Magnétisme photosphérique/circumstellaire des étoiles froides évoluées et autres apports insoupçonnés de la spectropolarimétrie…

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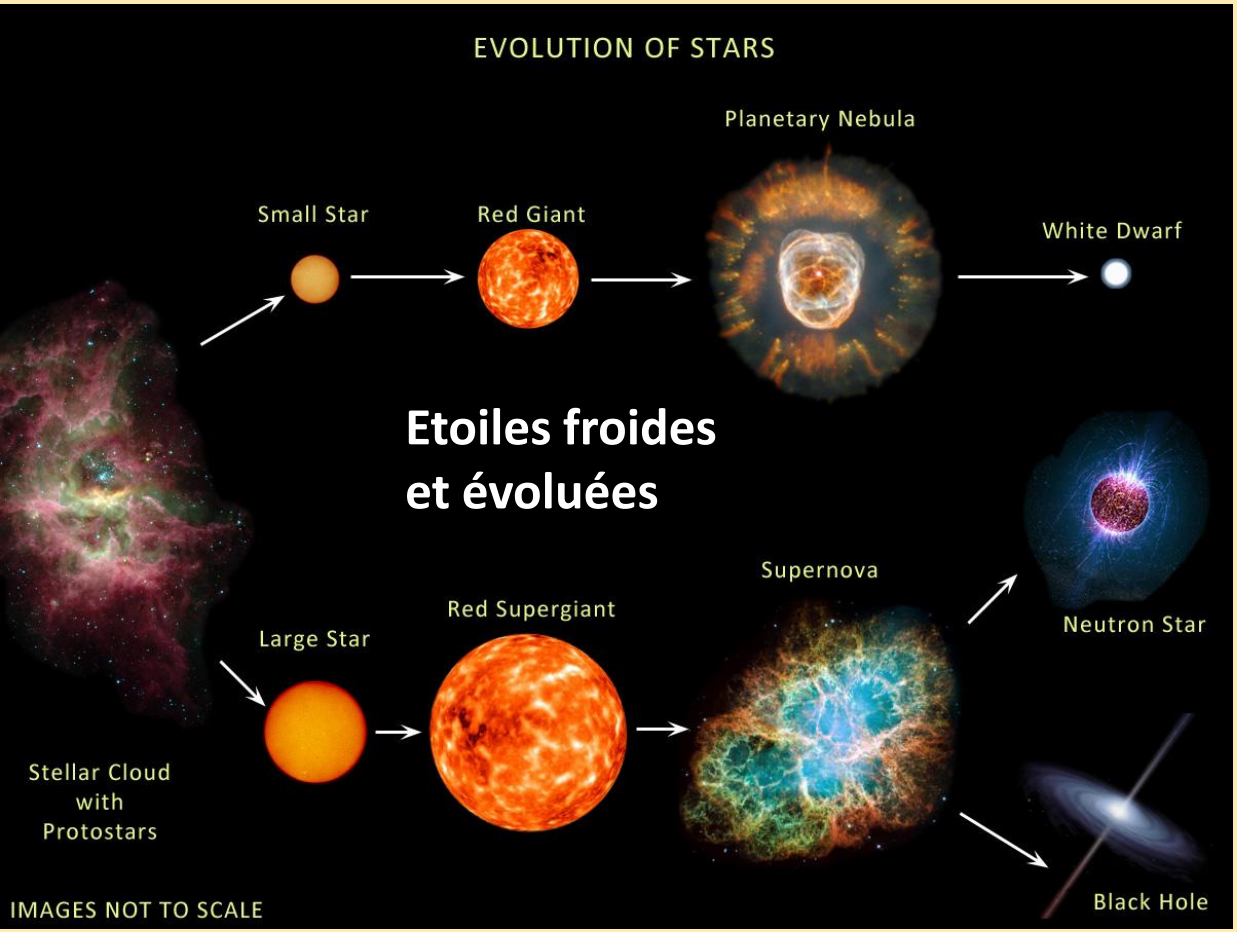
Et les membres du projet PNPS ***MAGEVOL/FIESTA*** *: IRAP-LAB-LUPM-OHP*

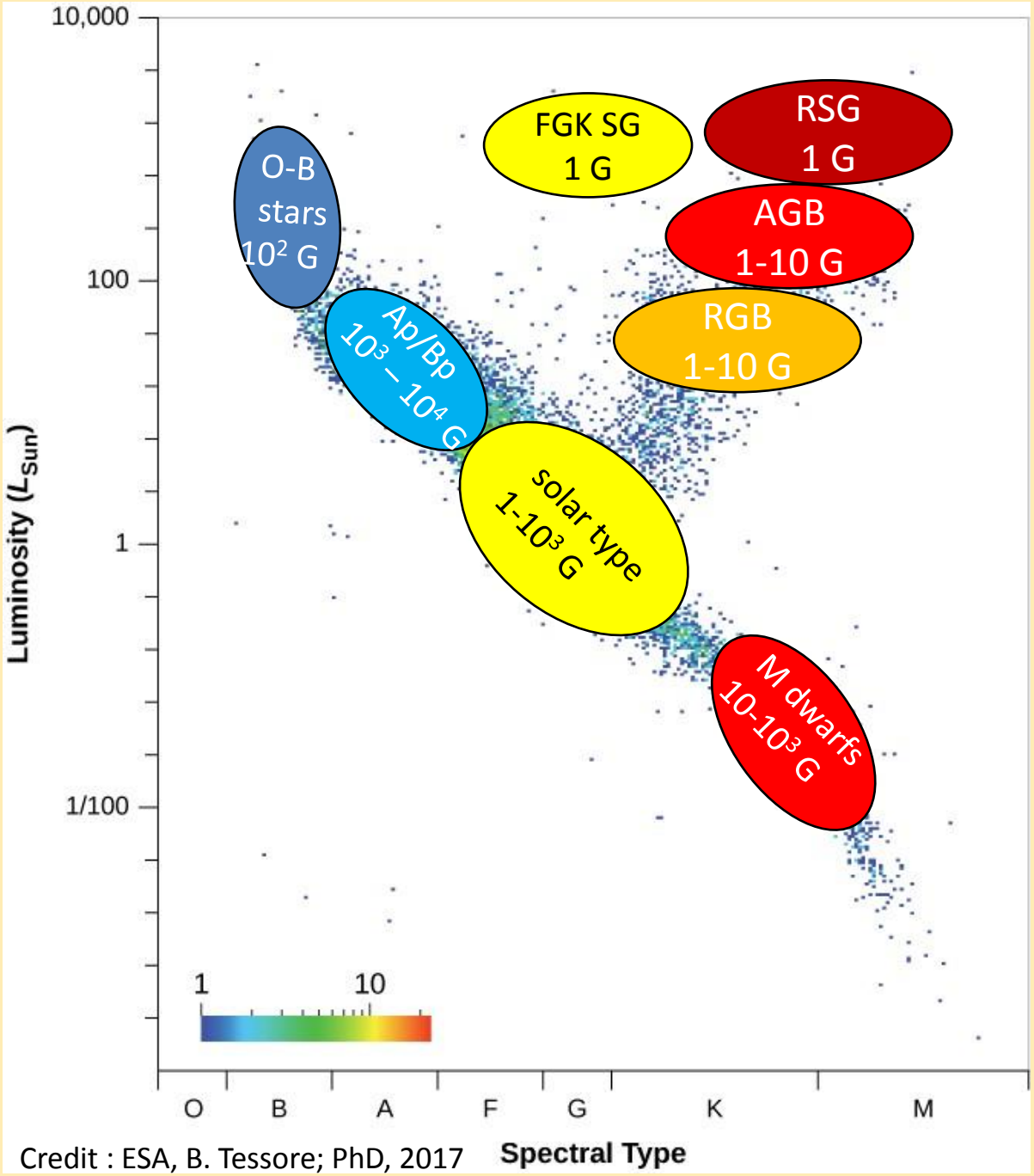
Magnétisme photosphérique/circumstellaire des étoiles froides évoluées et autres apports insoupçonnés de la spectropolarimétrie…



2- AGB/Post-AGB :
connecter le magnétisme de surface et dans l'ECS

3- Géantes Rouges :
Magnétisme de surface le long de la branche des géantes

1- **RSG** : Focus sur **Bételgeuse**



Credit : ESA, B. Tessore; PhD, 2017

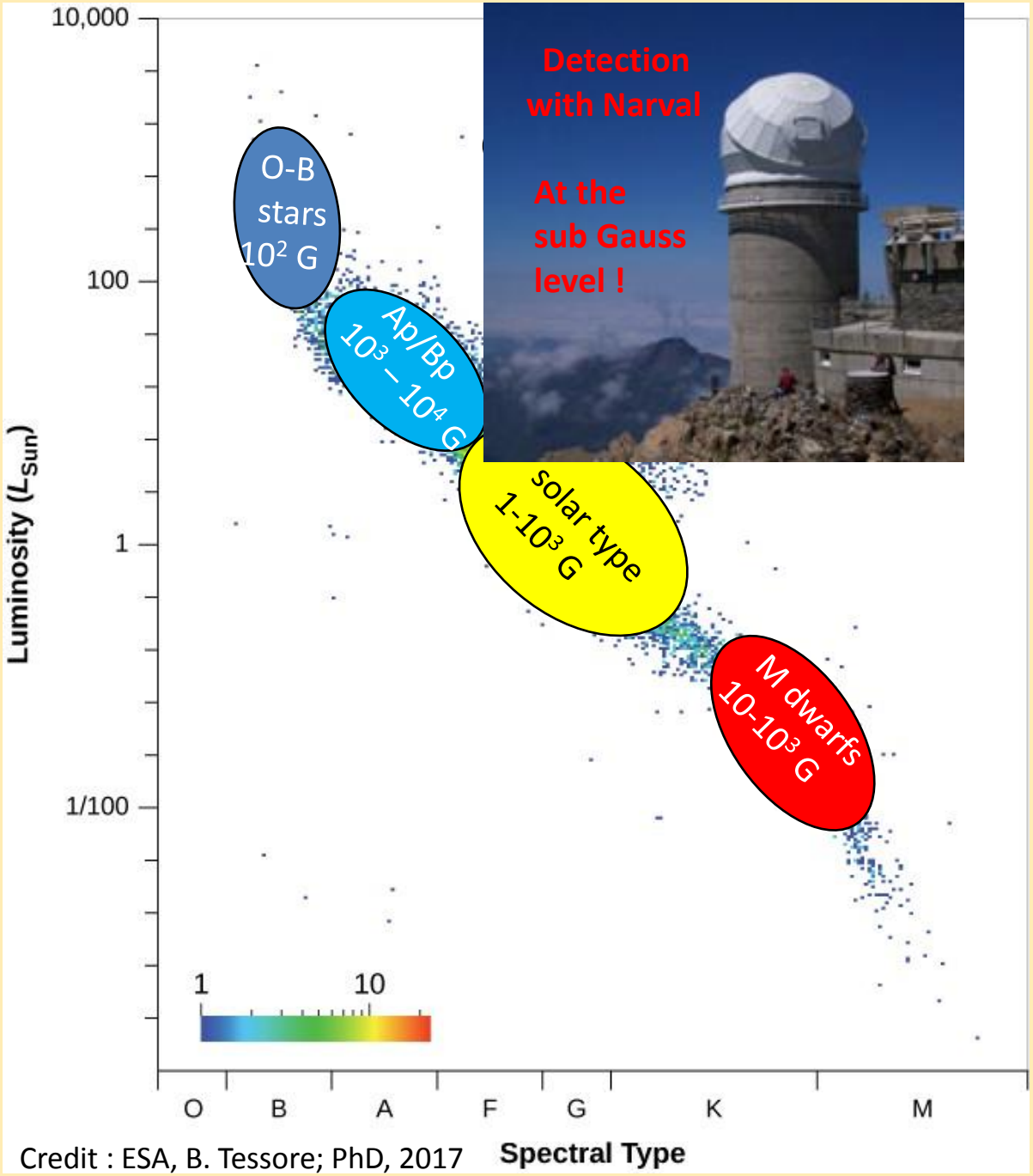
The (very) weak field regime ….

Cool Evolved Stars

among the

Magnetic HR Diagram

(from 15 years of spectropolarimetry)



The (very) weak field regime ….

Cool Evolved Stars

among the

Magnetic HR Diagram

(from 15 years of spectropolarimetry)

Cool Evolved Stars

RGB, RSG stars : core He-burning phase

AGB stars : He- and H-shell burning phase

Teff = 4000-2500 K ; log g = 0 − 2

Convection :

Large-scale convective motions in an **extended atmosphere** with a **few giant cells** at the surface *(Schwarzschild,1975 ; see also papers from Stothers)*

Radiative hydrodynamic simulations *(Chiavassa+ 2010 ; Freytag, 2015)*

Pulsations :

In AGB (Miras) : pulsations are expected to generate shocks (also in some Post-AGB)

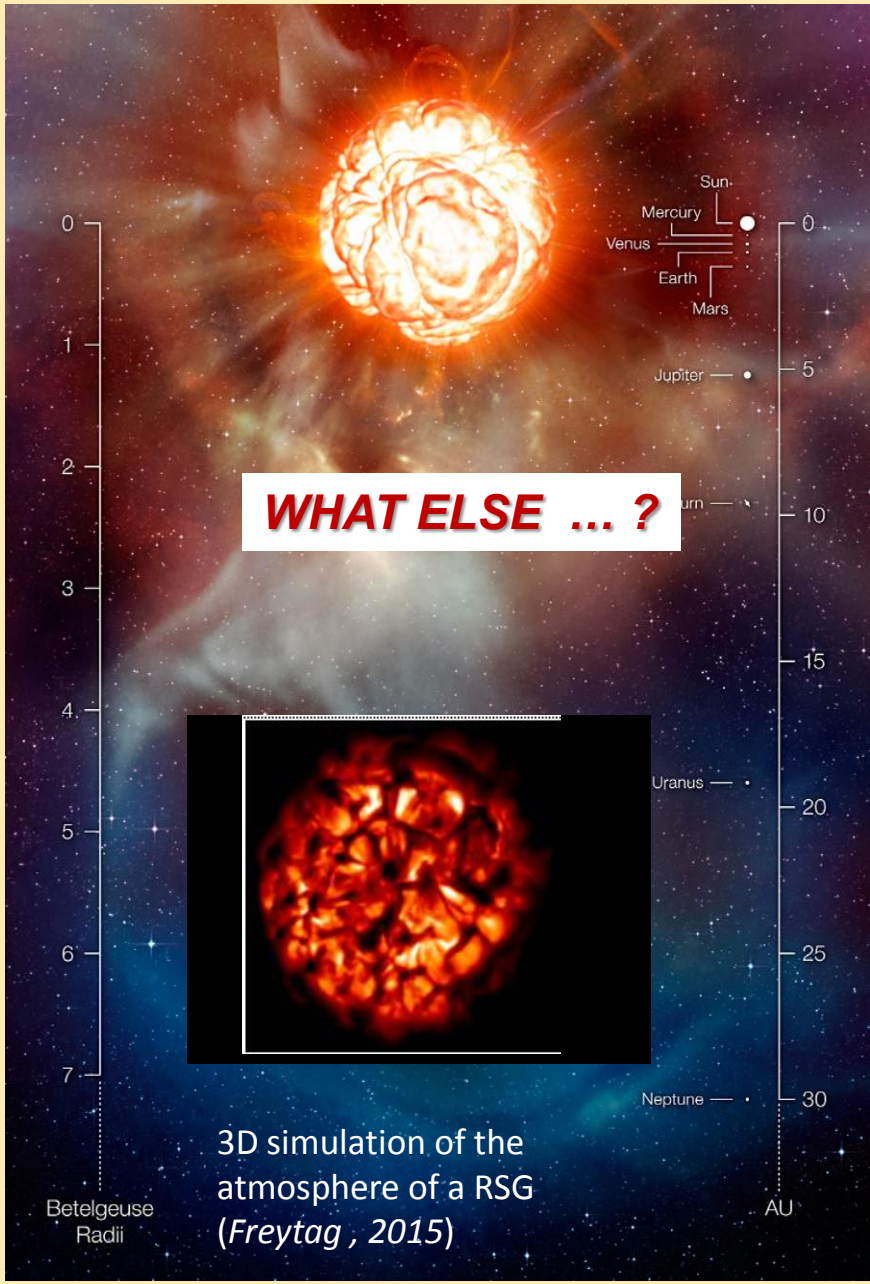
In RSG : convection is expected to generate supersonic motions and shocks

Mass loss :

up to $10^{-4}\ M_{\odot}/y$

Radiation pressure on dust *(Höfner, 2011)*
+ levitation due to shocks
Convection triggered mass loss *(Josselin+2007)*

⇒ **Photospheric and atmospheric dynamics**



3D simulation of the atmosphere of a RSG (*Freytag , 2015*)

Spectropolarimetry : Circular and Linear Polarisation

ESPaDOnS@CFHT
2004+
3.60m Telescope

Narval@TBL
2006+
2mTelescope

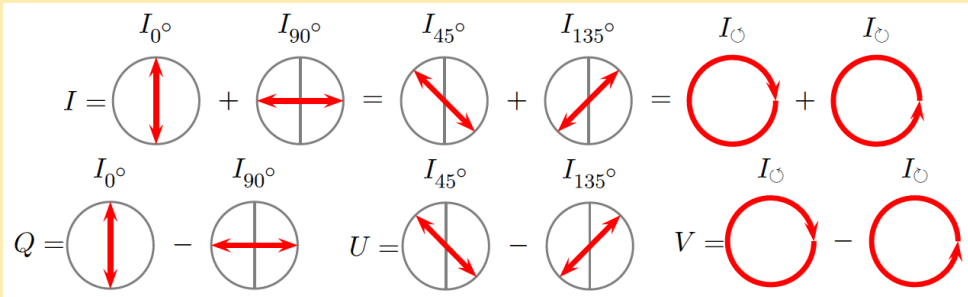
HARPSpol@ESO
2009+
3.60m Telescope

Spectral Range : 375 – 1050 nm
Spectral Resolution : 65 000

Spectral Range : 380 – 690 nm
Spectral Resolution : 115 000

Simultaneous measurements in two polarisation states :

⇒ Stokes I (unpolarised) spectrum
+ Stokes V (circularly) or Stokes U
or Stokes Q (linearly) polarised spectrum

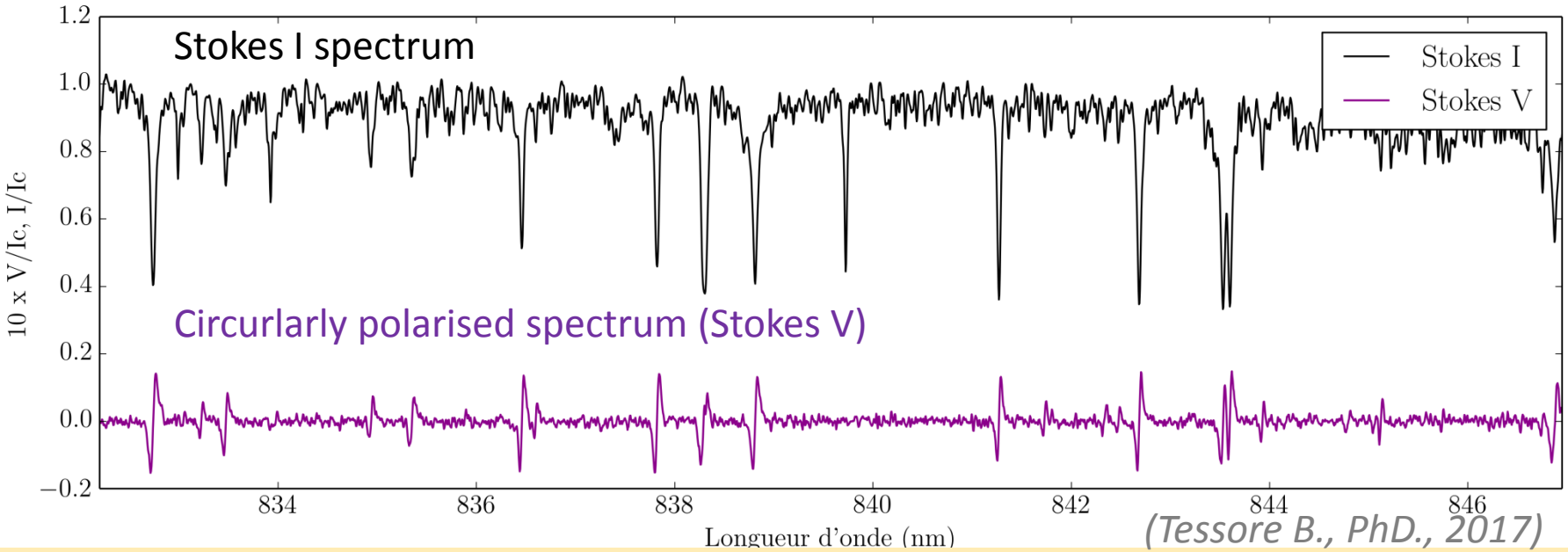


⇒ Polarisation **within spectral** (atomic) **lines**

Polarimetric sensitivity $\sim 10^{-4}$ of the unpolarised continuum

Spectropolarimetric data : what do they look like ?

The M Dwarf AD LEO Spectral Type = M4V ; Teff = 3400 K ; log g = 5.0



(Tessore B., PhD., 2017)

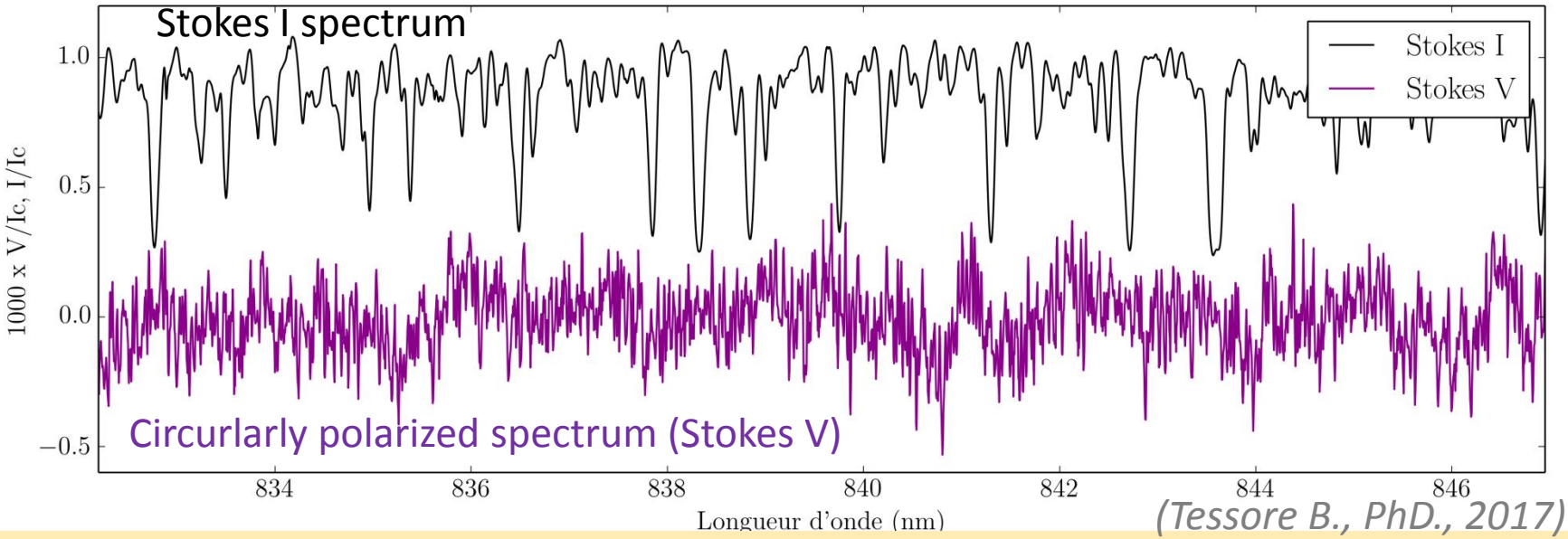
-Classical *S-type* Zeeman profile associated to individual atomic lines

- Estimation of the longitudinal component of the magnetic field :

Bl = 200 G *(Morin et al., 2008)*

Spectropolarimetric data : what do they look like ?

The Red Super Giant Betelgeuse Spectral Type = M2I ; Teff = 3500 K ; log g = 0.0



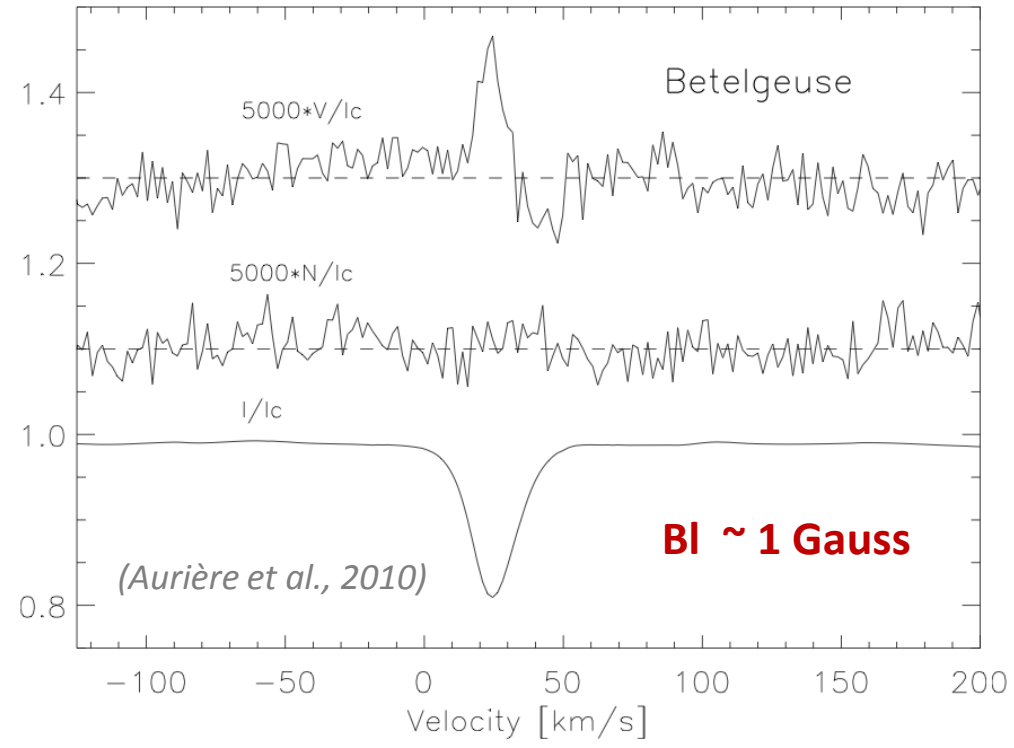
(Tessore B., PhD., 2017)

⇒ The field is too weak to allow its measurements from individual atomic lines

⇒ Need to use a multi-lines method (LSD software, *Donati et al., 1997*) exploring the **whole spectral domain** in the visible : 380 nm – 1100 nm

Circular Polarisation :

Zeeman detection : sub-Gauss field



Mean Zeeman shift of a transition

$$\Delta\lambda_B = \frac{\lambda_0^2 eB}{4\pi m_e c^2} = 4.67 \times 10^{-12}\,\lambda_0^2\, g_{eff} B$$

g_{eff} : **Landè factor** (sensitivity of a transition to B)

If **weak magnetic field** (< 100 G) :

Polarised signatures undetectable at the level of individual lines

=> A multiplex approach over the observed spectral range (thousands of **atomic lines** involved)

The Least Square Deconvolution (L.S.D.)
(Donati et al., 1997)

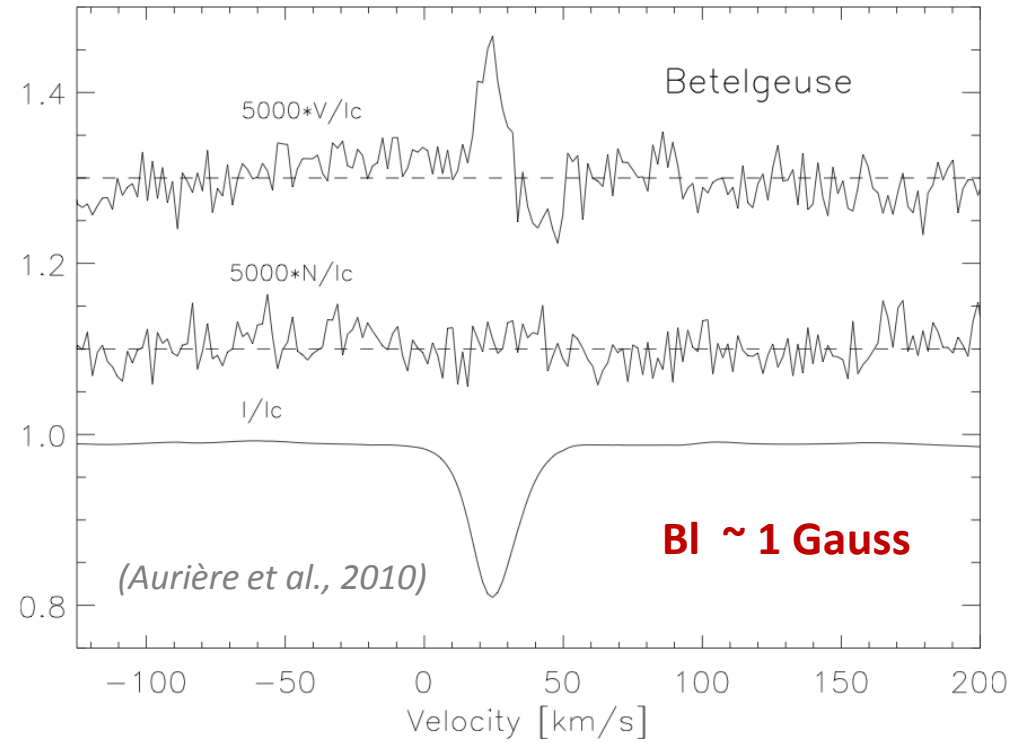
Estimation of Bl, the **Longitudinal Component of the Magnetic Field** :

$$B_l(G) = -2.14 \times 10^{11} \frac{\int v V(v)\,\mathrm{d}v}{\lambda_0 g_{eff} c \int [I_c - I(v)]\,\mathrm{d}v}$$

First-order moment method
(Rees & Semel, 1979)
adapted to LSD profiles.

1- RSG: Surface Magnetism

Zeeman detection : sub-Gauss field



Bételgeuse : M2 Iab

Teff = 3650 K

(Levesque et al., 2005)

P_{rot} = 36 +/- 8 years

(Kervella et al., 2017)

$Ro \sim P_{rot} / \tau_{conv}$

$=> R_o > 100$!!

not able to sustain a α-ω type dynamo

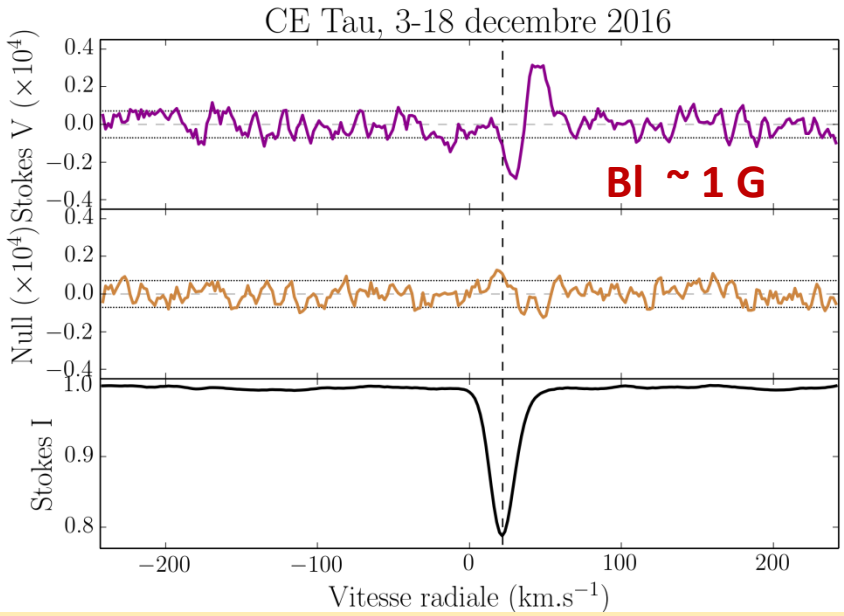
MHD simulations

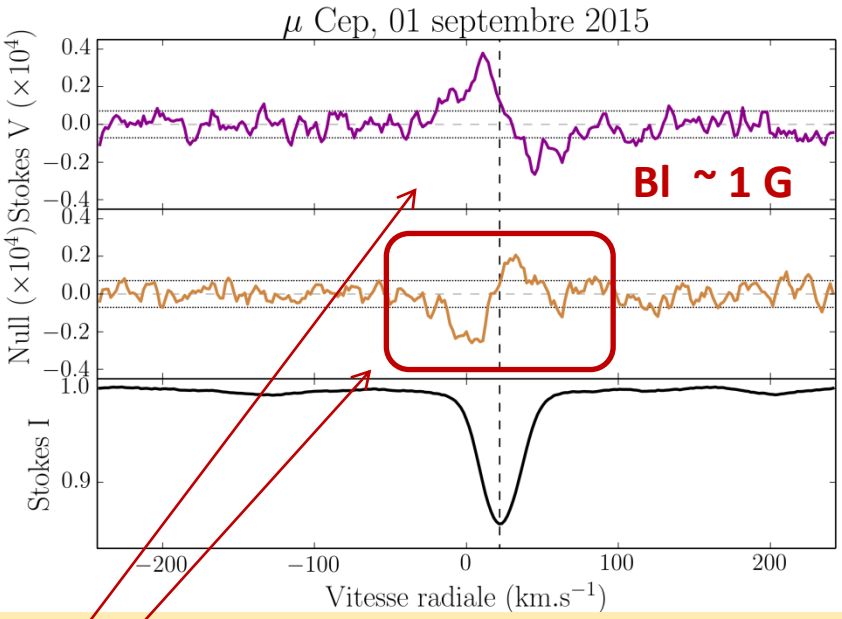
(Dorch & Freytag, 2003)

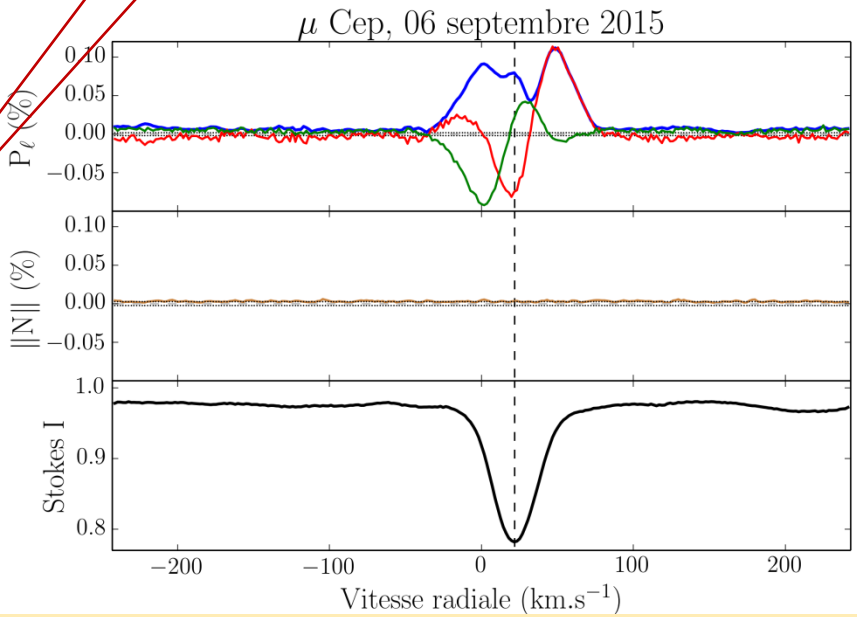
The large-scale convective motions can generate **small-scale dynamo action,** and thus transitory fields.

But the geometry of magnetic field remains unknown !

Two new detections of surface field in M-type RSG







Detection of strong linear polarisation

V << U & Q => Non Zeeman origin

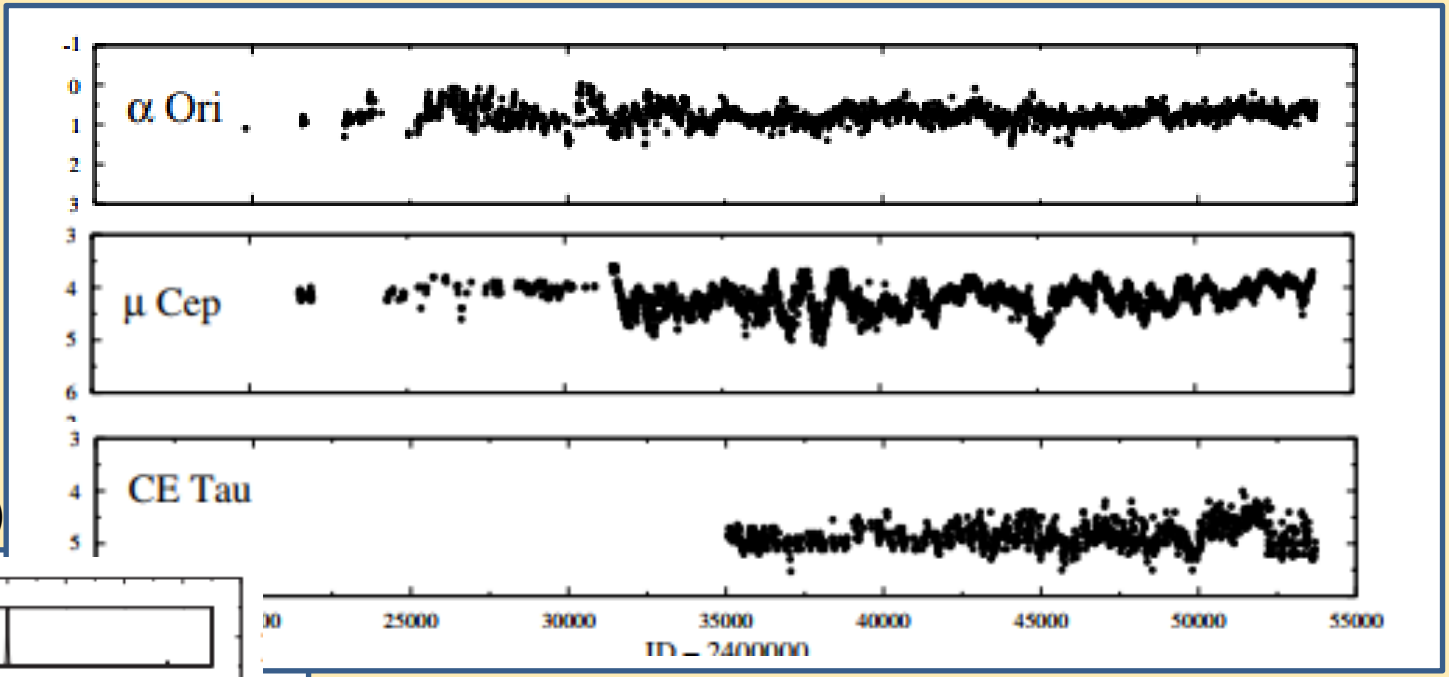
=> Crosstalk from linear polarisation

(Tessore et al., 2017 and Tessore B., PhD., 2017)

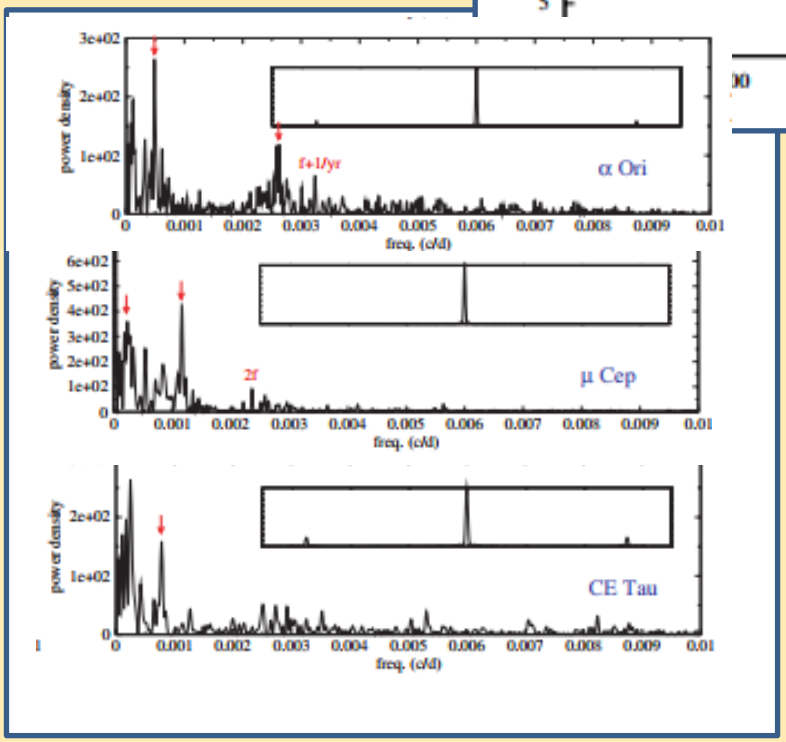
Light variations and characteristic timescales in RSG

AAVSO light curves of RSG variables (10-d bins)

(Kiss et al., 2006)



Power density spectra of AAVSO data (insets : spectral window)



α Ori : P_1= **388** +/- 30 d P_2 = **2 050** +/- 460 d (**LSP**)

μ Cep : P_1= 860 +/- 50 d P_2 = 4 400 +/- 1 060 d

CE Tau : P_1= 1 300 +/- 100 d

Betelgeuse :

A spectropolarimetric monitoring along

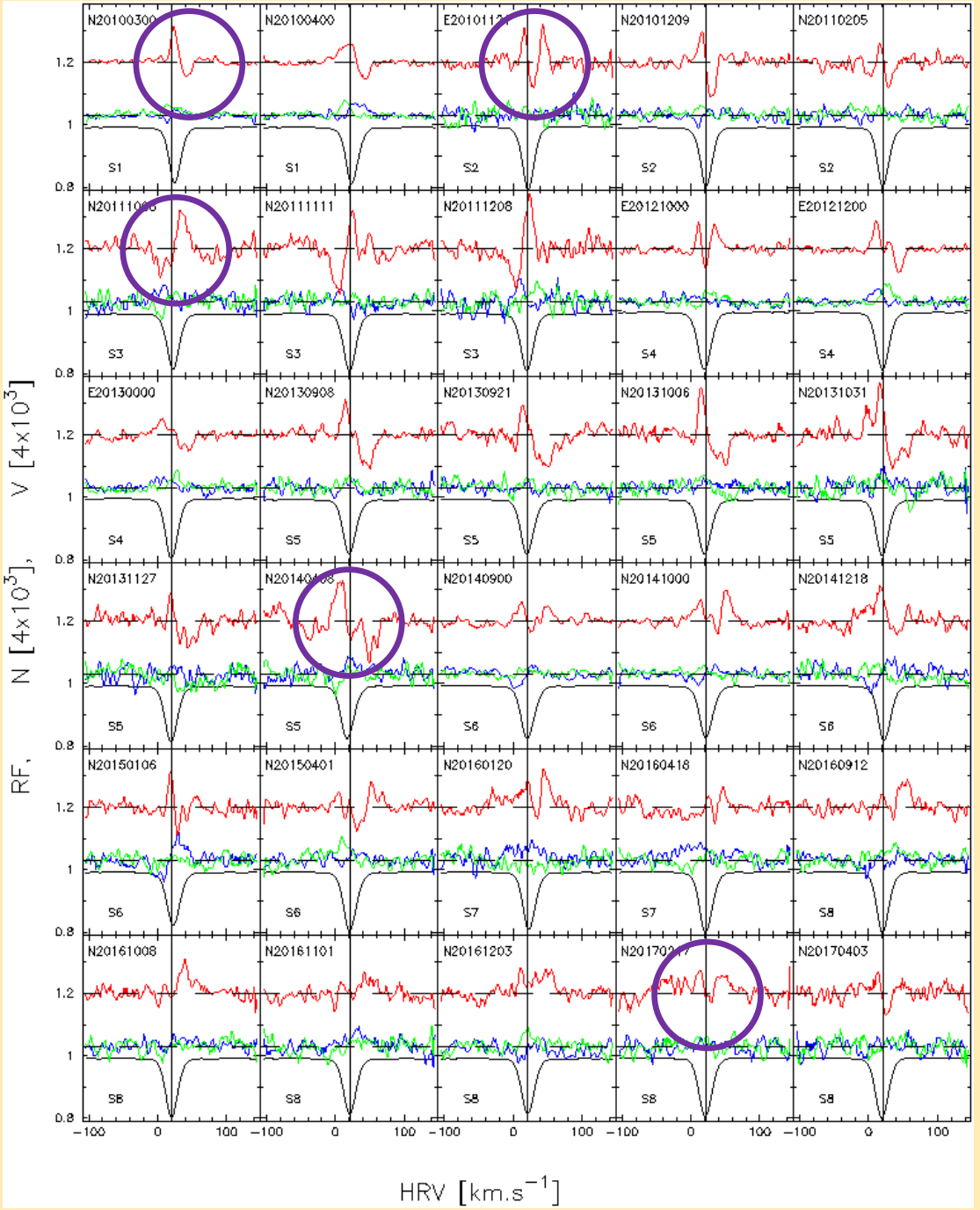
7 years !

From march 2010 to April 2017
over 8 seasons
(still in progress in QUVI)

Any *periodicity* ?

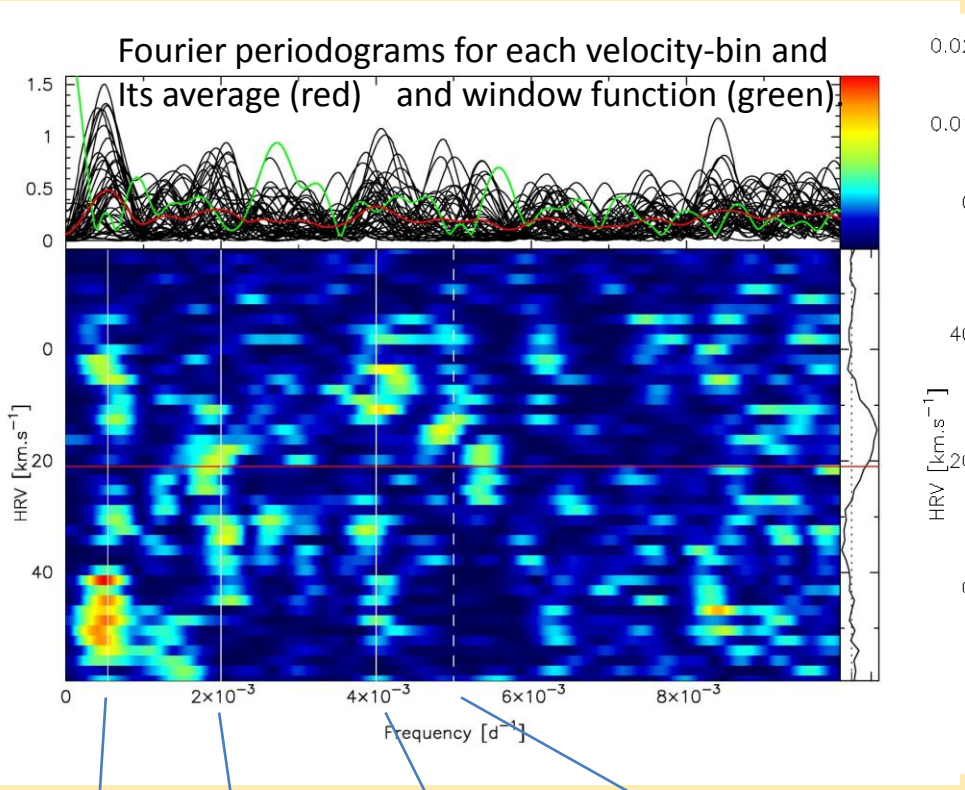
Magnetic spot(s) model

(Mathias et al., 2018)



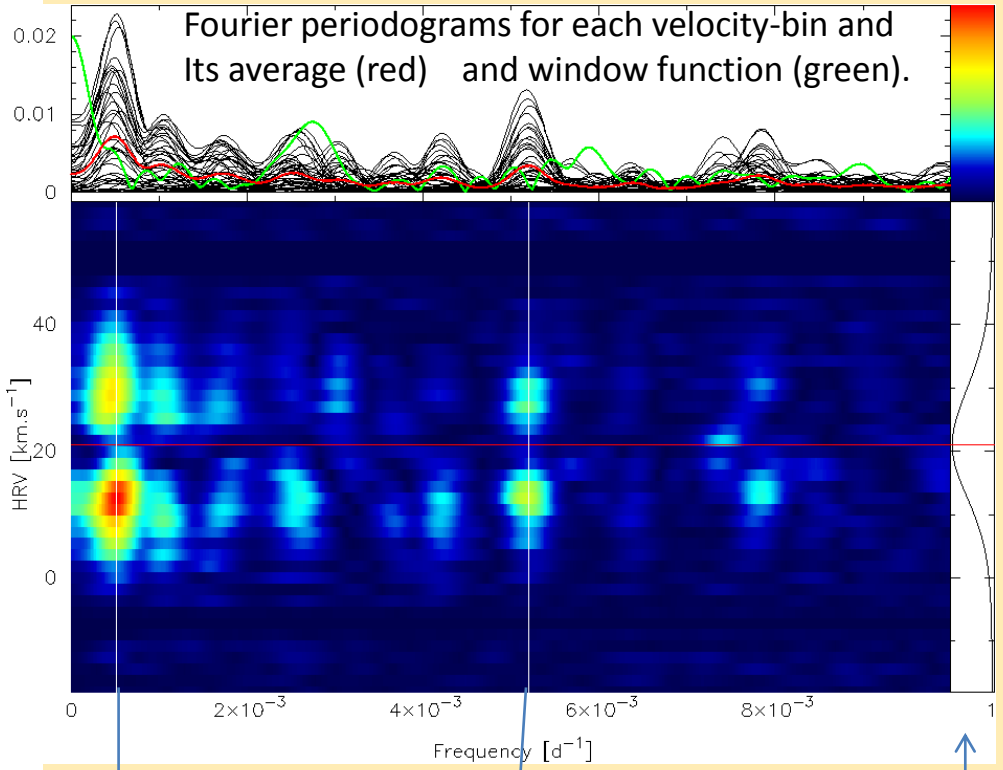
2D Fourier analysis (CLEAN analysis)

Stokes-V parameters (30 data)



1850 d 500 d 250 d 200 d

Stokes-I parameters (150 data)



1850 d 200 d mean-I profile (star velocity)

Characteristic timescales *(Mathias et al., 2018)*

A common information (@ 1 850 d) in both Stokes V and Stokes I parameters !

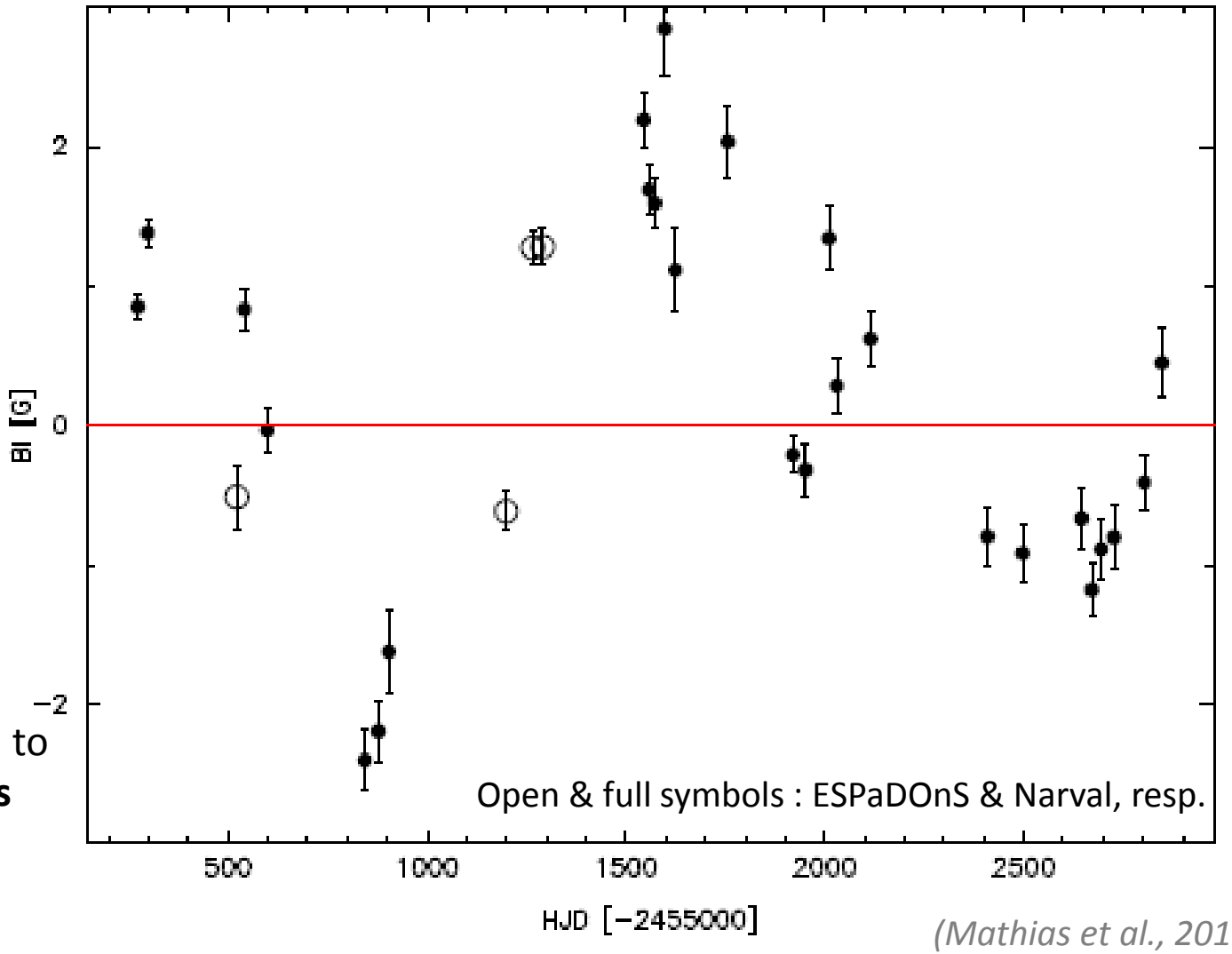
Evolution of the longitudinal component Bℓ along the 8 seasons.

A 1 850 d *period* ?

A connexion to the Long Secondary Period (LSP) ?

LSP : origin from convective motions
(Stothers, 2010)

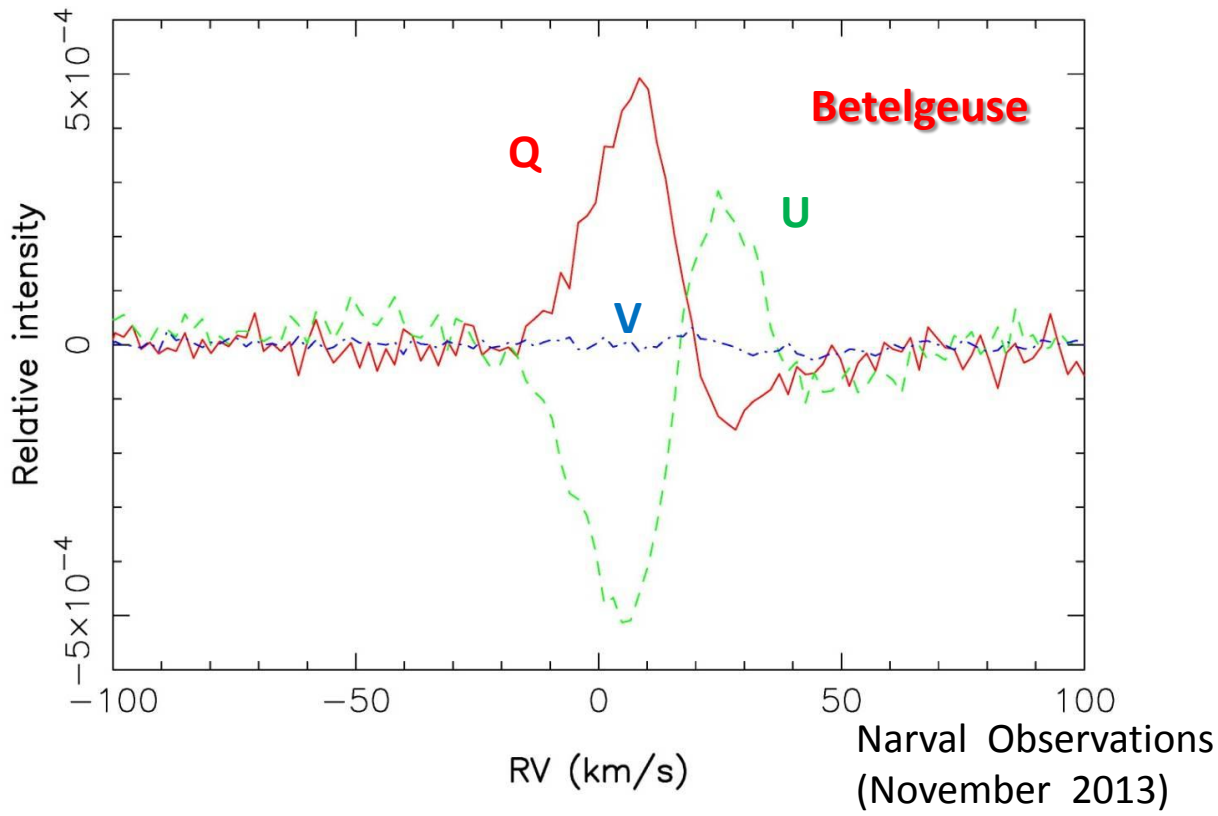
Surface magnetism might be connected to a **long term process** e.g. the turnover timescale of giant convective cells.



(Mathias et al., 2018)

Apport insoupçonné de la spectropolarimétrie…

Strong linear polarisation signal within atomic lines
(and a **marginal detection on V**, from a single sequence)



LSD with maks composed of ~16 000 metallic lines !

Linear polarisation in the lines (individual / global)

(Aurière et al., 2016)

Also detected in other RSGs *(Tessore+2017)*, and
in pulsating AGB (Mira stars) and P-AGB (RV Tauri stars) - *(Lèbre+2015)*

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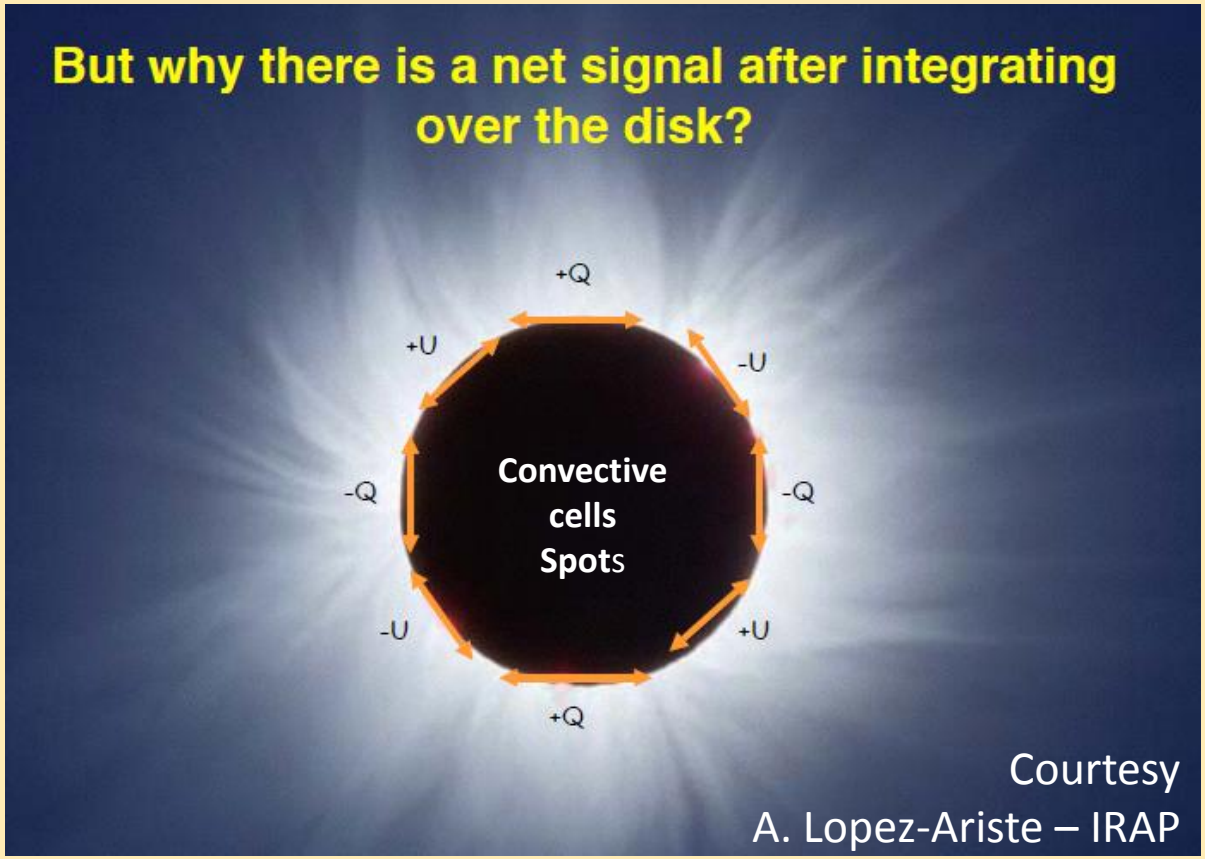


LSD with maks composed of ~16 000 metallic lines !

Linear polarisation in the lines (individual / global)

Cf. solar case

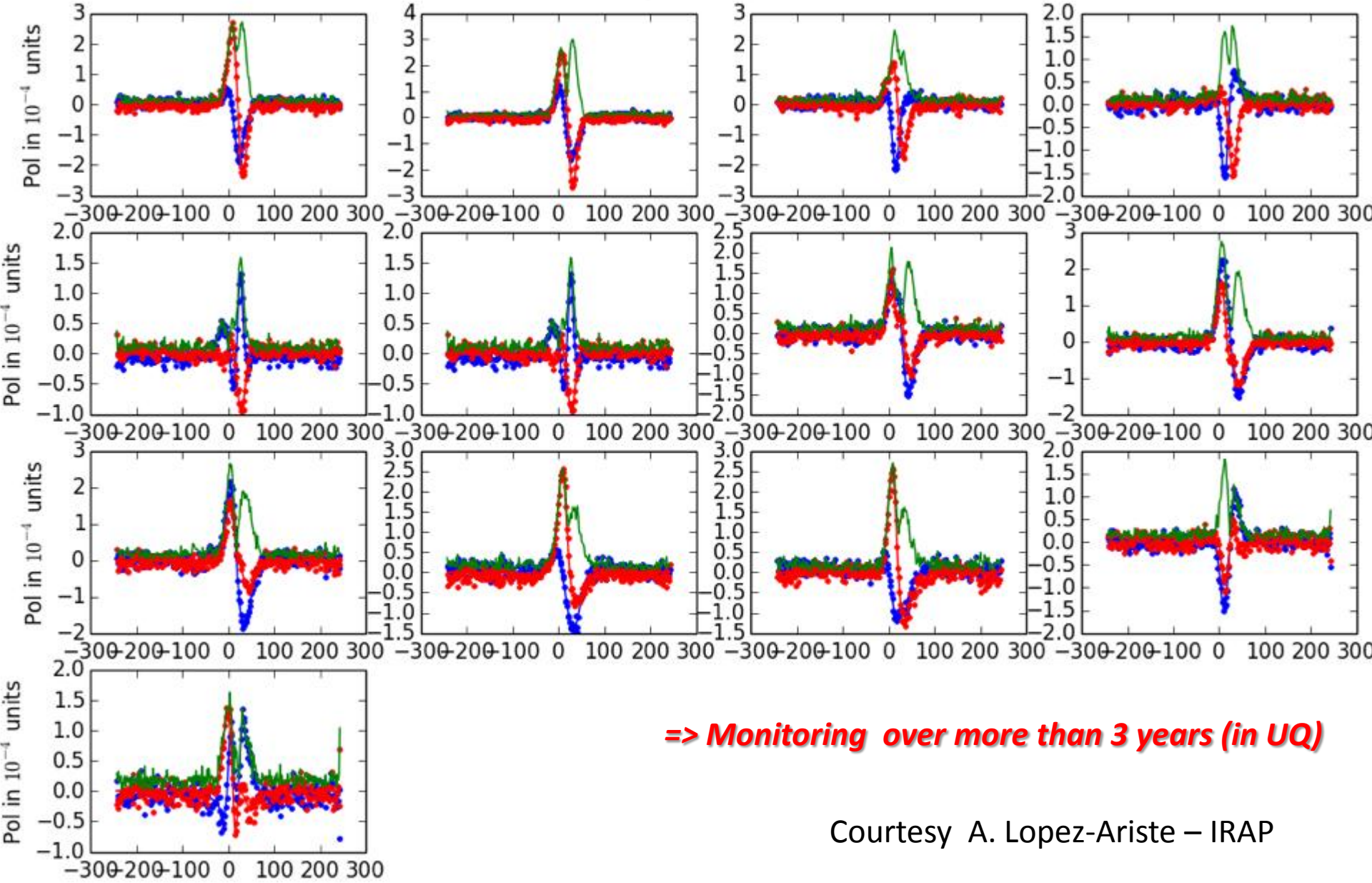
Line depolarisation of the continuum polarised by Rayleigh scattering.

Potential diagnostic of photospheric asymmetries ...

(Aurière et al., 2016)

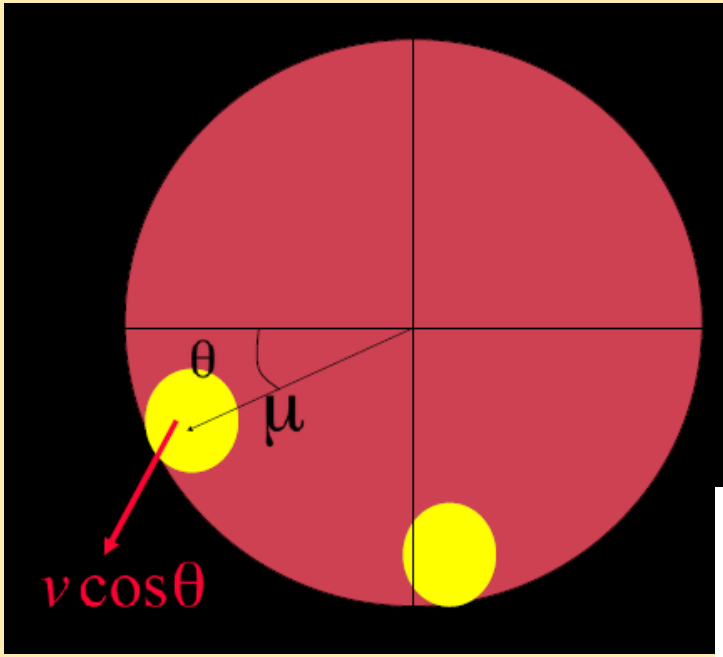
Also detected in other RSGs *(Tessore+2017)* , and in pulsating AGB (Mira stars) and P-AGB (RV Tauri stars) - *(Lèbre+2015)*

Time variable linear polarisation in Betelgeuse !



=> Monitoring over more than 3 years (in UQ)

Courtesy A. Lopez-Ariste – IRAP



$$\tan 2\theta = \frac{U}{Q}$$

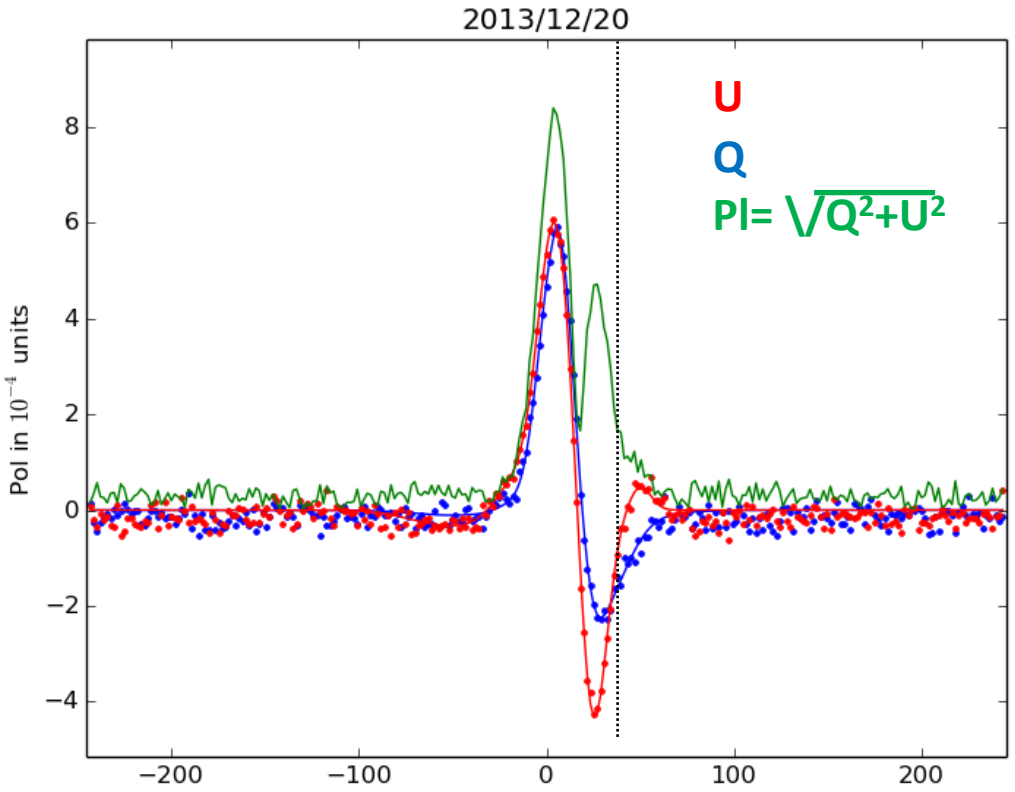
$$Q^2 + U^2 = B \sin^2 \mu$$

$$\Delta\lambda = \frac{v}{c} \cos\epsilon \, \mu$$

A geometrical interpretation

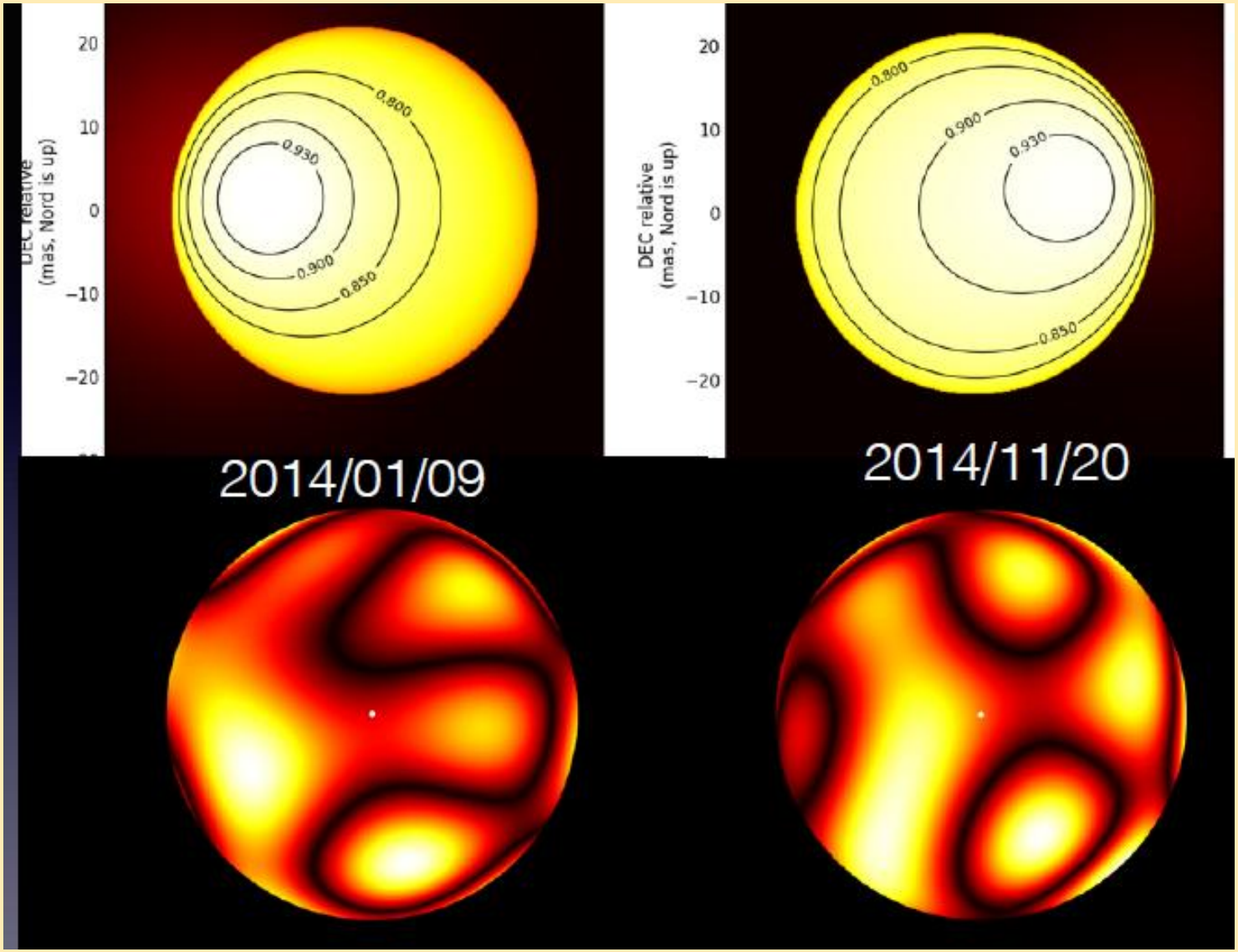
position/brightness of spots vs observational parameters

=> surface location and relative brightness of the spots inducing anisotropies in the radiation field.



Courtesy A. Lopez-Ariste – IRAP

Betelgeuse : confrontation to VLTI/PIONIER data



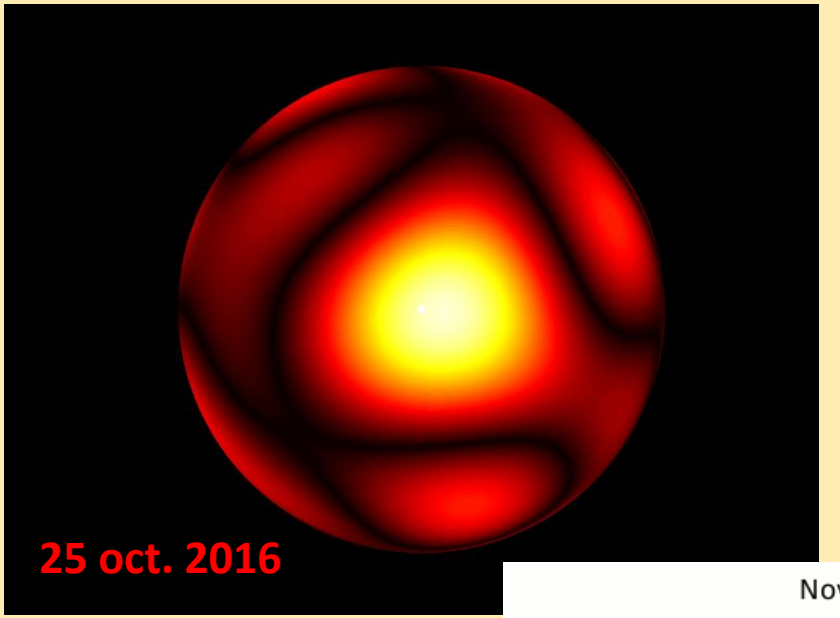
single spot model

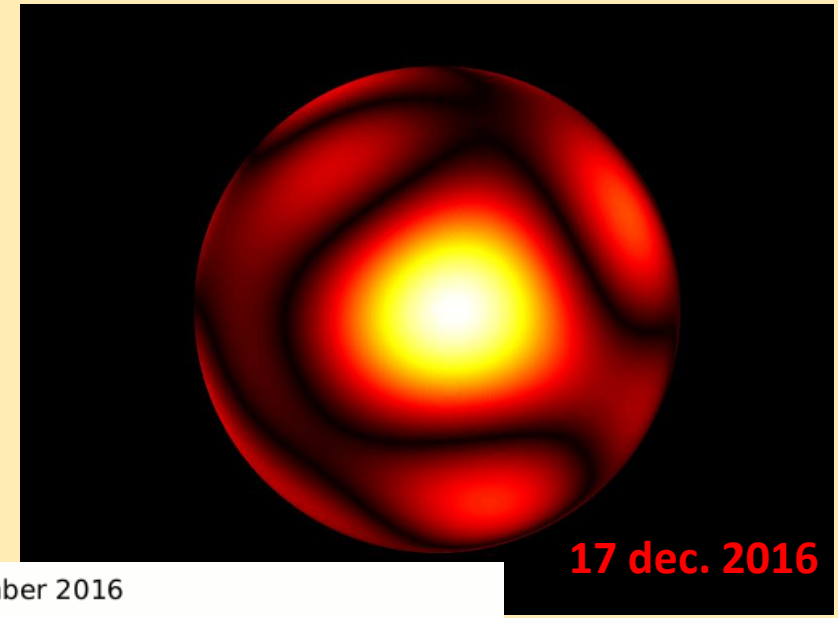
(Montargès+ 2016)

spectropola. maps

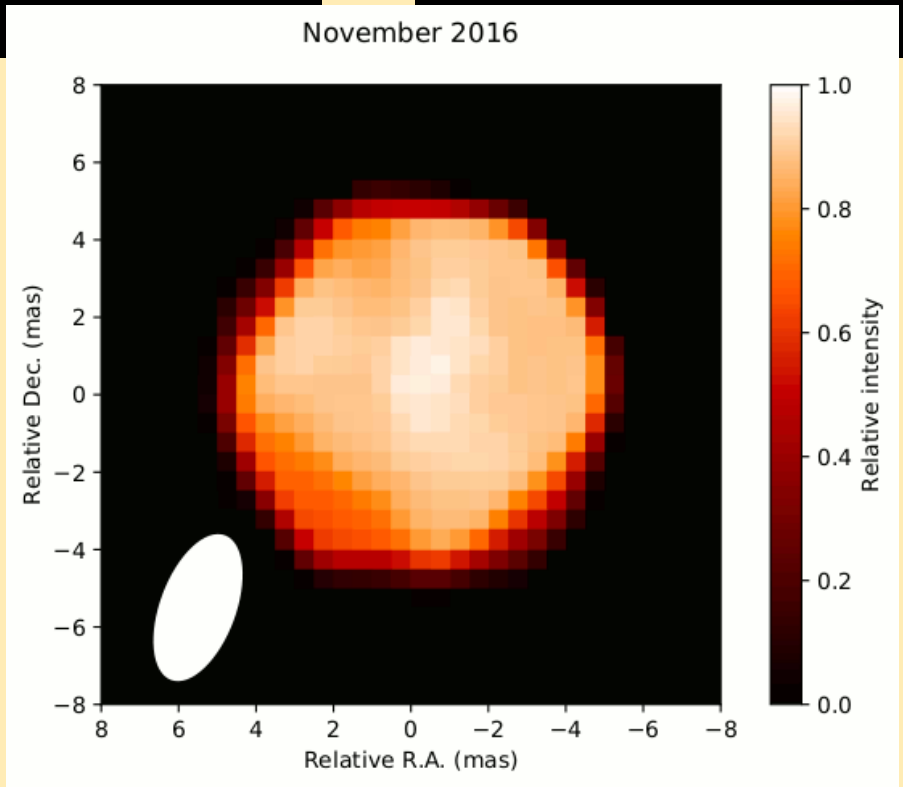
Courtesy A. Lopez-Ariste (IRAP)

CE Tau : Spectropolarimetry vs VLTI/PIONIER image reconstruction





Tessore+2018, en préparation



SQUEEZE
image reconstruction
(Baron+2010)

Montargès+2018

Courtesy
A. Lopez-Ariste – IRAP
M. Montargès -Louvain

2- Connecting Surface to Circumstellar Magnetic Fields (AGB ; P-AGB)

Magnetic field strength and structure in Circumstellar Envelope (CSE) from :

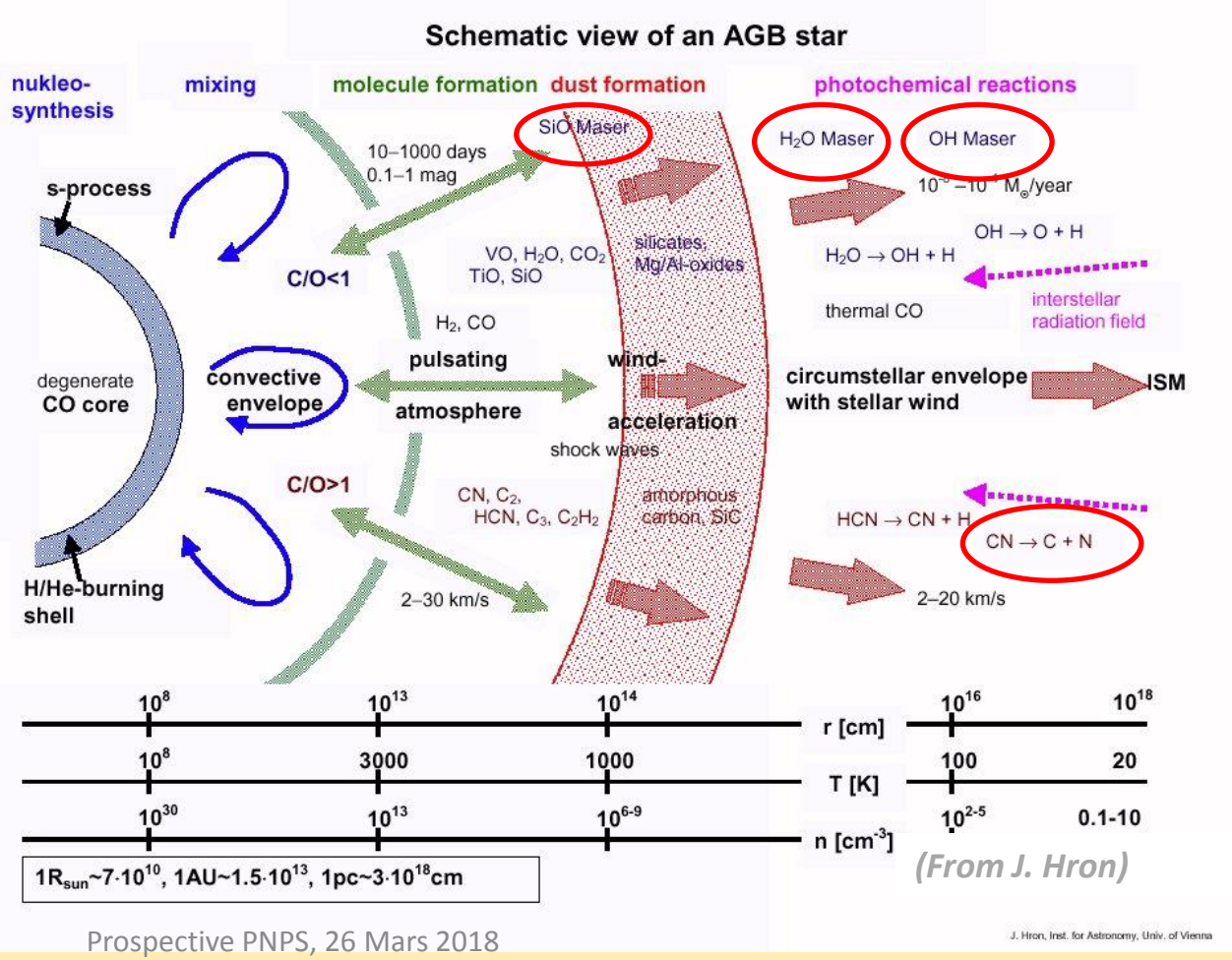
Circular polarization
=> Line of sight component of Magnetic Field + constraints on its geometry

Best tracers
(compactness and strength) :
maser circular polarization
(sub)-mm regime

Typical molecules
probing different zones in CSE

SiO, **H_2O**, **OH** for O-rich stars

CN lines for C-rich stars
(Herpin+2009)
1rst attempt to detect
Zeeman splitting
of non-maser molecular lines
Confirmed by *Duthu+2017*



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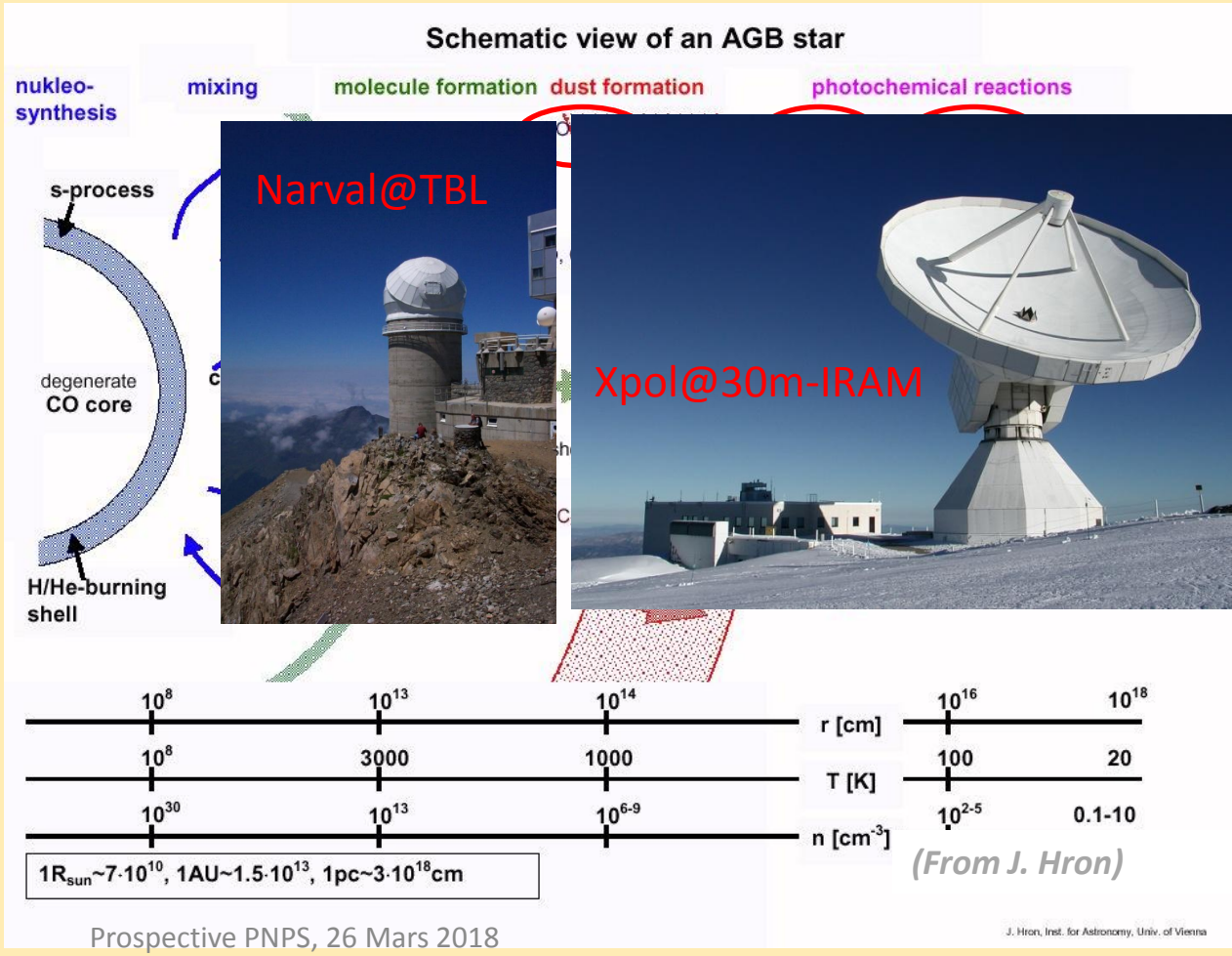
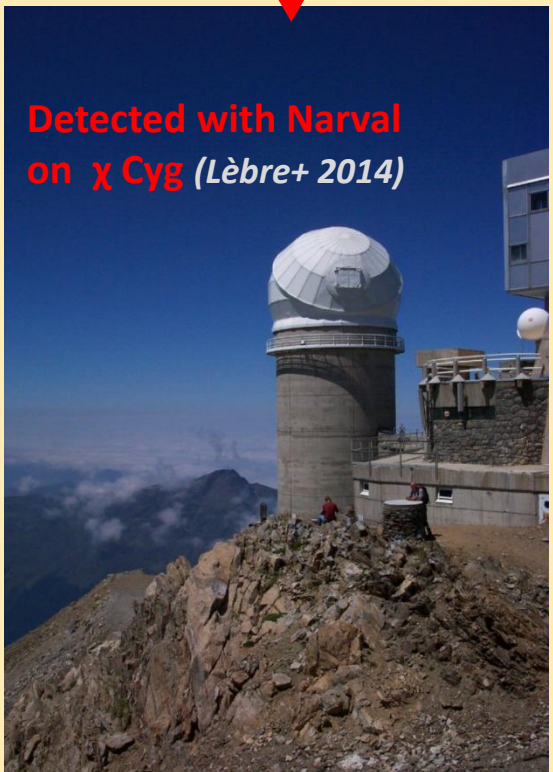


Magnetic field strength vs. radius relation

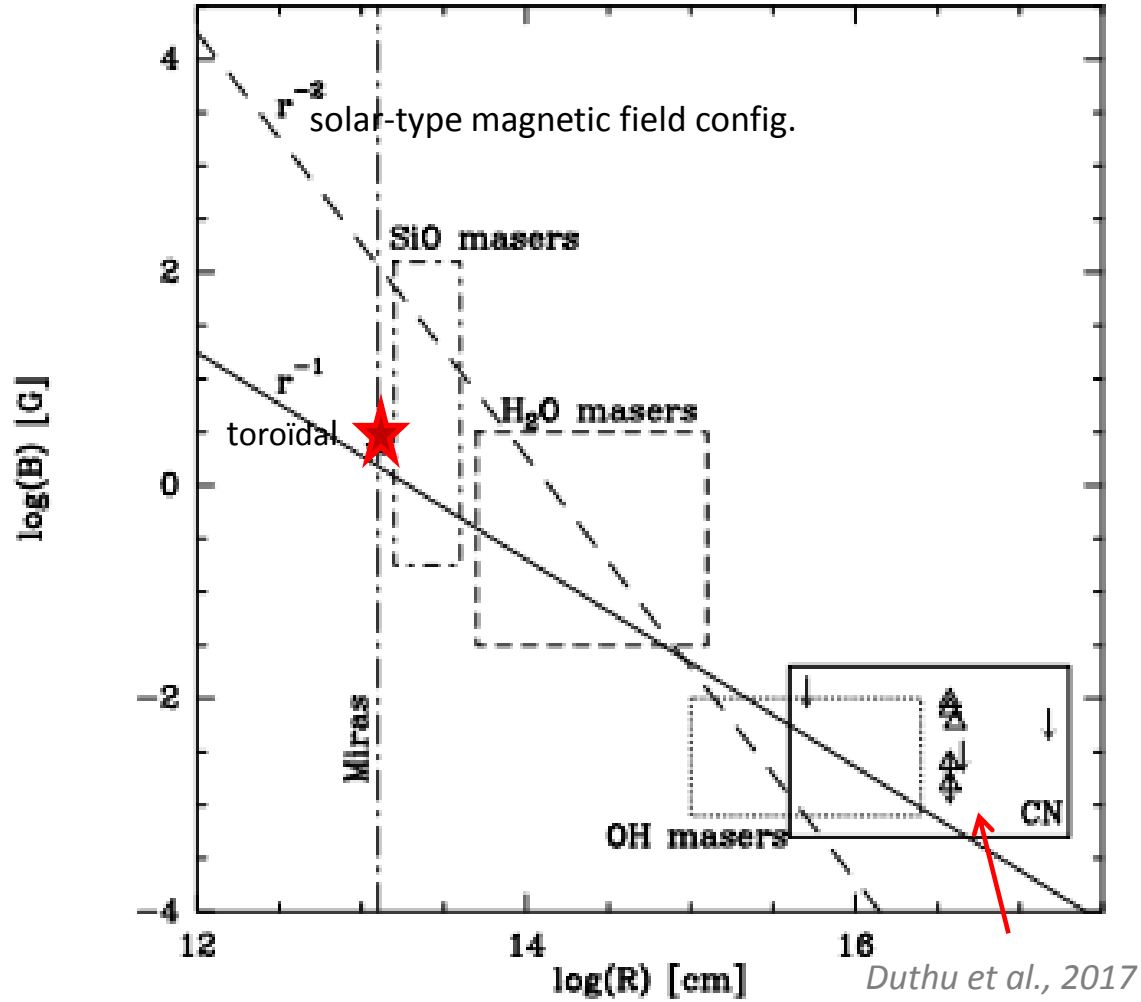
as indicated by current maser polarization observation of Miras, carbon stars, ..

Extrapolating the 1/r law (toroïdal field) toward the photosphere

→ **the magnetic field strength at the stellar surface of Mira stars could be of the order of a few G.**



(Duthu et al., 2017, from Vlemmings et al., 2011)



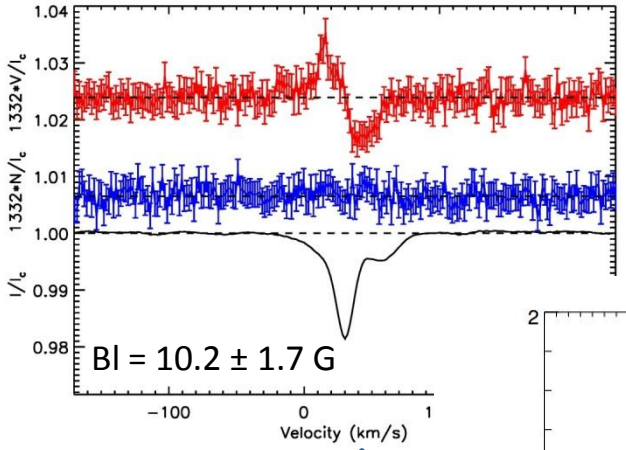
Duthu et al., 2017

Post-AGB stars (incl. Pulsating RV Tauri stars)

RV Tauri stars

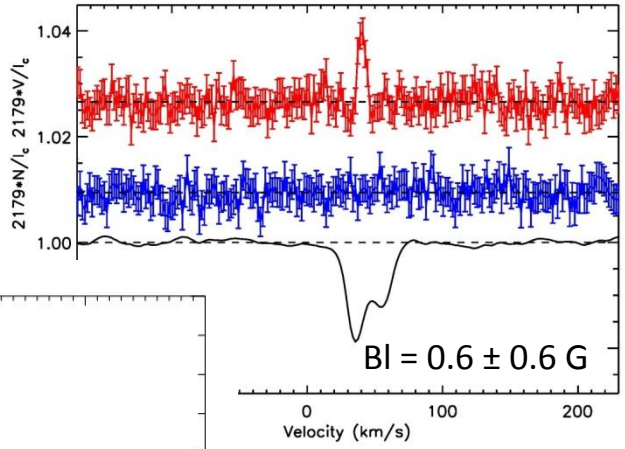
The first positive detections of a photospheric magnetic field *(Sabin et al., 2015)*

U Mon (ESPaDOnS april 2014)
pulsation period ~ 92 days

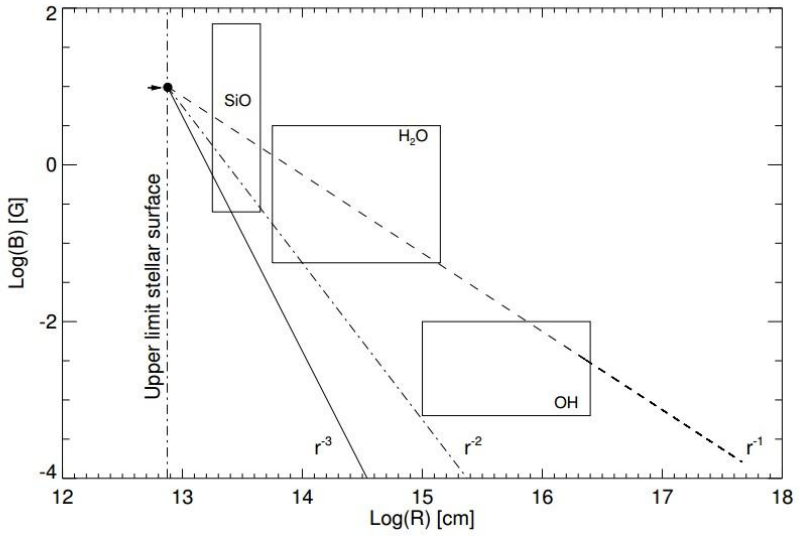


Impact of atmospheric shock waves?

R Sct (Narval july 2014)
pulsation period ~ 142 days

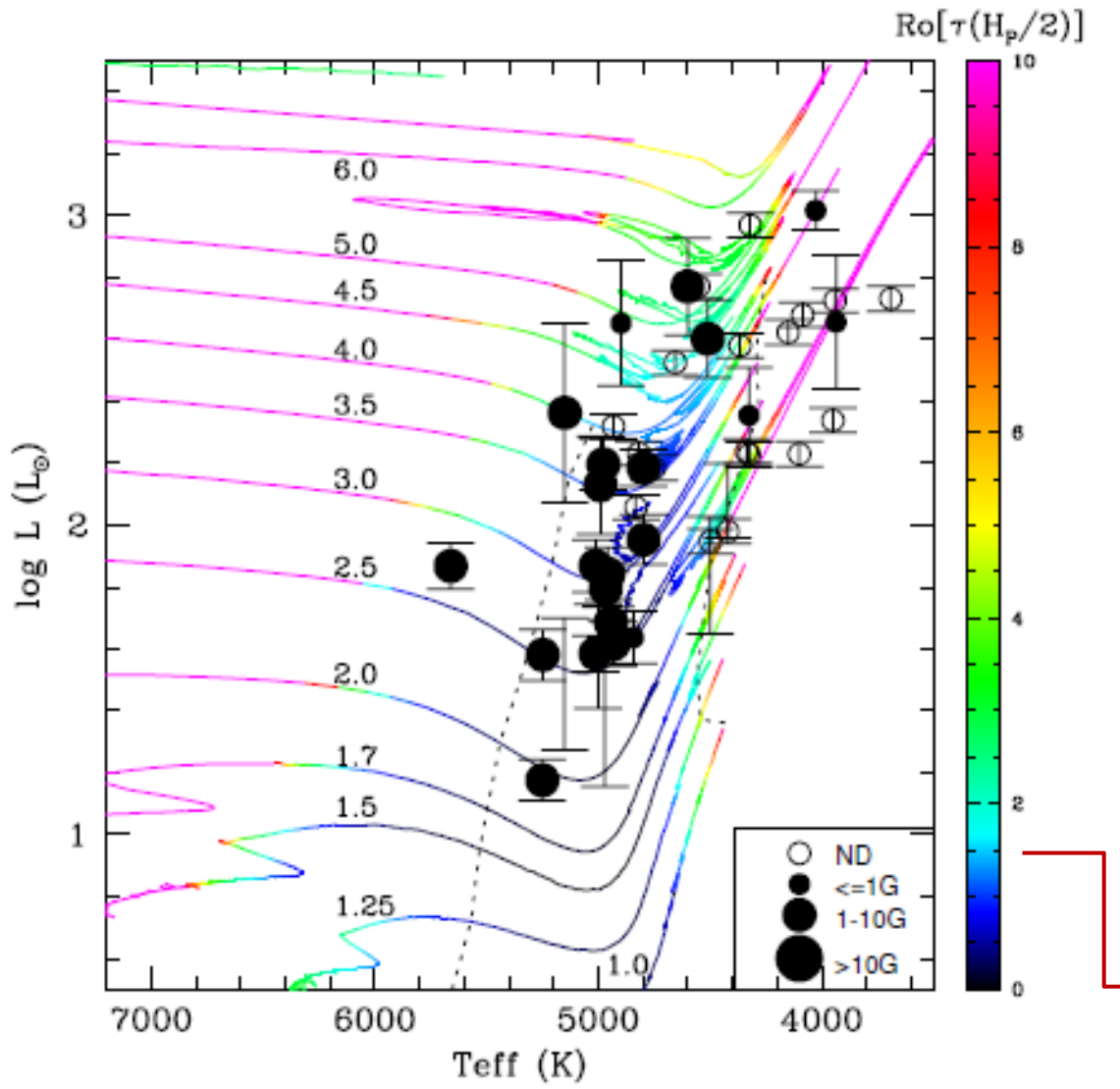


Prediction of maser strengths in the envelope of U Mon ?



Favoring again toroidal field
(Sabin et al., 2015)

Theoretical trends with Rossby number for G-K giants



(Charbonnel et al., 2017) (Observations: *Aurière et al., 2015)*

Evolution (from the ZAMS to the tip of RGB/AGB) of the **Rossby number**
(Ratio of inertial to Coriolis force)

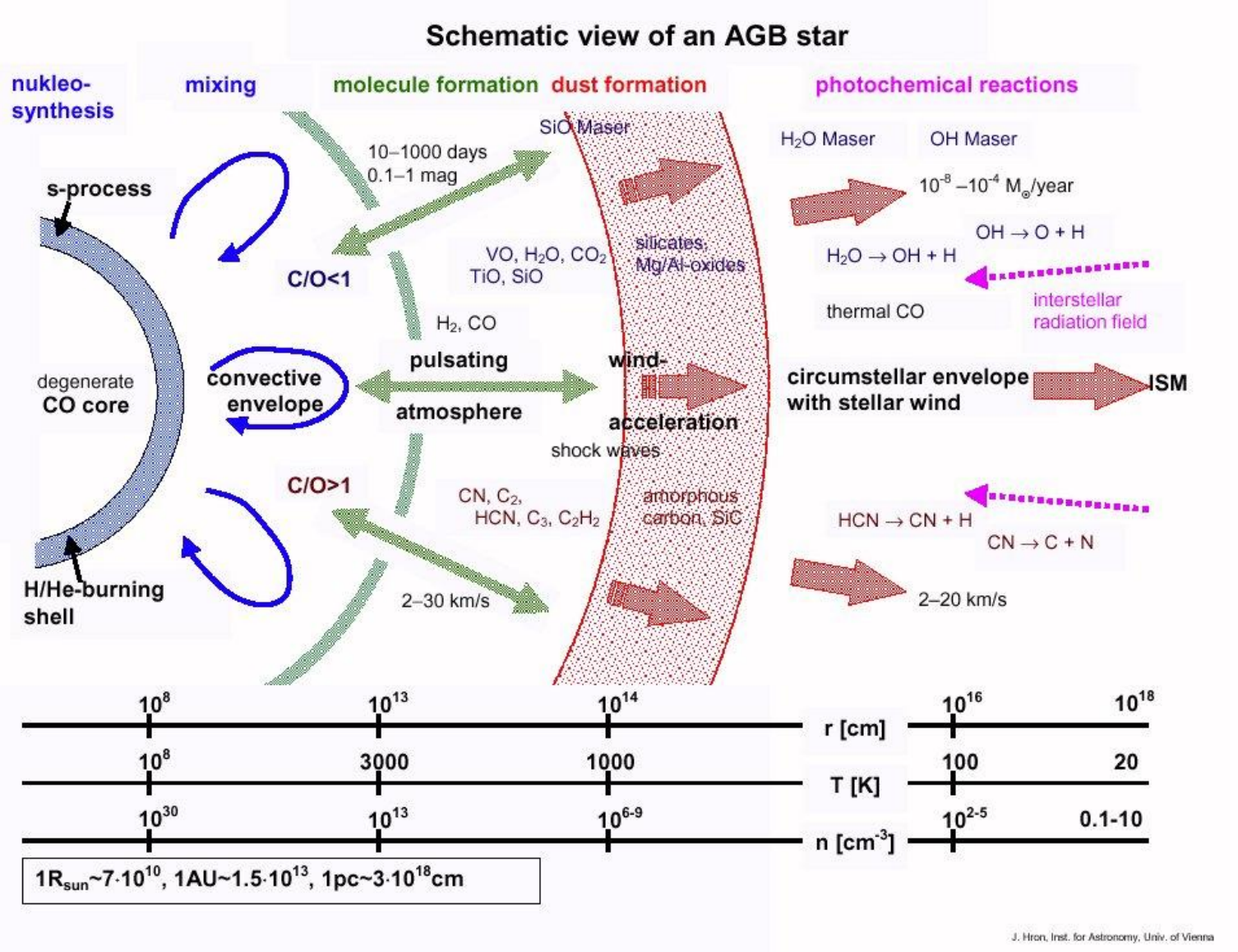
$Ro = Prot / \tau$

Magnetic Strip :
1rst D-up and
core He burning phase

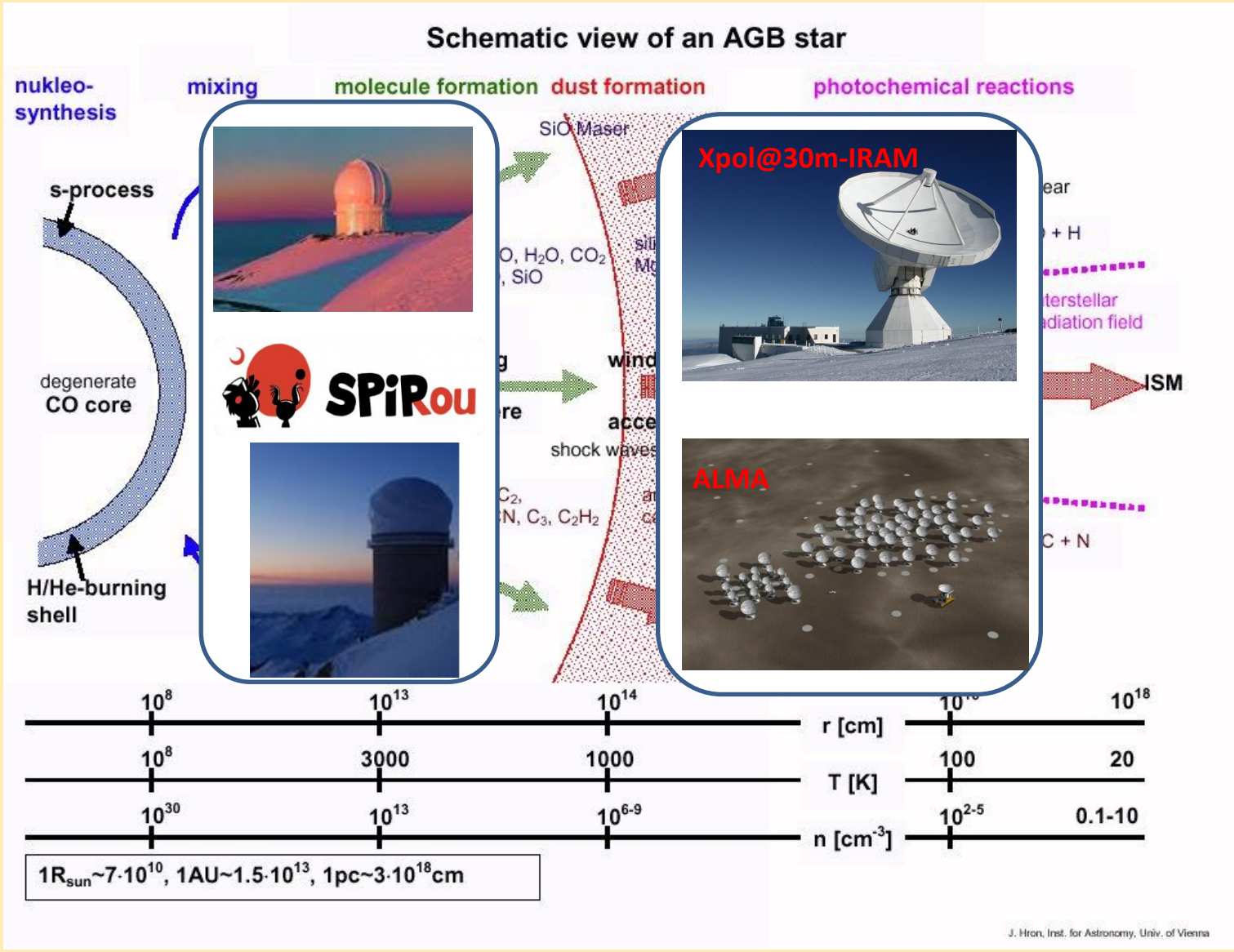
α-ω type dynamo

$R_O \sim 1$ => Magnetic Strip !

PERSPECTIVES



PERSPECTIVES



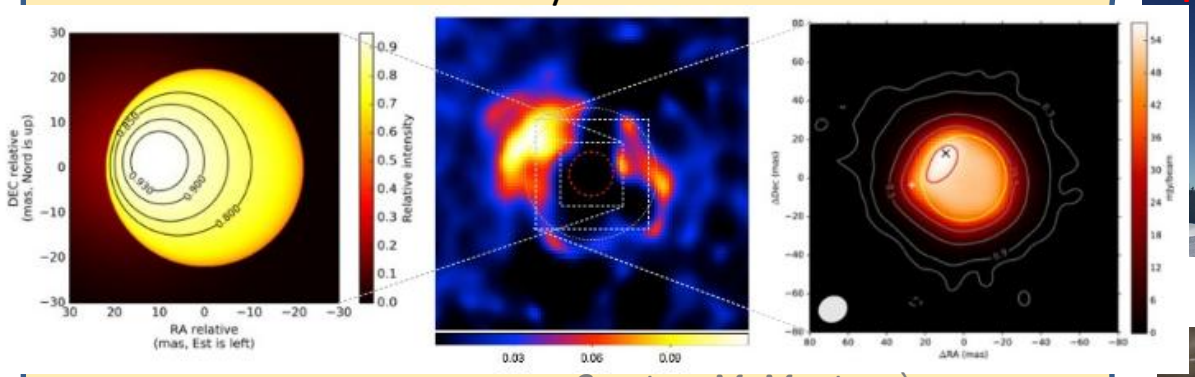
PERSPECTIVES

Magnétisme : origine/évolution/impact

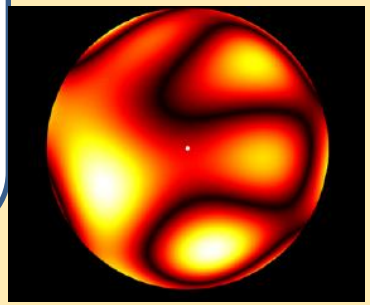
SPIRou

et aussi
CRIRES+@VLT
Neo-Narval@TBL

VLTI VLT/SPHERE ALMA

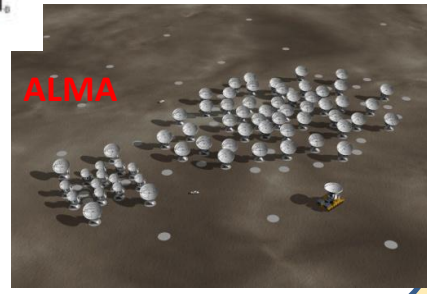


Courtesy M. Montargès

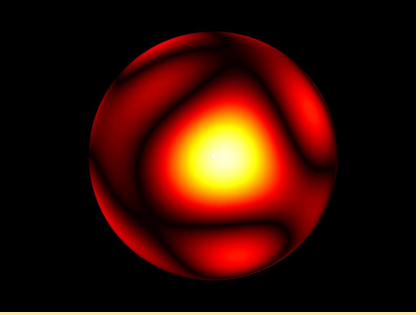


Exploitation d'autres traceurs : maser HCN
Besoin de facteurs de Landé

Exploitation des raies moléculaires :
besoin de listes de raies et de facteurs de Landé
(oxydes TiO, VO, ZrO et molécules carbonées CN, CH, CO, C_2)



et aussi
NOEMA@IRAM



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