On the evolution of the magnetic field of Ap star $\alpha^2$ CVn

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Abstract

New high-precision measurements of the longitudinal magnetic field of Ap stars suggest the existence of secular intrinsic variations of the global magnetic field in some stars. We argue that such changes are apparent in the Ap star $\alpha^2$ CVn in the time scale of $\sim 10$ years, which results from the analysis of literature data. Therefore, such an observation implies, that the rate of magnetic field evolution of Ap stars is much higher than was previously thought.

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1 Introduction

The study of evolution of the global magnetic fields of Ap stars is a very important recent research subject. Theoretical studies of the evolution of these objects were carried out by a number of authors and were extensively summarized by Moss (1990). According to his results, magnetic fields of stars also must evolve in the time scale of a general evolution of stars, i.e. in time scale of about $2.5 \times 10^7 - 1.31 \times 10^8$ years. Landstreet et al. (2007) presented the most accurate estimates of the rate of magnetic field evolution of Ap stars obtained on the basis of observational data.

Estimates of the characteristic time of the magnetic field evolution yield $2 - 3 \times 10^7$ years for massive A stars of mass $M$ higher than 3 solar masses, $M > 3M_\odot$. For stars with masses lower than 3 solar masses, $M < 3M_\odot$, the rate of evolution is of the order of $10^8$ years. These numbers basically refer to stars which have the global magnetic field of a simple dipole structure and are fully consistent with theoretical estimates by Kochukhov and Bagnulo (2006).

According to theoretical studies by Krause and Raedler (1980), if the global magnetic field has a more complex structure of the quadrupole, octupole, etc., then its evolution proceeds much more rapidly than in the case of a simple dipole.

2 New observational data

Currently, accuracy of determination of the longitudinal magnetic field in stars has substantially improved due to the use of modern light detectors and new methods of processing of observational data. New techniques revealed a number of subtle effects in the run of the longitudinal magnetic field variations, which previously were unavailable for research.

Two series of projects were recently carried out on exact measurements of $B_e$ in stars during past two decades, which enabled us for the construction of the magnetic phase curves of some Ap stars. Results of the first high-precision measurements of the longitudinal magnetic fields $B_e$ using the Least Squares Deconvolution (LSD) method (Donati et al. 1997) and WLSD (Wade et al. 2000a), obtained at the end of the XXth century, were published in Wade et al. (2000b). In the latter study, series of $B_e$ measurements were obtained for 14 Ap stars and for 11 of stars in that set observations cover all phases of the rotational period. Silvester et al. (2012) also published $B_e$ series obtained by analogous methods for 7 Ap stars.

The latter measurements were carried out in years 2006 - 2010 and for three stars they satisfactorily cover all phases of the rotational period. In both quoted papers the average $B_e$ measurement error corresponding to $1\sigma$ is lower than 50 G. There are 6 stars studied in both sets of $B_e$ mea-
Figure 1: Magnetic phase curves of $\alpha^2$ CVn. Red line denotes phase curve derived from $B_e$ points in Wade et al. (2000), whereas black line was derived from Silvester et al. (2012).

Measurements for which authors presented data on two high-precision phase curves separated by several years of observations and obtained using the same methodology. Therefore, these phase curves can be directly compared in order to search for possible changes in the magnetic phase curves of CP stars for 10 years.

2.1 $\alpha^2$ CVn

Significant changes of the magnetic phase curve showed up in the well-studied magnetic Ap star $\alpha^2$ CVn (SiCrEuHg type). Periodic variability of the longitudinal (effective) magnetic field $B_e$ with the rotational phase has a complex double-wave curve which corresponds to the structure of a quadrupole magnetic field (at the first approximation). Results of the first high-precision measurements using the LSD method were first published by Donati et al. (1997) and Wade et al. (2000b). Authors of the latter paper presented a series of 18 measurements distributed over 700 days (1.9 years) around the average date JD 2550848.56, see open circles in Fig. 1. It was found that the average accuracy of $B_e$ measurements equals 27.8 G.

The second set of high-precision measurements was obtained by the same methods and was published in Silvester et al. (2012). Their results form a
Figure 2: Difference between both phase curves of $\alpha^2$ CVn, $B_e[2000] - B_e[2012]$, is given by the solid line. The amplitude of the residual phase curve strongly exceeds the $3\sigma$ uncertainty range of the magnetic phase curve determination.

A series of 27 measurements obtained over 1295 days (3.5 years) with the average date JD 2554722.51. These estimates are plotted in Fig. 1 as filled circles with the corresponding magnetic phase curve. Phase curve and its amplitude was found with the average accuracy of 9.4 G (solid line).

Rotational phases of $\alpha^2$ CVn in Fig. 1 were determined using the ephemeris by Farnsworth (1932), $JD(EuIImax) = 2419869.720 + 5.46939 E$.

Time interval between the centers of these two sets equals 3874 days (10.6 years). Figure 1 clearly shows that during the period of about 10 years phase curve markedly changed. Calculated difference between both phase curves is plotted as the function of the rotational phase in Figure 2, which also shows the $1\sigma$ uncertainty of the amplitude of the residual phase curves equal to 29.4 G.

The largest difference of 222 G occurs in the rotational phase 0.96, which equals 7.5 sigma. In phase of 0.39 the difference between both phase curves equals -125 G, or 4.3 sigma. Therefore, it is a very significant difference. It is very likely that this is a real change of the magnetic phase curve occurring during about 10 years. Therefore, we note that the rate of evolution of the magnetic field in this star by about 5 - 6 orders of magnitude faster than
It should be noted that, according to Krause and Raedler (1980), evo-
lution of the global magnetic fields of stars with a complicated structure
(quadrupole, octupole, etc.) should take place significantly faster than in
stars with a simple dipole structure of the magnetic field. But even in such
a case it turns out that the magnetic field of \( \alpha^2 \) CVn actually evolves much
faster (4 - 5 orders of magnitude) than was predicted before (Krause and
Raedler 1980).

3 Discussion

Naturally the following question arises - how realistic is this effect? To con-
firm that this is a real feature we demonstrate lack of such phase curves
differences in some other Ap stars in which the longitudinal magnetic field
was measured by the same instrument and methods, published by the same
authors in the same papers. We have not found such significant changes of
the magnetic phase curves for the other CP stars from the list.

As an example, consider magnetic Ap star HD62140. In the paper by
Wade et al. (2000a), 14 high-precision measurements of the longitudinal
magnetic field \( B_e \) were obtained during 705 days of observations (1.9 years)
centered on JD 24550858.0. Fig. 3 presents two magnetic phase curves, again
the second curve was derived from Silvester et al. (2012). The latter paper
presented 19 measurements obtained during 1171 days (3.2 years) about JD
24554666.3.

Time span between the centers of both sets of \( B_e \) measurements equals
3808.3 days (10.4 years). Duration of sets, number of \( B_e \) points and the

time interval between sets is very close to that obtained for \( \alpha^2 \) CVn. At the
rotational phase \( \psi = 0.01 \) the difference between phase curves amounts to
1.51\( \sigma \), for \( \psi = 0.51 \) to 4.91\( \sigma \).

For HD62140 long-term changes of the phase curve are much lower and
apparently show the opposite sign. I.e. the amplitude value estimates for
\( \alpha^2 \) CVn increased as compared with the first set (phase change and the
shape of the curve), while for the opposite HD62140 slightly decreased in
high magnetic field. Similar results were obtained for other stars have been
investigated in these studies.

Fig. 4 shows results of another set of high-precision of \( B_e \) measurements
of HD71866, derived from the same two papers using the same methods,
instrument and similar dates of observation.

4 Conclusions

We noted the probable existence of secular changes of the global magnetic
field in Ap star \( \alpha^2 \) CVn exceeding the estimated 3\( \sigma \) uncertainty level. Our
observation was derived from two published papers which presented series of the longitudinal magnetic field $B_e$ of a small group of Ap stars obtained by the precise Least Squares Deconvolution method. We compared here $B_e$ rotational phase curves of $\alpha^2$ CVn separated by a time span of $\approx 10$ years.

At present it is still too early to draw definite conclusions on the prompt secular evolution of the magnetic field of $\alpha^2$ CVn. That problem requires obtaining more high-precision observational data. Actually we prepare new instrument at SAO in order to verify the complex and subtle problem of secular variations of the magnetic field in Ap stars (Valyavin et al. 2014). If the change of the magnetic phase curve of $\alpha^2$ CVn is confirmed, it will radically change the whole idea of the evolution of global magnetic fields Ap stars.

5  Acknowledgements

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Figure 4: Phase curves of HD71866. Open circles - Wade et al. (2000a), filled circles - Silvester et al. (2012).

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