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MAGNETIC FIELD VARIABILITY IN RZ ARI – A FAIRLY EVOLVED M GIANT

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Abstract. RZ Ari is a fast rotating apparently single M giant of 2.2 Msun. It is fairly evolved to tip RGB or early AGB stage. In addition, the star is known as semi-regular variable. We have studied its longitudinal magnetic field variability using spectropolarimetric data obtained with Narval at Telescope Bernard Lyot, Pic du Midi Observatory, France in the period 2008 – 2018. Two periods were identified using the Lomb – Scargle method: 1310 days and 498 days. The second one is very close to the Long Secondary Period of RZ Ari (480 days) and maybe we observe for first time an interplay of the magnetic field and pulsations for a M giant. The first period is rather possible due to rotation modulation caused by the surface magnetic structures. Taking into account literature data we determined the radius of the star (~117 Rsun) that is consistent with the AGB phase. On the basis of the observed period of 1310 days and the calculated Psini (using radius of 117 Rsun and Vsini = 9.6 km/s) we found an inclination angle for the star of about 29 degrees.

Our work hypothesis is that RZ Ari with its fast rotation is an intermediate case of dynamo generated magnetic field and shock wave compression generated fields as we observe in Miras. These stars are the next evolutionary stage, after early-AGB stars. Further study is required to confirm or reject the hypothesis and to understand better the interplay of the magnetic field and pulsation in this fairly evolved giant.

1. 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). While the reasons for the MFs generation in G,K giants is mostly α-ω dynamo and remnant MF in the Ap star descendants, for the M giants the reasons are not completely clear. 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. In addition, some of these stars possess faster rotation that could not be explained by the theory of the stellar evolution, yet. On the other hand, most of these M giants are semi-regular variable stars with pulsations and it is still unclear how these pulsations relate to the MF generation. What is also found recently for the magnetic M giants is that they occupy a certain area on the Hertzsprung-Russel diagram (HRD), the so-called "second magnetic strip" (Konstantinova-Antova et al. 2014). This strip coinsides with the tip of the red giant branch (RGB) and early-AGB phase, in agreement with the theoretical models of Charbonnel et al. (2017).

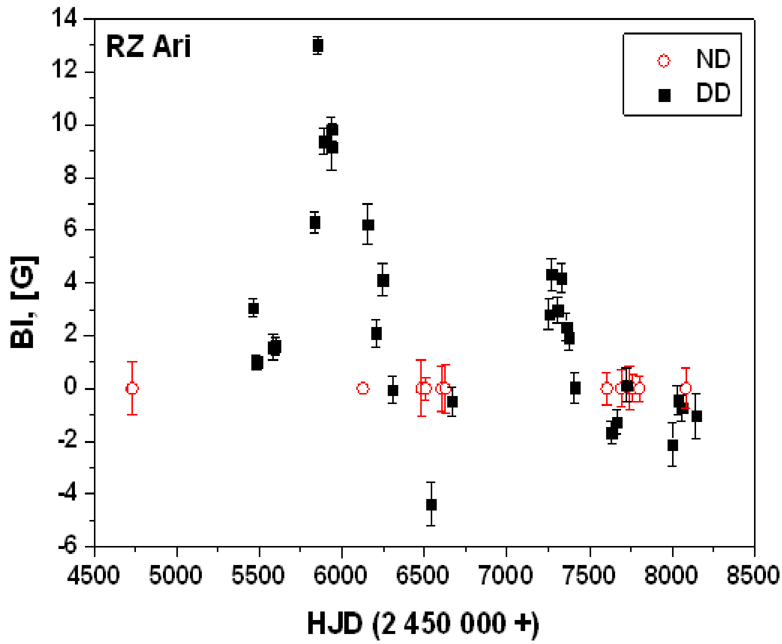

Figure 1: Bl variability of RZ Ari in the period Sept. 2008 – Jan. 2018. The black filled squares stand for magnetic field definite detection (DD) and the red open circles stand for non-detection (ND).

RZ Arietis = HD 18191 is a 6 mag single star of M6 III spectral class. It is the star with largest Vsini = 9.6 km/s and the strongest longitudinal MF (Bl = 13 G) among all M giants studied by our group. According to Konstantinova-Antova et al. (2010) its effective temperature Teff = 3450 K and log (L/Lsun) = 3.11. The star is of about 2.2 Msun and is situated either on the tip RGB or in the beginning of AGB. On the other hand, taking into account the measured angular diameter for RZ Ari of 0".01022 (Richichi et al. 2005) and the distance to the star of 107.76 pc (van Leeuven et al. 2007) we obtain a radius of 117.2 Rsun that is consistent with the AGB phase.

Also, RZ Ari is 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). Here we present the first results of about 10 years of spectropolarimetric observations and magnetic field study for this fairly evolved giant with fast rotation.

2. OBSERVATIONS AND DATA PROCESSING

The observations were carried out with the 2m Bernard Lyot telescope (TBL) at Pic du Midi Observatory, France. The telescope is equipped with Narval spectropolarimeter (Aurière, 2003). Narval has a spectral resolution in polarimetric mode of 65 000 and covers the spectral region of 360 to 1000 nm. Stokes I (unpolarized) and Stokes V (circular polarization) parameters were obtained. The technique of observations is similar to the one described in detail in Konstantinova-Antova et al. (2010). For the Zeeman analysis of the observations we applied the Least-Square Deconvolution technique (LSD, Donati et al. 1997). We used a mask calculated for solar chemical abundances and consistent with the effective temperature and log g of RZ Ari. The LSD method enables us in the case of RZ Ari to average more than 12 000 spectral lines to get the Stokes I and V profiles. The so-called "null spectrum" (obtained as a result of rotation of the retarders in the instrument, the Freshnel rhombs) given by the standard procedure was also examined, but no signal was found. That confirms that the detected signatures in the V profile are not spurious ones. From the obtained mean LSD profiles for each night the surface-average longitudinal MF Bl was computed (Rees & Semel 1979; Donati et al. 1997). For RZ Ari the typical Bl accuracy is of 0.5 G.

3. RESULTS AND DISCUSSION

A strong MF variability was found for RZ Ari in the period 2008-2018 (Fig.1). The longitudinal MF varied in the interval +13 G to -5 G with short periods of non-detection. This MF behavior is typical for the magnetic M giants (Konstantinova-Antova et al. 2013) and is different to what we observe in the magnetic G and K giants (Konstantinova-Antova et al. 2013; Aurière et al. 2015). A possible explanation is a non-uniform surface distribution of the magnetic areas. Lomb – Scargle method (Scargle, 1982) was applied for period search to the whole Bl dataset. A period of 1310 +85/-73 days was determined with a false alarm probability (fap) of 0.3%. In addition, a second, shorter period of 498 +8/-5 days was identified with a fap of 35% (Fig. 2). The phased Bl regarding the period 1310 days is presented in Figure 3. The shorter period is close to the LSP (~480 d) determined on the basis of photometric observations for RZ Ari (Percy et al. 2008, 2016). Such LSP is typical for the semi-regular variable stars, but its origin remains still unclear. Percy et al. (2016) give some assumptions for it like turnover of giant convection cells; oscillatory convective modes; dusty cloud orbiting the red giant; rotation modulation due to spots. Also, no more than one LSP is known for the stars they have studied. What could be concluded by the analysis of the published information: 1. in many cases Prot > LSP, hence rotation modulation is not likely; 2. the LSP color variations from photometry are similar to those of the pulsation period and with a sine shape (in the case of RZ Ari P ~ 50 d), and in this way the assumption for a dusty cloud and rotation modulation are excluded. In addition, contrary to the supergiant Betelgeuse (Aurière et al. 2016; Mathias et al. 2018) no evidences for giant convection cells are found for early-AGB stars. We have no idea if the convective oscillatory modes produce color variations similar to pulsations. It seems more natural that the LSP origin relates to pulsations and in this case we observe the interaction between the MF and pulsations of some kind in RZ Ari. However, more observations and their analysis are required to confirm this assumption.

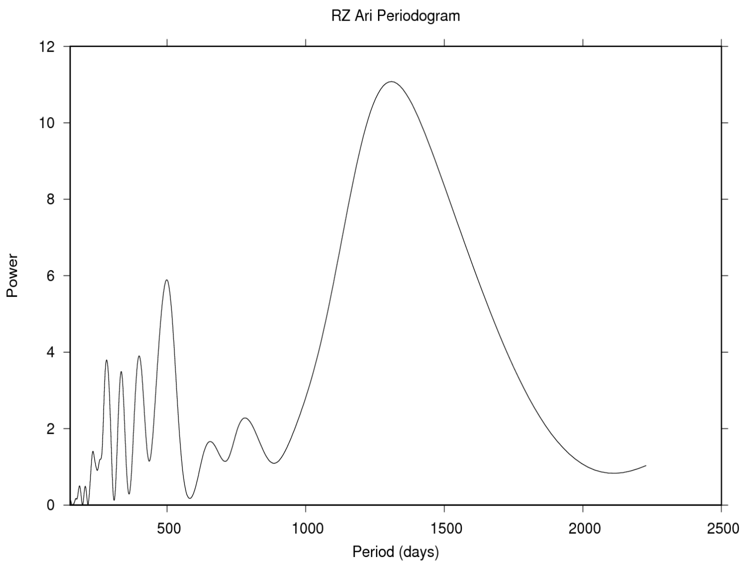

Figure 2: RZ Ari periodogram applying the Lomb-Scargle method. Two periods are identified – 1310 days and 498 days. The fap for the first one is 0.3% and for the second one it is 35%.

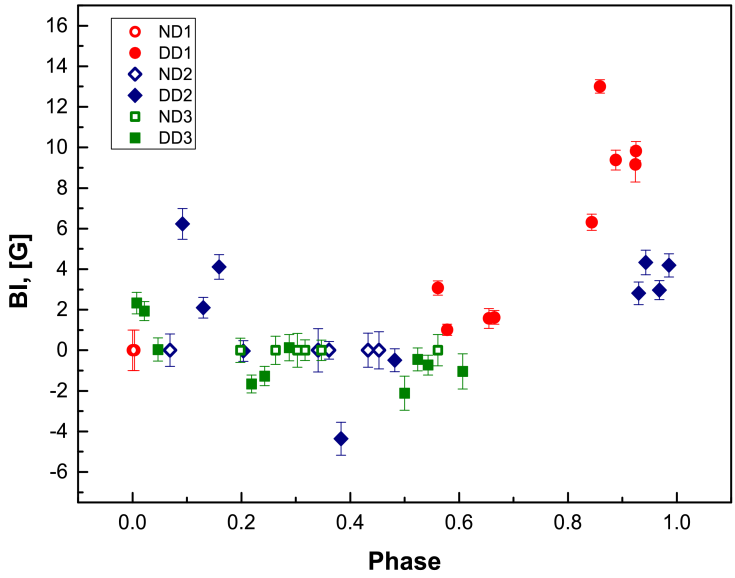

Figure 3: Bl variability of RZ Ari phased regarding the period of 1310 days.

For the longer Bl periodic variability the question is whether it is due to rotation modulation. Taking into account the Vsini and radius values mentioned in Sect.1 and the determined period, in the case of rotation modulation we obtain inclination angle i ~ 30°. That means, the star is rather tilted and in such a case the south pole is not observed. This assumption is consistent with the strong positive polarity we observe and the weaker negative one. Our next aim is to perform Zeeman Doppler Imaging (ZDI) for this M giant.

4. CONCLUSIONS

The longitudinal magnetic field variability of RZ Ari was studied on the basis of spectropolarimetric observations obtained in the period Sept. 2008 – Jan. 2018.

Two periods were identified: a long period of 1310 days and a shorter one of 498 days. The last one is very close to the LSP determined on the basis of photometric observations. After analysis of the eventual hypotheses for the origin of the LSP our conclusion is that for RZ Ari it is rather related to some kind of pulsations. If this is the case, maybe we observe for the first time an interplay between the MF and pulsations for a M giant. The longer period of 1310 days we determined is rather possible due to the rotation modulation and the inclination angle of the star (determined by using the calculated Psini) is about 29 degrees.

Taking into account that RZ Ari is an early-AGB star, but fast rotating, our work hypothesis is that it appears a case of transition between pure dynamo generated MFs and the shock wave compressed MFs found in the AGB Mira star χ

Cyg that is just at the next evolutionary stage after RZ Ari (Lèbre et al. 2014). A further study is required to verify this assumption.

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