# The magnetic fields in pulsating AGB and post-AGB stars

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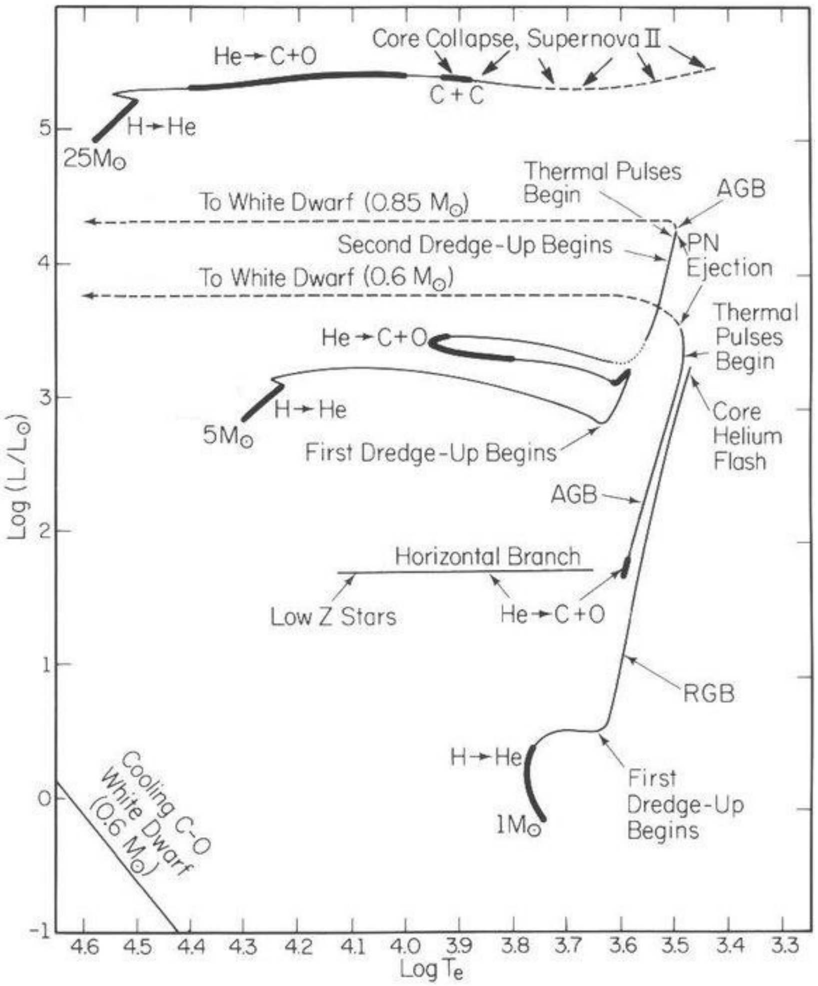
# Introduction

Magnetic fields (MF) in evolved stars situated at the tip RGB, AGB and beyond on the H-R diagram were poorly studied. While for the observed MFs in the less evolved G,K giants the origins is mostly α – ω dynamo and remnant MF in the Ap star descendants (**Konstantinova-Antova et al. 2013; Auriere et al. 2015**), for these more evolved stars different mechanisms could contribute for the MF generation. **Charbonnel et al. (2017)** consider that α – ω dynamo could operate even in early AGB stars due to the properties of their convective envelopes. In addition, from observations, some of these stars possess faster rotation that could not be explained by the theory of stellar evolution. Also, most of these giants are pulsating stars and the question is whether the pulsations could contaminate their MF.




Evolutionary tracks on the HRD of stars with $1M_{\odot}$, $5M_{\odot}$ and $25M_{\odot}$. Figure adapted from Iben (1985).

# Telescope and Method:

## Telescope Bernard Lyot (TBL)

## NARVAL

**(Spectropolarimeter)**
**R~6500, 370 – 1050 nm**

**ZEEMAN EFFECT**

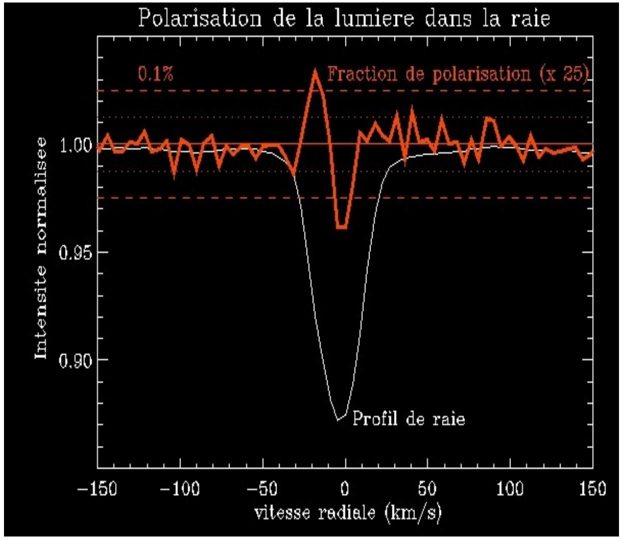
**LSD (Least Square Deconvolution)**

**Donati et al. (1997)**

# The method LSD (Donati et al. 1997):

Cross-correlation method: uses thousand absorption lines from one spectrum
Improves S/N ratio
Obtains the mean profiles of Stokes I and V
Detects weak magnetic signatures which would not be visible in individual lines.

In the cool giants, the method enables to average about 12 000 lines to get Stokes I and Stokes V profiles with greatly improved S/N. The longitudinal magnetic field Bl is computed in Gauss using the first moment method (Donati et al., 1997; Rees&Semel, 1979). The method and the equipment enable a precise Bl determination with an accuracy of the order one Gauss and even less for our sample stars.



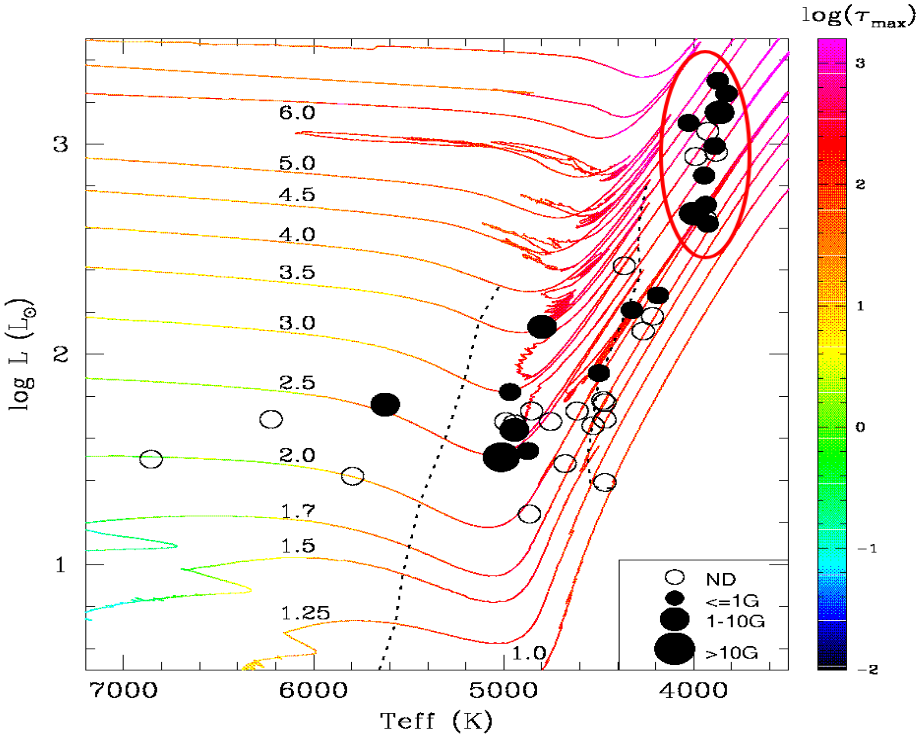
# Tip RGB and AGB stars

The evolutionary tracks by Charbonnel et al. (2017) are used. The color indicates for the convective turnover time. The locus of the second magnetic strip is shown as it is in Konstantinova-Antova et al. (2014).

**First Zeeman detected M giant star** with MF is the M5 giant **EK Boo** (**Konstantinova-Antova et al. 2010**). Later, we studied two samples.

**In the first sample:** 7 of 9 M giants possess surface MF in 1-13 G interval (**Konstantinova-Antova et al. 2013**).

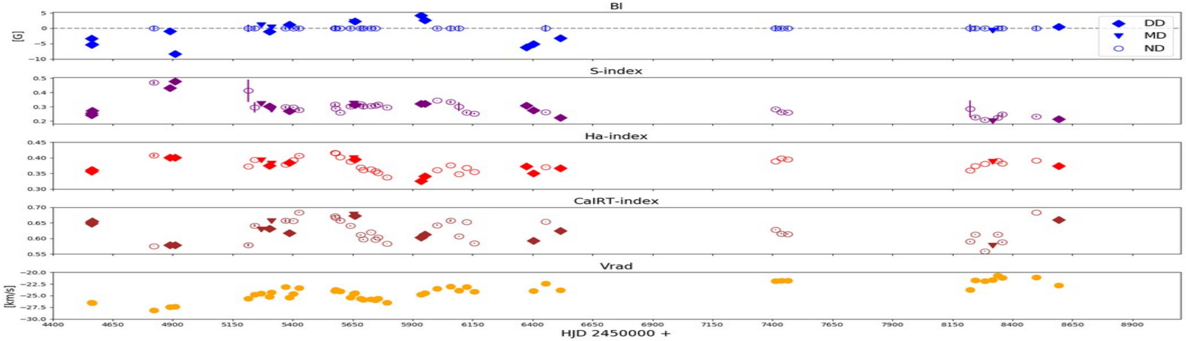
**The second sample**: all tip RGB and AGB apparently single stars up to V=4 mag in the Solar vicinity, available for TBL, Narval (northern hemisphere). **MF was detected in more than 60% of them** (**Konstantinova-Antova et al. 2014**). MFs are of the order 0.5-3 G. All these form the so-called “second magnetic strip”, a concentration on the H-R diagram where α – ω dynamo could operate (**Charbonnel et al. 2017**). MF was not detected in M giants less massive than 1.7 Msun.



# Long-term study of magnetic activity in M giants:

## 3 stars are studied for about 10 years - RZ Ari, EK Boo and β Peg

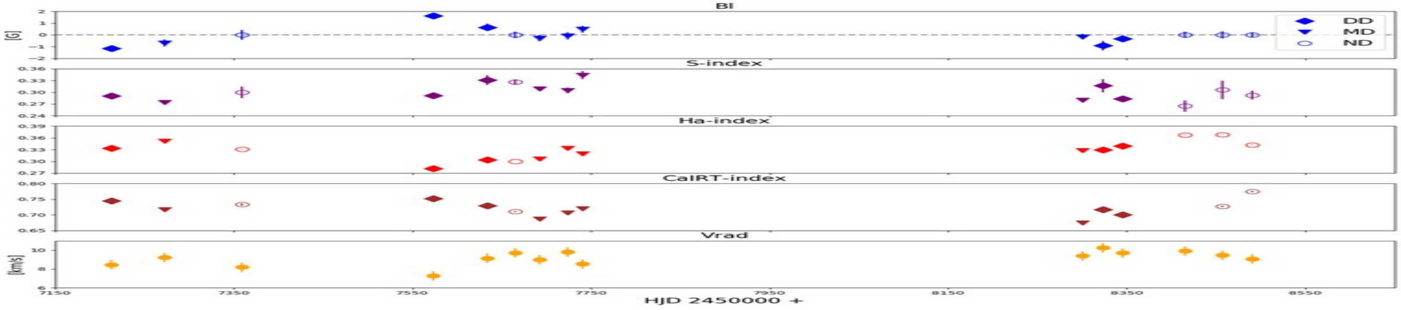
### EK Boo |Bl|max = 10.20 ± 0.6 G




Sp=M5III, semiregular variable
*(Kholopov et al. 1998)*
M = 3.0 Msun, T=3450 K
Evolutionary stage: TP-AGB
$v \sin i$ = 8.5 km/s
*(Konstantinova-Antova et al. 2010)*
Lx > $10^{30}$ erg/s *(Hünsch et al. 1998)*

### β Peg:

Sp=M2.5II-III
semiregular variable,P = 43.3d
*(Tabur et al. 2009)*
T = 3864 K
*(Massarotti et al. 2008)*
M = 3.5 Msun
$v \sin i$ = 7 km/s
Evolutionary status: AGB
*(Konstantinova-Antova et al. 2014)*

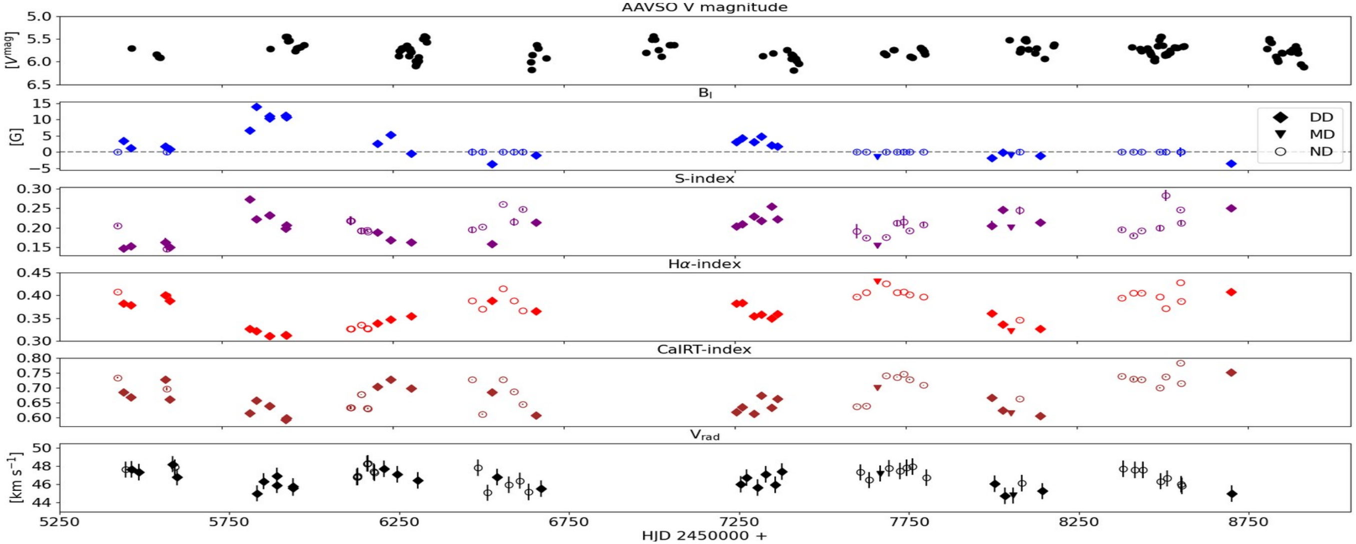


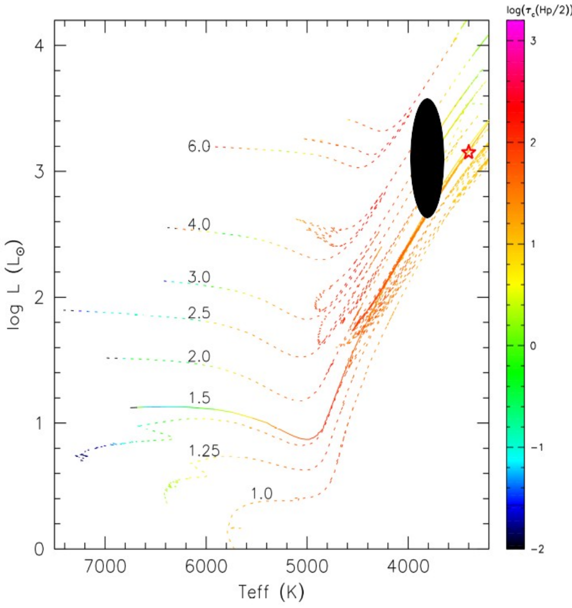

|Bl|max = 3.16 ± 0.26 G

**Georgiev et al. 2020a**

# RZ Ari: a case of planet engulfment?

|Bl|max = 13.01 ± 0.33G

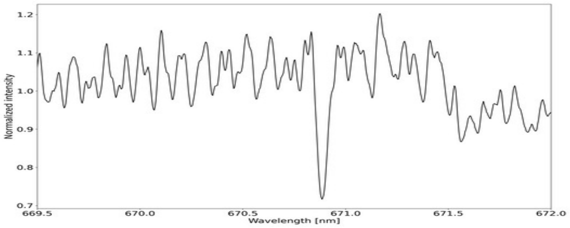



Sp =M6 III, T = 3400 K, *vsini* = 6 km/s (Georgiev et al., 2020b)
tipRGB or AGB, 1.5 Msun, rotation period (calculated UPPER limit) 909d;
ZDI&photometry – Prot 530 d, *i~40 deg* (***Konstantinova-Antova et al., 2023, A&A, submitted***)

SRb variable star - P~56d; LSP~480d, ampl. - 0.4 – 0.6mag (Percy et al.2008; Tabur et al. 2009). Our dataset: **No evidence for shock waves!**

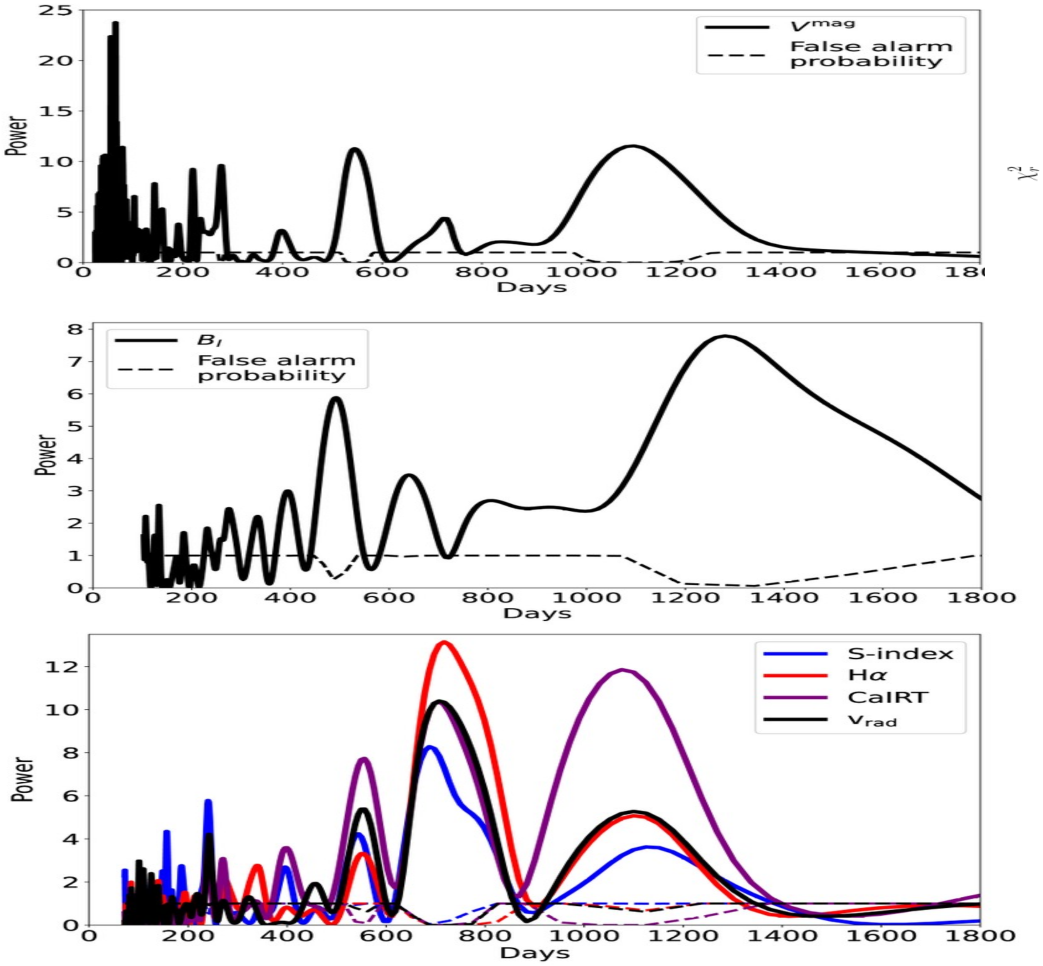
**What kind of dynamo operates there?** $R_o$>>1 → α – ω unlikely; $\alpha^2$ – ω?



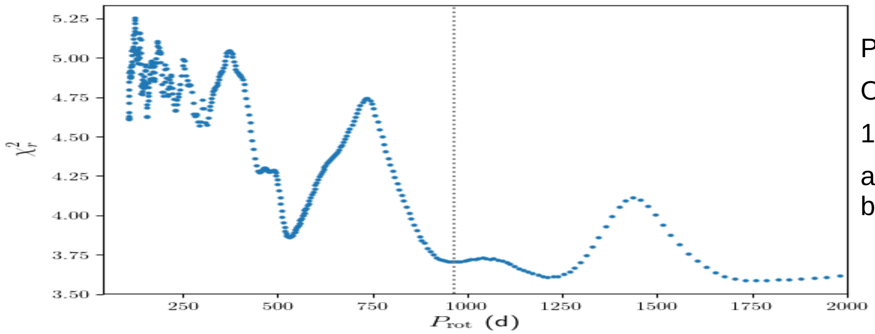

A(Li) = 1.2 ± 0.2 dex

# The plenty of periods in RZ Ari and their meaning:

## Lomb-Scargle method has been used for the period search.




ZDI period search (Petit et al. 2002) for RZ Ari:




Prot = 530 ± 2 d;

Other period:

1271 ± 11 d

as a part of a broader minimum

| Indicator | Period days | Accuracy interval | FAP percent |
|---|---|---|---|
| BI | 1280 | 1243,1319 | 6.1 |
| | 493 | 487,498 | 26.4 |
| S-index | 688 | 668, 707 | 2.0 |
| CaII IRT | 717 | 696,738 | 0 |
| Halpha | 707 | 687, 728 | 0.8 |
| Vrad | 707 | 687, 728 | 0.6 |
| V band<br>Photom. | 1105<br>544 | 1089,1122<br>540, 548 | 0.7<br>1.0 |

# RZ Ari periods: explanations

- Some of the periods (observed in BI, ZDI, photometry) are longer than the upper limit of the rotation period → are not related to rotation. Possible explanation is the lifetime of some large convective structures as predicted by **Freytag et al. (2017)**. Large convective cells are observed by interferometry on the AGB star of similar mass $\pi^1$ Gru (**Paladini et al. 2018**).

- The period of 530d is probably the rotation period of the star. With this period into account the Rosby number >>1, hence $\alpha - \omega$ is unlikely, but other types of dynamo could operate in RZ Ari, like $\alpha^2 - \omega$ dynamo, predicted to operate in AGB stars by **Soker (2000)**.

- The period of ~707d identified in the activity indicators and Vrad does not present in the MF. It is possible a big stable vortex to exist in the atmosphere, as described in Käpylä et al. (2011).

# Mira-type stars. The case of χ Cyg.

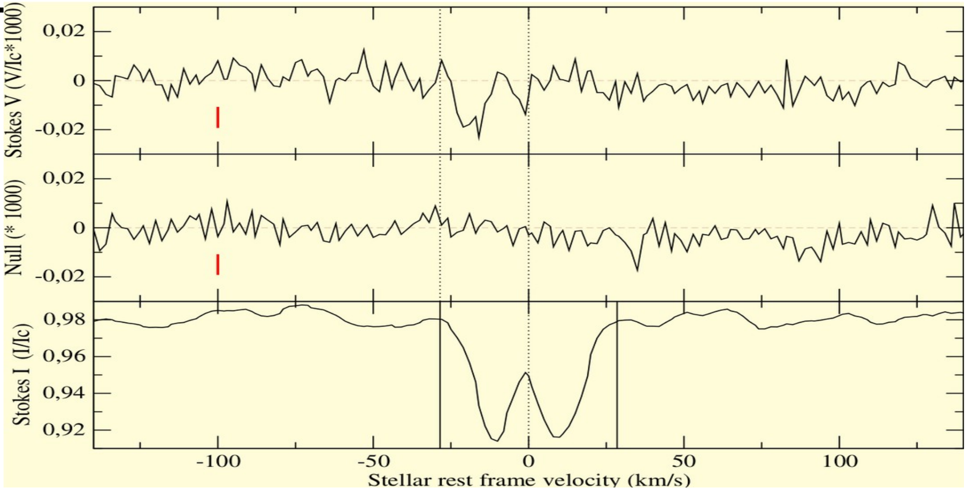
Miras are cool and evolved pulsating stars that belong to the AGB, the key evolutionary stage of an intermediate mass star before its transition toward the planetary nebulae.

Magnetic fields in Mira-type stars are poorly studied due to their large brightness amplitudes during the pulsation cycle. One exception is the brighter star χ Cyg, but it has also been studied with Narval near its maximum by ***Lèbre* et al. (2014)**. Weak MF of 2-3 G was detected. The authors explore the link with the pulsations and found that the **shock wave periodic propagation amplify a weak stellar magnetic field existing in the atmosphere.**

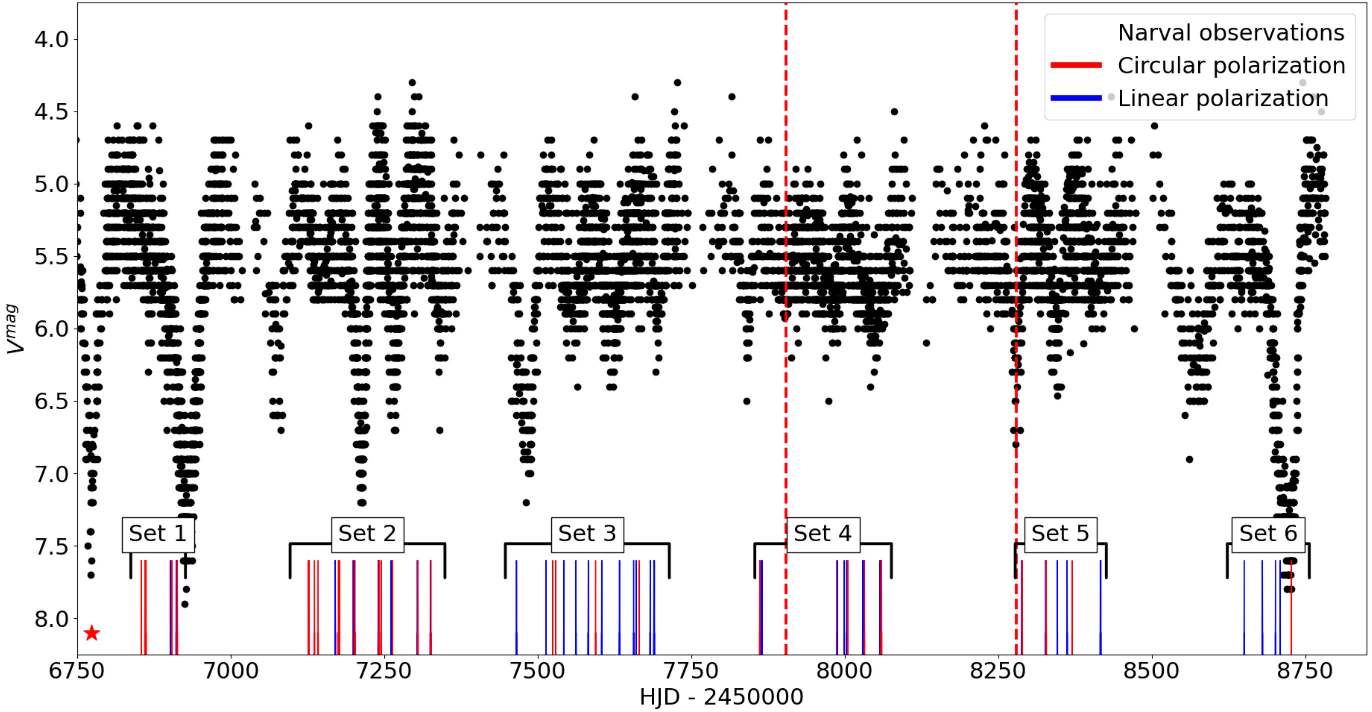
The S-type Mira star, χ Cyg has a period of pulsation of 408 days and a very high amplitude (more than 10 in V mag). The spectral type varies from S6.2 to S10.4 (Samus et al., 2012). It is about 5 mag in V near maximum.

χ Cyg at maximum light in 2012, ***Lèbre* et al. (2014)**.

LSD results are cumulative of 174 Stokes V sequences. That results in a total S/N of about 10 000 allowing a detection at the sub-Gauss level.



# Post-AGB stars. The case of R Sct.

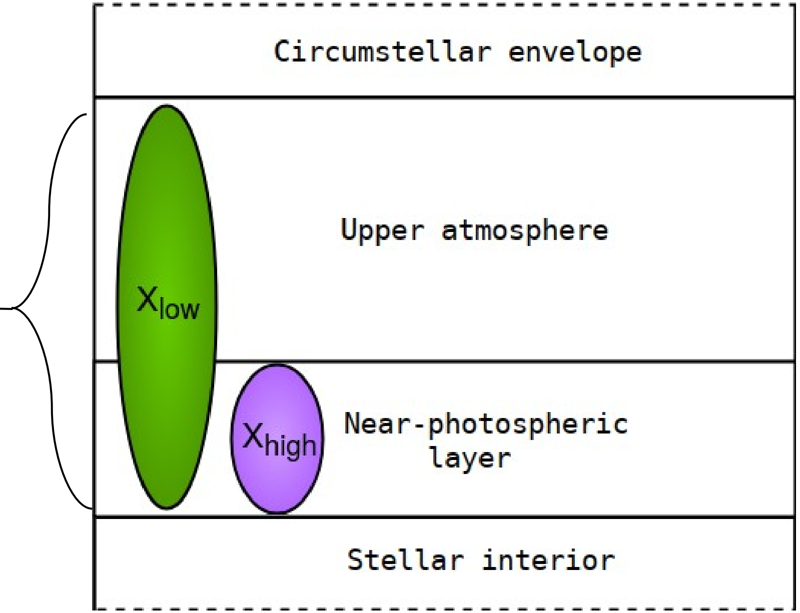



Visual lightcurve of RSct *(AAVSO)* with available Narval observations noted. The vertical dashed red lines mark an interval where the lightcurve is irregular, which is typical for RV Tauri variable stars.
Figure from **Georgiev et al. (2023, MNRAS)**.

- RV Tauri variable type star:
  P = 138.5 ÷ 146.5 d *(GCVS)*
- G0Iae @ maximum
  K2p(M3) @ deep minimum
- Teff = 4500 K, log*g* = 0,
  [Fe/H] = -0.5 @ shallow minimum and after maximum
  *(Kipper & Klochkova 2013)*
- Two radiative shockwaves per photometric period *(Gillet et al. 1989)*
- First discovery of a surface magnetic field: $B_l$ = 0.9 ± 0.6 G ***(Lèbre et al. 2015)***
- Surface field is time-variable: **shockwave amplification?** ***(Sabin et al. 2015)***

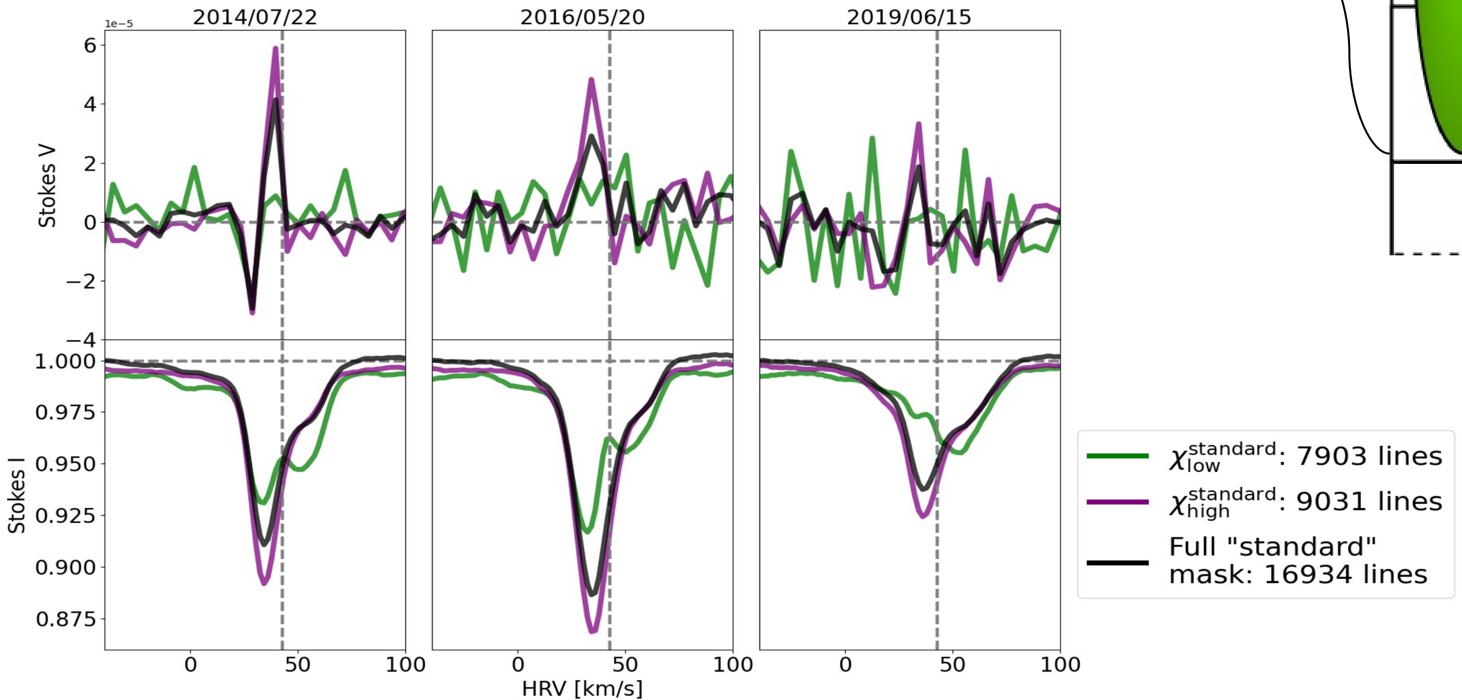
# R Sct – probing the lower atmosphere with LSD

Altitude and extent of line formation depend on the excitation potential χ




Full line mask
($\chi_{low}$ + $\chi_{high}$)

LSD profiles are different for different χ



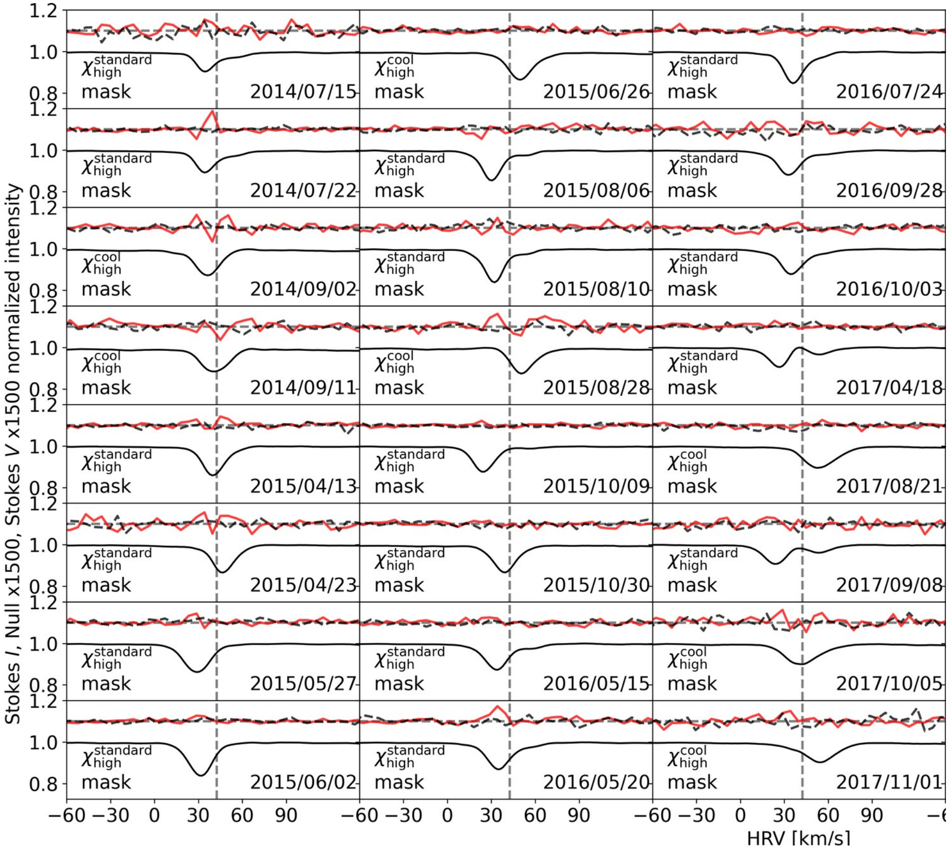

Figures from **Georgiev et al. (2023, MNRAS)**

$\chi < 2$eV (all altitudes)

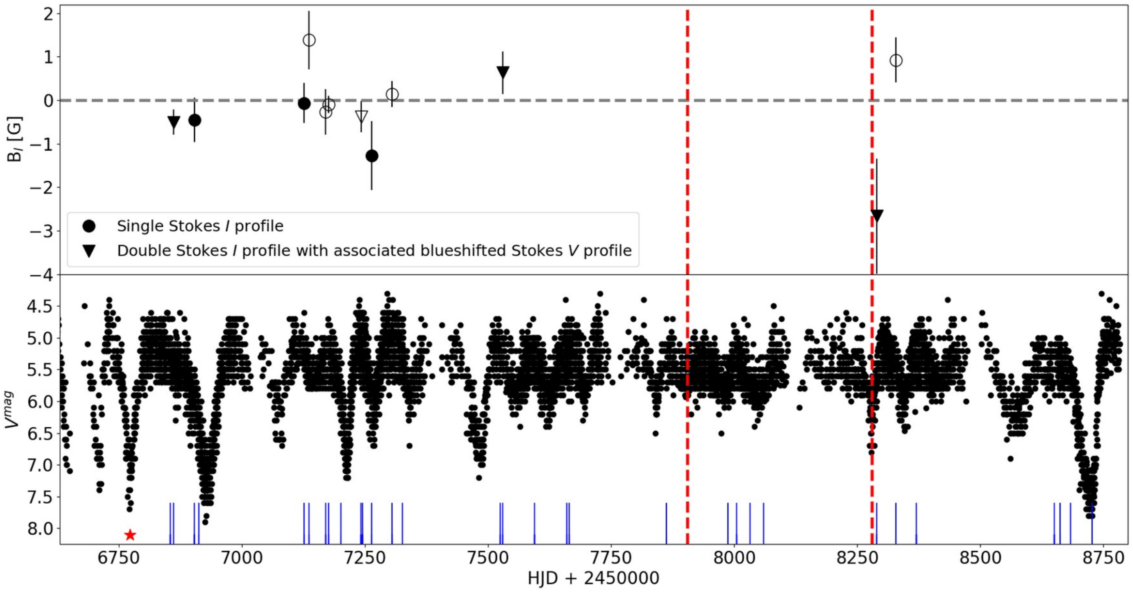
$\chi \geq 2$eV (lower atmosphere)

All χ (all altitudes, mostly lower)

# R Sct – surface magnetic field & pulsations




LSD profiles of R Sct calculated for χ ≥ 2eV with a "standard" (4500K) or "cool" (3500K) mask depending on the absence or presence of cool TiO bands in the spectrum.




Upper panel: Bl(t); lower panel: visual lightcurve.

Stokes V signatures vary on a timescale of 2-3 months, similar to that of pulsations. Signatures seem to be associated to the blue lobe of the intensity profile, similar to the case of χ Cyg.

**These results support the hypothesis that shockwaves locally amplify the surface magnetic field.**

# MFs in AGB and post-AGB stars: Possible mechanisms.

Such stars possess a **vigorous convection and deep convective envelope**. In addition, during the course of the evolution at certain phases **additional angular momentum as a result of core-envelope interaction or eventual planet engulfment** could speed up the stellar rotation (**Schröder & Konstantinova-Antova, 2022**).

In these cases, **depending on the rotation rate $\alpha - \omega$ or $\alpha^2 - \omega$ dynamo** appear possible. **$\alpha - \omega$** – in the tipRGB/AGB stars **in the Second magnetic strip** (**Konstantinova-Antova et al. 2014; Charbonnel et al. 2017**). **RZ Ar**i that possible has undergone **planet engulfment episode** (**Konstantinova-Antova et al.,2023, A&A, submitted**) cannot be explained by $\alpha - \omega$ dynamo, and **$\alpha^2 - \omega$ could be a likely mechanism**.
In addition, **giant convective cells** are observed in $\pi^1$ Gru, 2 Msun AGB star (**Paladini et al. 2018**). In the case of **RZ Ari**, taking into account the **periods longer than rotation one, observed in the MF and photometry**, such ones are not excluded and also a **local dynamo** as suggested for the MF in Betelgeuse (**Auriere et al., 2010**) and **theoretically predicted by Dorch& Freytag (2002)**. **Further interferometric study of RZ Ari with CHARA will be very valuable.**

On the other hand, **strong shock waves enables compression of the existing very weak MFs** in the **Miras and post AGB pulsating stars** (**Lebre et al. 2014; Georgiev et al., 2023**). **No evidence for strong shocks in the semi-regular M giants we studied** (**Georgiev et al. 2020**).

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THANK YOU!