Evolved stars science cases for a visible interferometer

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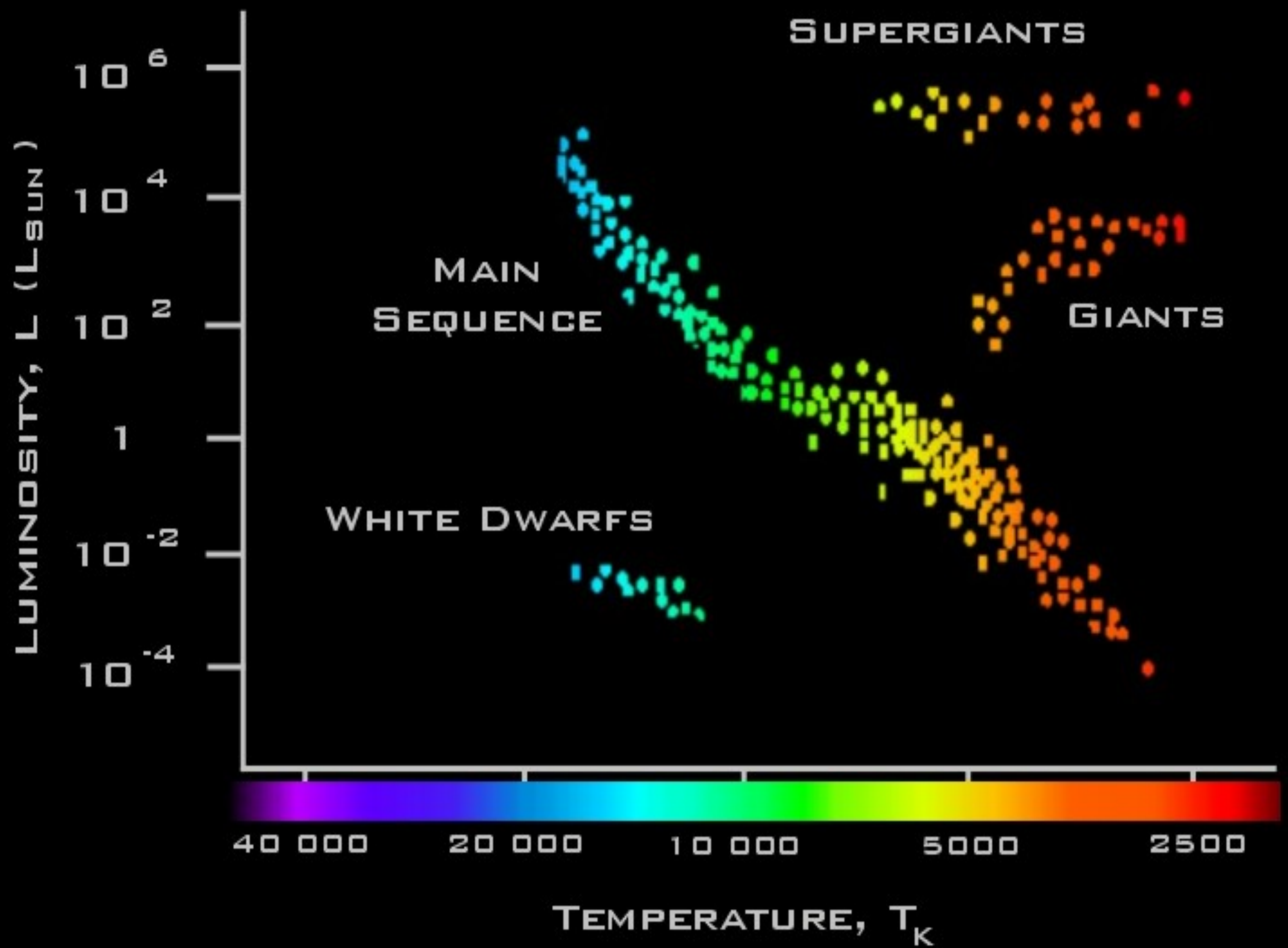
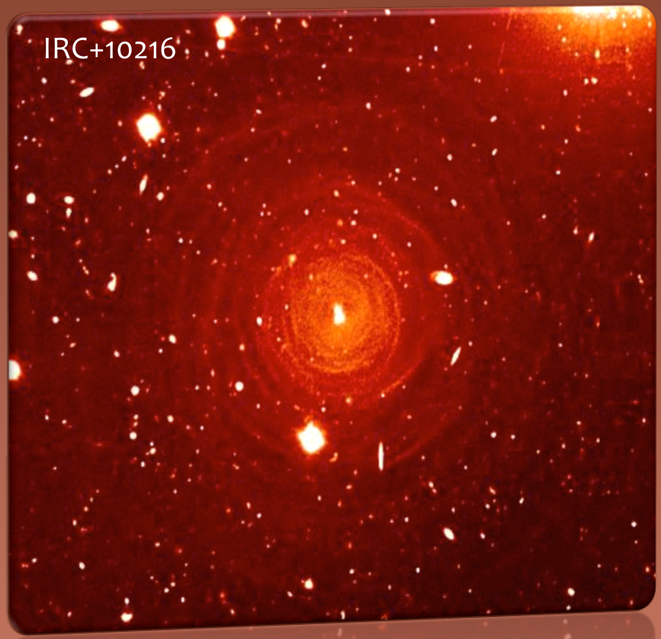
K. Ohnaka, N. Fabas, M. Hillen, N. Nardetto, van Winckel H., Wittkowski M., M. Ireland, and J.D. Monnier



Supergiants
Main Sequence
Giants
White Dwarfs
Luminosity, L (Lsun)
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40 000
20 000
10 000
5000
2500
Temperature, T_K



Asymptotic Giant Branch (AGB) stars

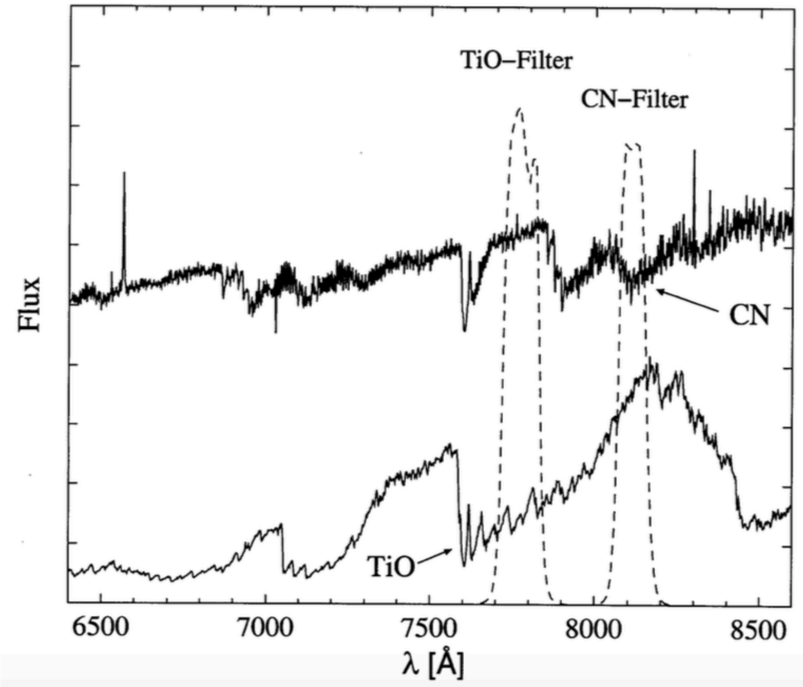
AGBs in the visible

Molecules:

- M-type (C/O<1)
  - TiO, H_2O, VO
- S-type (0.5<C/O<1)
  - TiO, H_2O, VO, LaO, ZrO
- C-type (C/O>1)
  - CN, C_2, CO…

And several atomic lines:

H_α, CaII, Li, Tc, Rb…

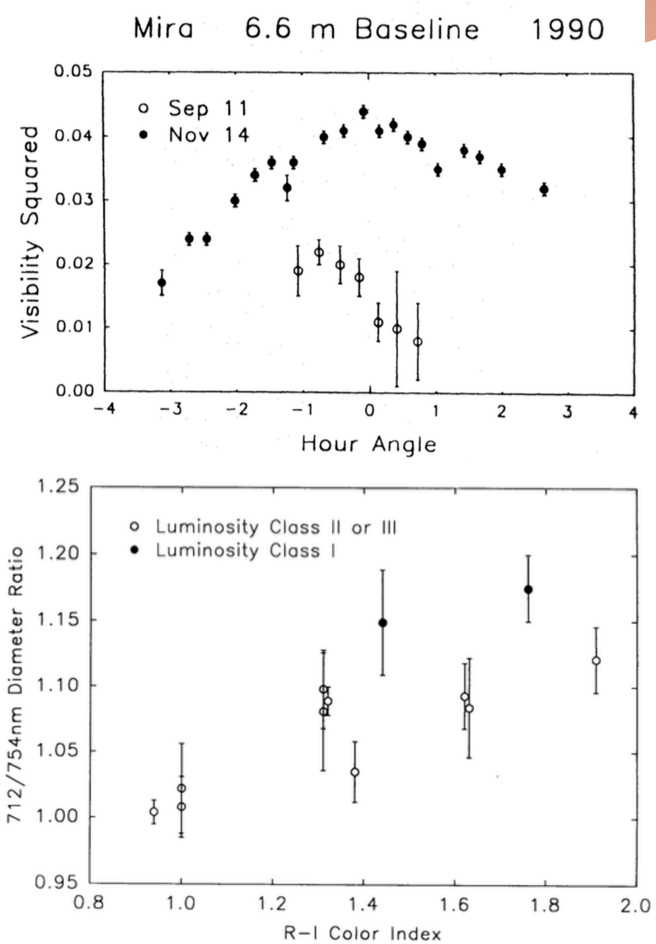


Schultheis 1998

Interferometry of AGB in the visible

* Temporal variation
* Weaker dependency of diameter with wavelength for stars with different chemistry
* K5III => M0III same diameter across the spectrum; M3III => M5III 10% difference
* Asymmetries

Quirrenbach et al. (1991=>1994); Mozurkewich et al. (1991); …
+lunar occultations + speckle interferometry



Measuring… what?

Atomic lines and molecular bands used for parameters determination and abundances

BUT

Very complex atmospheres: pulsation, dust formation, non-LTE, convection (inhomogenites), magnetic field..

What's the effect of these phenomena on the measurements?

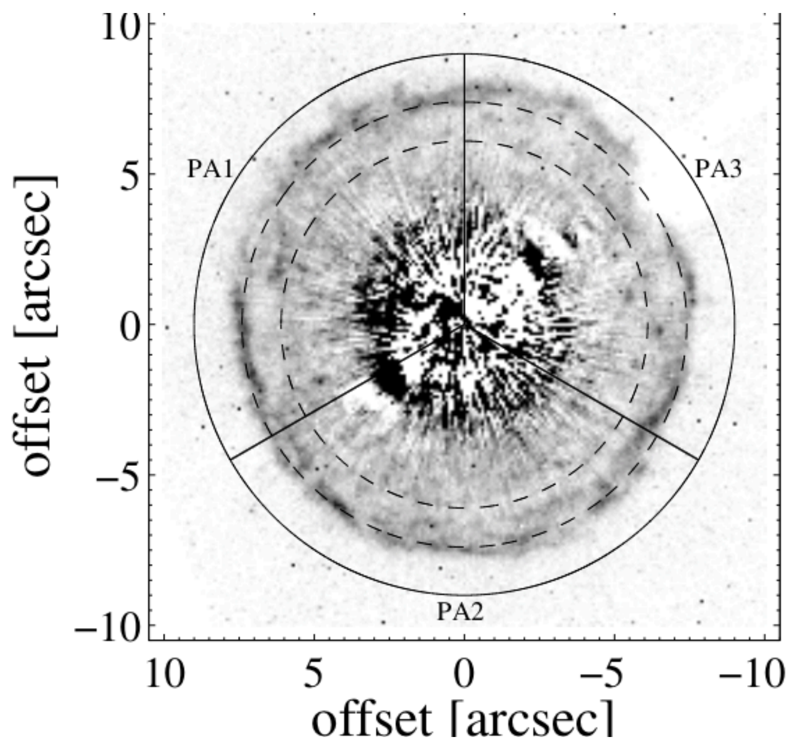
Science case 1:
The dust around AGBs

What drives the wind in M-type AGBs?

* Norris et al. 2012 confirms the "wind driven by scattering on micron-size Fe-free silicate dust" hypothesis => aperture masking & polarimetry

What is the dust distribution?

* Maercker et al. 2012, Olofsson et al. detached shell works => visible polarimetry

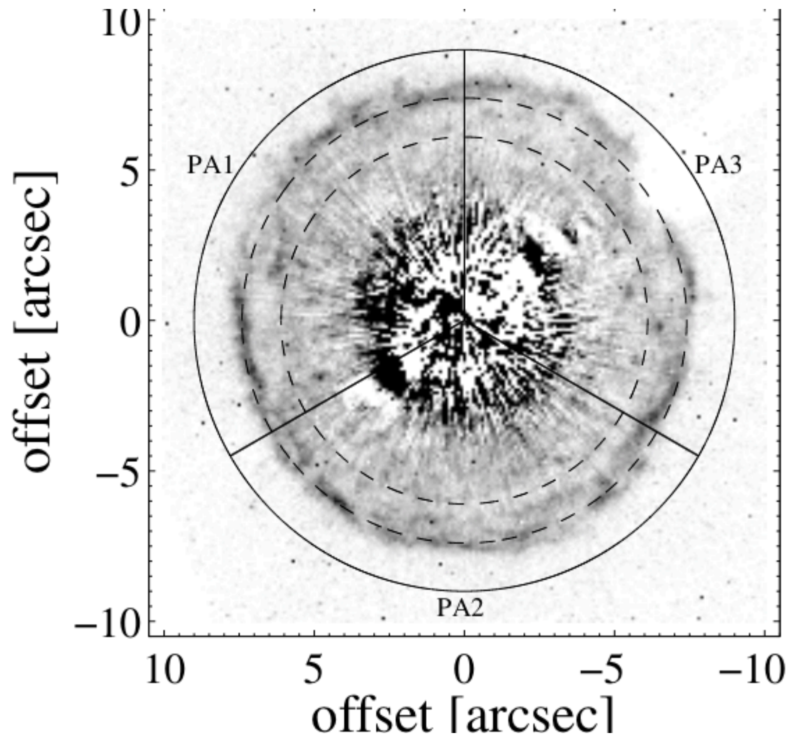


Olofsson et al. 2010

Science case 1:
The dust around AGBs

Direct imaging with interferometry?

Polarimetry mode?



Olofsson et al. 2010

Science case 2: the magnetic field

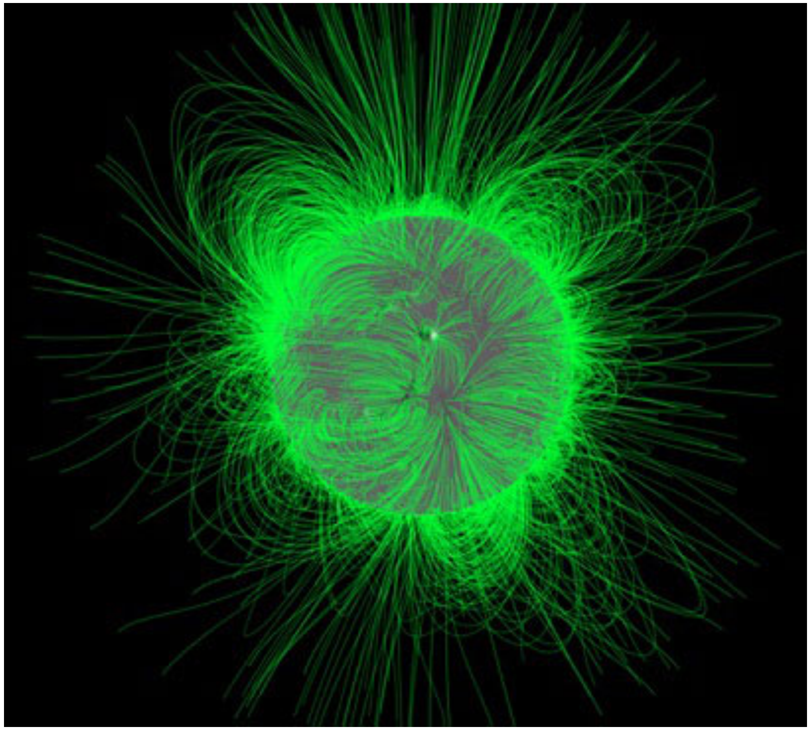
What's the effect of magnetic field on the mass-loss?

A LOT done with masers

Wolak et al. 2012; Vlemmings et al. 2012; Pérez-Sánchez et al. 2011 ; Amiri et al. 2011

* polarization found in most of the sources ~50 mG and ~330 mG

Spectropolarimetry (Lebre et al. 2014) on photosphere: 2-3 Gauss
=> Only 1 object!

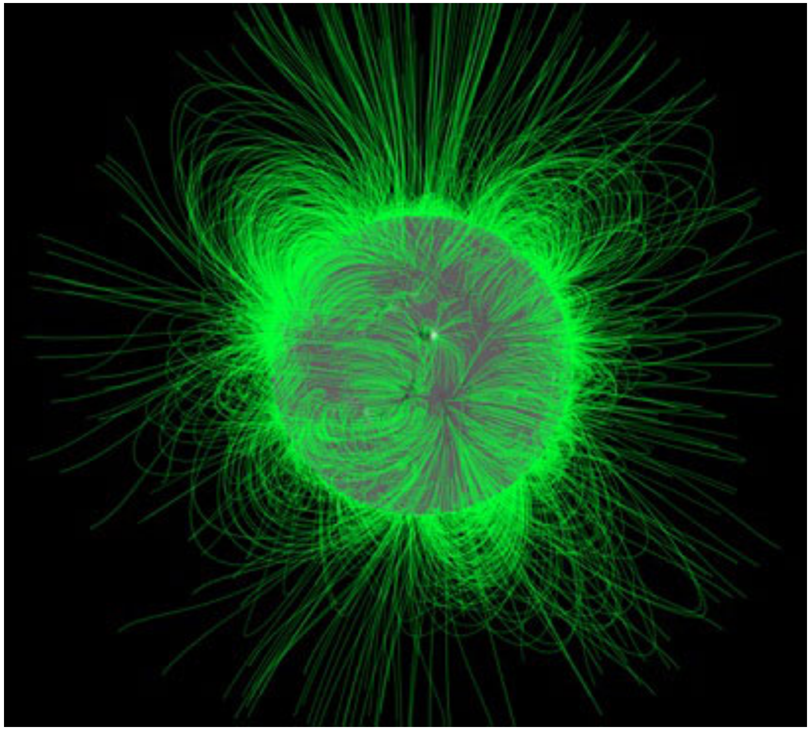


Credits: NASA

Science case 2: the magnetic field

What are the characteristics of the field at different spatial scales?

⇒ Visible interferometer+ high resolution spectrograph +polarimetry mode



Credits: NASA

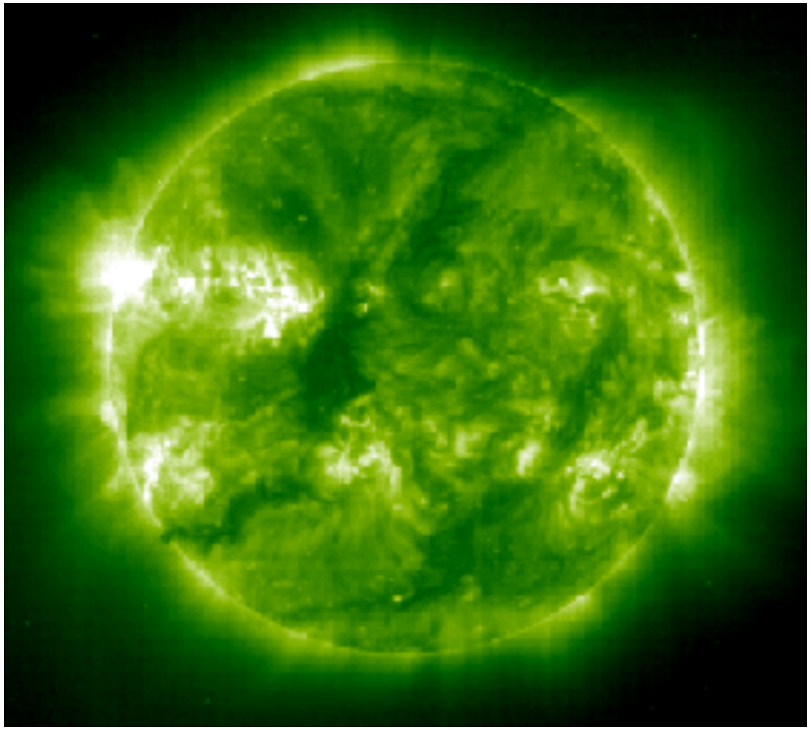
Science case 3: the chromosphere

What is the role of the heating mechanism of the chromosphere on the mass-loss?

* Harper et al. 2001; Harper & Brown 2006 suggest hot plasma + cool gas for RSG

VEGA studied chromosphere on a K-giant (Berio et al. 2011)..

Not much known about chromosphere @ AGB stage…

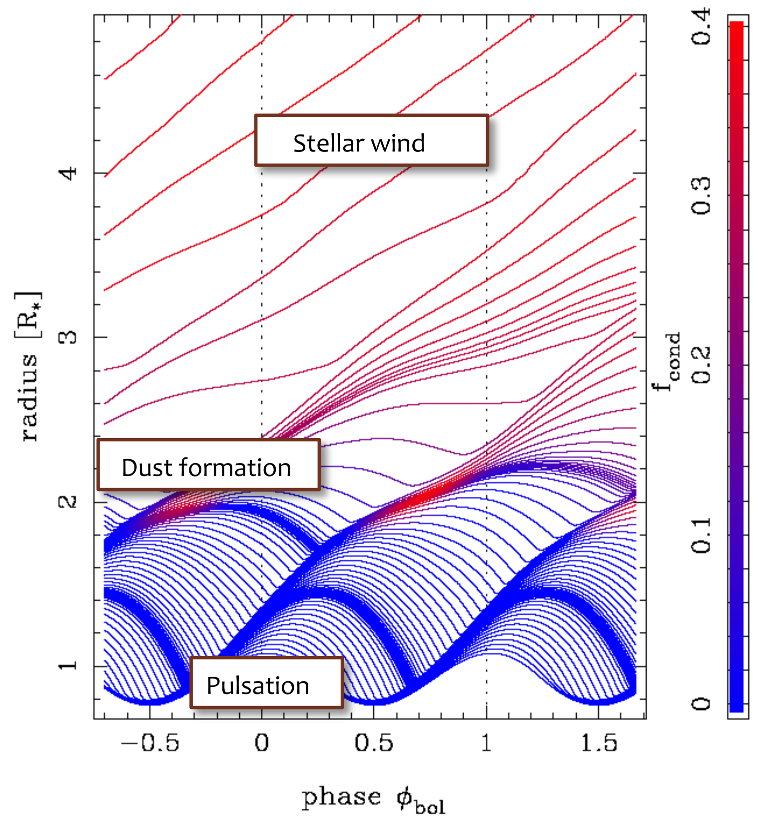


Credits: NASA

Science case 3bis: tracing the shock waves!

Icke 1992, Ireland et al. 2008, 2011 showed models prediction

* emerging at pre-maximum phase ~0.3 to -0.1
* traveling outward 1 to 1,5 cycles
* becoming weaker and slower
* subsequent front catches up and both fronts merge



Nowotny et al. (2005)

Science case 3bis: tracing the shock waves!

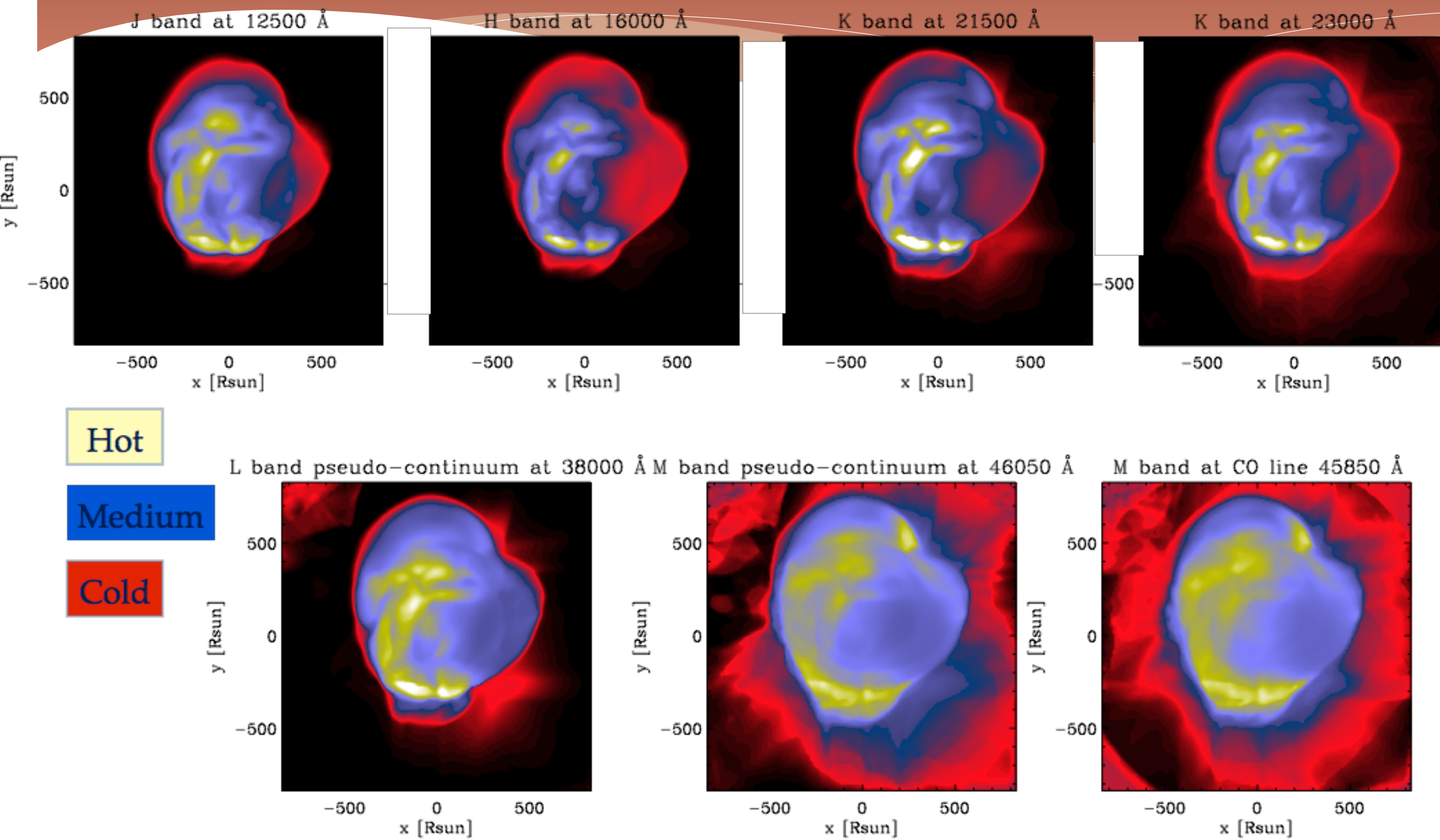
How does the shock-wave affect the molecular stratification?

Is the propagation spherical? (probably not, see Fabas et al. 2011)

⇒ Imaging in the Hα

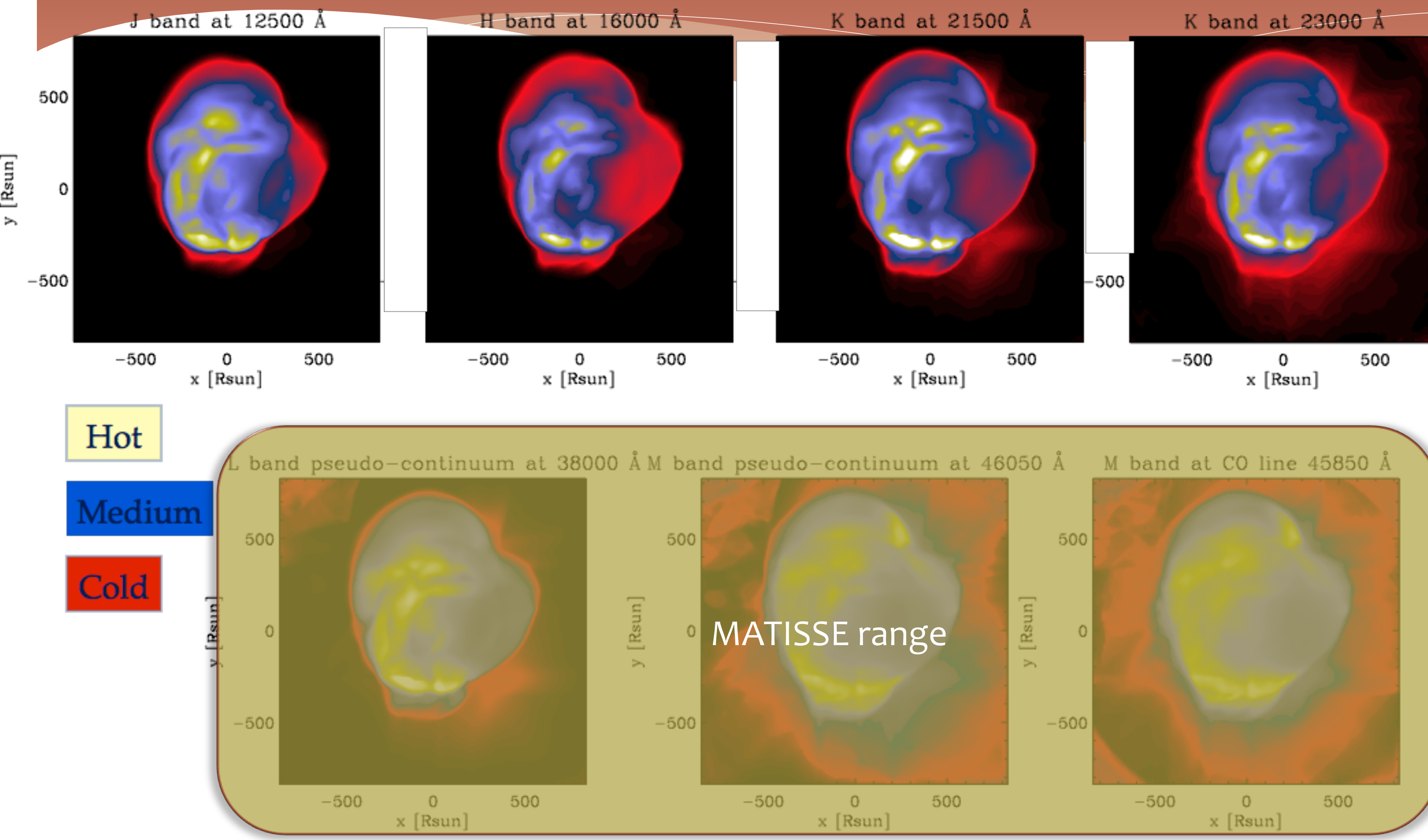
Movies ☺

Science case 4: stratification and 3D structures



Chiavassa & Freytag GALAGB3 arxiv: 1410.3868

Science case 4: stratification and 3D structures



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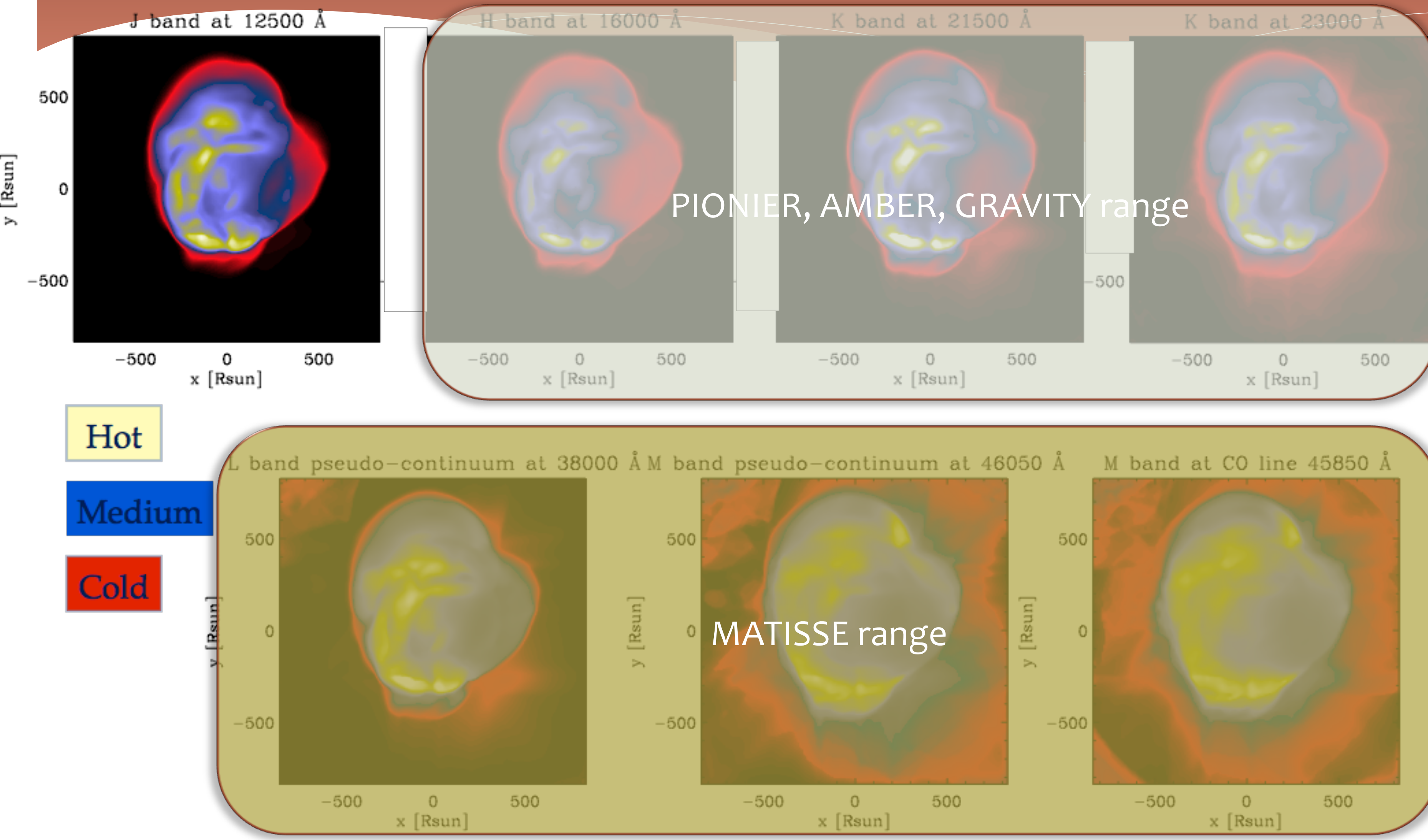
Science case 4: stratification and 3D structures



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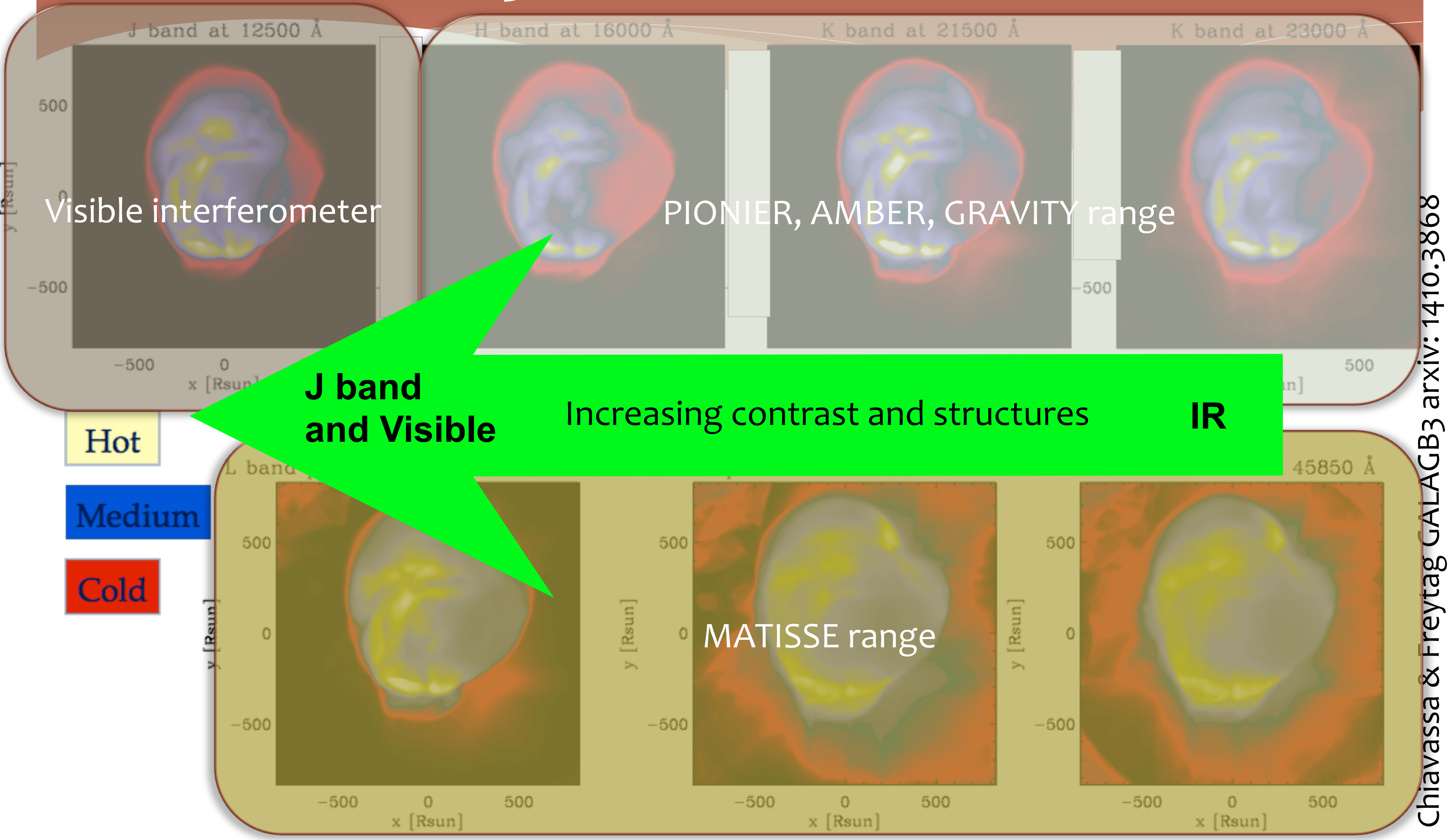
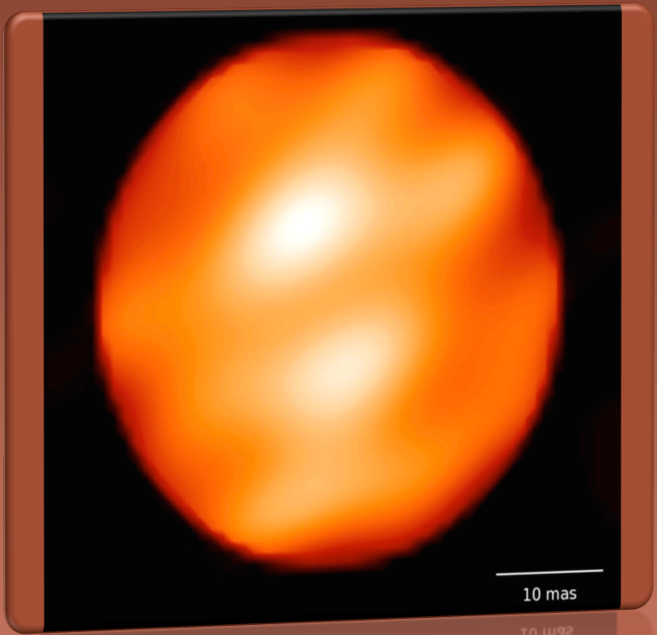
Science case 4: stratification and 3D structures



Requirements

- AGBs in the visible get faint, especially the Miras (8-13 mag)
- 200 objects to be observed from VLTI
- AGBs are variable (up to 9 mag in V-band)
  - if the telescopes need to be moved then do it fast! (1-2 weeks)
- Close objects are big (up to 30 mas)
  - Need of short baselines (<8m) as well as long. A diffraction limited single dish may help, but spectral resolution need to match the one of the interferometer
- Precision ~5% visibility, 2-3deg closure phase
- Spectral resolution depending on the science (30 – 10^5)
- Polarimetry…?



Red Super Giants (RSG)

Evolved Massive stars

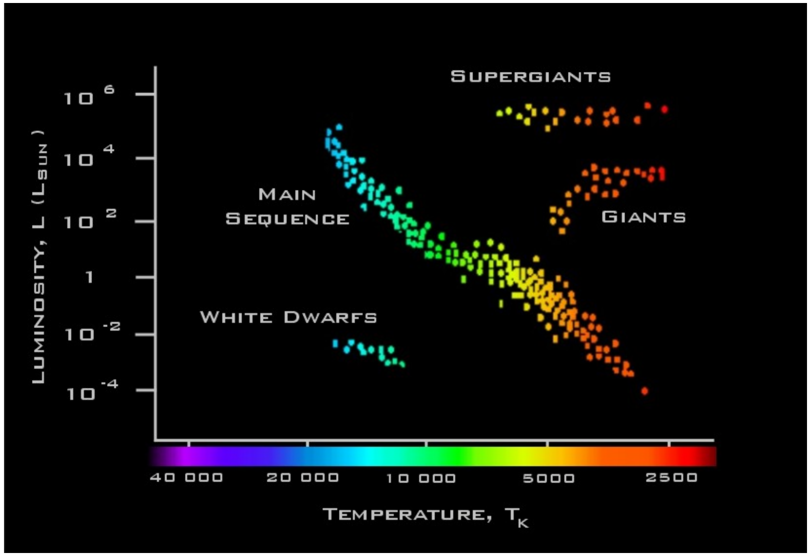
* 10-25 $M_\odot$
* 3450 – T_{eff} – 4100 K
* 20,000 – L – 300,000 $L_\odot$
* R ~1500 $T_\odot$

Losing mass through unidentified process

=>radiation pressure on molecules

=>dissipation of Alfven waves through magnetic field

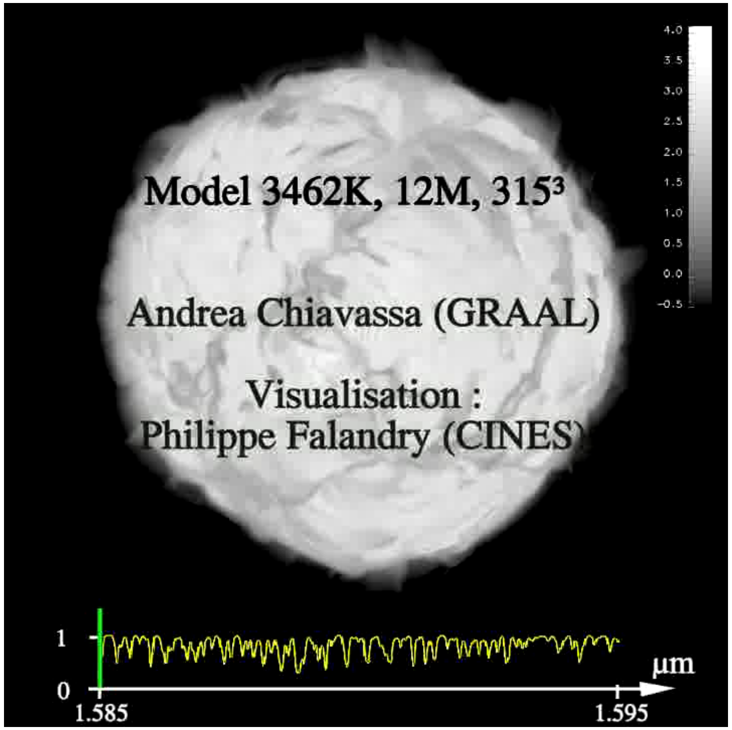
(Josselin & Plez 2007; Auriere et al. 2010; Grunhut et al. 2010)



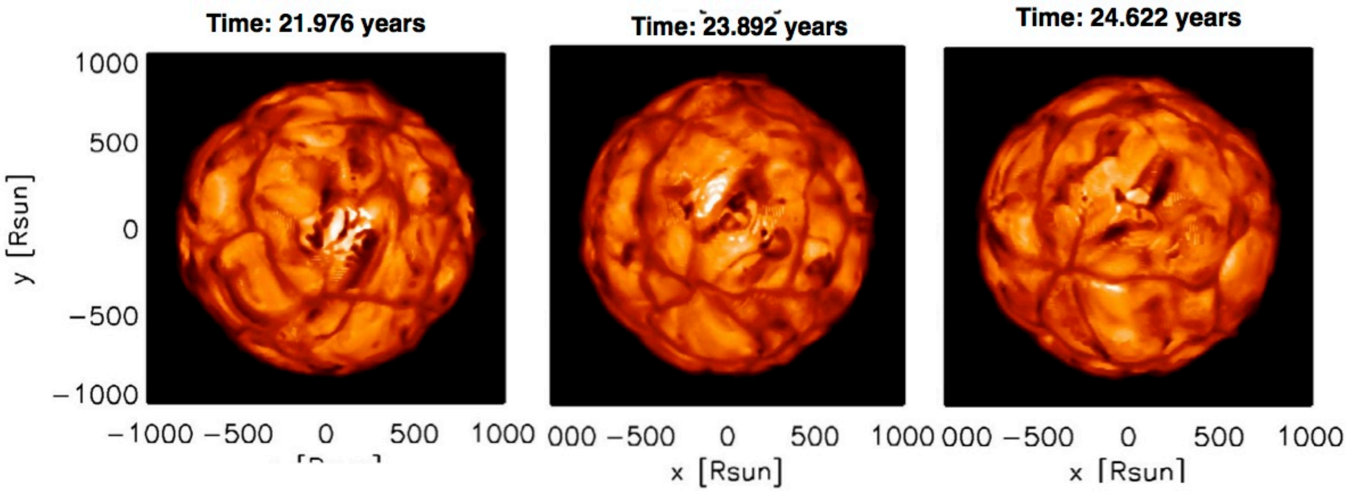
3D hydrodynamical simulations of stellar atmosphere

* Chiavassa, Haubois, Young, et al. 2010, A&A, 515, A12
* Chiavassa, Plez, Josselin, Freytag 2009, A&A, 506, 1351
* Chiavassa, Pasquato, Jorissen, et al. 2011 A&A, 528, id.A120

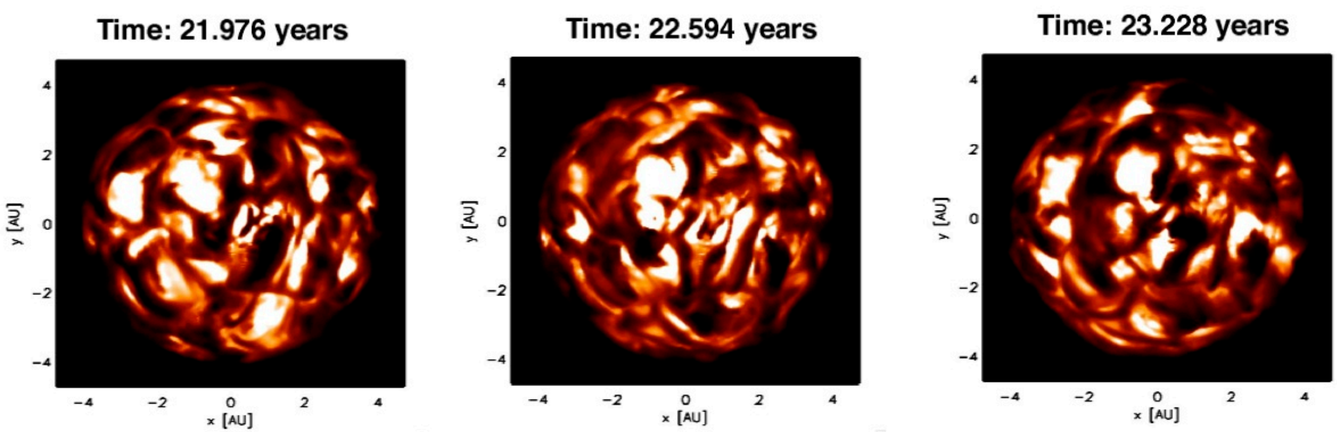
<u>Observational constraints needed</u>



Science case 1: time-scale, contrast, size

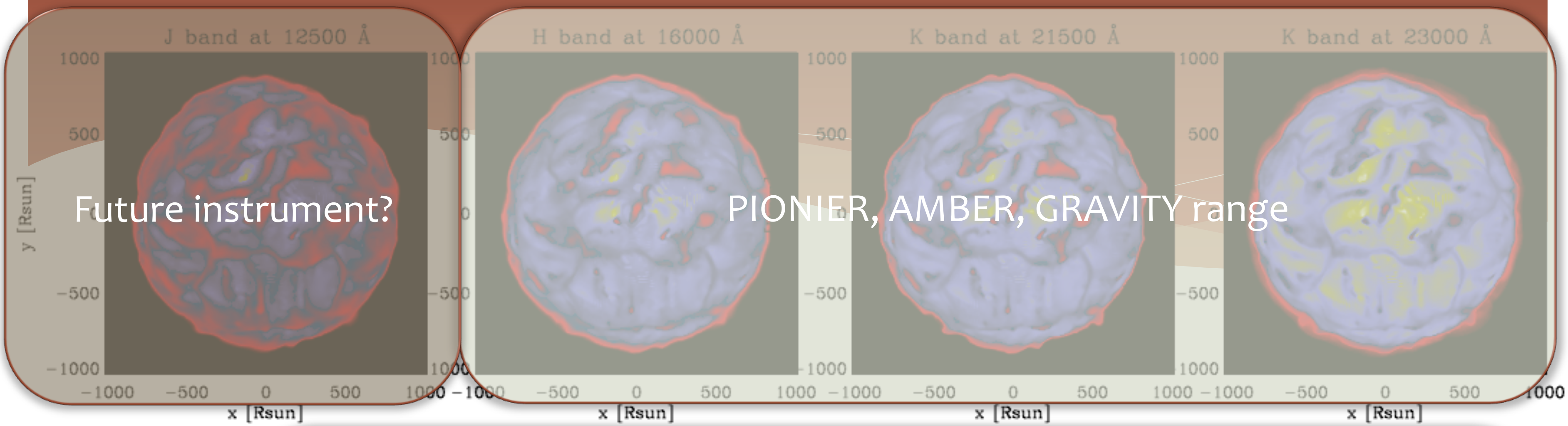


Timescale in the continuum H-K band of years…



Timescale in the optical band of few weeks to few months…

Science case 1-2: stratification

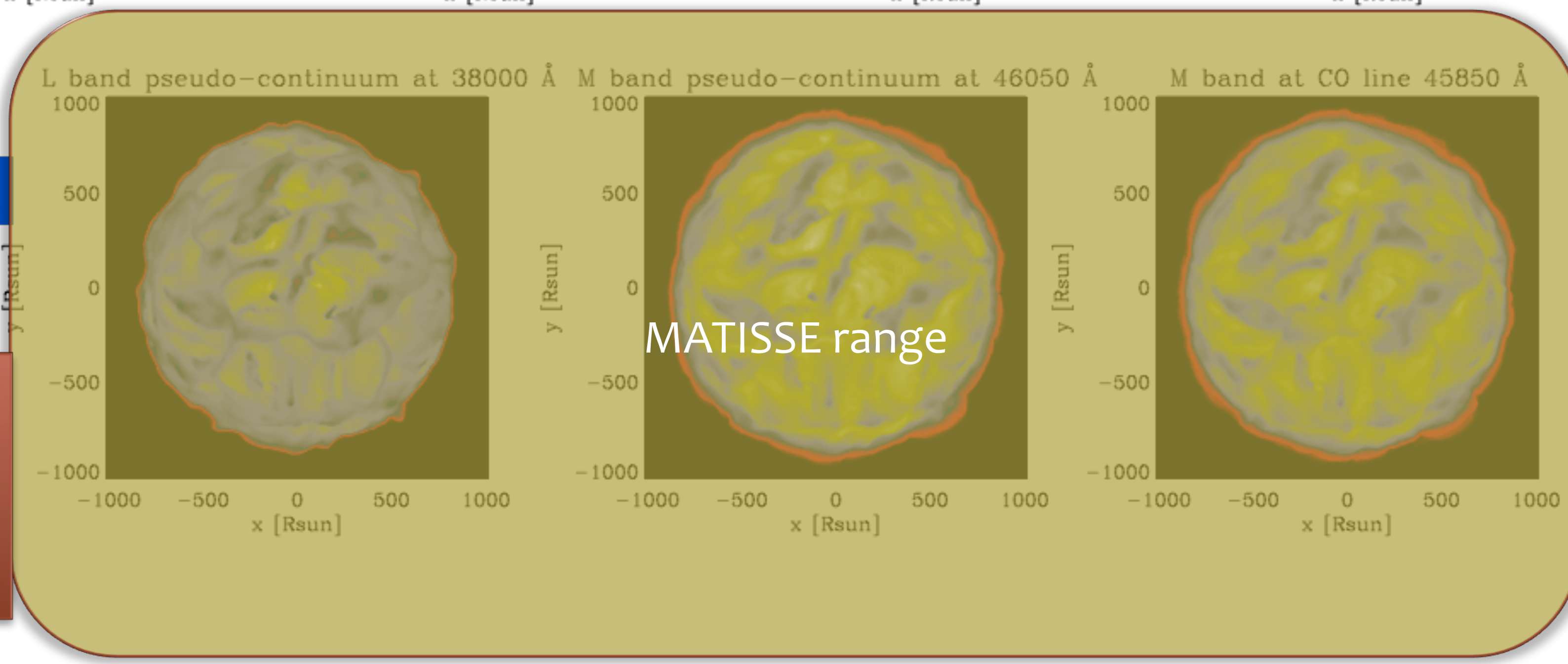


Hot

Medium

Cold

Red Supergiant star



Chiavassa & Freytag GALAGB3 arxiv: 1410.3868

Science case 3: velocity field & time scale of convective motion

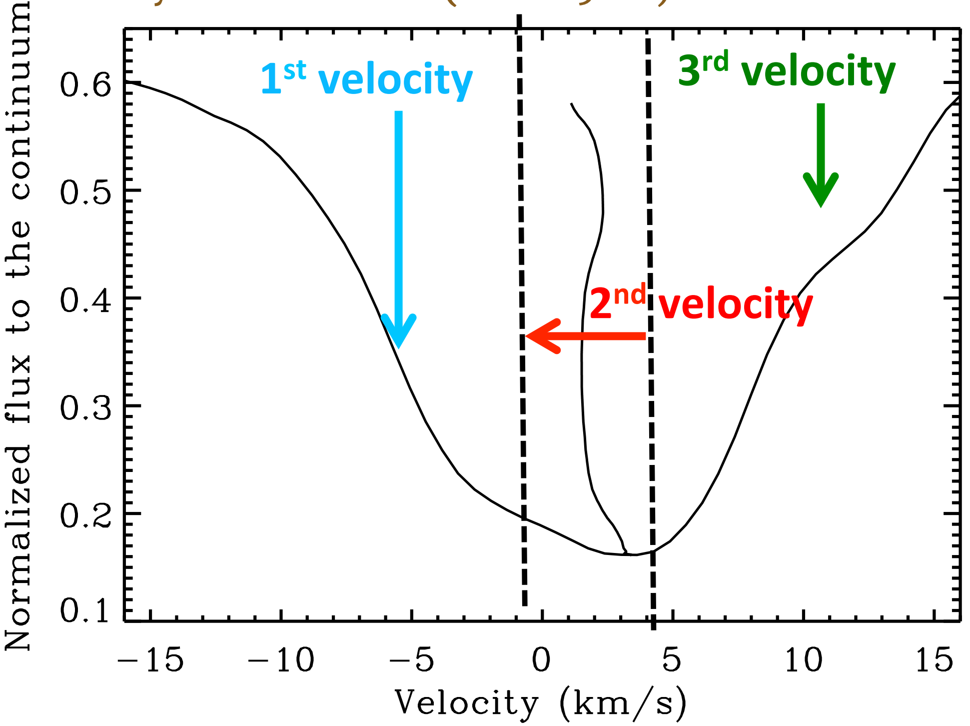
Extremely heterogeneous velocity field (2-3 components)

- Same behaviour in the infrared

→ **Very complicated to measure radial velocities!**

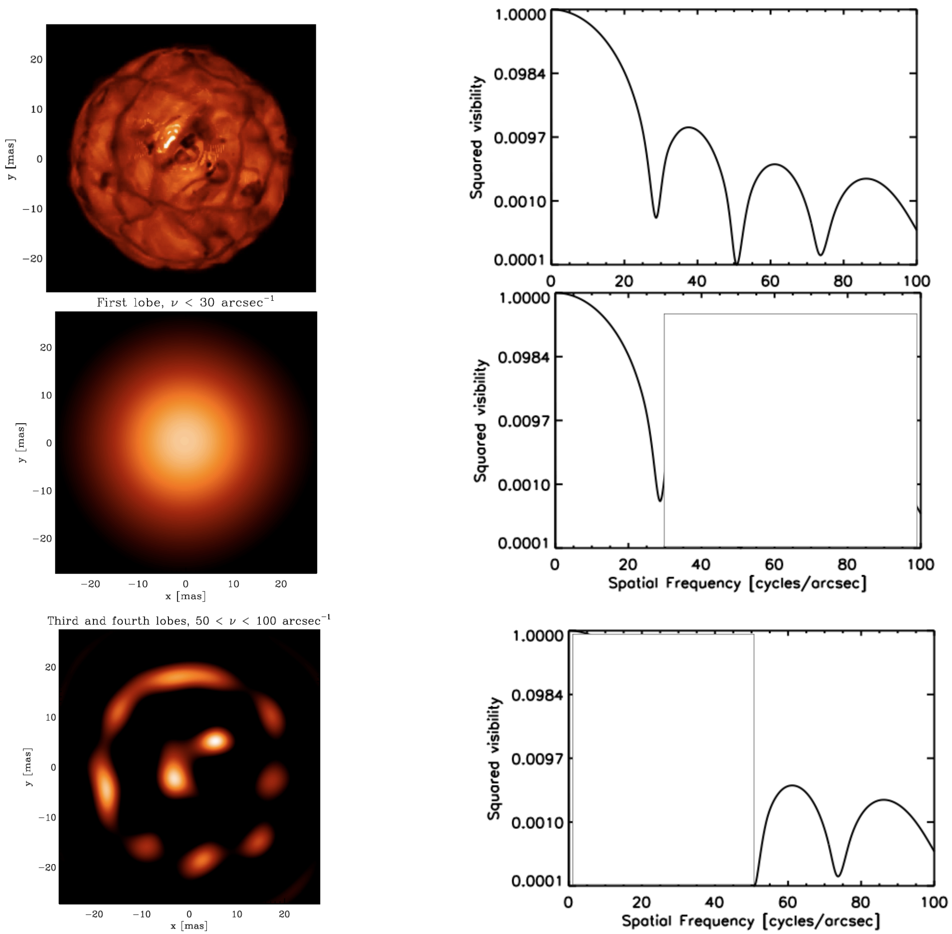
Bisector values range ≈ 2-3 km/s

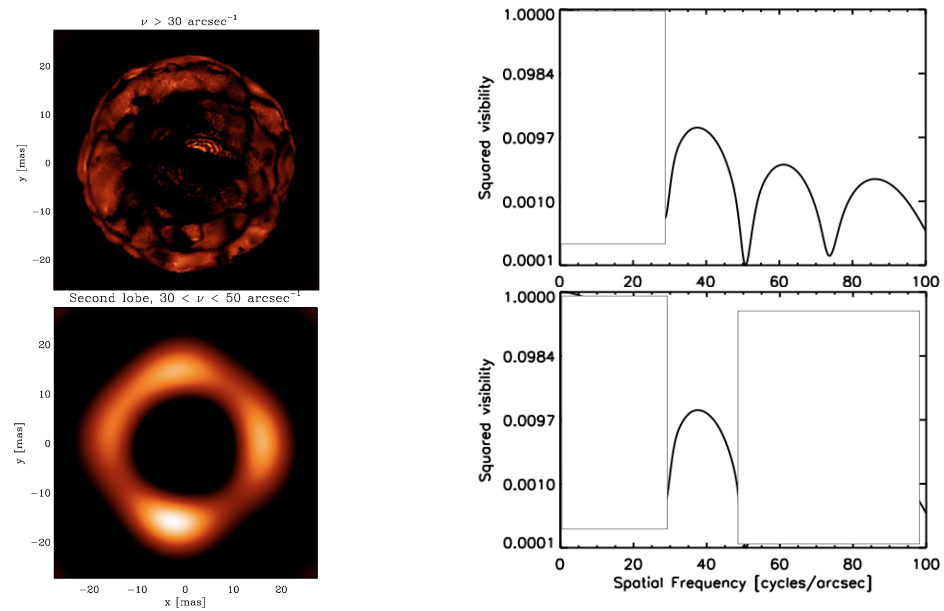
Synthetic Ti I line (6261.098 Å) with bisector



Chiavassa & Freytag GALAGB3 arxiv: 1410.3868

Requirements: sampling all spatial frequencies





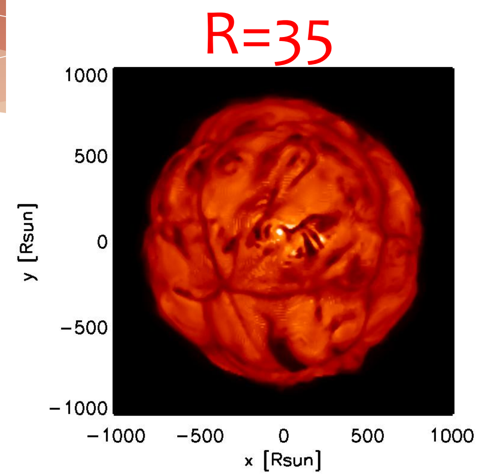
Chiavassa, Haubois, Young, et al. 2010, A&A, 515, A12

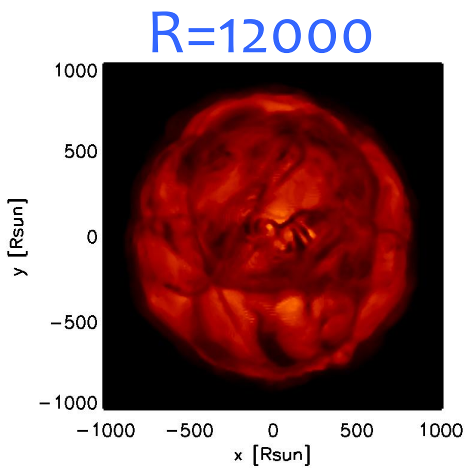
Requiremets: spectral & temporal resolution

3 spectral modes:

* R~30 size granulation pattern
* R~3000 temperature stratification
* R>30,000 kinematic in the spectral lines

Monitoring program needed





Post-AGB

=> invasion in the binary business, sorry Nicolas (Blind)!

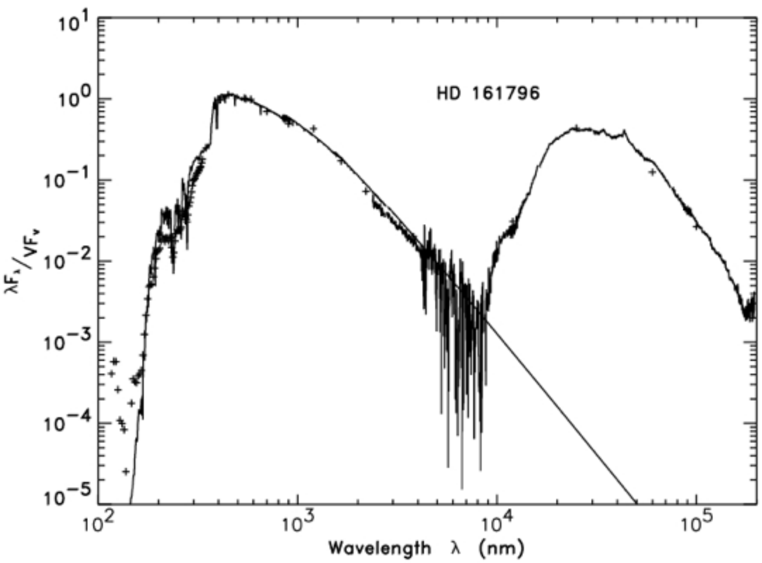
Characteristics

* Fast evolution ! ~ 1000- 10000 years
* 3000K to 100 000K
* R_* ~1 AU on the AGB to ~ R_{wd}
* Variable (Pop II Ceph. Instability strip)
* often with large amplitudes
* From very obscured to naked

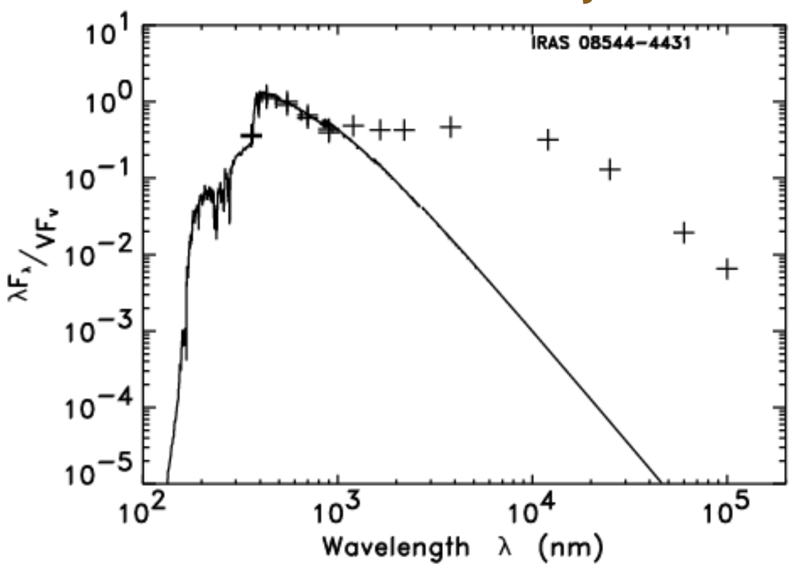
Very diverse and prone to a large variety of observational biases…
van Winckel et al., 2003
Toruń catalogue for Galactic post-AGB

Different SEDs in post-AGB stars

Shell sources



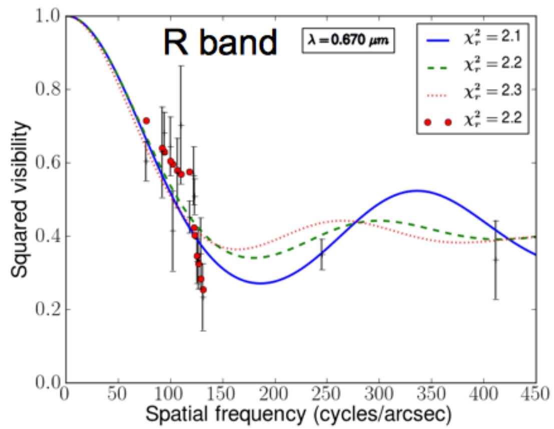
Dust at sublimation temperature = stable circumbinary disc



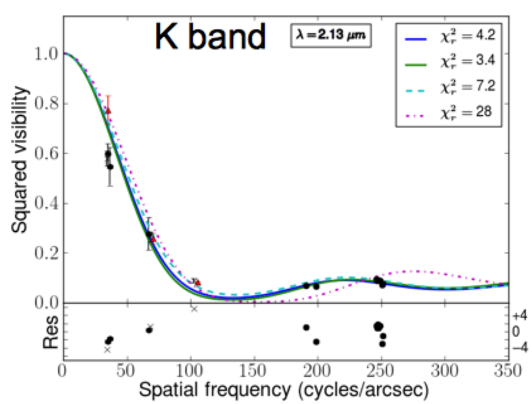
Binaries!

A detailed case study: 89 Her

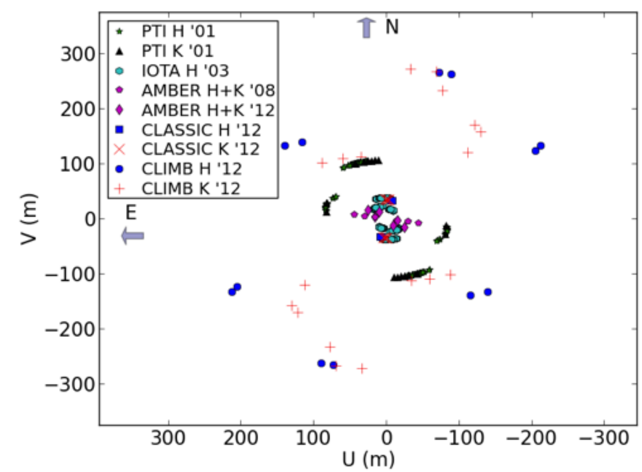
(Hillen et al. 2013)



Uniform ring models



A multiwavelength interferometric data set

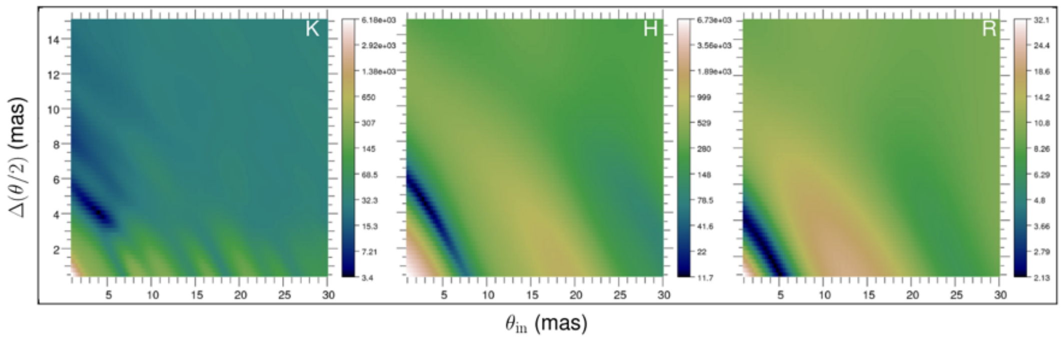


H+K UV coverage

35-40% of the total optical flux
@ 673 nm is resolved!

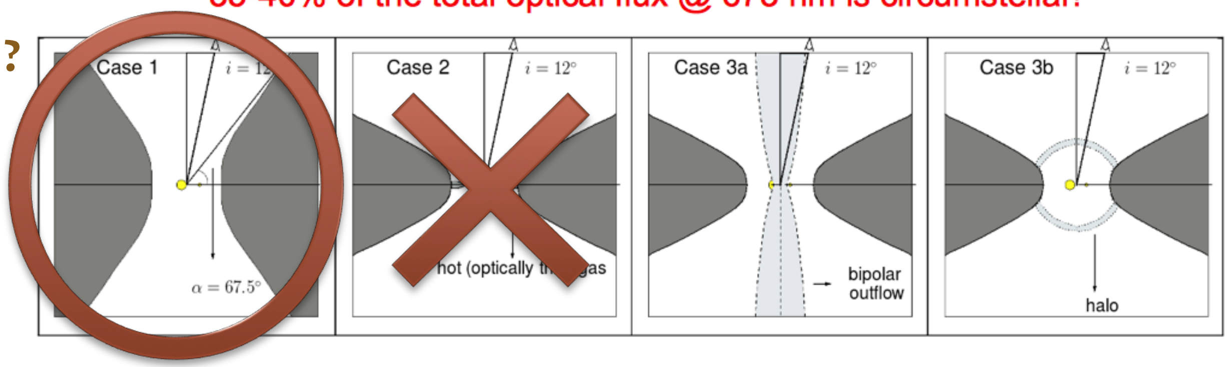
HIRES 2014

A detailed case study: 89 Her



Size ↘ if λ ↘!
Not a thin ring
in the near-IR!

35-40% of the total optical flux @ 673 nm is circumstellar!

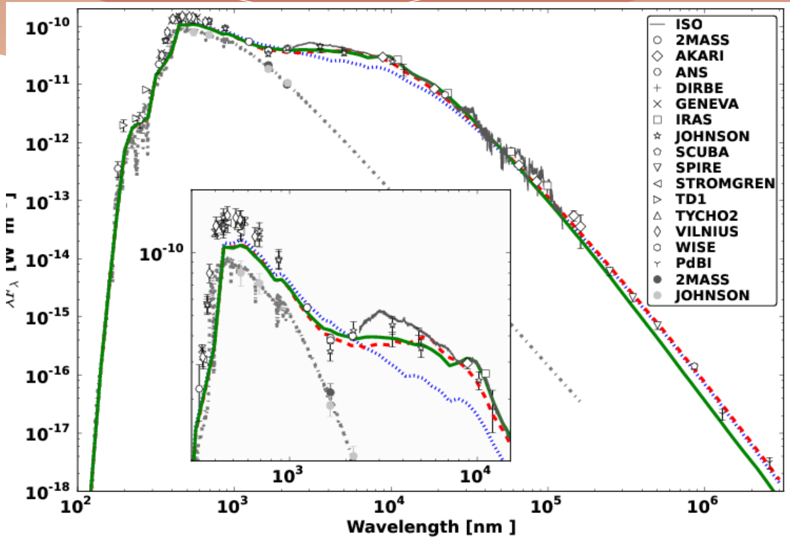


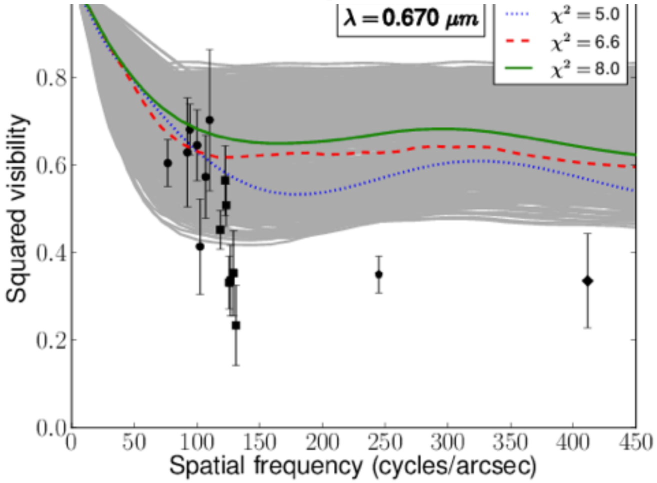
HIRES 2014

Science case 1:
Locating the continuum scattered light

Hillen 2014

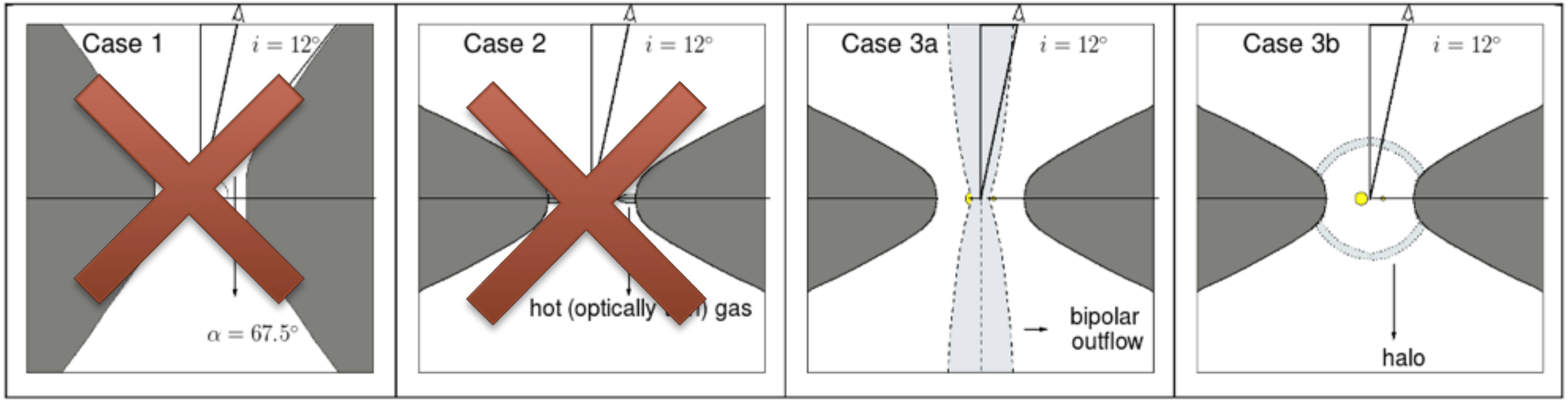
* IR observables fit well with smoothened inner rim.
* The 35-40% of optical scattered light is not reproduced!





Science case 1: Locating the continuum scattered light

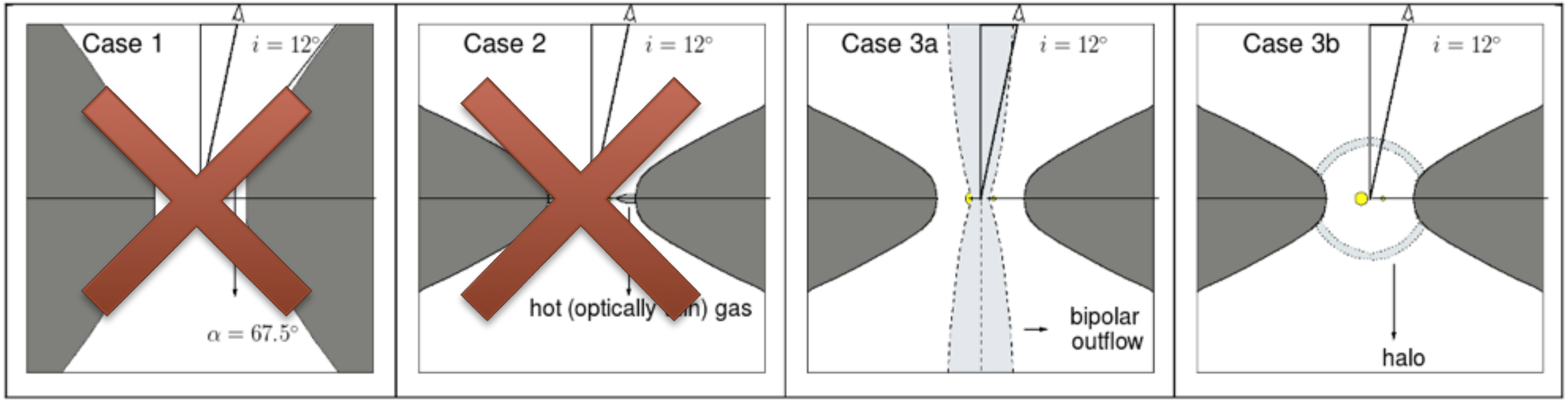
* Observations fitted with models
  * **The binary system is surrounded by a puffed-up, passive circumbinary disk, probably in HE, with large grains settled to the mid-plane!**
* The large fraction of **optical scattered light cannot be reproduced**, although its *projected* spatial distribution is predicted correctly.
* We propose to **adapt the geometry of the system**: a large-volume, low-density/ low-optical depth component of small dust grains should be added!



Science case 1:
Locating the continuum scattered light

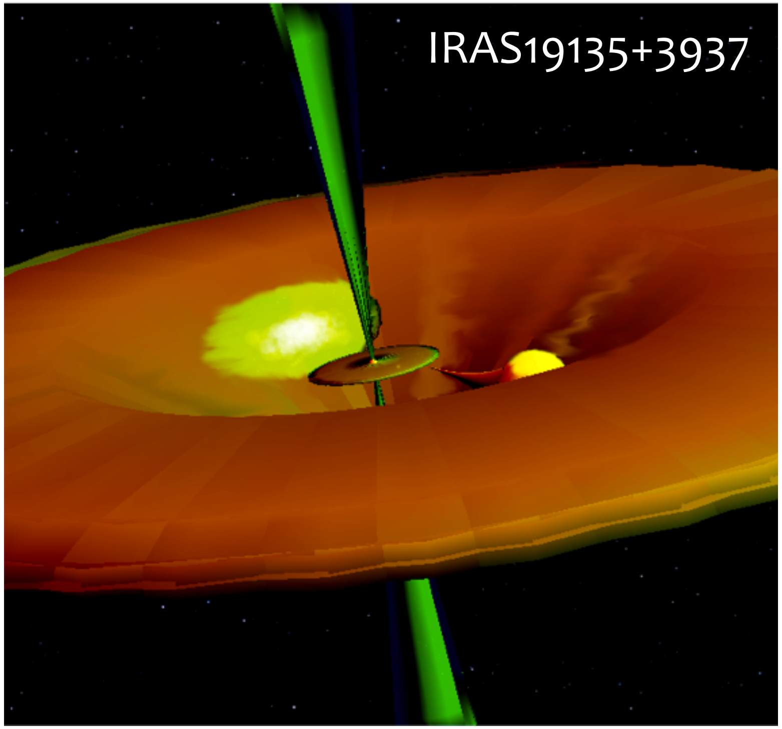
Need of a visible interferometer!

- Locate the continuum scattered light around the post AGB
- Polarimetric mode to differentiate 3D distribution of the material



Science case 2: accretion disc and/or jets?

* Very few outflows detected in optical continuum
* Other techniques more succesful (ALMA, spectroscopic monitoring)



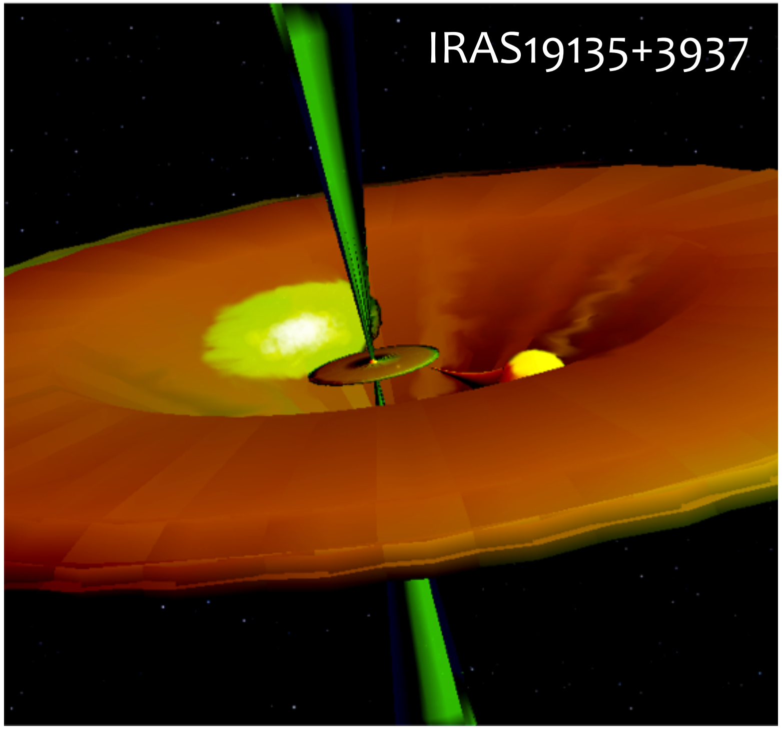
Artist's view of the system
Spot of reflected light!

Science case 2: accretion disc and/or jets?

Direct imaging with interferometry?

- Detect inner flow and connect with the outer one
- Driving mechanism for the outflow
- What is feeding the outflow?
- Accretion disc around secondary?

=> H_α lines



Artist's view of the system
Spot of reflected light!

Requirements

* V < 12-13 mag
* Spectral Resolution = 30 and 10,000
* Spectral range down to B-band would be nice
* Spectral resolution 1 mas
* Precision: V~5% and CP~1-3%
* Imaging + monitoring
* 60 sources fro VLTI

Discussion

Strong science cases

* AGB
  * Tracing the shock fronts
  * Time-scales of the convection!
  * Magnetic field
  * Dust distribution

It depends… polarimetry

* RSG
  * Chromosphere & mass-loss
  * Time-scales of the convection!
* Post-AGBs
  * Scattering & outflow

Existing facilities

Can be implemented on an existing infrastructure?

* VLTI is designed as infrared machine,
  * no long baselines,
  * some science can be already done @ J, I, R-band => feasible?!
  * More telescopes to be efficient for imaging…
* CHARA misses the very short baselines,
  * magnitude limit is a problem
* MROI?
  * Money… ?

Multi-wavelengths & techniques

* Infrared interferometry
* ALMA Cycle 3 will have polarimetry! Need to stress what we can add
* VLT/SPHERE, VISIR…