Physical variability of the magnetic field of some stars

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Abstract
Apparent variability of the longitudinal magnetic fields in most stars is caused by rotation, which quantitatively changes projection of the magnetic field configuration on the line of sight. This is a purely geometrical effect and is not related to possible intrinsic changes of the field. In some stars we observe changes of the magnetic phase curve with time, which means that parameters of the magnetic field change. Such changes occur in some objects in time scale of several year, which is few orders of magnitude faster than predicted by theory. Those changes imply need for improvement of the theory of magnetic field evolution. We demonstrate changes of the rotational phase curves in few stars.

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1 OT Ser

This is a red dwarf star of the spectral type M1.5V and mass $0.55\,M_\odot$ and is a well known flare star with the period of rotation $P_{\text{rot}} = 3.424$ days. Longitudinal magnetic field $B_e$ measurements of the star were published in the paper by Donati et al. (2013). Measurements of the magnetic field were carried out in two sets, separated approximately by six months. The magnetic behavior of this star significantly changed in this time period.

Fig. 1 shows two magnetic phase curves of OT Ser derived from $B_e$ measurements obtained in both sets. As can be seen from Fig. 1, magnetic behavior of this object has significantly changed in just half a year.

It is well known that atmospheres of such stars rotate differentially and it causes constant generation of local magnetic fields on the surface. Due to chaotic motions lines of force of these local fields sporadically entwine with one another which eventually causes flares in the red dwarf atmosphere. Flare activity in general and even annihilation of the strongest local magnetic fields (superflares) do not affect global magnetic field of these stars (Bychkov et al. 2015).

Local fields can be generated, accumulate their energy and annihilate in presence of the global magnetic field. Probably only sometimes local magnetic fields add and reinforce one another and finally form a global magnetic field of a complex structure in some approximation close to the dipole configuration. We believe that such a process was seen in OT Ser. In other words, parameters of the magnetic field configuration in OT Ser considerably changed in time period of about six months.

![Figure 1: Phase curves of OT Ser obtained from magnetic observations separated by half a year.](image)
2 HD190073 = V1295 Aql.

This is a well known Herbig Ae/Be star. Magnetic monitoring of this star was performed under the MiMeS program (Alecian et al. 2013). This monitoring revealed that the magnetic behavior of the star significantly changed during a very short time period (less than 4 years). It is well seen in Fig. 2, which was taken from Alecian et al. (2013). Global longitudinal magnetic field became variable with the period of rotation $P_{\text{rot}} = 39.8 \pm 0.5$ days. Authors of this discovery (Alecian et al. 2013) suggested, that the change was due to interaction between frozen relic magnetic field and generation of new emerging field in the convective core. Again, we observe rapid change of physical parameters of the magnetic field configuration on the time interval from months to years.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{Phase curve drawn with the recent magnetic measurements obtained in two separated sets of observations. This Figure was taken from Alecian et al. (2013).}
\end{figure}

3 $\alpha^2 CV n.$

This is probably the most famous magnetic chemically peculiar Ap star showing abnormal content of Si, Cr, Eu and Hg. Magnetic field of the star was discovered by Babcock (1958). Since then it was actively studied by various authors, but the most important high-precision measurements were obtained by Wade et al. (2000) and Silvester et al. (2012). Both research groups carried out the analysis of their observations with precise Least Squares Deconvolution (LSD) method defined by Donati et al. (1997) and Wade et al. (2000), the latter variant known as the WLSD method.

The first set of high-precision magnetic field measurements by Wade et al.
(2000) for $\alpha^2$ CVn consisted of 18 data points, obtained during 700 days (1.9 years) with the central date JD2550848.56. Fig. 3 presents their $B_e$ points (open circles) and the average magnetic phase curve, the latter drawn with the average accuracy of $B_e$ points of 27.8 G (dotted line). The second set of high-precision magnetic measurements by Silvester et al. (2012) consists of 27 measurements obtained during 1295 days (3.5 years) with the central date JD2554722.51. These estimates are also displayed in Fig. 3 (filled circles) and the corresponding average magnetic phase curve was determined with the average uncertainty 9.4 G (solid line). Time interval between the midpoints of both sets equals 3874 days, or 10.6 years.

Fig. 3 shows, that the average magnetic phase curve markedly changed during this time period. Calculated differences between both phase curves as function of the rotational phase are shown in Fig. 4, which also shows the total uncertainty of both phase curves, equal 29.4 G (1σ uncertainty). The highest differences occur at phases close to the peak strength of the effective magnetic field and approach 222 G, which equals 7.5σ. At phases near the minimum $B_e$ differences between both phase curves amount to 4.3σ. These are very meaningful differences.

Observed changes of the magnetic phase curve in $\alpha^2$ CVn, if real, developed rapidly in the time period of about 10 years. This is much less then the time scale of evolutionary changes predicted by Krause and Raedler (1980).

Reality of the above phase curve changes in $\alpha^2$ CVn is clear when we compare with other Ap stars observed by Wade et al. (2000) and Silvester et al. (2012), with the same instrumentation and LSD method used for analysing of raw polarimetric observations. Other well known magnetic Ap stars, HD62140 and HD71866, did not show any significant difference between magnetic phase curves which were derived from both papers, see Bychkov et al. (2016).

Secular changes of the rotational magnetic phase curve of $\alpha^2$ CVn still need further confirmation by new high-precision measurements of the longitudinal field strength in this star. Over 10 years is gone after the last set of $B_e$ points for this star was obtained by Silvester et al. (2012). Therefore, we plan to run a new research program on the longitudinal magnetic field observations using the 6-meter SAO telescope after completing of new Eshel spectrometer of high spectral resolution at Special Astrophysical Observatory (Valyavin et al. 2014).

4 Conclusions

Abundance spots on surfaces of Ap stars were considered as very stable structures which could change only in very long timescales. However, as was shown by Kochukhov et al. (2007), chemical spots on some CP stars evolve in time scale of about 4 years ($\alpha$ And, HgII 3984). Therefore, these
processes are much more rapid than was previously assumed. It would be extremely interesting to obtain distribution maps for various elements on the surface of $\alpha^2$ CVn in 10 - 15 years from now and compare with the distributions presented already by Silvester et al. (2014). Magnetic field of a complex structure must evolve much faster than a simple dipole (Krause & Rädler 1980). Such complex magnetic field was observed in $\alpha^2$ CVn. Theoretical evaluations of the timescale of the quadrupole
field evolution give the scale of the order $\sim 10^4$ years according to Krause & Raedler (1980).

Evolution timescale of the magnetic field was estimated as $3 \times 10^7$ years from observations of stars in open clusters of different ages (Landstreet et al. 2008). However, this estimate was obtained for many stars and represents only some average value. Moreover, their estimate in general refers to stars which have simple dipole magnetic fields. According to Bychkov et al. (2016), 68 % of Ap stars have simple dipole magnetic field and only 32 % have more complex quadrupole fields.

We demonstrated existence of quite rapid change of the rotational phase curve of the longitudinal magnetic field of Ap star $\alpha^2$ CVn. This is a signature of the intrinsic changes of the global magnetic field parameters on the star’s surface. Time scale of these variations, if real, is much shorter than the existing theoretical predictions which gave estimates of much longer timescales for some average magnetic star.

Magnetic field of this particular object needs further monitoring in future to verify the above hypothesis on fast global field changes.

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References

[1] Alecian, E. et al. 2013, A&A, 549, L8
[2] Babcock, H.W. 1958, ApJS, 30, 141
[3] Bychkov, V.D., Bychkova, L.V., Madej, J. 2005, A&A, 430, 1143
[4] Bychkov, V.D., Bychkova, L.V., Madej, J. 2016, in press
[5] Bychkov, V.D., Bychkova, L.V., Madej, J., Panferov, A.A. 2015, ASP conf. ser., 494, 210
[6] Bychkov V.D., Bychkova L.V., Madej J., Topilskaya G.P. 2016, arXiv:1606.09562
[7] Donati, J.F., Semel, M., Carter, B.D., Rees, D.E., Cameron, A.C. 1997, MNRAS, 291, 658
[8] Donati, J.-F., Morin, J., Petit, P. et al. 2008, MNRAS, 390, 545
[9] Kochukhov, O., Adelman, S.J., Gulliver, A.F., Piskunov, N. 2007, Nature Physics, 3, 526
[10] Krause, F., Raedler, K.-H. 1980, Mean-field magnetohydrodynamics and dynamo theory (Oxford, Pergamon Press), 271

[11] Landstreet J.D., Silaj J., Andretta V. et al. 2008, A&A, 481, 465

[12] Silvester, J., Wade, G.A., Kochukhov, O. et al. 2012, MNRAS, 426, 1003

[13] Silvester, J., Kochukhov, O., Wade, G.A. 2014, MNRAS, 444, 1442

[14] Valyavin, G.G., Bychkov, V.D. et al. 2014, Astr. Bulletin, 69, 224

[15] Wade, G.A. et al. 2000, MNRAS, 313, 851