Magnetic activity in single AGB and post-AGB stars

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in collaboration with:

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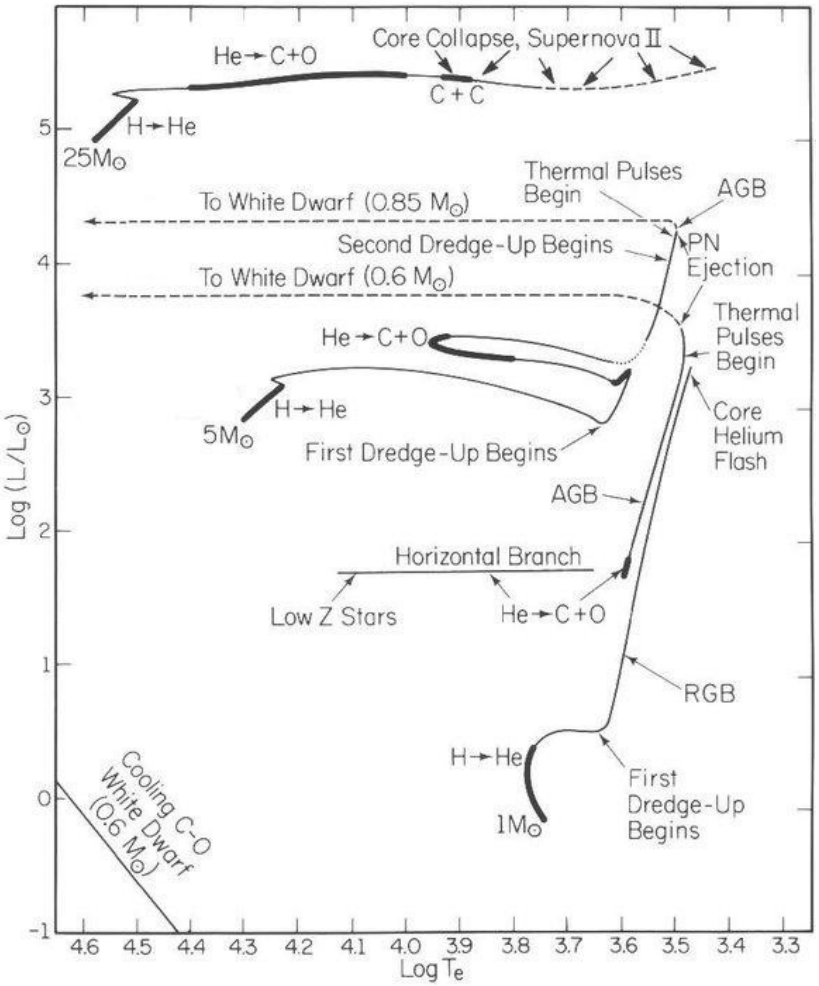
Introduction

Until recently, magnetic fields (MF) in such evolved stars as situated at the tip RGB, AGB and beyond on the H-R diagram were poorly studied. The new generation spectropolarimeters NARVAL@TBL and ESPaDOnS@CFHT (Donati et al. 2006; Aurière 2003) together with the Least Square Deconvolution (LSD) method (Donati et al. 1997) enabled detection of weak magnetic fields of the order of 1 G and below in cool stars. While for the observed MFs in the less evolved G,K giants the origins is mostly $\alpha - \omega$ dynamo and remnant MF in the Ap star descendants (Konstantinova-Antova et al. 2013; Auriere et al. 2015), for these more evolved giants different mechanisms could contribute for the MF generation. Charbonnel et al. (2017) consider that $\alpha - \omega$ dynamo could operate even in early AGB stars due to the properties of their convective envelopes. In addition, some of these stars possess faster rotation that could not be explained by the theory of the stellar evolution. Also, most of these giants are pulsating stars and 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).

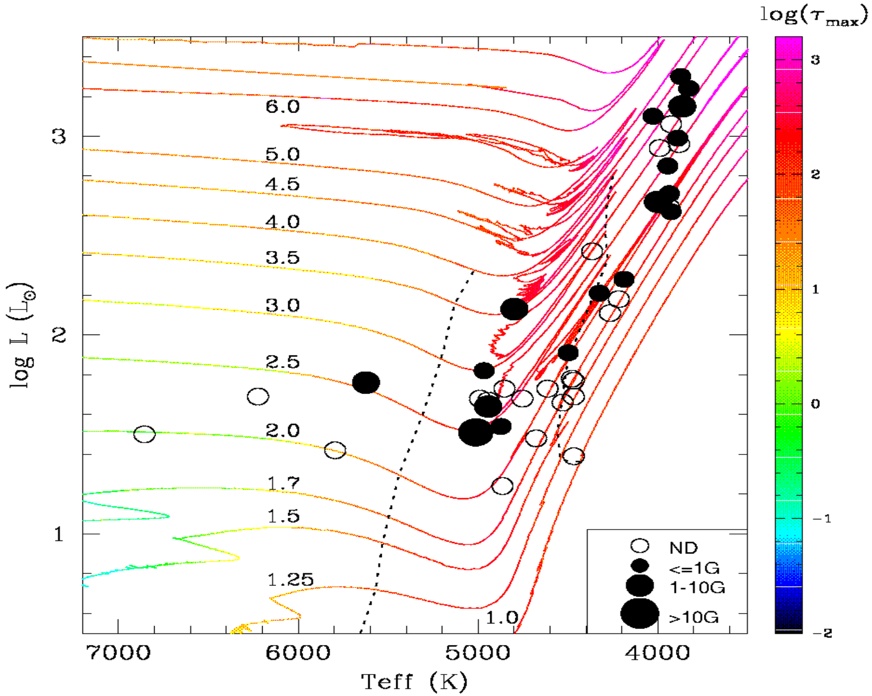
Tip RGB and AGB stars –

for small mass stars they occupy one and the same place on the H-R diagram

Stellar models by Charbonnel et al. (2010) are used for the Solar vicinity sample.

We studied 2 samples. First Zeeman detected star with MF is the M5 giant EK Boo (Konstantinova-Antova et al. 2010). Later, more stars are detected. In the first sample, 7 of 9 giants possess MF. It is of the order 1-8 G (Konstantinova-Antova et al. 2013).

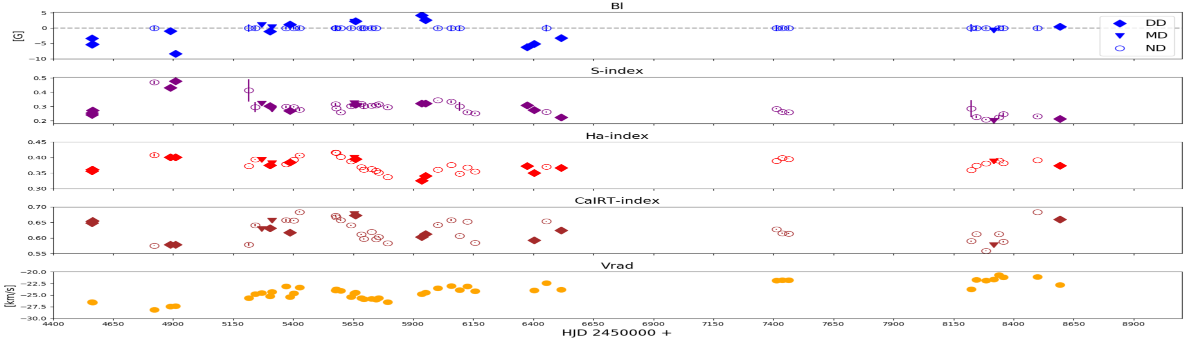
The second sample: all tip RGB and AGB apparently single stars up to V=4 mag in the northern hemispere, available for Narval@TBL. MF was detected in more than 60% of them (Konstantinova-Antova et al. 2014). They possess weak MFs of the order 0.5-3 G. All these form the so-called "second magnetic strip", a concentration on the H-R diagram where $\alpha - \omega$ dynamo could operate (Charbonnel et al. 2017). MF was not detected is giants less massive than 1.5 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

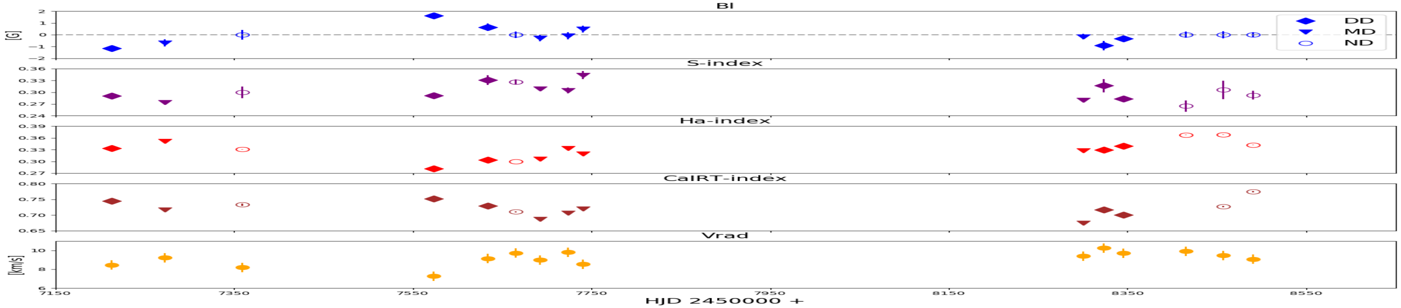
EK Boo |Bl|max = 10.20 ± 0.6 G



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:

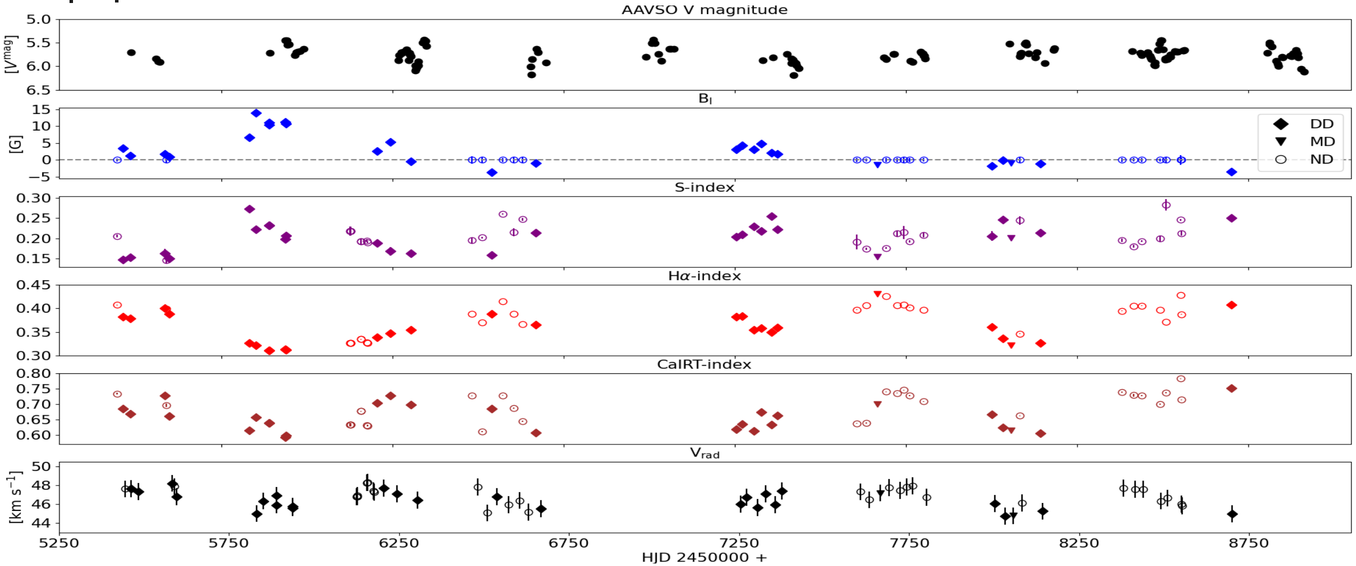
Sp=M2.5II-III
semiregular variable,P = 43.3d
(Tabur et al. 2009)
T = 3864 K
(Massarotti et al. 2008)
M = 3.5 Msun
***v* sin*i* = 7 km/s**
Evolutionary status: AGB
(Konstantinova-Antova et al. 2014)

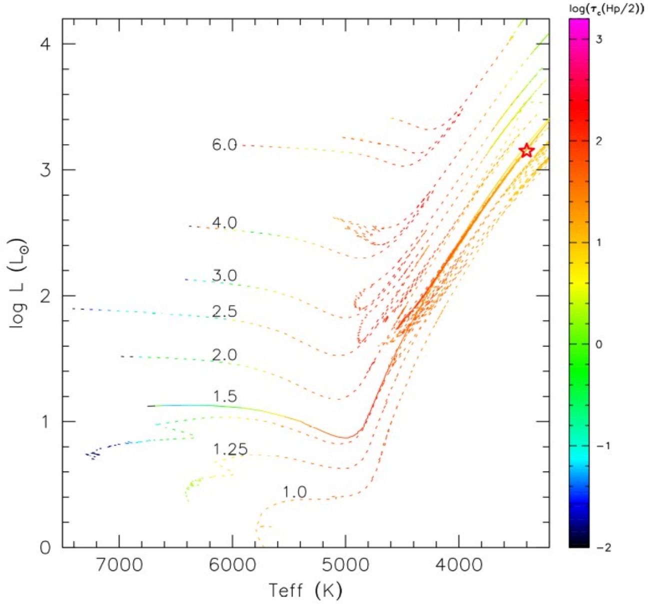


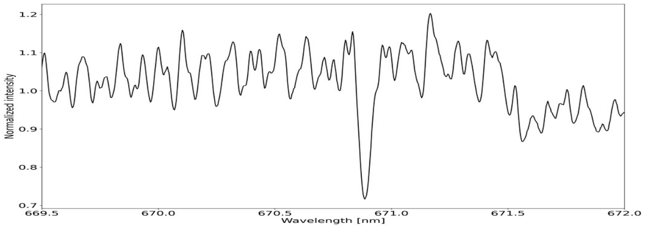
|Bl|max = 3.16 ± 0.26 G   Georgiev et al. 2020

RZ Ari: a case of planet engulfment?

$|B_l|_{max} = 13.01 \pm 0.33G$







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 (Konstantinova-Antova et al., 2022, in prep.)*

SRb variable star - P~56d; LSP~480d, amplitude - 0.4 – 0.6mag

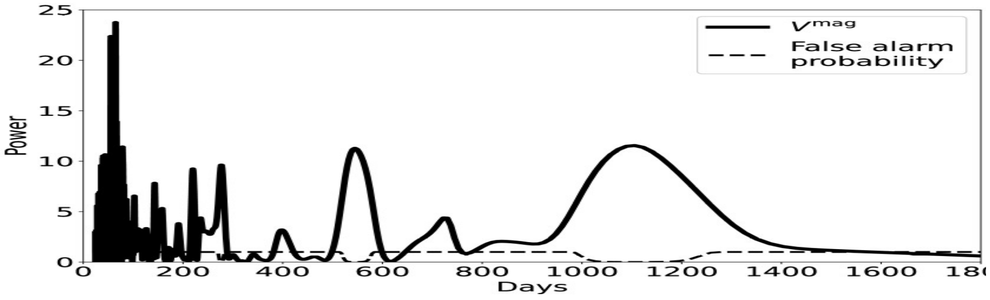
(Percy et al. 2008; 2016; Tabur et al. 2009)

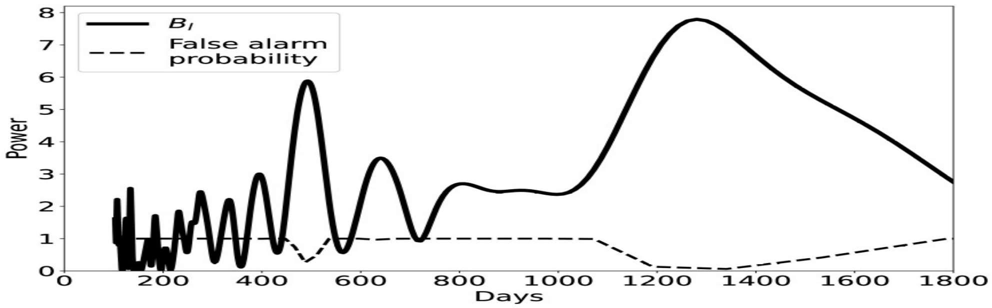
What kind of dynamo operates there? Ro>>1 → alpha-omega unlikely

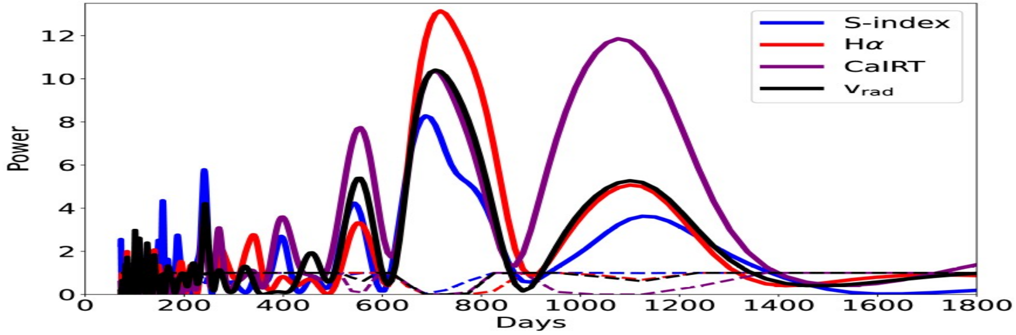
A(Li) = 1.2 ± 0.2 dex

The plenty of periods in RZ Ari and their meaning:

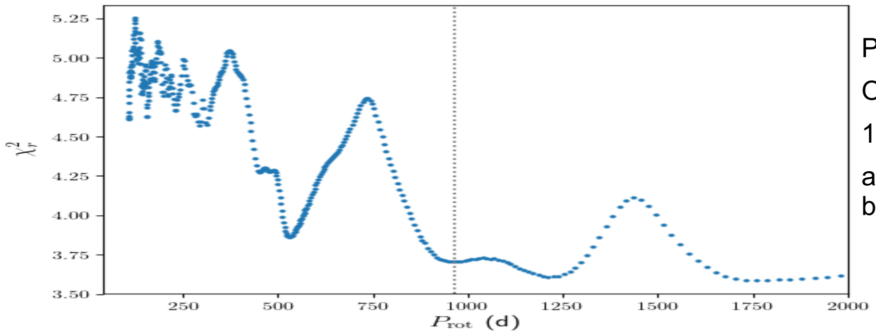
Lomb-Scargle method has been used for the period search.







ZDI period search method (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 Photom.	1105 544	1089,1122 540, 548	0.7 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 π1 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 is >>1, hence alpha-omega dynamo 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.

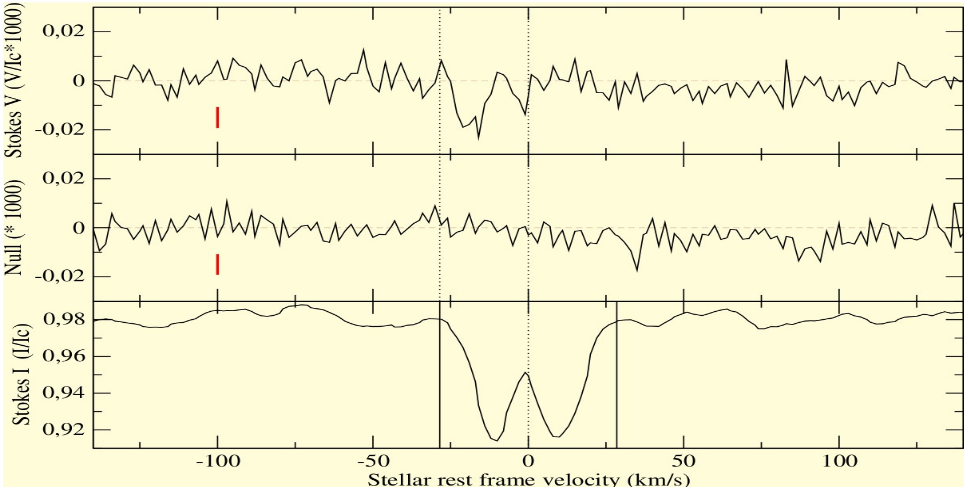
Miras are cool and evolved pulsating stars that belong to the AGB, the key evolutionary stage of an intermediate mass star before its transition toward the planetary nebulae.

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 Lebre 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 propagations amplify a weak stellar magnetic field existing in the atmosphere.

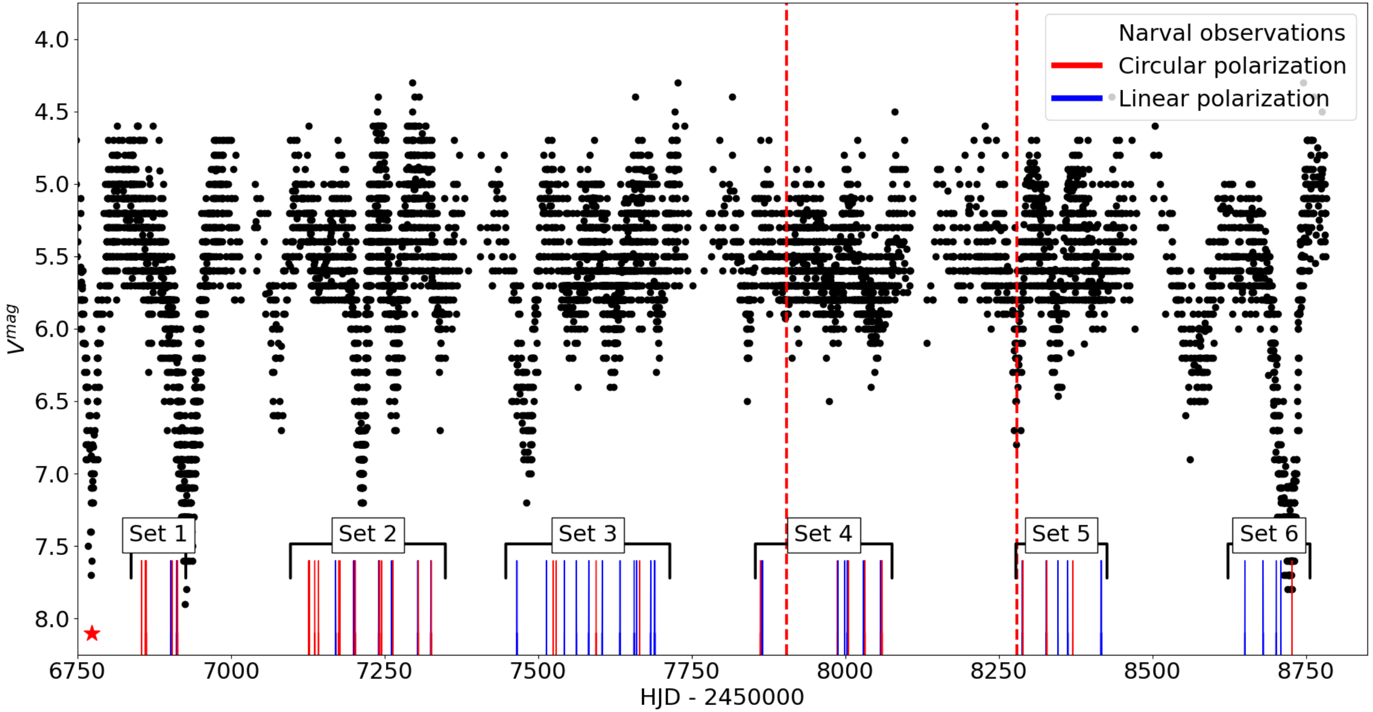
The S-type Mira star, χ Cyg has a period of pulsation of 408 days and a very high amplitude (more than 10 in V magnitude). The spectral type varies from S6.2 to S10.4 (Samus et al., 2012). It is about 5 mag in V near maximum.

χ Cyg at maximum light in 2012, **Lebre 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. (2022, MNRAS, in revision)**.

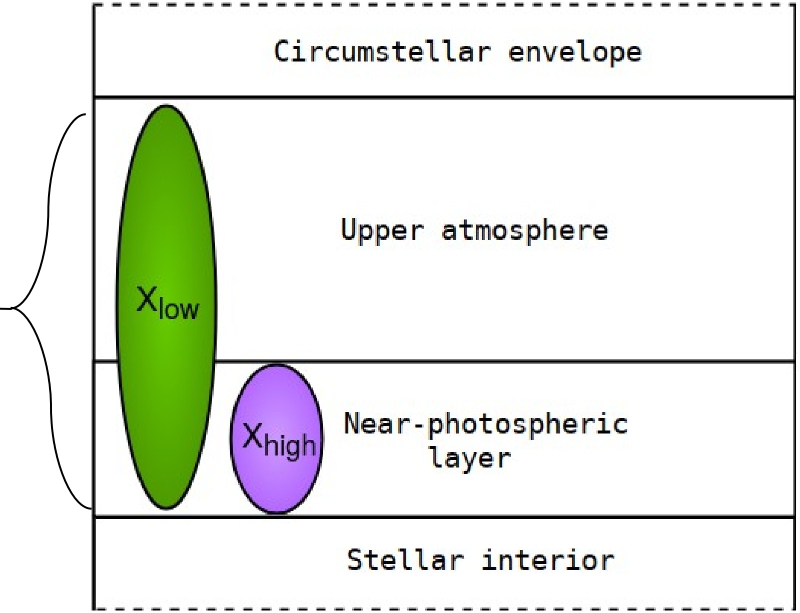
- RV Tauri variable type star: P = 138.5 ÷ 146.5 d *(GCVS)*
- G0Iae @ maximum
K2p(M3) @ deep minimum
- Teff = 4500 K, logg = 0, [Fe/H] = -0.5 @ shallow minimum and after maximum *(Kipper & Klochkova 2013)*
- Two radiative shockwaves per photometric period *(Gillet et al. 1989)*
- First discovery of a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

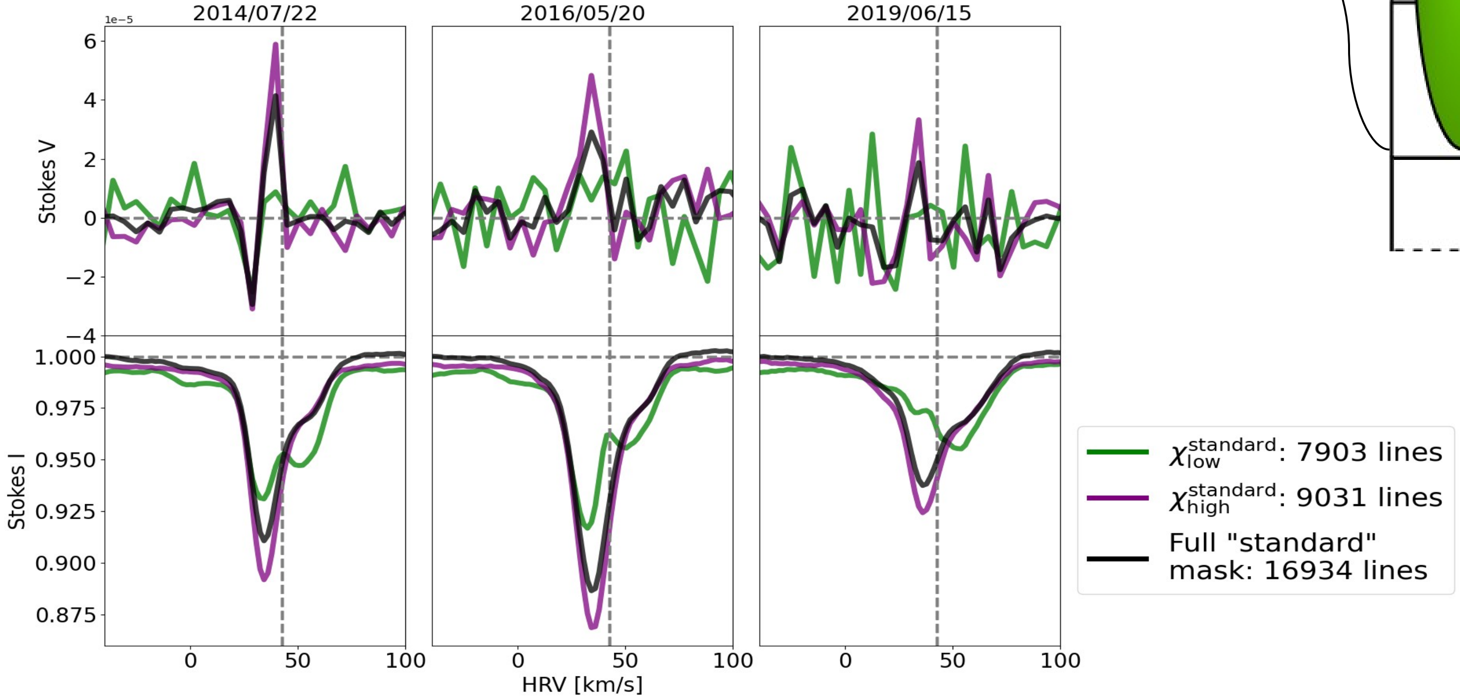
R Sct – probing the lower atmosphere with LSD

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

LSD profiles are different for different χ

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





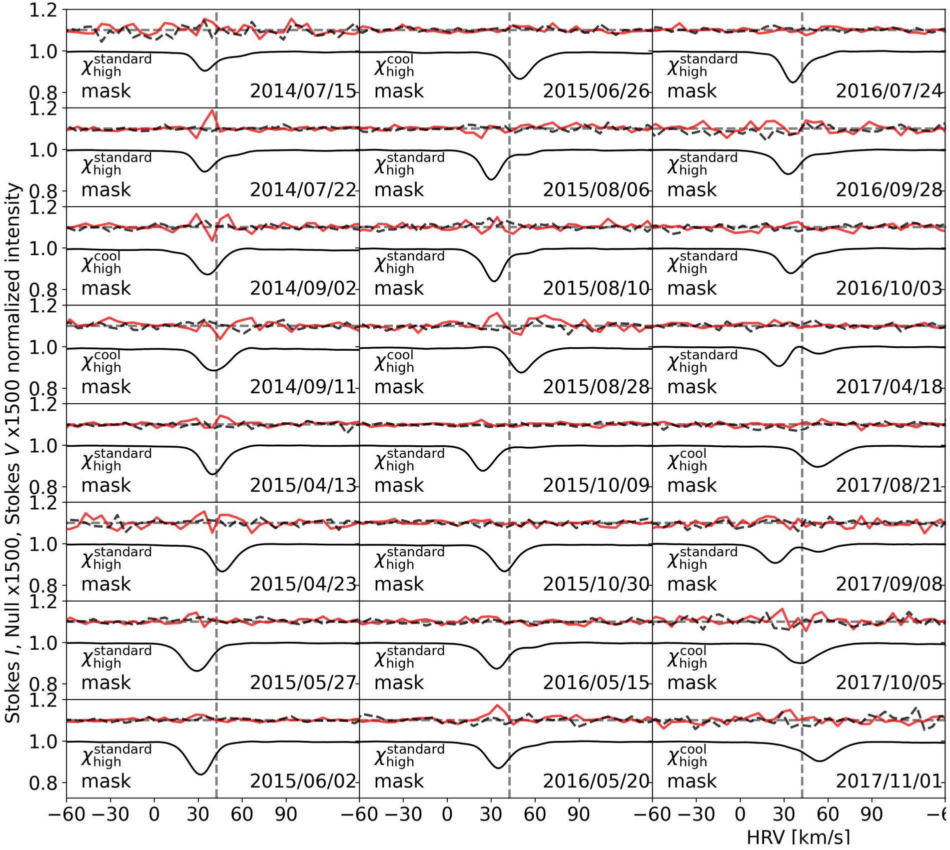
Figures from Georgiev et al. (2022 MNRAS, in revision)

$\chi < 2$eV (all altitudes)

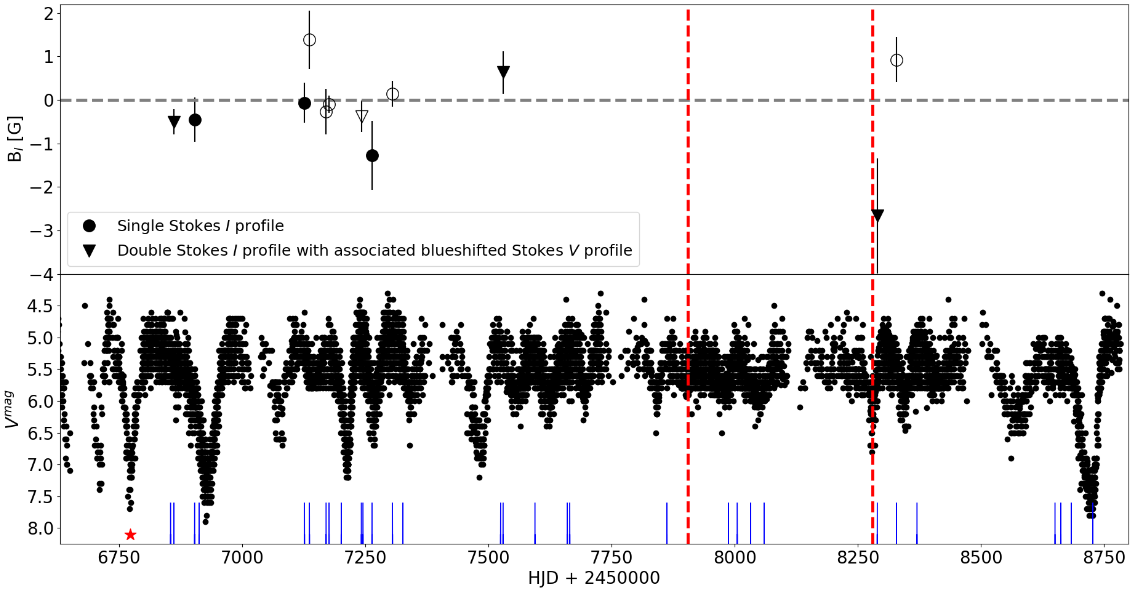
$\chi \geq 2$eV (lower atmosphere)

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: Summary.

When a star evolves after the main sequence its structure changes along the giant branches. Such stars possess a vigorous convection and deep convective envelopes. In addition, in the course of the evolution at certain phases the core-envelope interaction and eventual planet engulfment could speed up the stellar rotation (Schroder & Konstantinova-Antova, 2022).

In these cases, depending on the rotation rate alpha-omega or alpha2-omega dynamo appear possible. Such an example are the tipRGB/AGB stars in the Second magnetic strip (Konstantinova-Antova et al. 2014; Charbonnel et al. (2017). RZ Ari that possible has undergone planet engulfment episode (Konstantinova-Antova et al.,2022, in prep.) cannot be explained by alpha-omega dynamo. Possible mechanism for MF generation there could be alpha2-omega. In addition, giant convective cells are observed in AGB stars (Paladini et al. 2018). In the case of RZ Ari such ones are not excluded and also the possibility for a local dynamo as suggested for the MF in Betelgeuse by Auriere et al. (2010) and theoretically predicted by Dorch& Freytag (2003).

On the other hand, strong shock waves propagation enables compression of the existing very weak MF in Miras and post AGB pulsating stars (Lebre et al. 2014; Georgiev et al., 2022, in revision).

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