The convection of close red supergiant stars observed with near-infrared interferometry

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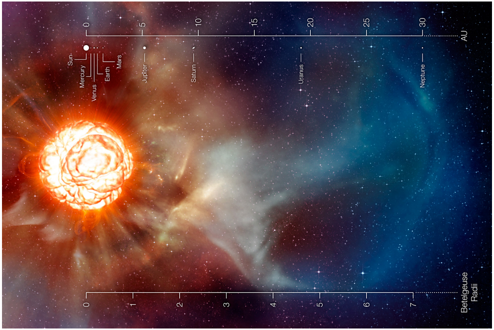
4: Lagrange - Observatoire de la Côte d'Azur
5: IRAP - Université de Toulouse
6: IPAG

Physics of Evolved Stars - In memory of Olivier Chesneau
Nice - June 11th 2015

Trigerring the RSG mass loss

- Physical process remains unknown (no flares, no large pulsations)
- Verhoelst et al. (2006) proposed Al_2O_3 as nucleus for dust condensation
- Josselin & Plez (2007) suggested a convection triggered mass loss
- Auriere et al. (2010) observed magnetic field $\sim$ 1 G



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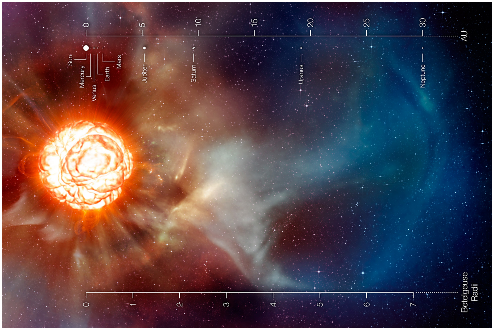
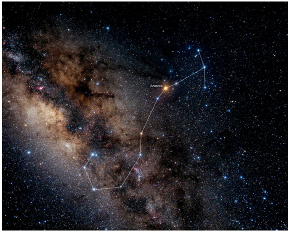
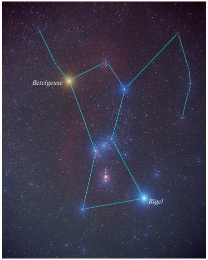
$\longrightarrow$ Study of the photosphere + CSE



Antares (α Sco) & Betelgeuse (α Ori)

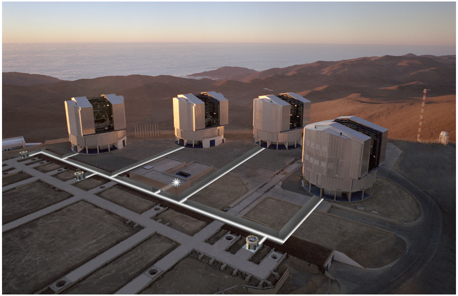
Parameter	Antares	Betelgeuse
m (visible)	0.91	0.42
m (IR)	-3.49	-3.73
M ($M_\odot$)	15 ± 5	21 ± 2
R ($R_\odot$)	~ 680	897 ± 211
$T_{\rm eff}$ (K)	3707 ± 77	3690 ± 54
d (pc)	~ 170	197 ± 45
$\nu_{\rm rad}$ (km.s^{-1})	-3.50 ± 0.8	21.91 ± 0.51
Spectral Type	M0.5Iab	M2Ib

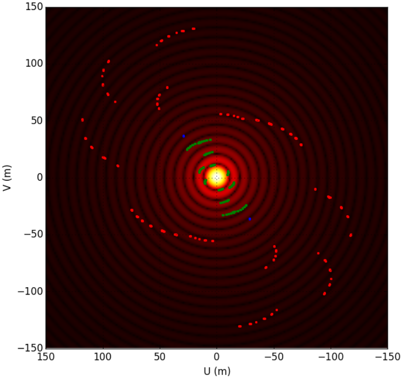




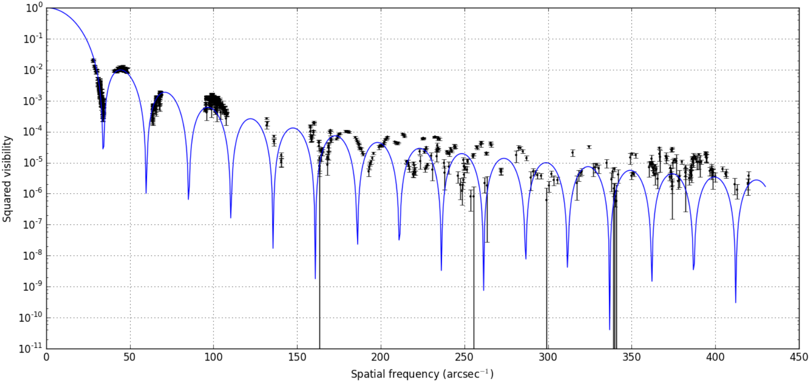
Interferometric observations of Antares

- VLTI/PIONIER observations : 4 telescopes, H band (low spectral resolution)
- 3 array configurations (baseline lengths from 11m to 153m)





Antares@PIONIER : analytical model



$\longrightarrow$ Fit in 1st lobe only

- $\theta_{\mathrm{LDD}} = 39.8 \pm 0.70$ mas, $\alpha_{\mathrm{LDD}} = 0.660 \pm 0.10$

Antares@PIONIER : RHD simulations

Receipt to fit RHD simulations (see Chiavassa et al. 2011):

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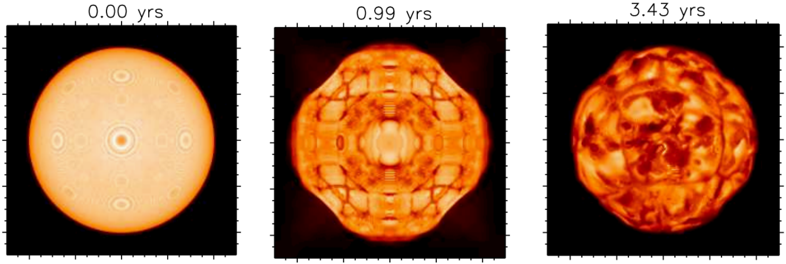

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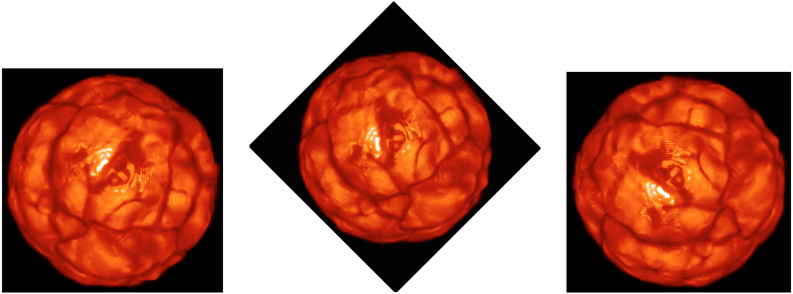

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More ? → Talk of A. Chiavassa at 3:20pm.

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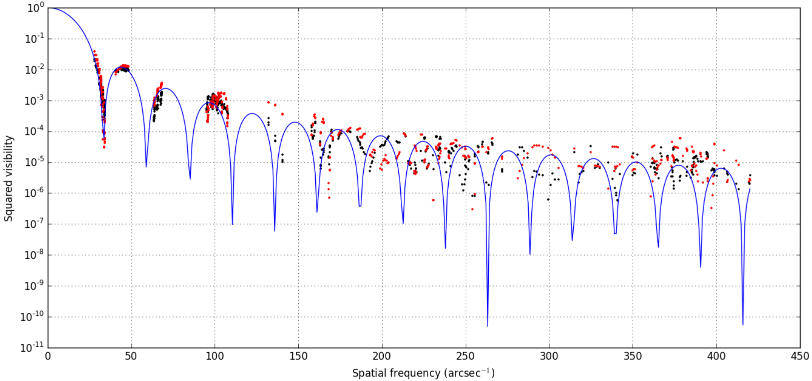
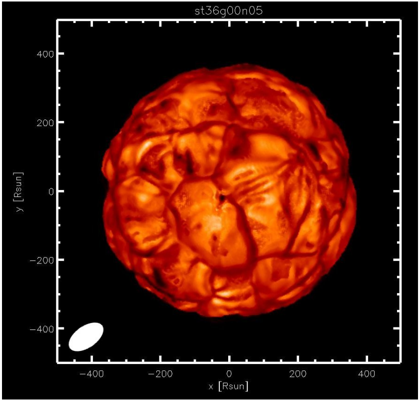


- Up to 16th lobe of visibility function

$\longrightarrow$ Very small scale structures

$\longrightarrow$ Statistical approach

Antares@PIONIER : RHD simulations



Parameter	Antares	st36g00m05
Grid	-	401^3
M ($M_\odot$)	6	15 ± 5
R ($R_\odot$)	376.7 ± 0.5	~ 680
$T_{\rm eff}$	3707 ± 77	3710 ± 20

(see in Chiavassa et al. 2011)

- Convection remains the best scenario to explain the high SF

  (See: Montargès et al. 2014 in A&A on Betelgeuse with VLTI/AMBER)

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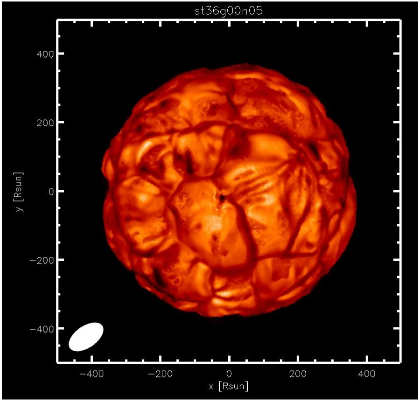

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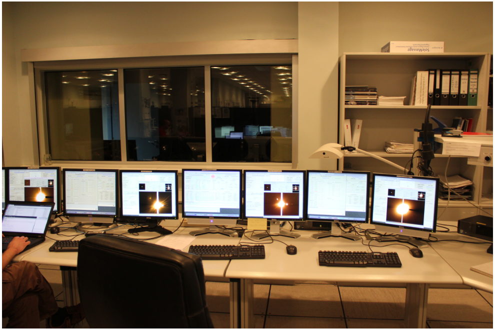
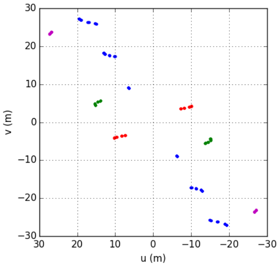
  (See: Montargès et al. 2014 in A&A on Betelgeuse with VLTI/AMBER)
- Numerical constraints on simulations

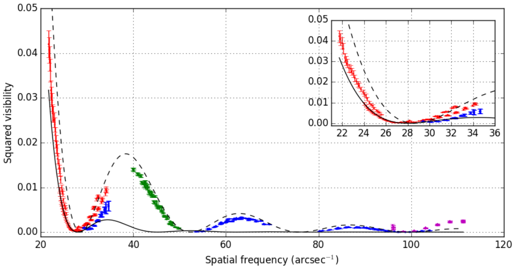
Interferometric observations of Betelgeuse

- VLTI/PIONIER observations (still 4 telescopes, H band, low spectral resolution)
- 4 epochs of monitoring: Jan. 2012, Feb. 2013, Jan. 2014 and Nov. 2014
- Only the compact array configuration



2012 observations





UD/LDD models

First lobe only :

- UD: $\theta_{\mathrm{UD}} = 42.64 \pm 0.97$ mas $\quad \chi^2 = 814$
- LDD: $\theta_{\mathrm{LDD}} = 60.64 \pm 2.27$ mas $\quad \alpha_{\mathrm{LDD}} = 2.30 \pm 0.27 \quad \chi^2 = 118$

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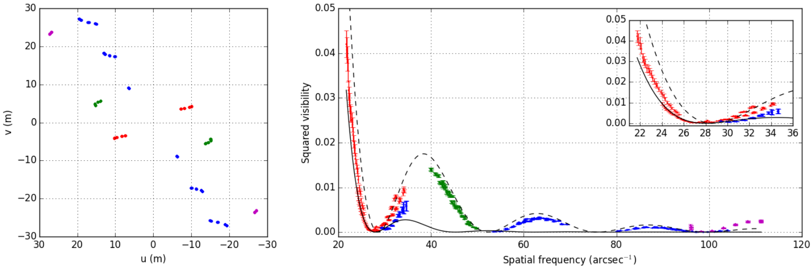

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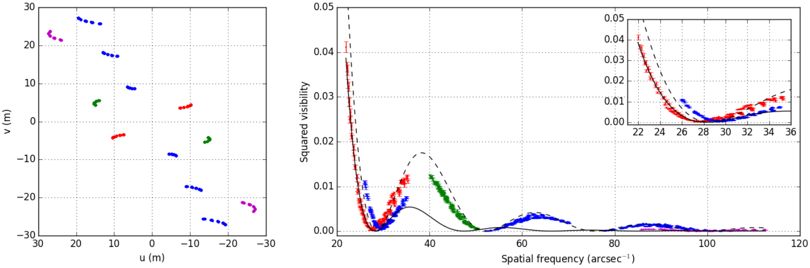
- 1st lobe shape: indication of non-spherical star, not expected

$\longrightarrow$ True feature or instrumental artifact ?

2012 vs 2013

- 2012: diaphragms to avoid saturation, calibrator: Sirius (d $= 27^\circ$)
- 2013: neutral densities + calibrators with $d \leq 7^\circ$

2013 observations : disk models



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- LDD: $\theta_{\mathrm{LDD}} = 53.64 \pm 1.52$ mas $\quad \alpha_{\mathrm{LDD}} = 1.41 \pm 0.19 \quad \chi^2 = 195$

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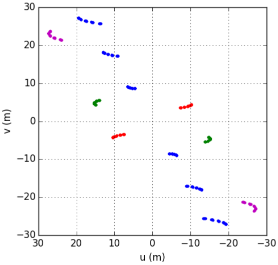

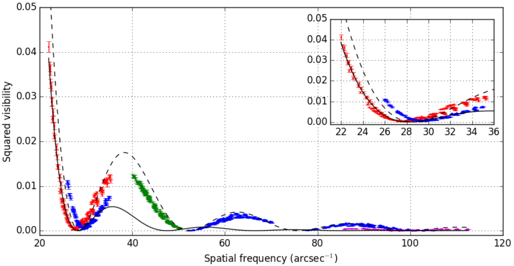

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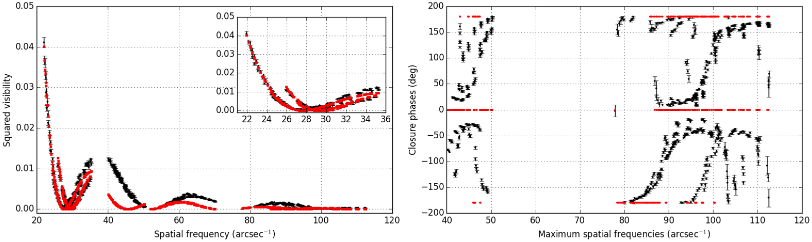
- Still the 1st lobe feature $\rightarrow$ cannot be ignored !

2013 observations: LD ellipse



- Visibilities $\sim$ ok ($\chi^2 = 70$, better than for disk models)

A little break : closure phases

- Visibility = amplitude of Fourier Transforn of light intensity distribution of the source

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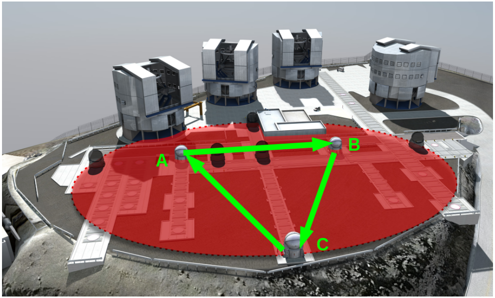
- Visibility = amplitude of Fourier Transforn of light intensity distribution of the source
- Closure phase = sum of the phases measured by 3 baselines on a closed triangle (independent from phases atmospheric pertubations)



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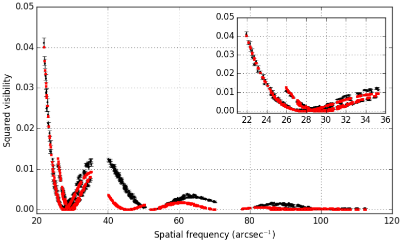
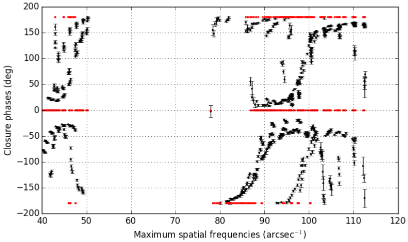
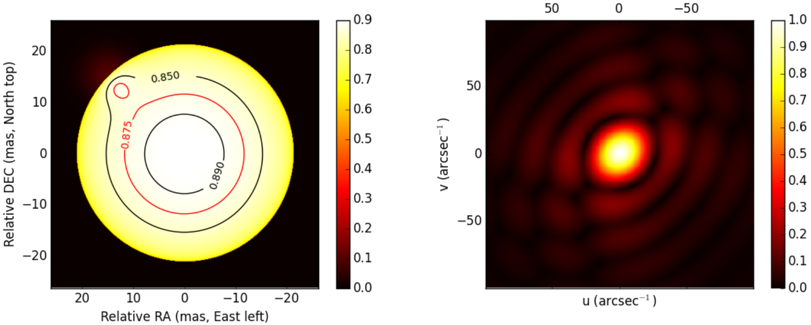




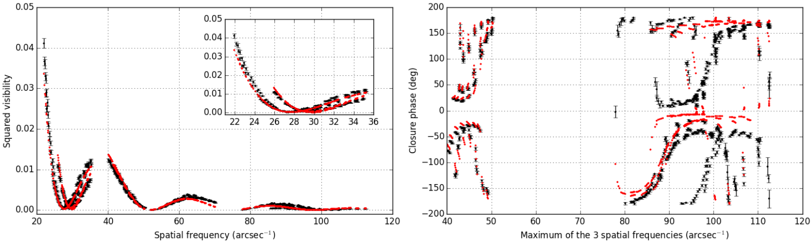
- Visibilities $\sim$ ok ($\chi^2 = 70$, better than for disk models)
- Difference between major/minor axes $\sim$ 25% of usual diameter of the star
- Closure phases bad ($\chi^2 = 718$, expected)

Hot spot hypothesis



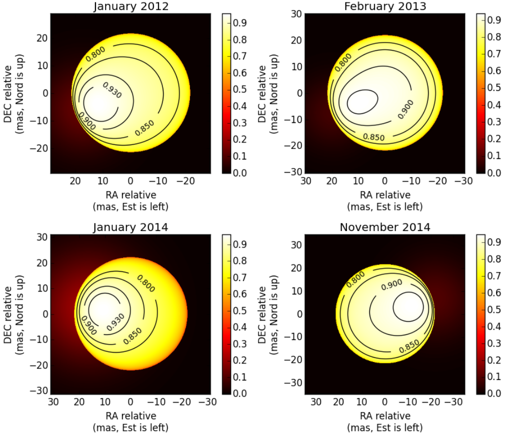
- Huge hotpost can affect the 1st lobe
- Difficulty: strong link between the star diameter and the spot characteristics

2013 observations : LDD+gaussian hotspot



Parameter	Value
θ_{LDD} (mas)	43.73 ± 0.50
α_{LDD}	0.19 ± 0.07
w_{spot}	0.08 ± 0.02
x_{center} (mas)	19.76 ± 2.02
y_{center} (mas)	-7.46 ± 2.42
FWHM (mas)	18.42 ± 2.42
χ^2	31

4 epochs of monitoring



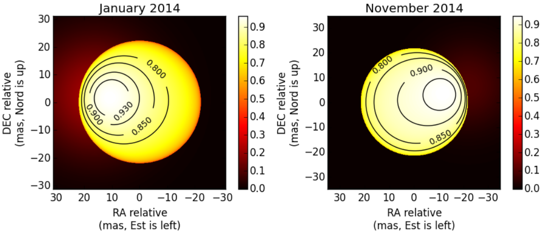
Fit with SF < 51 arcsec^{-1}

- $\chi^2_{2012\ 01} = 29$
- $\chi^2_{2013\ 02} = 31$
- $\chi^2_{2014\ 01} = 29$
- $\chi^2_{2014\ 11} = 70$

Nov. 2014 : need to use 2 spots (+ all SF range)

- Montargès et al. 2015 in prep.

2014: evolution of the signal



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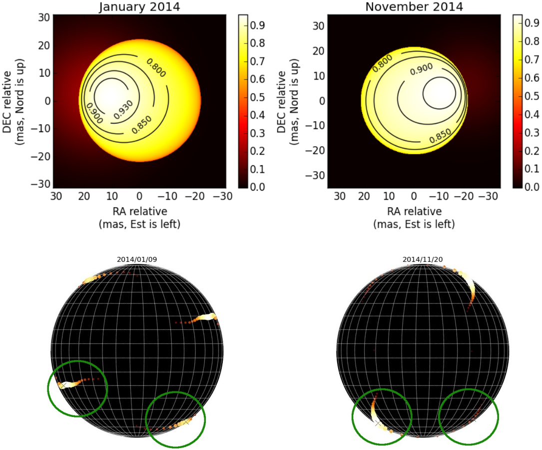
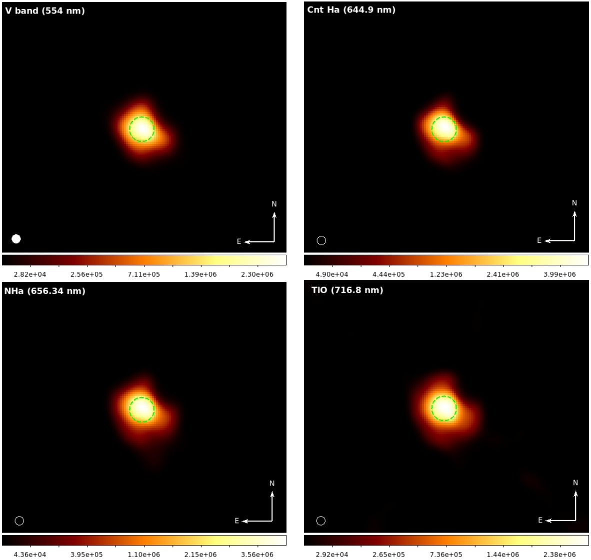


TBL/Narval (spectro-polarisation)
Aurière, Lopez Ariste, Mathias et al. in prep.

Spring 2015: VLT/SPHERE



Kervella et al. in prep. (preliminary)

Conclusion

Antares

- Convection : statistical approach using RHD simulations (resolution up to more than 1/10 of the star diameter)

Betelgeuse

- NIR photosphere, massive hot spot evolving over 4 years
- What would be the result with only one sample in the 1st lobe ?

$\longrightarrow$ Related to spectro-polarimetric measurements ?

$\longrightarrow$ Montargès et al. A&A in prep.

- Visible : higher photosphere domain ?

$\Rightarrow$ Complex and unexpected shape of RSG

$\Rightarrow$ Evolution clearly visibly from one epoch to one other

Backups

Polarization with SPHERE (Spring 2015)