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

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Physics of Evolved Stars - In memory of Olivier Chesneau
Nice - June 11th 2015
Mass loss of evolved stars

Trigerring the RSG mass loss

- Physical process remains unknown (no flares, no large pulsations)
- Verhoelst et al. (2006) proposed Al₂O₃ as nucleus for dust condensation
- Josselin & Plez (2007) suggested a convection triggered mass loss
- Auriere et al. (2010) observed magnetic field \( \sim 1 \, \text{G} \)
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→ 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$_{\text{eff}}$ (K)| 3707 ± 77   | 3690 ± 54   |
| d (pc)             | \(~ 170\)   | 197 ± 45    |
| $\nu_{\text{rad}}$ (km.s$^{-1}$)| $-3.50 \pm 0.8$| $21.91 \pm 0.51$|
| 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

→ Fit in 1st lobe only

θ_{\text{LDD}} = 39.8 \pm 0.70 \text{ mas}, \ \alpha_{\text{LDD}} = 0.660 \pm 0.10
Mass loss of evolved stars
Convection of \( \alpha \) Sco
The photosphere of \( \alpha \) Ori

Antares@PIONIER : RHD simulations

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

- Have a stellar model (CO\(^5\)BOLD, Freytag et al. 2012)
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More ? → Talk of A. Chiavassa at 3:20pm.
Antares@PIONIER : RHD simulations

- Up to 16th lobe of visibility function
- Very small scale structures
- Statistical approach
Antares@PIONIER : RHD simulations

| Parameter | Antares | st36g00m05 |
|-----------|---------|------------|
| Grid      | -       | 401³       |
| M (M☉)    | 6       | 15 ± 5     |
| R (R☉)    | 376.7 ± 0.5 | ~ 680     |
| $T_{\text{eff}}$ | 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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- Convection remains the best scenario to explain the high SF
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- 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: $\theta_{UD} = 42.64 \pm 0.97$ mas $\chi^2 = 814$
- LDD: $\theta_{LDD} = 60.64 \pm 2.27$ mas $\alpha_{LDD} = 2.30 \pm 0.27$ $\chi^2 = 118$
Mass loss of evolved stars

Convection of \( \alpha \) Sco

The photosphere of \( \alpha \) Ori

2012 observations

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- 1st lobe shape: indication of non-spherical star, not expected
  → True feature or instrumental artifact?
2012 vs 2013

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

UD/LDD models

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- LDD: $\theta_{LDD} = 53.64 \pm 1.52$ mas $\alpha_{LDD} = 1.41 \pm 0.19 \chi^2 = 195$
2013 observations: disk models

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- Still the 1st lobe feature \( \rightarrow \) cannot be ignored!
2013 observations: LD ellipse

- Visibilities ~ ok ($\chi^2 = 70$, better than for disk models)
A little break : closure phases

- Visibility = amplitude of Fourier Transform of light intensity distribution of the source
A little break: closure phases

- Visibility = amplitude of Fourier Transform 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 perturbations)
2013 observations: LD ellipse

- Visibilities ~ ok ($\chi^2 = 70$, better than for disk models)
- Difference between major/minor axes ~ 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          |
|----------------|----------------|
| $\theta_{\text{LDD}}$ (mas) | $43.73 \pm 0.50$ |
| $\alpha_{\text{LDD}}$  | $0.19 \pm 0.07$ |
| $\nu_{\text{spot}}$    | $0.08 \pm 0.02$ |
| $x_{\text{center}}$ (mas) | $19.76 \pm 2.02$ |
| $y_{\text{center}}$ (mas) | $-7.46 \pm 2.42$ |
| FWHM (mas)       | $18.42 \pm 2.42$ |
| $\chi^2$         | $31$           |
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

January 2014

November 2014

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2014: evolution of the signal

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?
  - Related to spectro-polarimetric measurements?
  - Montargès et al. A&A in prep.
- Visible: higher photosphere domain?

⇒ Complex and unexpected shape of RSG
⇒ Evolution clearly visibly from one epoch to one other
Backups
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