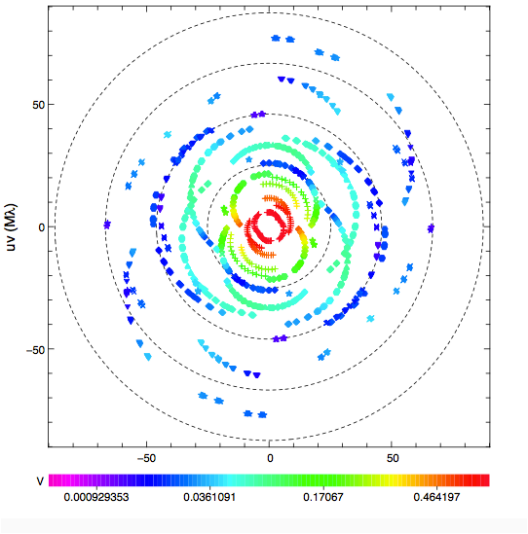
Paladini et al. (prep.)



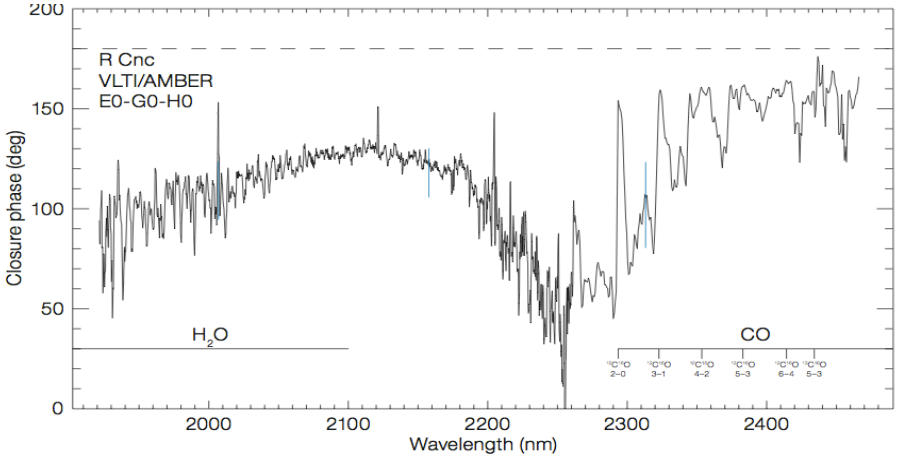
Clumps can be associated to
specific spectral features!
=> non-LTE processes of molecular formation
=> dust formation…

Second generation instruments

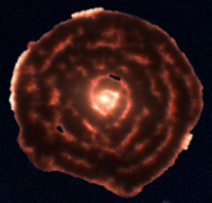
Imagine…

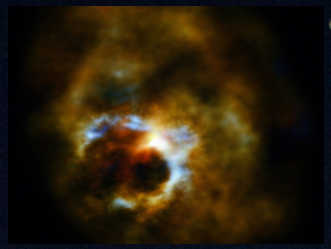


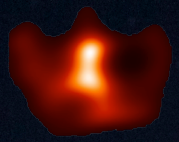
Wittkowski et al. 2011



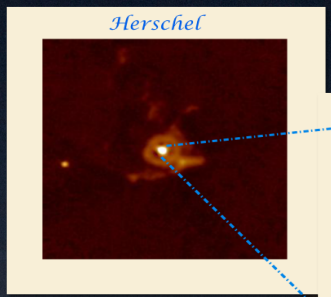
What will you do with GRAVITY? (K-band)
What will you do with MATISSE? (L-M-N band)



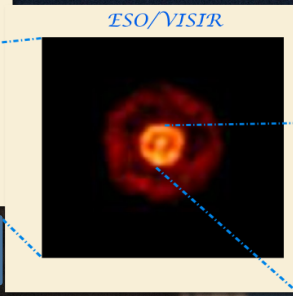




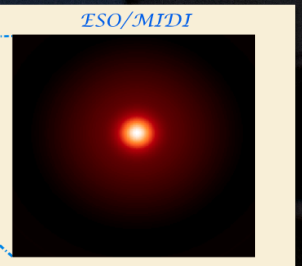
☺ i-Shooter interferometer? ☺



Herschel + ALMA



VISIR + SPHERE



ESO/MATISSE

+

GRAVITY+
PIONIER

+ ...

The 8th VLTI Summer School, Cologne, 6 – 13 September 2015

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Deadline 15 July!