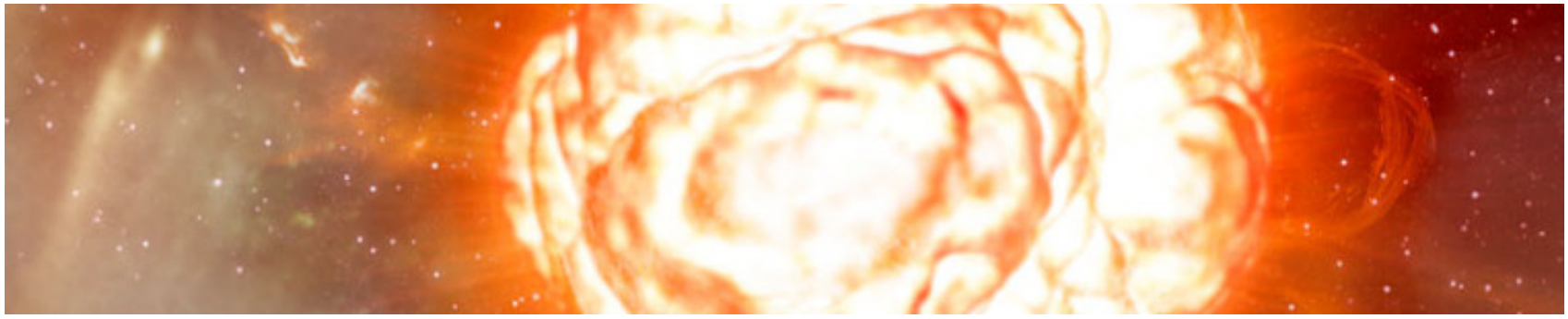


Spectropolarimetric view of the lower atmosphere of red supergiant stars

from magnetic fields to scattering polarisation

Benjamin Tessore, Miguel Montargès, Agnès Lèbre and Julien Morin

Laboratoire Univers et Particules de Montpellier

Programme National de Physique Stellaire

Outline

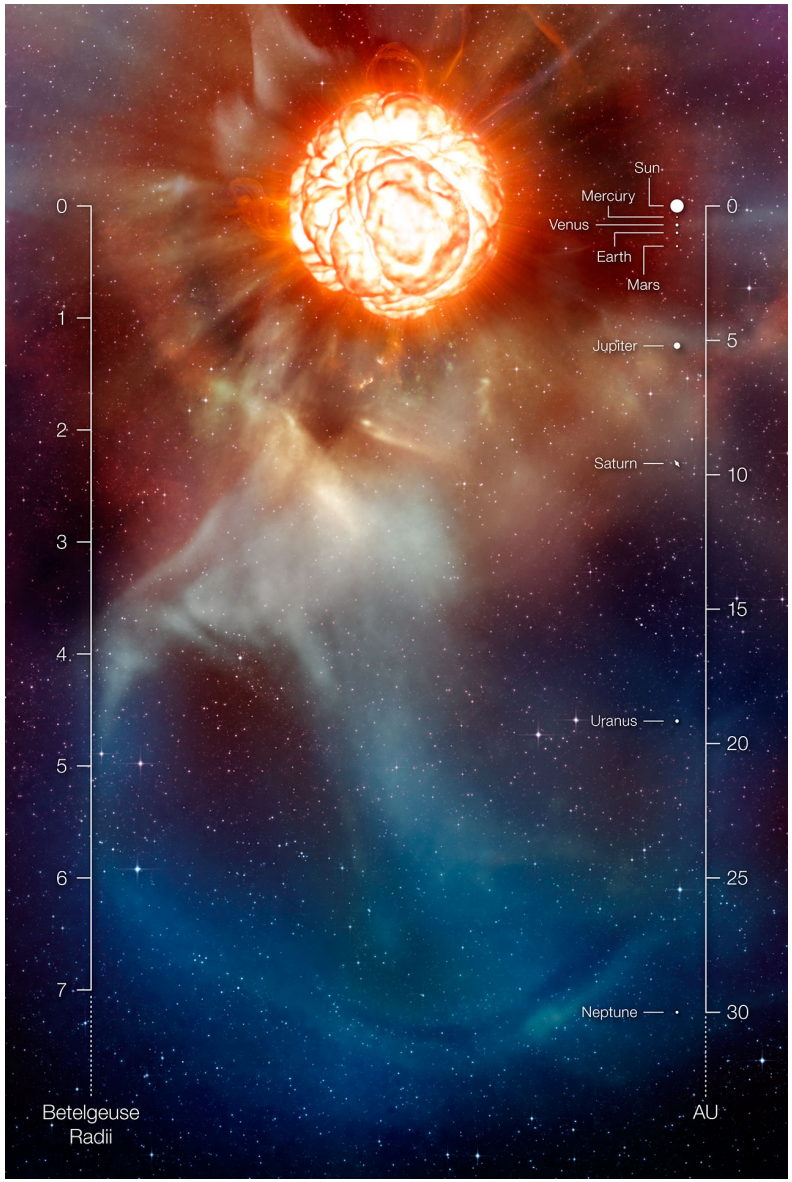
Red supergiant stars

Magnetic fields of RSG stars

Linear polarisation origin

Surface mapping of RSG stars

Red supergiants compared to the Sun



Typical scales: Betelgeuse in the Solar system

- RSG: (prototype Betelgeuse $= \alpha$ Ori)
  - ➔ Mass: 10 - 30 $\mathrm{M}_\odot$ (15 $\mathrm{M}_\odot$)
  - ➔ "Radius": $\sim$ 100-1000 $\mathrm{R}_\odot$ (600 $\mathrm{R}_\odot$)
  - ➔ $\mathrm{T}_{\mathrm{eff}}$: 3,000 - 4,000 K (3750 K)
  - ➔ Continuum polarised (0.5% in the blue)
- The Sun
  - ➔ Mass: 1 $\mathrm{M}_\odot$
  - ➔ Radius: 1 $\mathrm{R}_\odot$
  - ➔ $\mathrm{T}_{\mathrm{eff}}$: 5,777 K
  - ➔ Continuum polarised (->0% seen as a star)

Why do we care about red supergiant stars ?

- Prodigious mass loss: ($10^{-4} - 10^{-5}$ $M_\odot$/y, $\sim 10^{-14} M_\odot$/y for the Sun)

➔ Important recycling agents of the ISM
➔ Key ingredient in stellar evolution codes
➥ Still poorly understood

- Dust formation (where ?, how ?)

- At photospheric level:

➔ Vigorous surface convection (not well modelled by RHD codes)
➔ Importance of a global surface magnetic field
(1st detection on Betelgeuse, *Aurière et al. 2010*)
➥ Magnetic field generation (long period for a large-scale dynamo)

Surface magnetic field of Betelgeuse

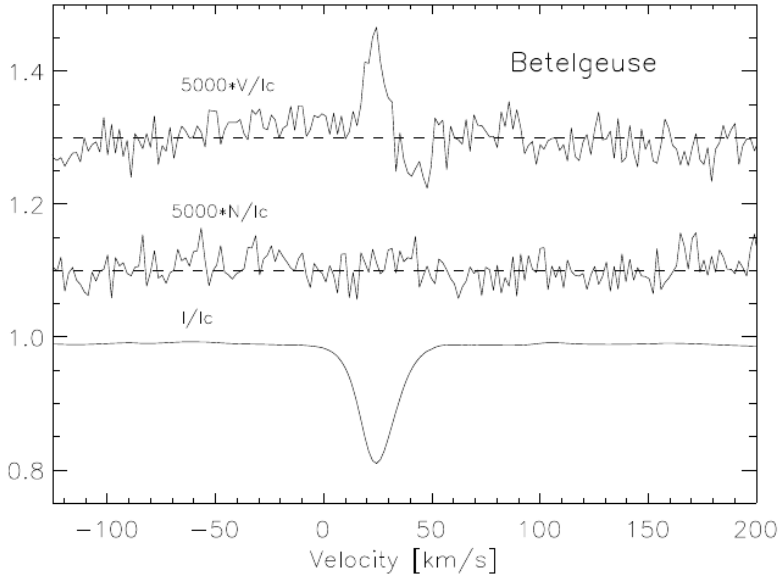
- *Aurière et al. 2010*:

➔ surface field in Betelgeuse

-> Only M type SG with a detected MF!

➥ Field at the Gauss level

$(\mathrm{B}_\ell \sim 1\mathrm{G})$



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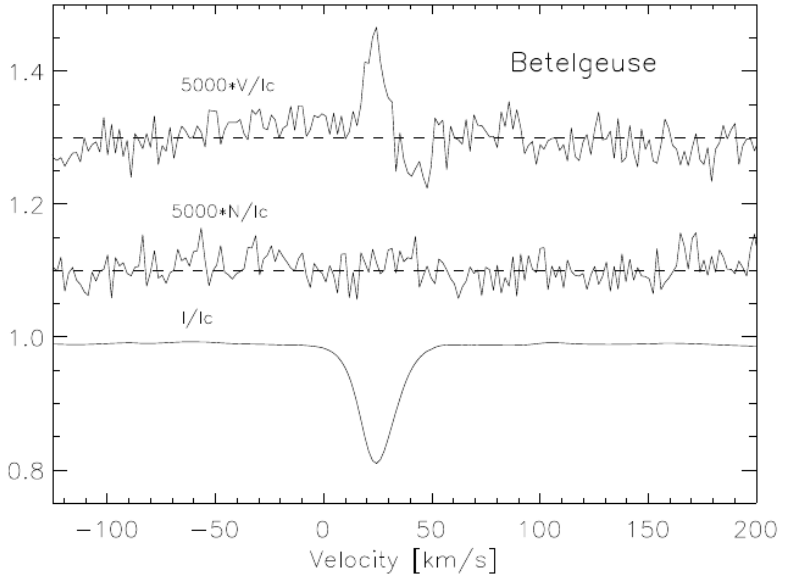
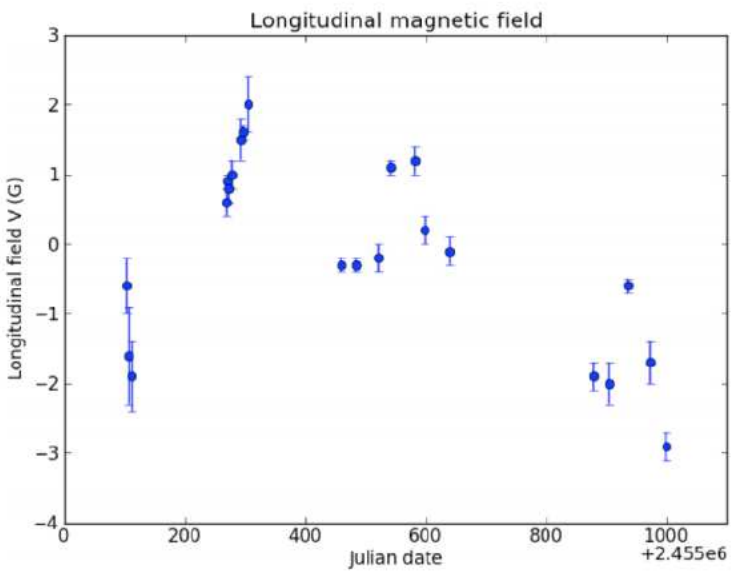


- *Bedecarrax et al. 2013*:

➔ Time-scale of B_ℓ variability $<$ month

➔ Period of Betelgeuse: 17 years (slow rotator!)



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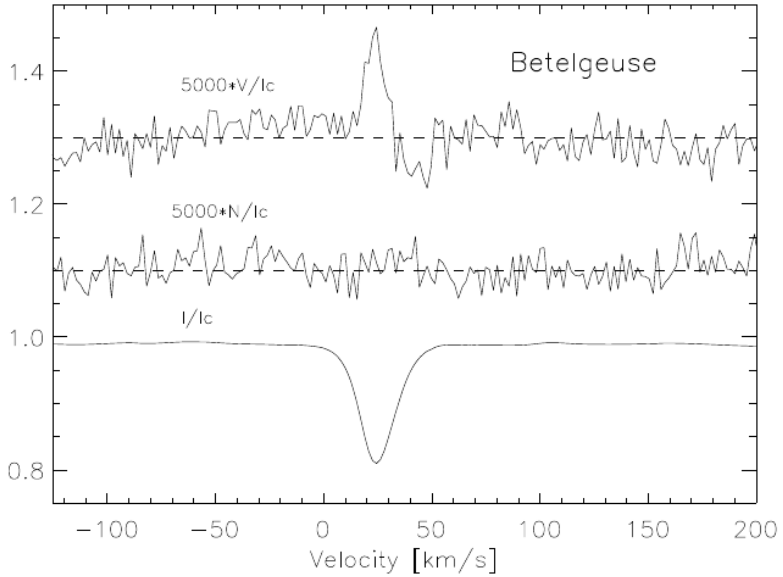

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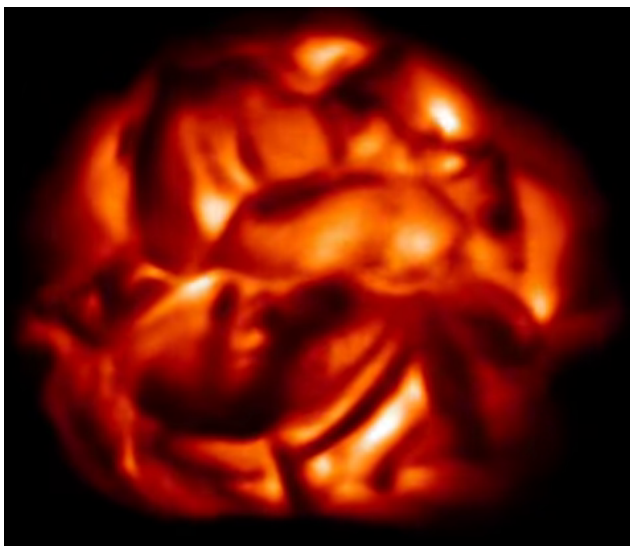
➥ Field variation consistent with convection time-scale

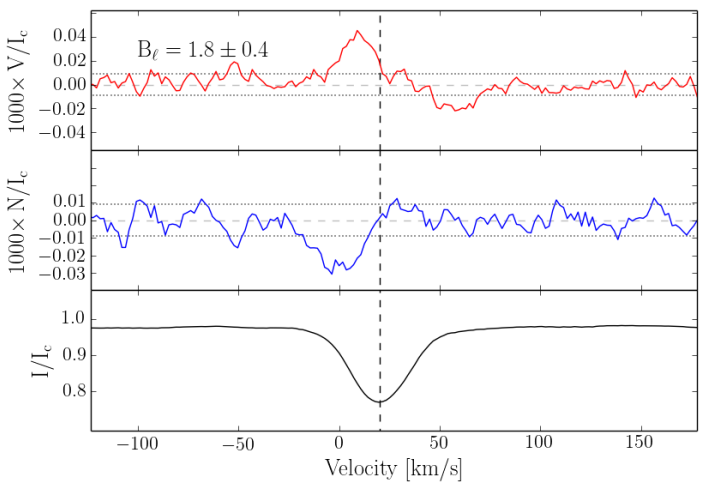
- (*Schwarzschild 1975*, *Freytag et al 2002)* and *Chiavassa et al. 2009*)



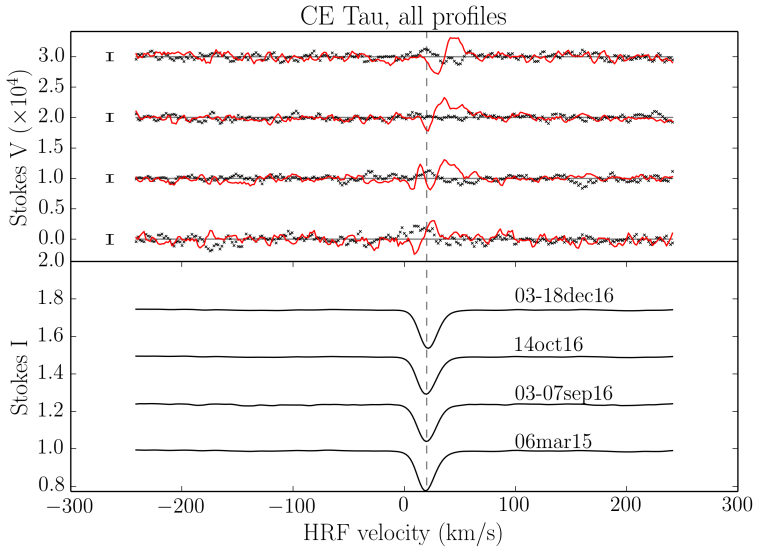
Freytag st35gm04n26

Surface magnetic field in red supergiants

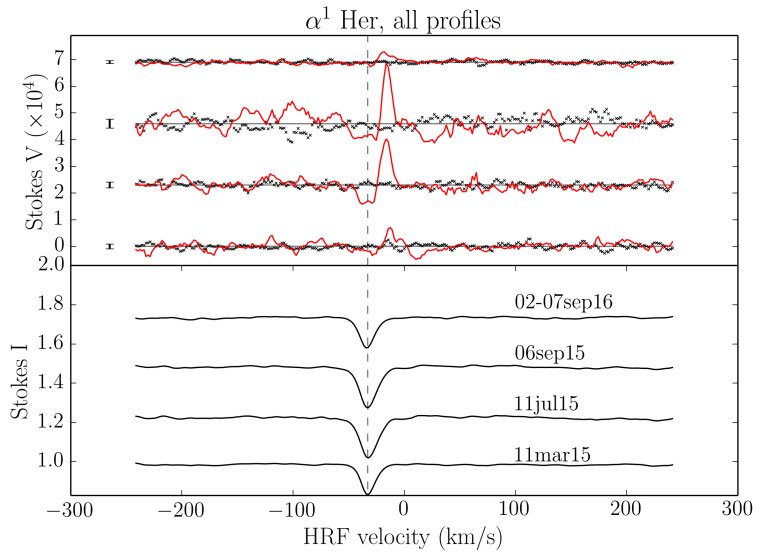
- Detection of a magnetic field in 3 RSG (*Tessore et al. 2017*)
  - "DD" ➔ in CE Tau
  - "DD" ➔ in α Her
  - Ambiguous detection in μ Cep (TBC) ↓



A LSD profile of μ Cep



LSD profiles of CE Tau

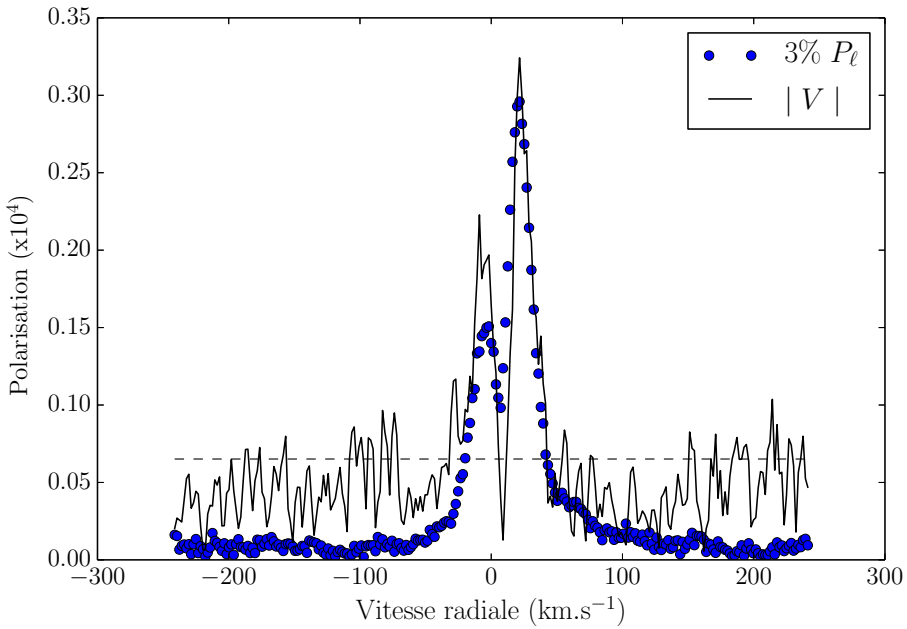


LSD profiles of α Her

- Weak surface fields (about 1 G)
- Hint of time variability

Disambiguation of μ Cep signal (Tessore et al. 17) (1/3)

-> Narval cross-talk QU->V about 3 % !



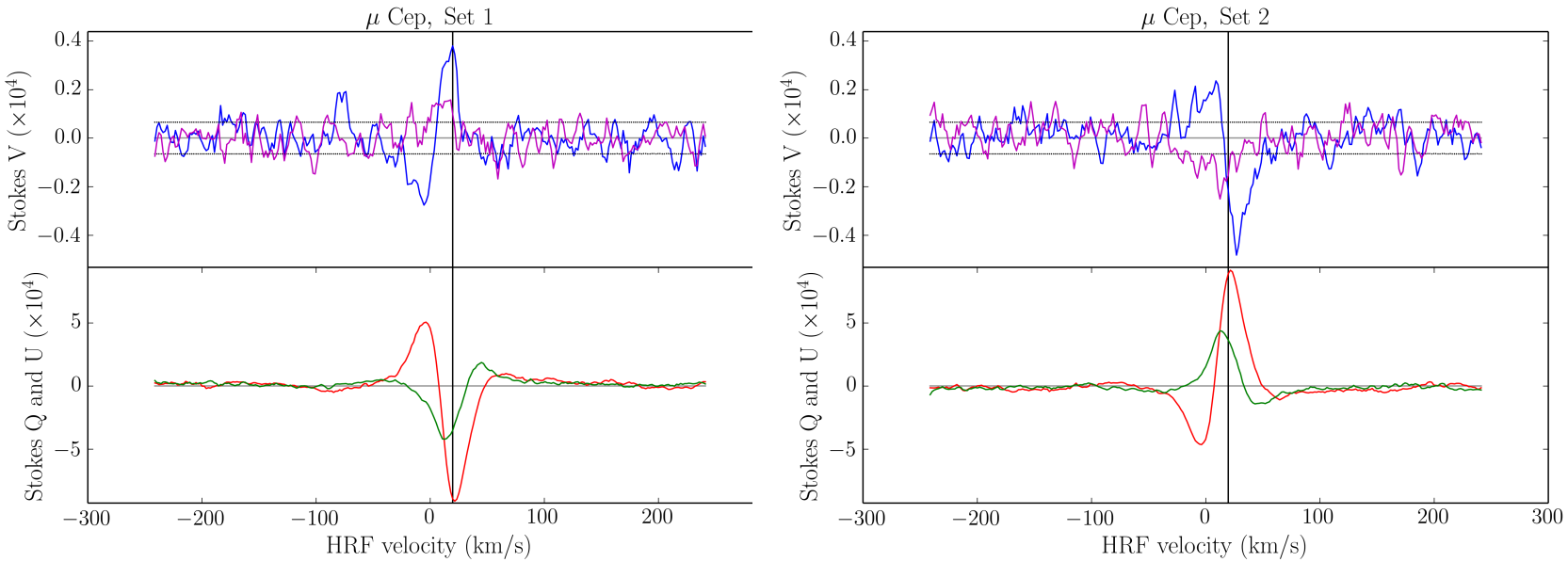
Scale of Stokes V compared to $P_\ell = \sqrt{Q^2 + U^2}$

➔ strong contamination by cross-talk

Disambiguation of μ Cep signal (Tessore et al. 17) (2/3)

-> 2 sets of observations: instrument PA: 0° and -90°

➔ **Q/U change their sign. V remains the same**



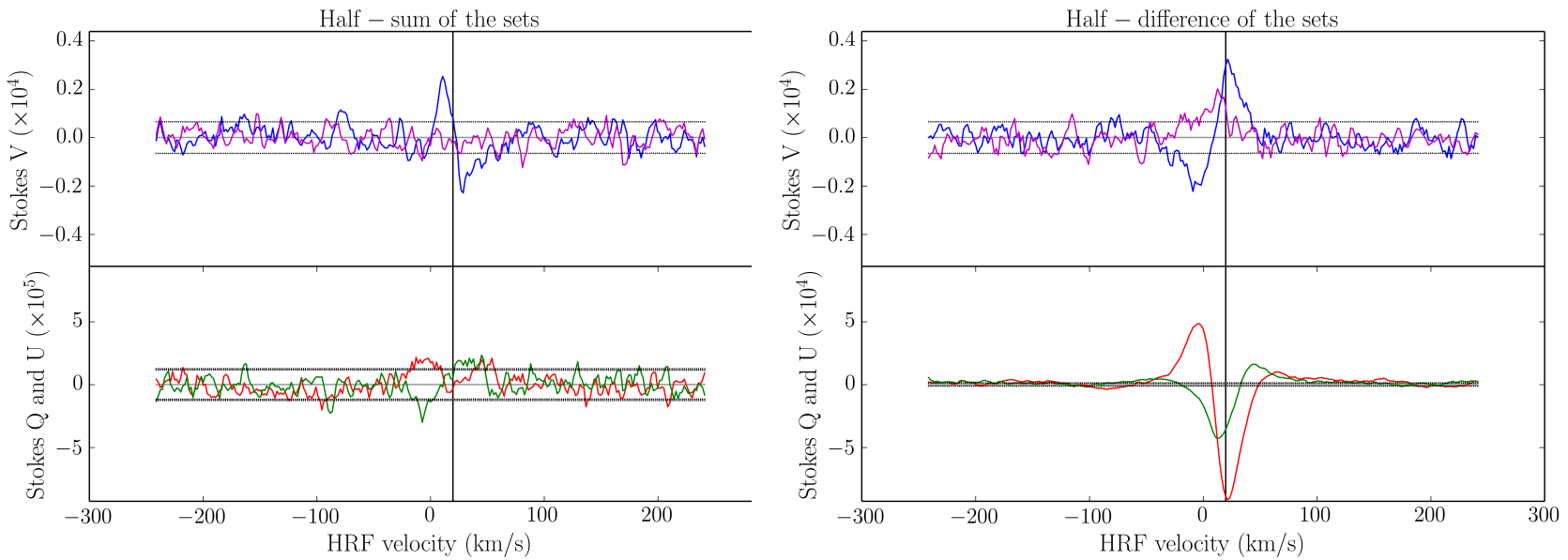
-> Spurious linear polarisation

➔ both in V and Null

Disambiguation of μ Cep signal (Tessore et al. 17) (3/3)

-> Half-sum and **half-difference** to recover genuine signal and **CT function**

➔ Unambiguous MF detection of about 1 G!



-> Origin of linear polarisation ?

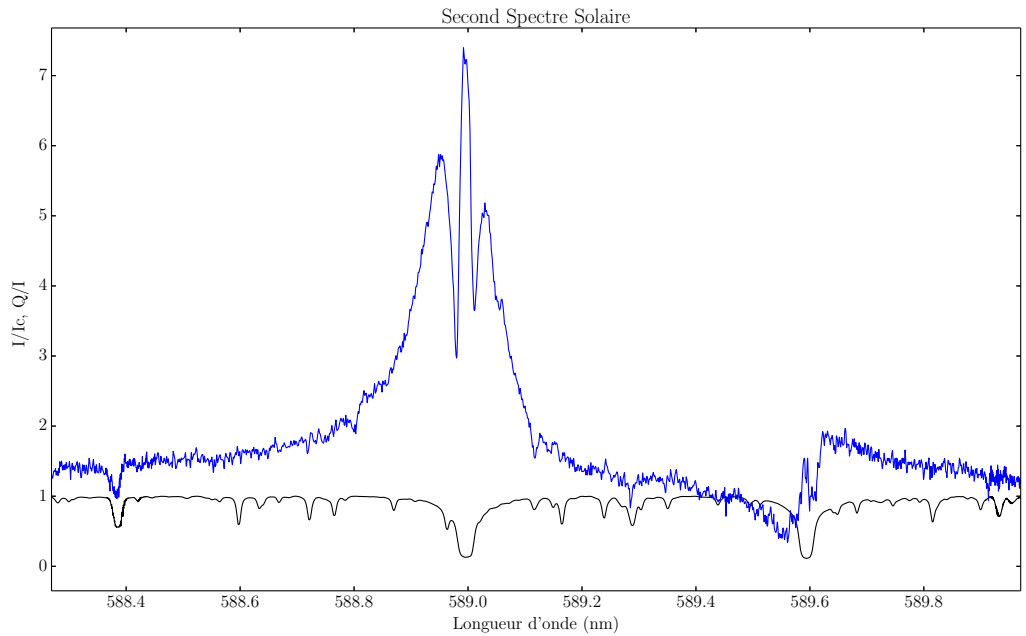
Continuum depolarisation (1/2)

-> Continuum of star is linearly polarised by Rayleigh and Thomson scattering

-> atomic (molecular) lines dilute this polarisation:

➔ continuum depolarisation

-> Second solar spectrum: intrinsic polarisation + depolarisation



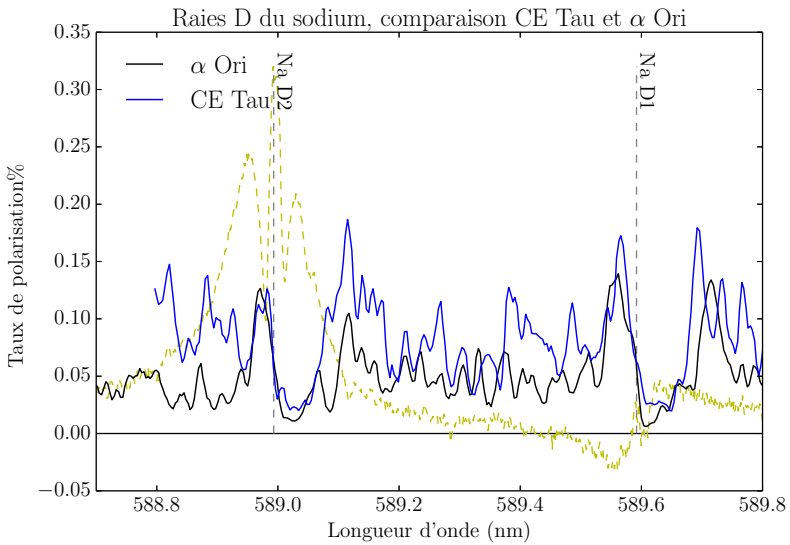
-> Na D lines polarisation -> quantum coherences = intrinsic polarisation

Continuum depolarisation (2/2)

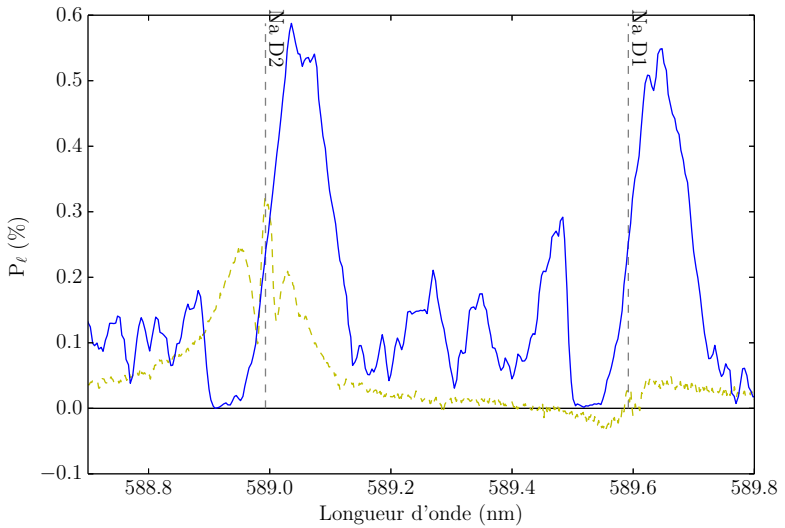
-> We observe mainly depolarisation of continuum

-> Two cases:

➔: Betelgeuse / CE Tau



➔: μ Cep



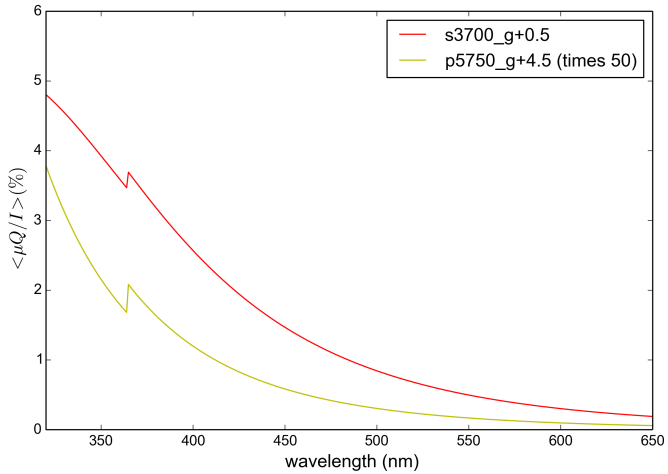
-> Questions:

1- Why not intrinsic polarisation ?

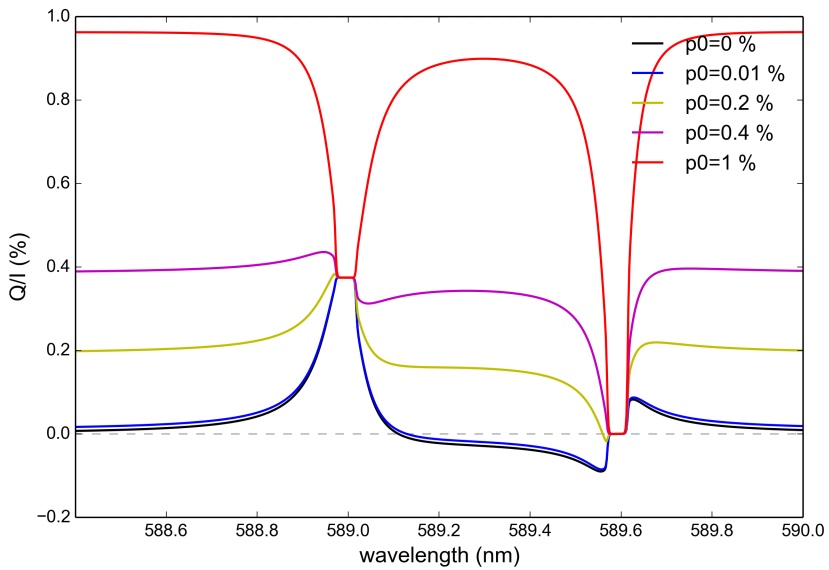
2- Shape of the D line profiles ?

1- Why not intrinsic polarisation ?

-> Continuum polarisation screens out intrinsic line polarisation



Continuum polarisation of a RSG and the Sun (x50)



Polarisation profile of D lines

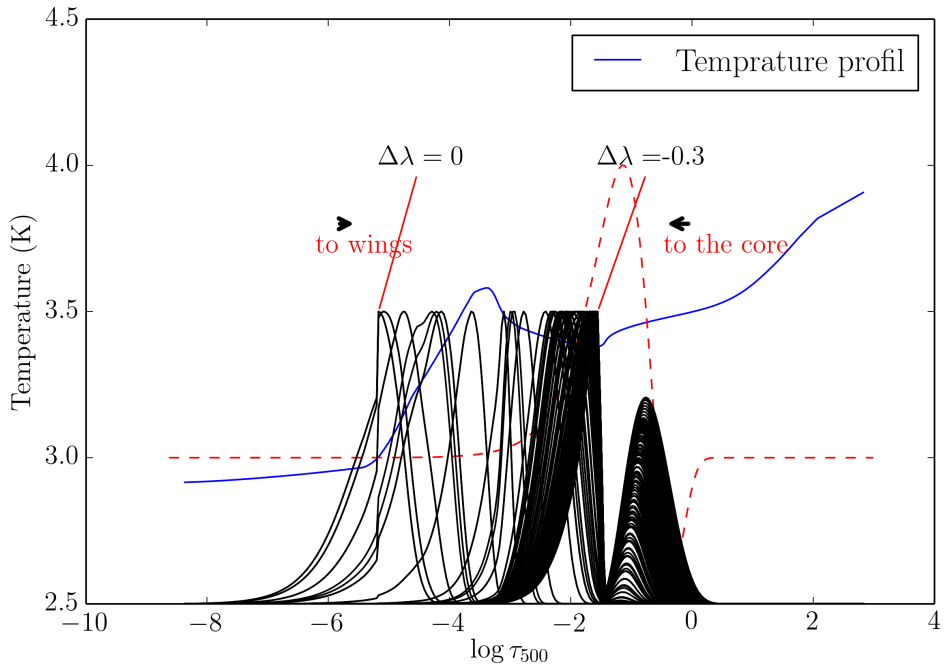
(continuum + line contr.)

2- Shape of the D lines profiles ?

-> The 2 peaks strucutre suggests 2 formation regions for the D lines

➔ solar D lines: wings->photospheric / core-> chromospheric

-> what about RSG stars ?



-> wings and continuum polarisation CF overlap ! depolarisation by wings

-> self-consistent photo-chromospheric models of RSG stars needed !

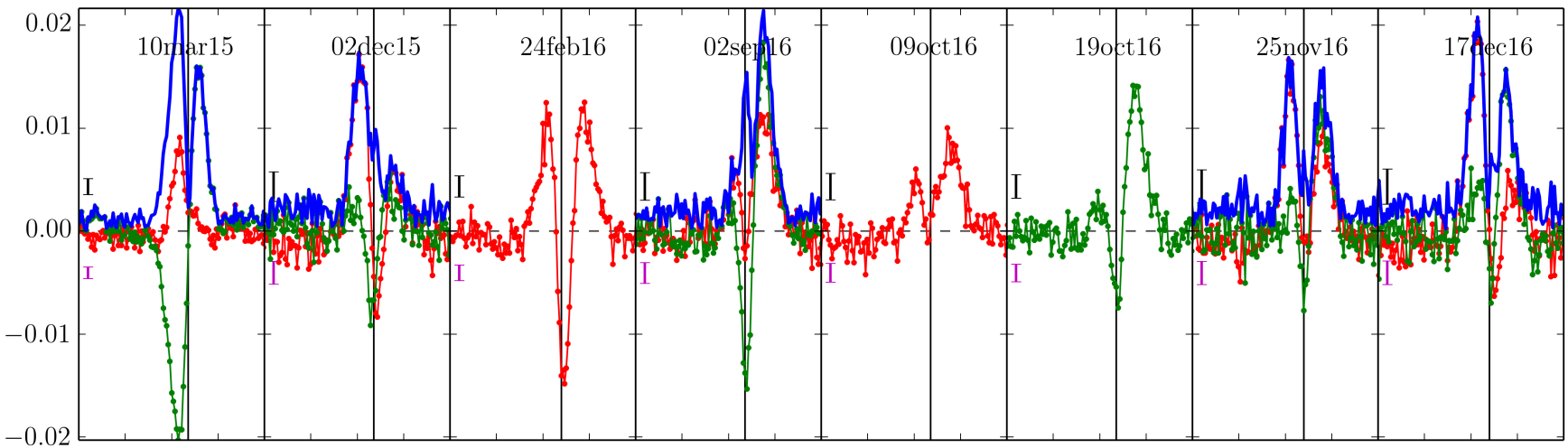
-> Depth dependant modelling of the Na D lines (de-)polarisation

Mapping of structures with spectropolarimetry: case of CE Tau (1/3)

-> we observe Q/U because of surface inhomogeneities

➔ from brightness map -> Q / U profiles

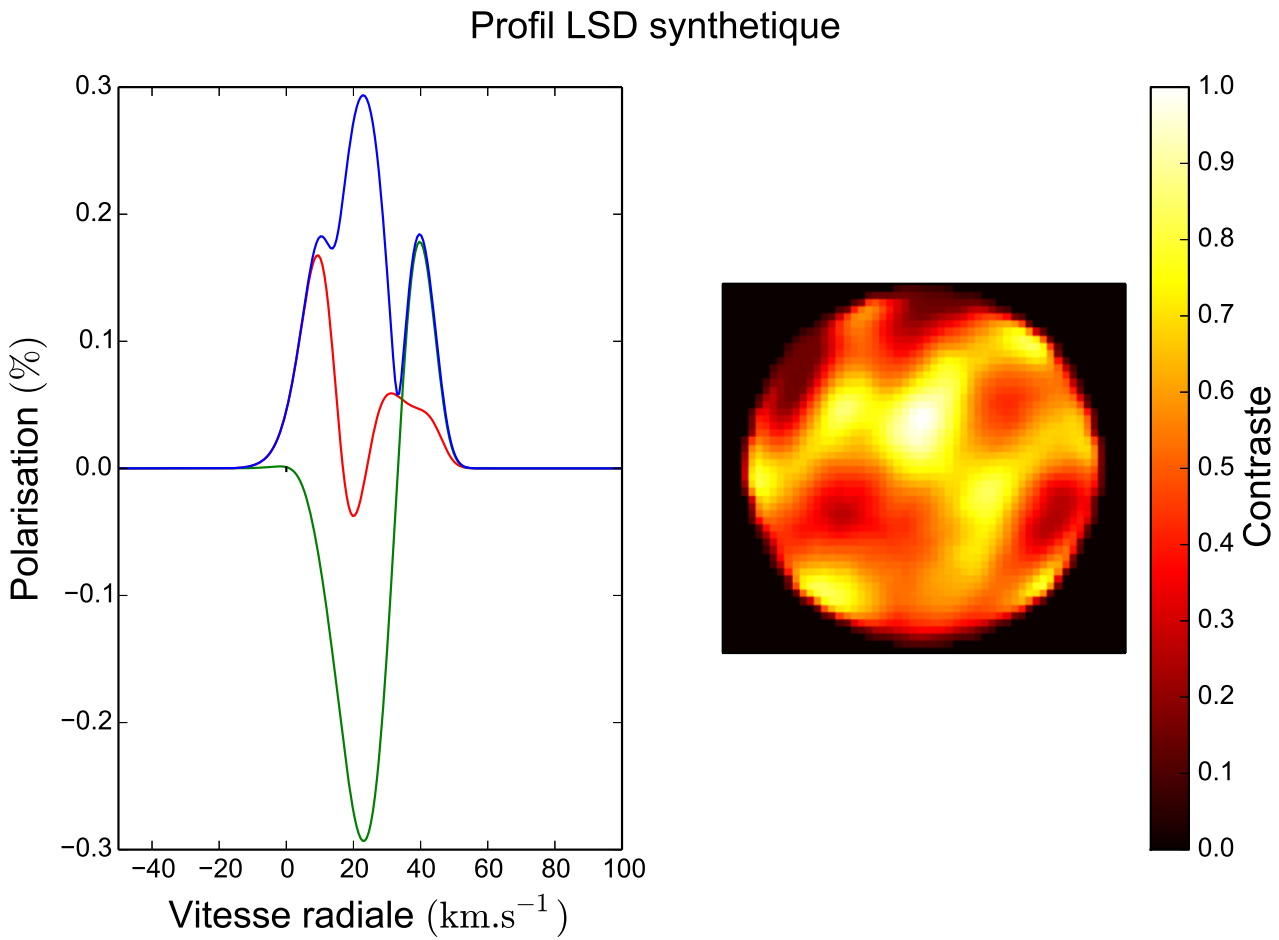
-> Linear polarisation (%) Q (red) U (green) and P_ℓ (blue)



HRF velocity (km/s)

- vertical back lines: radial velocity

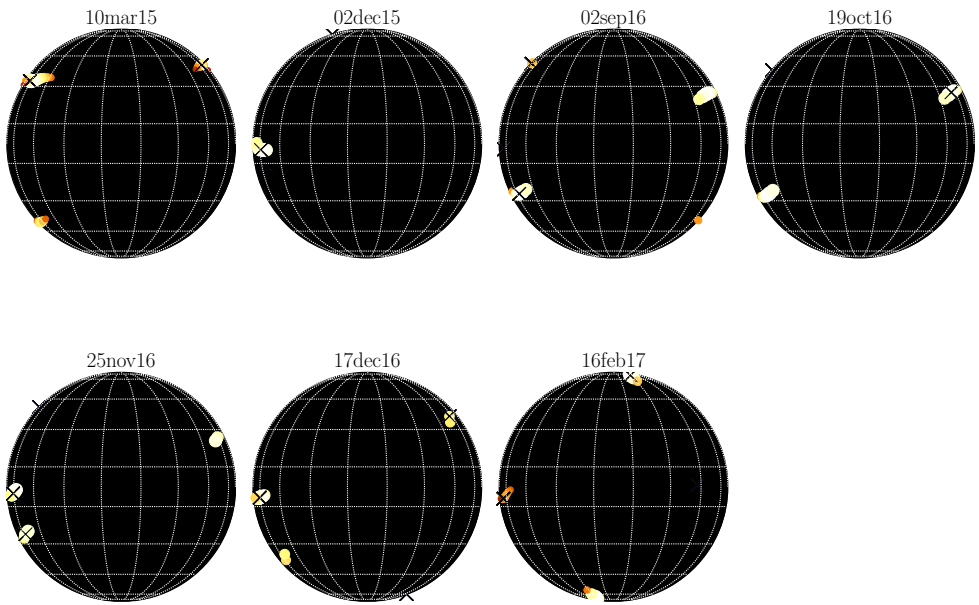
Mapping of structures with spectropolarimetry: case of CE Tau (2/3)



Mapping of structures with spectropolarimetry: case of CE Tau (3/3)

-> from Q / U profiles -> brightness map

➔ some similitude with interferometric obs.



-> A. LOPEZ ARISTE Talk ! for the case of Betelgeuse

Take away messages

results

-> DD of magnetic fields in 3 RSG stars (other than Betelgeuse)

-> Impact of scattering polarisation and cross-talk on Stokes V

-> Origin of the linear polarisation

ongoing works

-> 2 peaks structure of the D lines linearly polarised spectrum

-> Why different levels of polarisation for different RSG stars

-> Inversion method for mapping

-> GRAVITY observations of CE Tau