A LONG-TERM MAGNETIC FIELD AND ACTIVITY STUDY IN M GIANT STARS

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Abstract. In three selected M giants, EK Boo, RZ Ari and β Peg, we investigate the long-term behavior and the possible mechanims for magnetic field generation in the context of stellar evolution.

Introduction

Recently, magnetic fields (MF) were detected in many single G, K and M giants (Konstantinova-Antova et al. 2013, 2014; Aurière et al. 2015) with the spectropolarimeters NARVAL@TBL and ESPaDOnS@CFHT (Donati et al. 2006; Aurière 2003). While for the observed MFs in G,K giants the origins is mostly α – ω dynamo and remnant MF in the Ap star descendants, for the M giants the reasons are not explained. Charbonnel et al. (2017) consider that α – ω dynamo could operate even in early assymptotic giant branch stars (AGB) due to the properties of their convective envelopes. However, some of these stars possess faster rotation that could not be explained by the theory of the stellar evolution, yet. Also, most of these M giants are semi-regular variables with pulsations and it is still unclear if these pulsations relate to the MF.

What is also found for the magnetic M giants is that they occupy a definite area on the Hertzsprung-Russel diagram (HRD), the so-called "second magnetic strip" (Konstantinova-Antova et al. 2014). The strip coincides with the tip of the red giant branch (RGB) and early-AGB phase, in agreement with the theoretical models of Charbonnel et al. (2017).

EK Boo:

EK Boo (HD 130144) is a 6 mag M5III semiregular variable giant star (Samus et al. 2017). This star is an X-rays emitter (Lx>10^{30} erg.s−1) (Hunsch et al. 1998), which is unusually high for an M giant. EK Boo has a projected rotational velocity vsini= 8.5±0.5 km/s and is the first apparently single M giant with a direct detection of a surface MF (Konstantinova-Antova et al. 2010).

We obtained 51 Stokes V observations of EK Boo between April 2008 and April 2019, of which 18 show detections. The longitudinal MF Bl varies in the range of −10.20±0.86 G to 4.93±0.71 G. Figure 1 shows the MF, radial velocity and activity indicators variabiity of EK Boo. The behavior of the magnetic field strength and activity indicators might be indicative that the magnetic activity of EK Boo declines in the second half of the dataset with respect to the level in the first half. In addition, a long-term trend in the radial velocity is apparent, suggesting the existence of a companion. The secondary component must be much fainter than the primary star and not present in the spectrum. Hence, the observed polarized signatures are related to the primary star. The dataset spans over 11 years and during this time the Vrad variation does not exhibit periodicity. This suggests that the orbital period of the system is long, meaning that it is a wide binary system and synchronization plays no role for its faster rotation and magnetic activity.More on the topic is presented in Georgiev et al. (2020b).

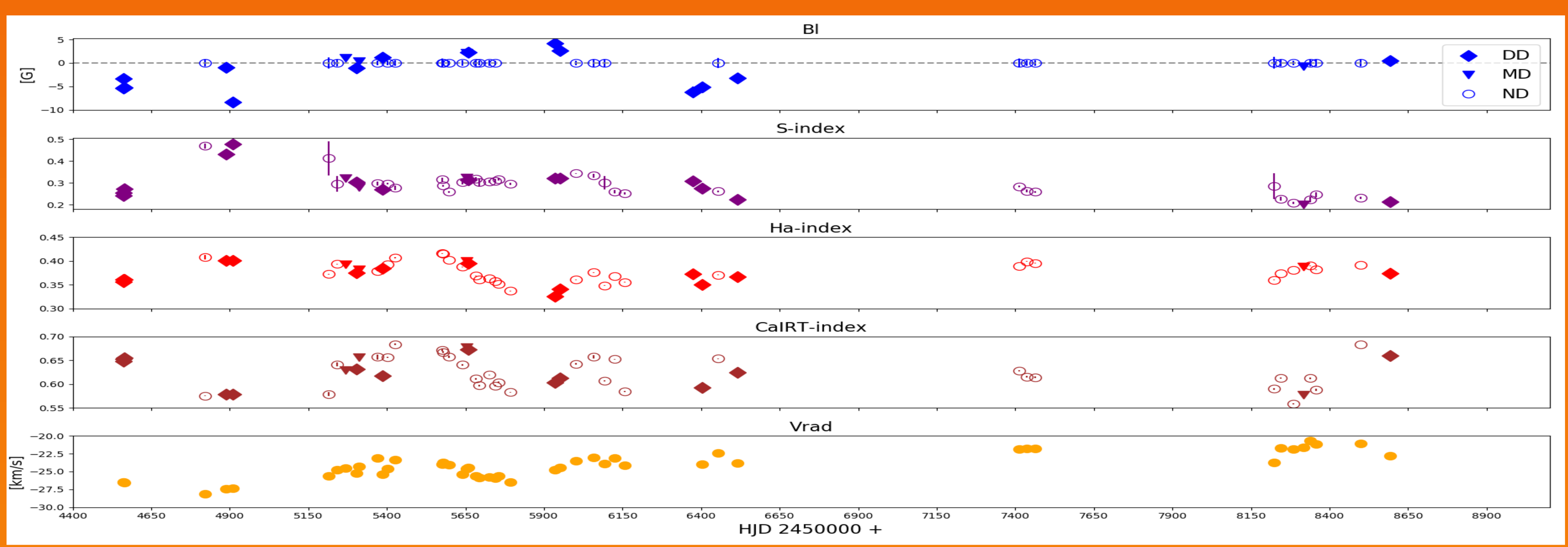

Figure 1: The long-term behavior of Bl, radial velocity and spectral activity indicators of EK Boo. ND stands for non-detection, MD – marginal detection, DD – definite detection.

β Peg:

β Peg (HD 217906) is a M2.5II-III semiregular variable star in the Solar vicinity with pulsation period P= 43.3d (Tabur et al. 2009). A value of vsini = 7 km/s was determined for this giant. β Peg is known to be a magnetic early-AGB star of 3.6 Msun (Konstantinova-Antova et al. 2014).

15 observations in circular polarisation were obtained in the period July 2015 – January 2019. For 10 of them MF was detected (Georgiev et al. 2020b). The variability of Bl, radial velocity and spectral activity indicators is presented in Fig. 2. The activity indicators seem to vary together with the magnetic field. We interpret the observed correlation between the Bl and the spectral activity indicators as an indication of a magnetic field dominated by large-scale structures. This result presumes a more simple MF geometry. The radial velocity variability could be caused by pulsations, as expected for a semiregular variable star like β Peg.

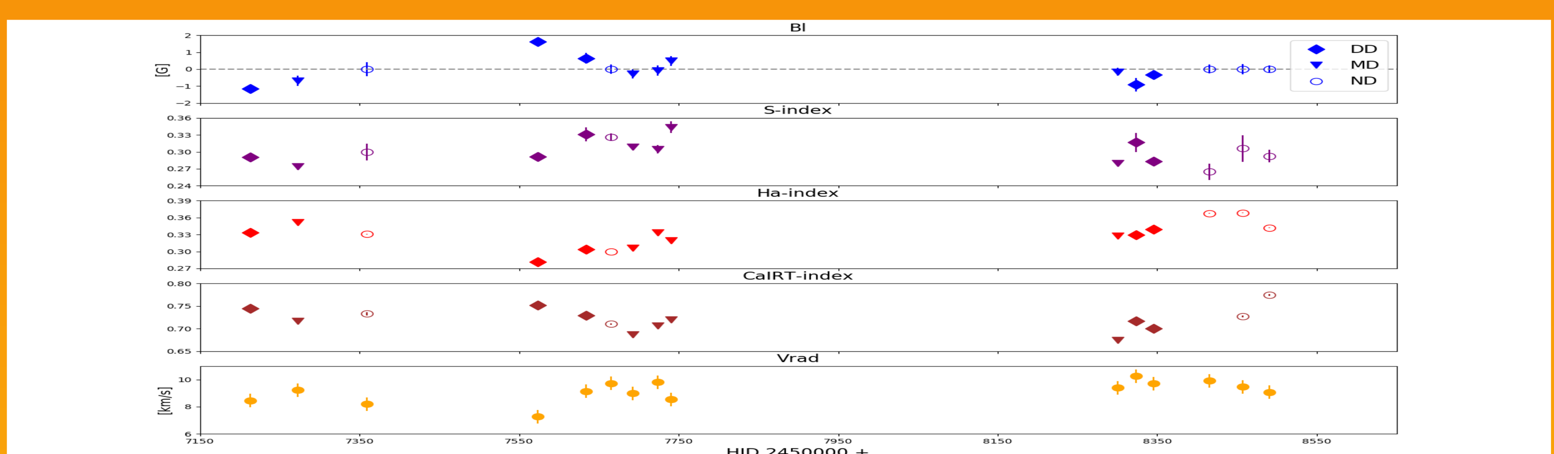

Figure 2: Bl , radial velocity and spectral activity indicators variability of β Peg. Designations are the same as in Fig.1.

Observations and data processing

The observations were performed at the 2-m Bernard Lyot Telescope (TBL),Pic du Midi with spestropolarimeter NARVAL (Auriere 2003) in the period April 2008 - August 2019. NARVAL is a fiber-fed echelle spectrometer allowing the whole spectrum from 370 nm to 1000 nm to be recorded in each exposure, in 40 orders aligned in the CCD frame. NARVAL was used in polarimetric mode with a spectral resolution of 65000. Stokes I (unpolarised) and Stokes V (circular polarization) parameters were obtained. For each star, series of 8 to 16 spectra are done for one date. The extraction of the spectra was performed using Libre-ESpRIT (Donati et al. 1997), a fully automatic reduction package installed at TBL. For the Zeeman analysis, Least-Squares Deconvolution (LSD, Donati et al. 1997) was applied. In the present case, the method enables to average several thousand 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).

Three M giants, EK Boo, RZ Ari and β Peg were selected on the basis of their previous magnetic field detection and faster rotation (Konstantinova-Antova et al. (2010, 2014), Zamanov et al. 2008). Basic data for them are presented in Table 1.

HD	Other name	Sp class	Vsini	Evolut. status	Mass	Bl max	sigma
			km/s		Msun	Gauss	Gauss
130144	EK Boo	M5 III	8.5	TP-AGB	3.0	-10.20	0.60
219706	β Peg	M2.5 II-III	7.0	early-AGB	3.6	3.16	0.26
18191	RZ Ari	M6 III	6.0	early-AGB	1.5	13.01	0.33

Table 1: Data for the studied M giants. They are published in Konstantinova-Antova et al. (2010, 2014) and Georgiev et al. (2020a).

RZ Ari:

RZ Ari = HD 18191 is a 6 mag single star of M6 III spectral class. It is the star with the strongest longitudinal MF (13 G) and with a large v\sin i (6.0 km/s, Georgiev et al. 2020a) among all M giants studied by us. According to Konstantinova-Antova et al. (2010) its effective temperature Teff is 3450 K. Taking into account its angular diameter measured during lunar occultation of 0".01022 (Richichi et al. 2005) and and the distance to the star 97.78 pc (Gaia DR3) we obtain a radius of 107,43 Rsun that is consistent with the AGB phase. On the basis of Long-base interferometry (Richichi et al. 2005) the angular diameter of 9."4 mas derived a radius of 100 Rsun. And, finally, in 2020 we obtained data with CHARA interferometer for RZ Ari. The determined angular diameter is 10.268+/-0.0066, in a good agreement with the previous measurements. The radius is 107.91 Rsun which is fully consistent with the luminosity of 1412 Lsun found by Villaume et al. (2017) from IR measurements, and indicates that RZ ARI is on the early AGB (Figure 3). Let us finally stress that the luminosity derived from Gaia photometry is inconsistent with these results as it gives a luminosity of about 600 Lsun, at least twice as low as the luminosity predicted by stellar evolution models (Charbonnel et al. 2017) and derived from IR photometry (Villaume et al. 2017, McDonald et al. 2012).

RZ Ari is also known as a semi-regular variable star with a period of pulsations of about 50 days and a Long Secondary Period (LSP) of 480 days (Percy et al. 2008, 2016; Tabur et al. 2009). Our results of more than 10 years (September 2008 – March 2019) observations of Bl, radial velocity and spectral activity indicators is presented in Figure 4. We applied Lomb-Scargle method to search for period in Bl and activity indicators and ZDI for period search in Stokes V profiles (Fig. 5). The significant periods are presented in Table 2.

The rotation period of RZ Ari:

Taking into account that vsini = 6 km/s and the radius of 119 Rsun we find 1002 days for an upper limit for the rotation period. If we consider the distance by Gaia DR3 (97.78 pc) then radius is ~108 Rsun and Psini is about 909d. Hence, the activity indicators and Vrad variability period of about 705 d could be the rotation period of the star. The ZDI one is not far to the upper limit, but the Bl period cannot be explained as due to rotational modulation. A period of about 700d presents in Fig.5, but seems not to be significant.

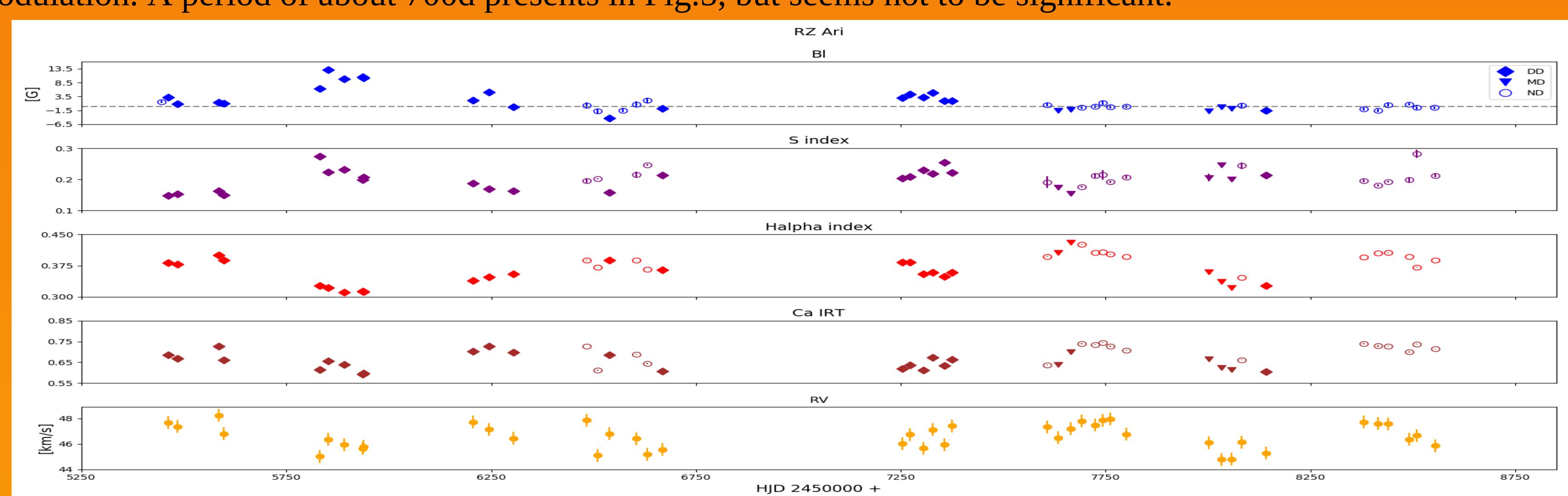

Figure 4: Bl, radial velocity and activity indicators variability of RZ Ari. Designations are the same as in Fig.1.

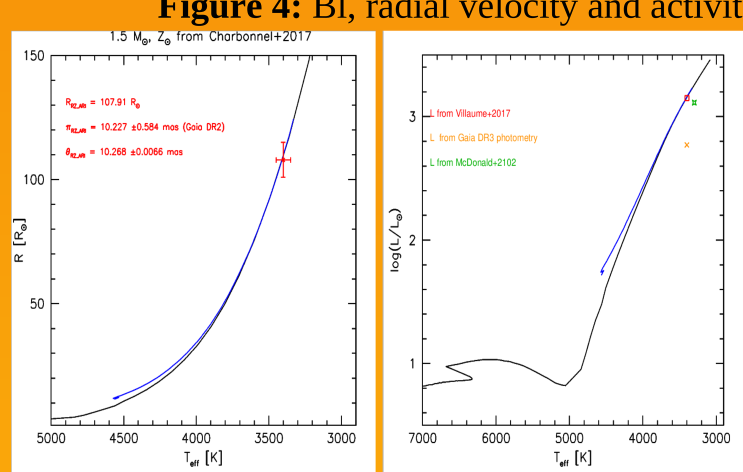

Figure 3: Situation of RZ Ari on the HR diagram.

Method	Bl P(d)	S-index P(d)	Ca IRT – index P(d)	Hα- index P(d)	Vrad P (d)
Lomb-Scargle	1280 [1243,1319]	688 [668,707]	717 [696,738]	707 [687,728]	707 [687,728]
ZDI	1090				

Table 2: Periods identified for Bl, Vrad and activity indicators. The lower and upper possible values are given in brackets.

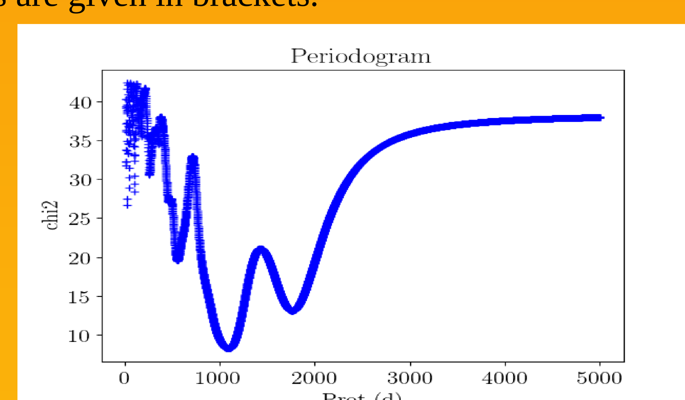

Fig.5: ZDI period search in Stokes V for RZ Ari.

Conclusions:

Long-term variability of the magnetic activity is found in EK Boo and RZ Ari. For β Peg we haven't such a long dataset to conclude. We found a possible decline of the magnetic activity level for EK Boo and RZ Ari. In addition, the variability is different than the observed one in G and K RGB stars: in these AGB stars we find episodes of detection of the MF followed by periods on non-detection.

We inspected Hα and other photosheric lines for presence of shock waves that might cause amplification of the MF as a result of compression, as it is in the Mira-type star chi Cyg (Lebre et al. 2014). No evidences for such waves were found in all these stars. We also observed them in linear polarization (assuming presence of giant convective cells like in Betelgeuse, Auriere et al. (2016)), but only for EK Boo, the most evolved one among these 3 M giants, linear polarization was detected. Further study will clarify the reason for it.

For RZ Ari, we found that the MF variability period is longer than the eventual rotation period. The long-term behavior of the spectral lines activity indicators is very indicative for the contribution of the magnetic component there. However, the magnetic heating is only part of the emission in these lines. It seems, there are other processes that also play role there. One possible explanation of the ~705 days period might be the presence of a large-scale vortex in the giant's atmosphere, like the big red spot in Jupiter (Käpylä et al. 2011).

Because of the fast rotation of these M giants, we cannot completely exclude an interface dynamo operation there, but its specifics could be rather different than in MS and RGB stars, moreover taking into account the big changes in the stellar structure in AGB stars. Further study on the topic that includes both spectropolarimetry and interferometry is under way.

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Acknowledgements: *We thank the TBL team for providing service observing with NARVAL. The observations were funded under OPTICON grants in 2008 and 2011, Bulgarian NSF project DSAB 01/2 in 2010 and the French PNPS program. R.K.-A., S.G., S.Ts., A.P. and A.L. acknowledge partial financial support under Bulgarian NSF contract DN 18/2.*