

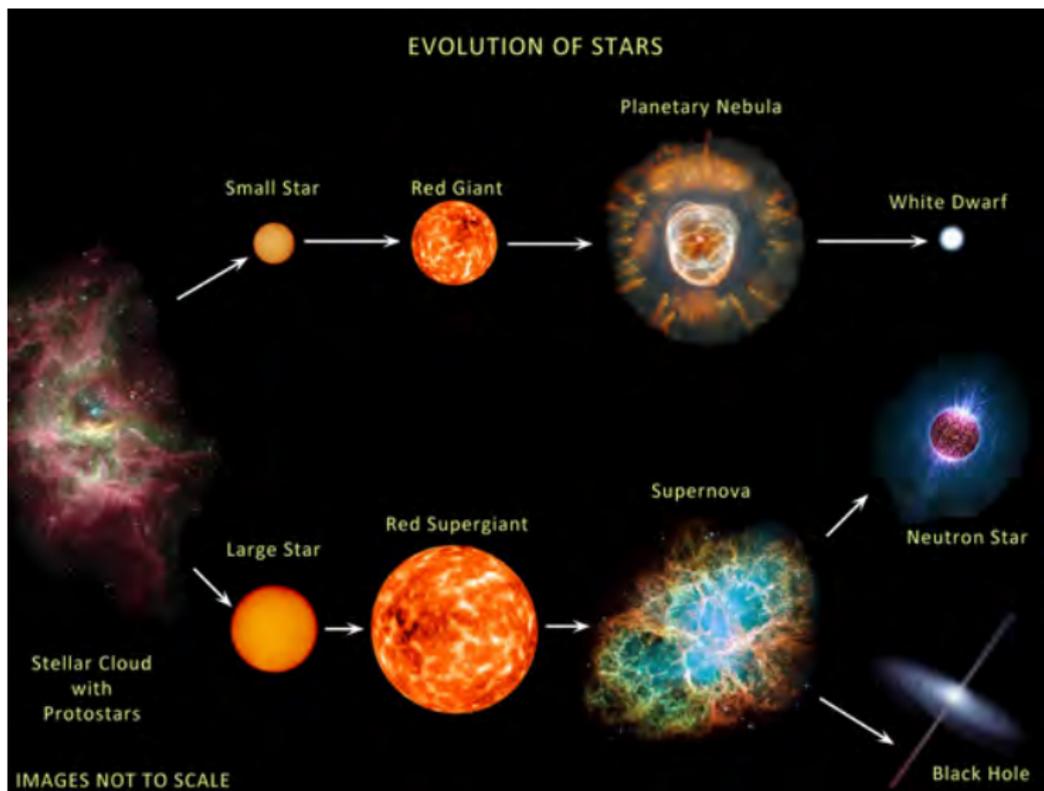
# Nearby red supergiants with the CHARA interferometer

Miguel Montargès (IRAM Grenoble)

in collaboration with P. Kervella (UMI Franco-Chilena), G. Perrin (LESIA/Observatoire de Paris),  
A. Chiavassa (LAGRANGE/OCA), S. T. Ridgway (NOAO)

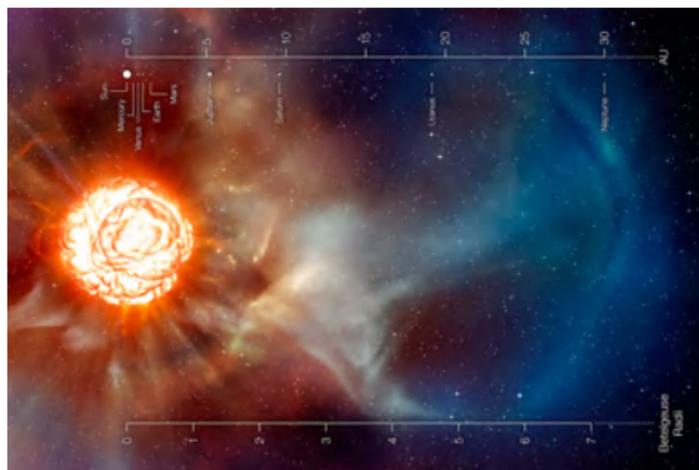
Nice - March 14th 2016

# Stellar evolution



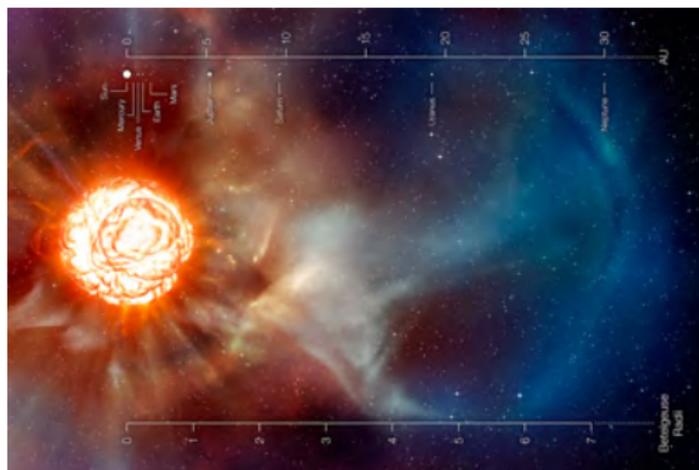
# Triggering the RSG mass loss

- Physical process remains unknown (no flares, no large pulsations)
- Verhoelst et al. (2006) proposed  $\text{Al}_2\text{O}_3$  as nucleus for dust condensation
- Josselin & Plez (2007) suggested a convection triggered mass loss
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- Study of the photosphere + CSE



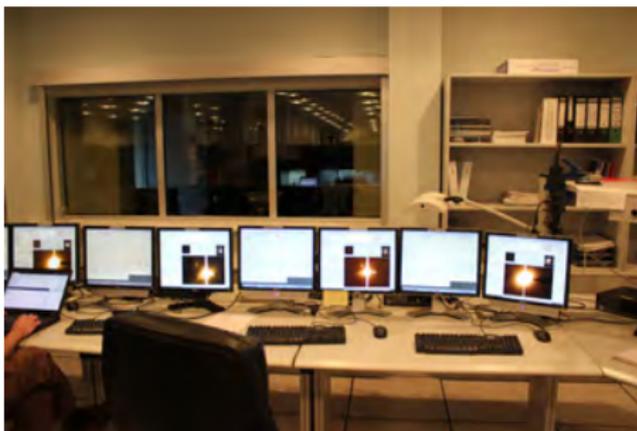
# Antares ( $\alpha$ Sco) & Betelgeuse ( $\alpha$ Ori)

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



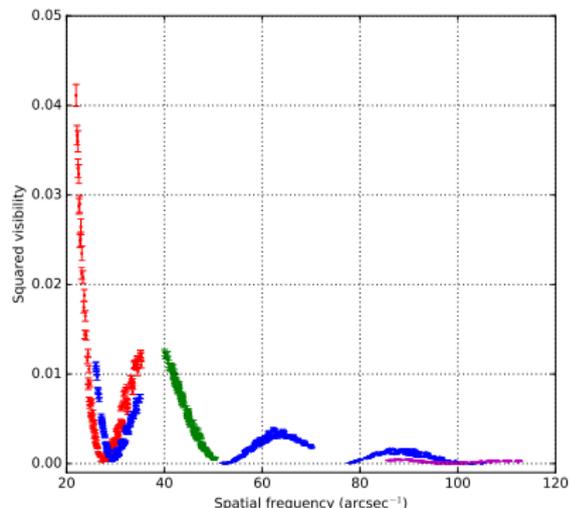
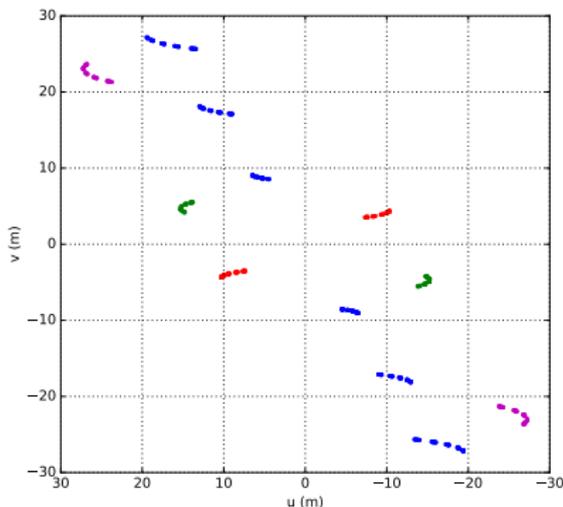
# Interferometric observations of Betelgeuse

- VLT/PIONIER observations (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 (baseline length  $\in [11; 36 \text{ m}]$ )
- Extended configuration lost to bad weather (3 times !)



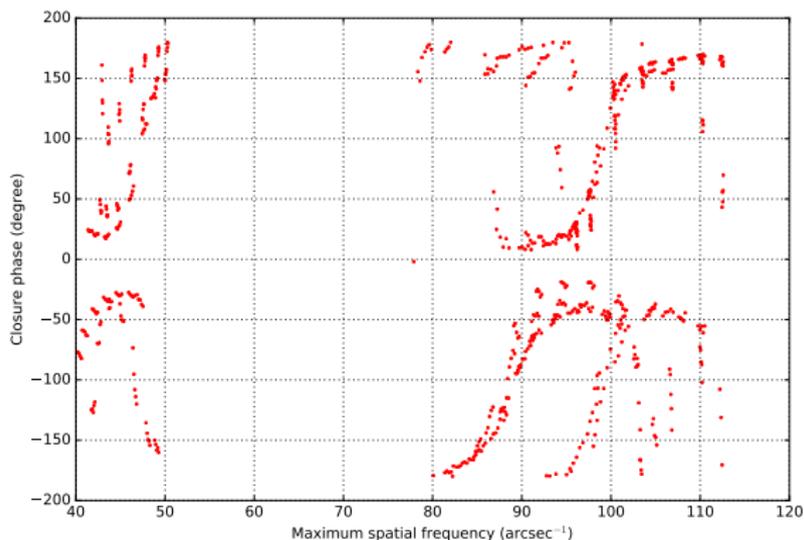


# Shape of the visibilities (2013)



- Consistent between the 4 epochs (3 different features to avoid detector saturation)
- Impossible to fit a UD or a LDD model

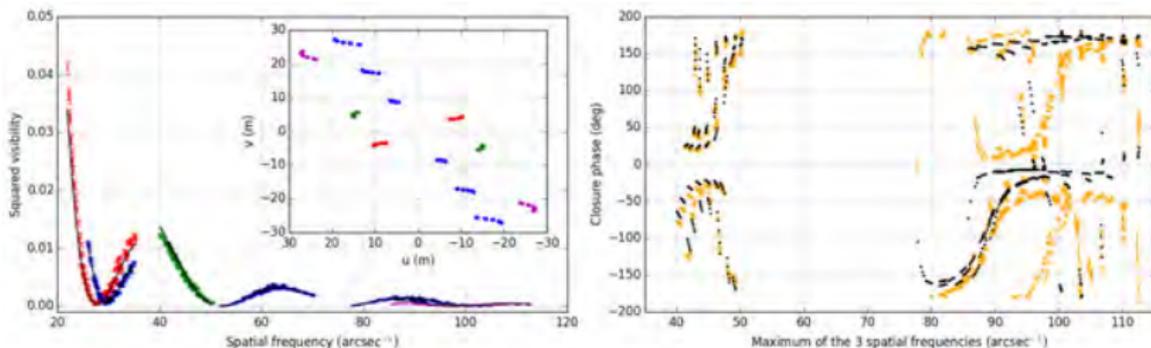
# Shape of the closure phase (2013)



- Strong signal
- Incompatible with elliptical model

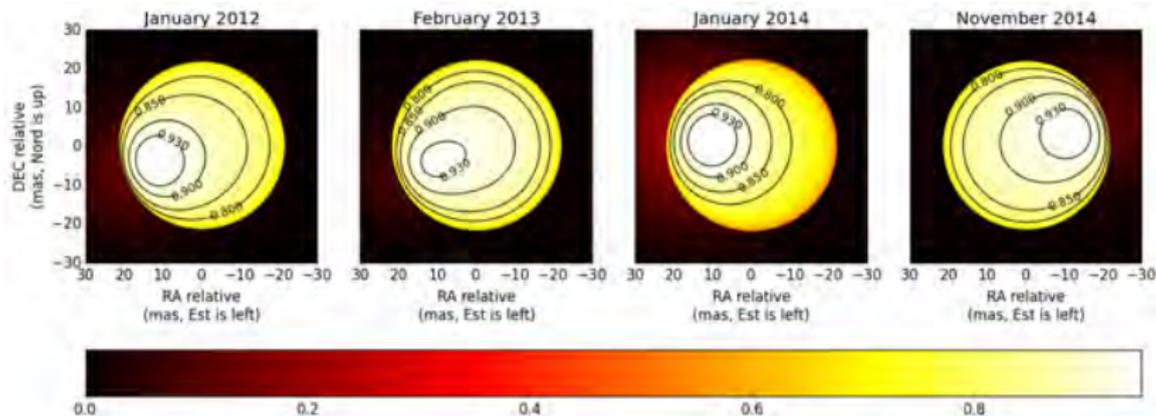
# LDD model + gaussian hotspot

- Chiavassa et al. (2009, 2010) showed that convection can displace the nulls of the visibility function (as a function of P. A.)
- Difficulty: angular diameter cannot be inferred from the first null anymore





# LDD model + gaussian hotspot



- Consistent on the 4 epochs
- Consistent with spectro-polarimetric observations at TBL/NARVAL (Auriere et al. *subm.*)
- Spots already observed on Betelgeuse (see Hauboys et al. 2009, Ravi et al. 2011, Ohnaka et al. 2011)

# Modeling the convection

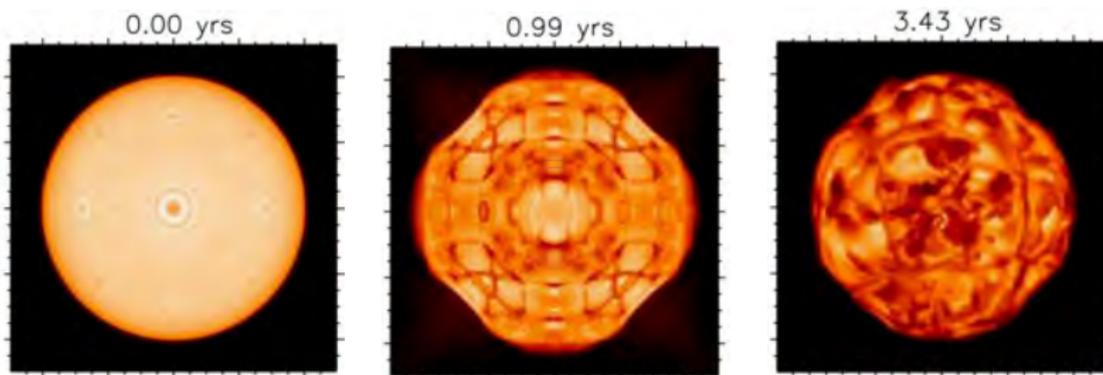
Receipt to fit RHD simulations (see Chiavassa et al. 2011):

- Have a stellar model (CO<sup>5</sup>BOLD, Freytag et al. 2012)

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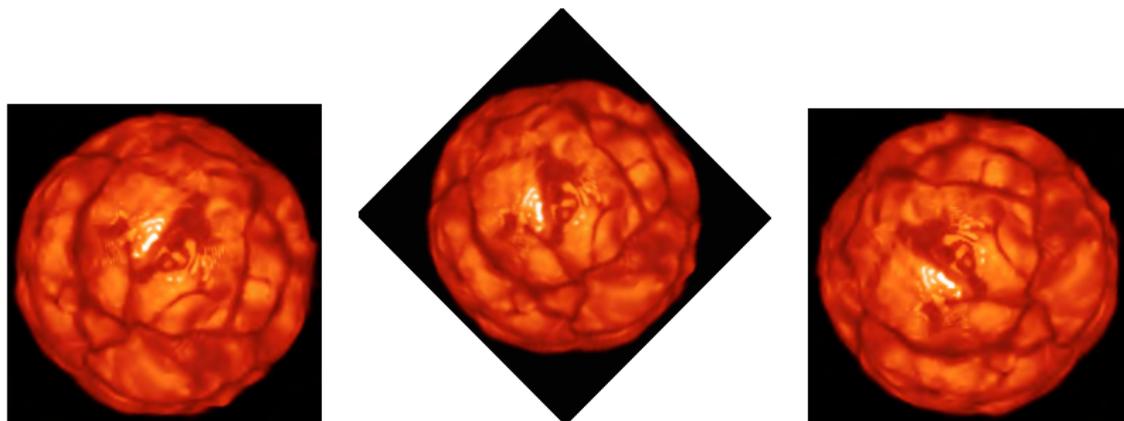
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- Take (a lot of) snapshots (= realizations of convective pattern)



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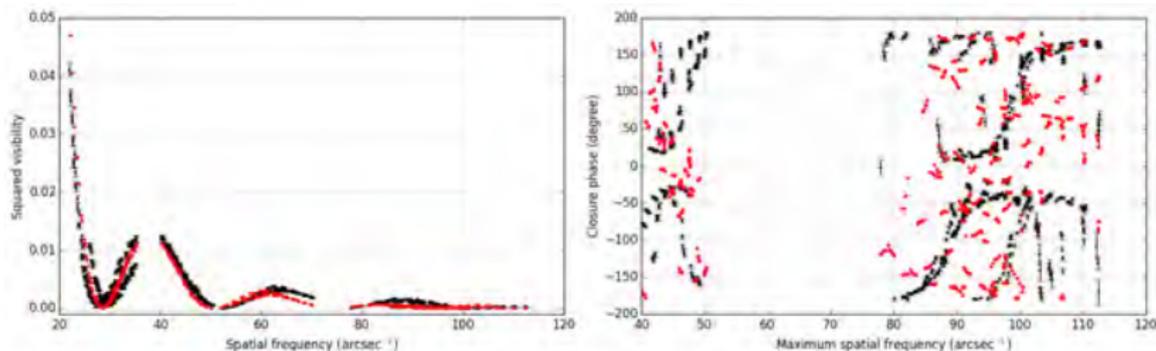


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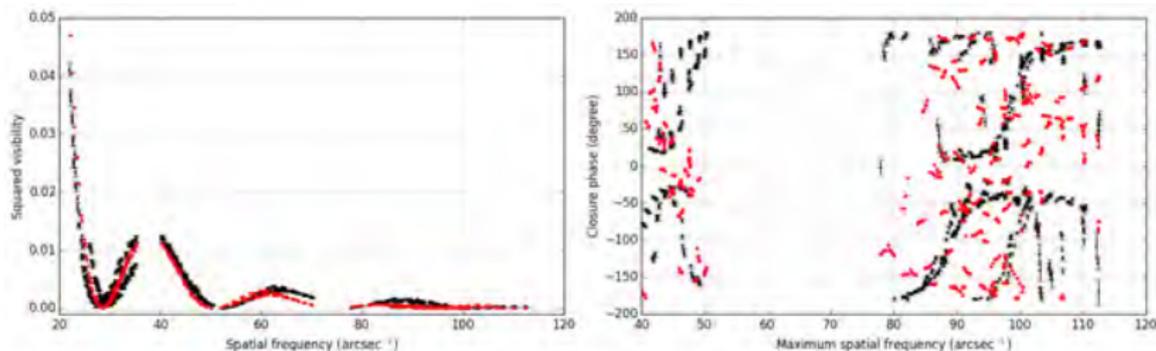
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- Rotate each snapshot (on-sky star orientation)
- FT to get interferometric characteristics

# Modeling the convection



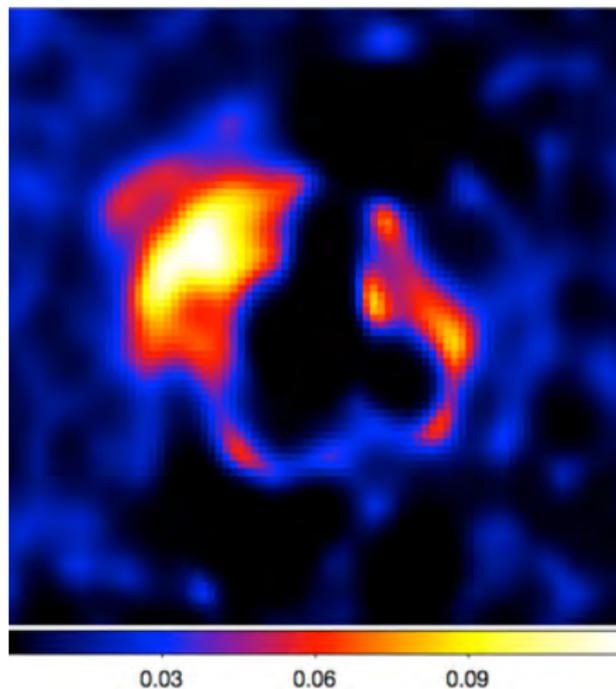
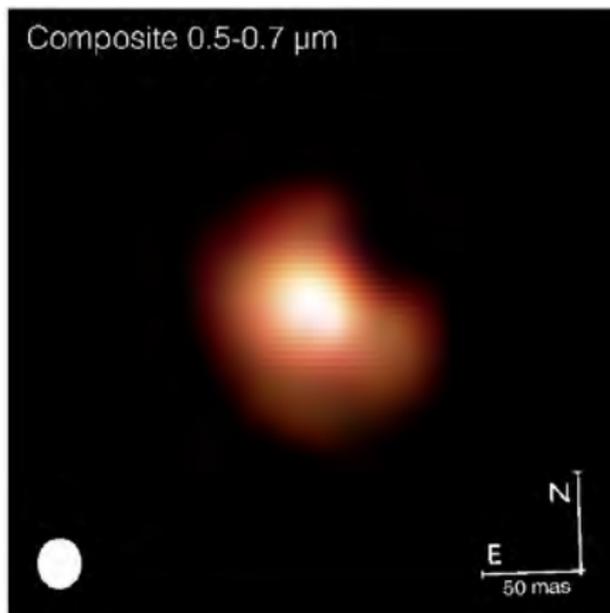
- Shape of the visibilities reproduced (a bit underestimated as Montargès et al. 2014)
  - Really bad fit of the closure phases
- Probably a missing ingredient in the simulations

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- Really bad fit of the closure phases
- Probably a missing ingredient in the simulations
- ⇒ These results in Montargès et al. (2016), *A&A*, in press.

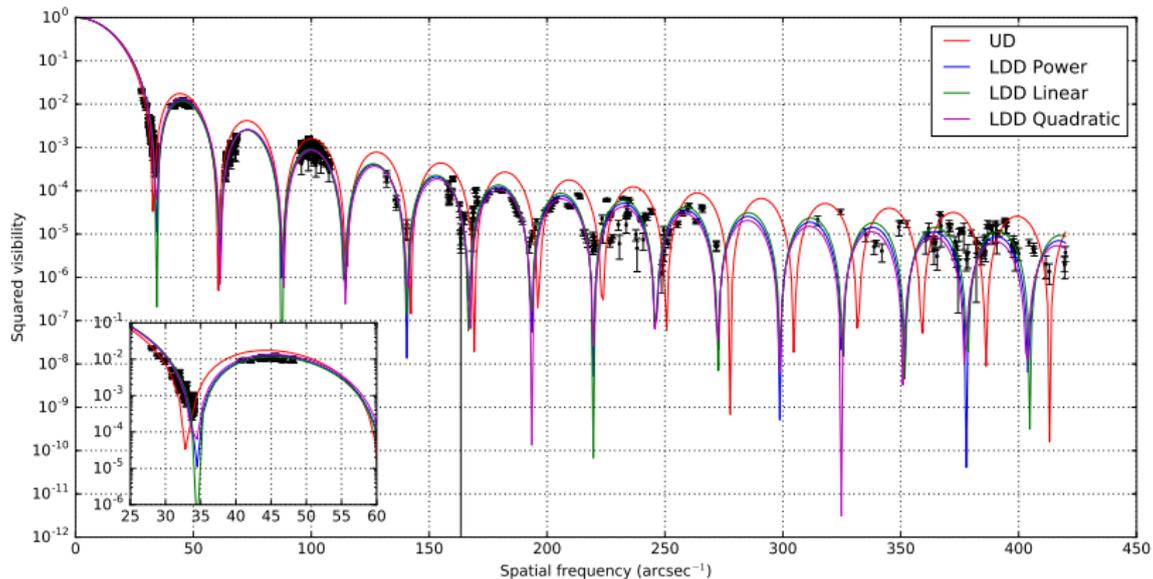
# The CSE with VLT/SPHERE (ZIMPOL)

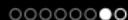


Kervella et al. (2016)

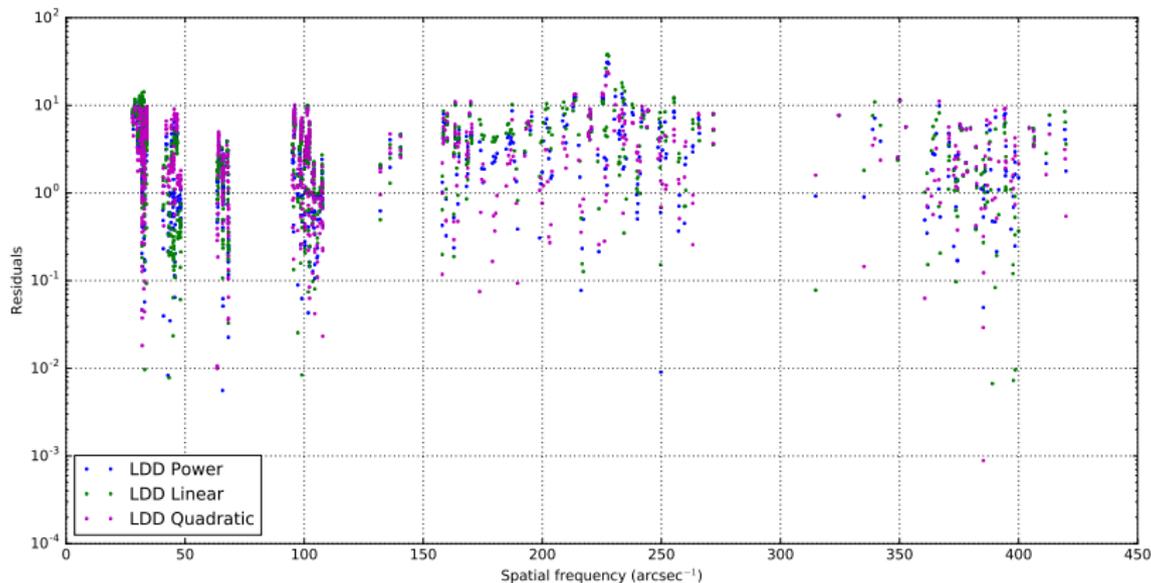


# Antares@PIONIER : analytical model



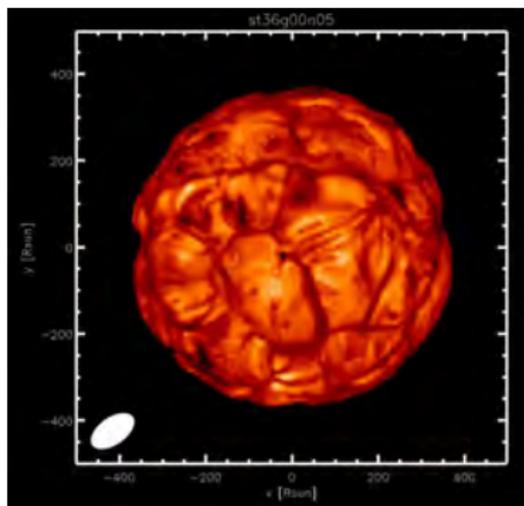


# Antares@PIONIER : analytical model



- $\chi^2_{\text{power}} = 23.6$
- $\chi^2_{\text{linear}} = 28.4$
- $\chi^2_{\text{quadratic}} = 22.1$

# Antares@PIONIER : RHD simulations



- Mean reduced  $\chi^2$  between 15 and 24 (3 simulations)
  - Visibilities overestimated ( $\neq$  Betelgeuse)
  - Convection remains the best scenario to explain the high SF
- ⇒ Montargès et al. in prep.

# Perspectives with CHARA

- 6 telescopes with MIRC + longest available baselines
- Higher and unexplored spatial frequency domain
- Convection signature : spatial power spectrum
- New numerical constraints on simulations

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## Previous attempts

3 proposals accepted (2 on Betelgeuse + 1 on  $\mu$  Cep)

# Current project

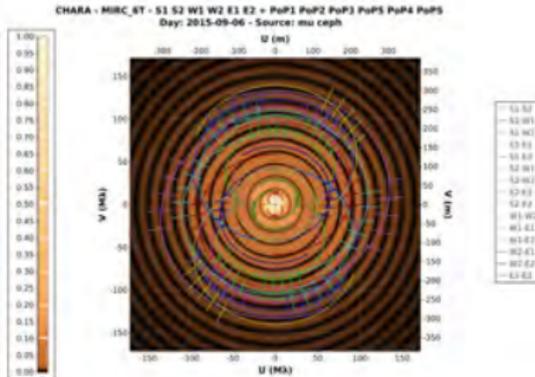
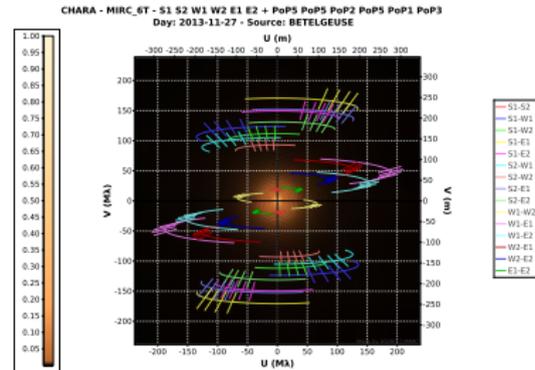
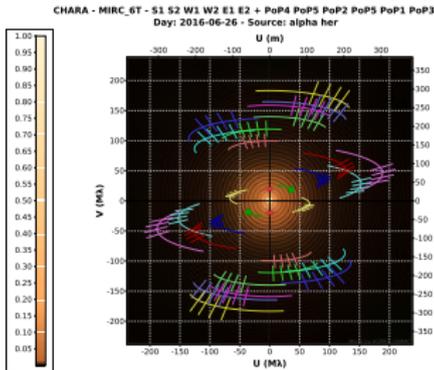
| Parameter      | $\alpha$ Her  | Betelgeuse    | $\mu$ Cep     |
|----------------|---------------|---------------|---------------|
| m (visible)    | 3.35          | 0.42          | 4.08          |
| m (IR)         | -3.05         | -3.73         | -1.27         |
| $\theta$ (mas) | $\sim 31$ (1) | $\sim 43$ (2) | $\sim 14$ (3) |
| Spectral Type  | M5Ib          | M2Ib          | M2ela         |

(1): Perrin et al. (2004), (2): Montargès et al. (2016), (3) : Perrin et al. (2007).

(see also. Ryan's talk tomorrow)



# Current project



# Conclusions

- An ingredient is apparently missing to explain the mass loss of RSG
- CHARA will give us access to an unknown spatial frequency domain on large RSG
- RSG with a similar spectral type can have a different convective activity

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Thank you for your attention !