The A-Star Puzzle
Proceedings IAU Symposium No. 224, 2004
J. Zverko, J. Žižňovský, S.J. Adelman, & W.W. Weiss, eds

DOI: 10.1017/S174392130500949X

A catalogue of average magnetic phase curves

V.D. Bychkov[1], L.V. Bychkova[1] and J. Madej[2]†

[1]Special Astrophysical Observatory, Russian Academy of Sciences, Nizhnij Arkhyz, Russia
email: vbych@sao.ru

[2]Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
email: jm@alkor.astrouw.edu.pl

Abstract. We collected published measurements of the effective magnetic fields of stars on the Main Sequence and above it, and compliled a catalogue of periodic $B_{\rm e}$ variations. We present magnetic phase curves for 139 stars and tables of their parameters. Most of catalogued objects are chemically peculiar A and B type stars (134 stars).

Keywords. Catalogs, stars: magnetic fields, stars: variables: other

1. Introduction

Variability of the effective magnetic fields $B_{\rm e}$ in Ap stars was discovered over 50 years ago (Babcock & Burd 1952). A large amount of observational data has been collected since then. We performed an extensive literature search and selected all available measurements of the effective (longitudinal) magnetic field $B_{\rm e}$ for Main Sequence and a few other stars. Average magnetic phase curves $B_{\rm e}(\phi)$ were constructed for those stars for which we know magnetic (i.e., rotational) periods or could determine them.

A star with a large-scale magnetic field can be described by the oblique rotator model, in which the axis of a magnetic dipole is inclined to the rotation axis. The dipole field itself does not change with time. Periodic variability of the effective magnetic field $B_{\rm e}$ is caused by changes of aspect due to stellar rotation. Therefore the period of magnetic $B_{\rm e}$ variations, $P_{\rm mag}$, can be identified with the rotational period $P_{\rm rot}$.

This model was proposed to explain the behavior of magnetic CP stars, which exhibit periodic variations of $B_{\rm e}$ (Stibbs 1950, Preston 1967). In that model, the dipole magnetic field is frozen into the stellar atmosphere, and is intrisically constant at each point.

Our catalog presents average magnetic phase curves in a homogeneous form. We have also determined other parameters of magnetic variability for all stars which are briefly described below.

2. Parameters of magnetic variability

In this section we list the parameters of the magnetic phase curves, and also the parameter r, which was defined by Stibbs (1950). These are: B_0, B_1, B_2, T_0, P and r.

2.1. *Sine wave*

For all stars with an adequate number of $B_{\rm e}$ determinations and for which the period of magnetic variability $P_{\rm mag}$ was known, we have determined the best fit for the relation of $B_{\rm e}$ vs. phase ϕ

$$B_{ei}(\phi) = B_0 + B_1 \cos\phi\,, \tag{2.1}$$

† Present address: SAO RAS, Nizhnij Arkhyz, 369167 Russia.

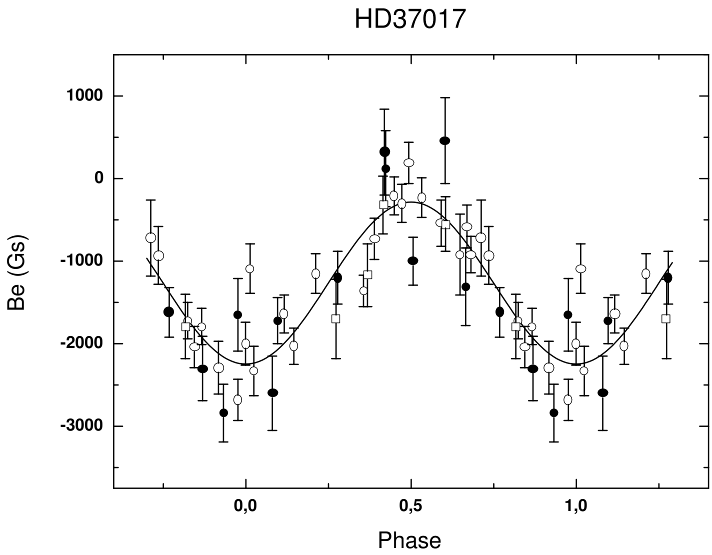

Figure 1. Sample phase curve: single wave for HD 37017. Open circles: Bohlender *et al.* (1987) (H lines), filled circles: Borra & Landstreet (1979) (H lines), open squares: Bohlender *et al.* (1987) (He λ5867).

where

$$\phi = 2\pi \left(\frac{T_i - T_0}{P} \right) . \tag{2.2}$$

by the least squares method. Here B_0 is the average field, B_1 stands for half of the amplitude, T_i, the time of measurement, P, the the period, and T_0 is the zero epoch, i.e., time corresponding to the zero phase ϕ. We have chosen the zero epoch T_0 so that the phase $\phi = 0$ corresponds to the minimum of the best fit magnetic curve for all stars.

2.2. *Parameter r*

Parameter r relates both angle β between the magnetic dipole axis and the rotational axis, and the angle i between the rotational axis and the line of sight

$$r = \frac{\cos\beta\cos i - \sin\beta\sin i}{\cos\beta\cos i + \sin\beta\sin i} . \tag{2.3}$$

Alternatively, one can write

$$r = \frac{B_{\rm e}(\min)}{B_{\rm e}(\max)} . \tag{2.4}$$

2.3. *Double wave*

If the shape of the magnetic phase curve is more complex than a simple cosine, we include the second harmonic

$$B_{ei}(\phi) = B_0 + B_1\cos(\phi + z_1) + B_2\cos(2\phi + z_2) . \tag{2.5}$$

https://doi.org/10.1017/S174392130500949X Published online by Cambridge University Press

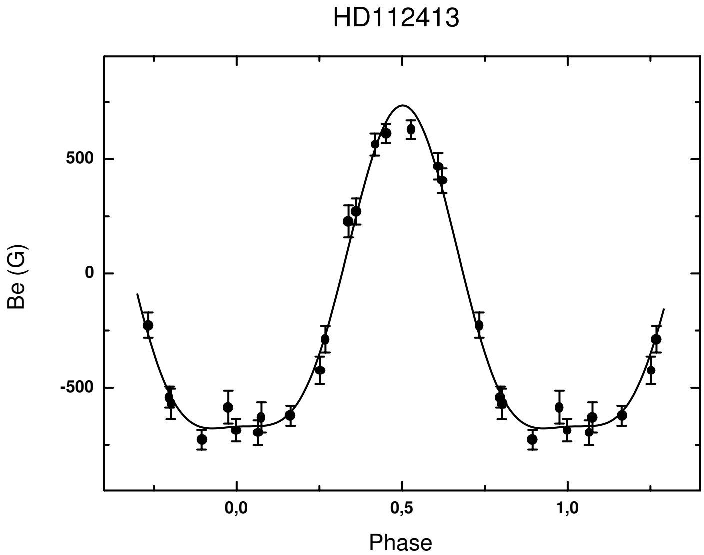

Figure 2. Sample phase curves: double wave. The HD 112413 phase curve $B_e(\phi)$ derived from B_e measurements of Wade *et al.* (2000) (metal lines, LSD method). The average phase curve $B_e(\phi)$ has the form of a double wave.

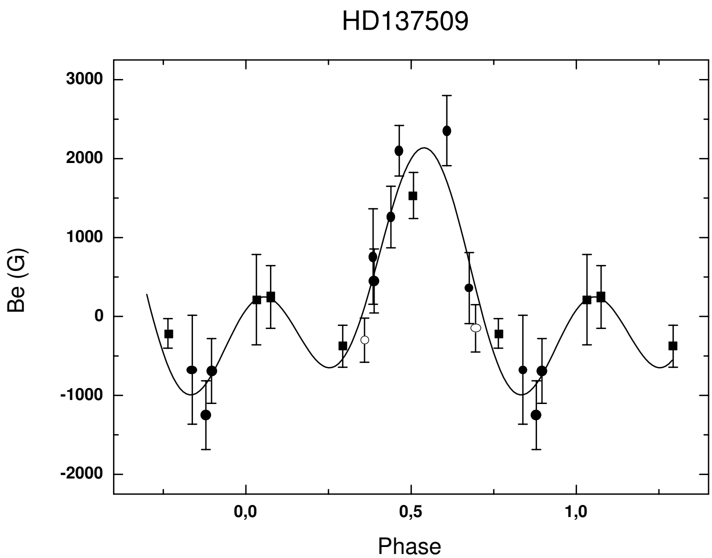

Figure 3. Sample phase curves: double wave for HD 137509. The magnetic phase curve is described best by a double wave. Filled squares, Mathys G.& Hubrig (1997); open circles, Bohlender *et al.* (1993); filled circles, Mathys (1991).

https://doi.org/10.1017/S174392130500949X Published online by Cambridge University Press

3. Error analysis

For each star in the sample we performed a χ^2 test to evaluate the goodness of the assumed fit, given either by Eq. 1 or Eq. 4, and estimated the scatter of the available B_e measurements. The χ^2 statistical test can indicate a large discrepancy between observed points and the assumed fitting curve if either the fitting curve is intrinsically inconsistent with observations, or the errors of observations (i.e. values of B_e) are overestimated.

Error estimates of all parameters T_0, B_0, B_1, B_2, and r, were performed as follows. For each B_{ei} measurement with known standard error σ_i we generated a series of secondary B_{ei}^{sec} values with a random number generator.The values of B_{ei}^{sec} had a normal distribution around the observed B_ei with the width σ_i. (When the authors did not provide σ_i estimate, we used an arbitrarily error typical for a given method of observation.) This method generated set of artificial values of B_e, for which the secondary parameters T_0, B_0, B_1, B_2, and r were determined.

These computations were repeated usually 1000 times or more. In this way we obtained numerous sets of fitting parameters, and were able to estimate errors of T_0, B_0, B_1, B_2, and r separately.

4. Tabular data

A complete catalog of the investigated stars and the corresponding parameters of the best fit sine magnetic curves (Eq. 2.1) is presented in Table 1, which will be available on the Internet. Table 1 lists the HD number, B_0, σ_{B_0}, B_1, σ_{B_1}, the period P, T_0, σ_{T_0}, N (the number of individual points, σ (the average scatter of B_{ei} about the fitting curve), r, σ_r, the value of χ^2 (for one degree of freedom), reference number, and (in some cases) the running number of brief comments.

Table 2 of our catalog presents for each star: the HD number, parameter r and its standard error σ_r, $N_V = N-3$ or $N-5$ (for sine wave. or double wave fits, respectively), χ^2 for one degree of freedom, method and reference numbers.

There are 18 magnetic stars which display more complex phase curves $B_e(\phi)$. For them phase curves were fitted by an expansion in the harmonic series with the second cosine term, see Eq. 2.5 (double wave).

Table 3 presents additional parameters necessary to define the double wave. These are coefficients B_2, phase shifts z_1 and z_2, and their errors σ_{B_2}, σ_{z_1}, σ_{z_2}, N_V, values of χ^2, number of references and comments. Here $N_V = N - 5$.

5. Summary

We compiled a catalog of magnetic phase curves $B_e(\phi)$ for 139 stars, which exhibit periodic variations of the effective magnetic field B_e. Most catalogued objects, 134 stars, are chemically peculiar A and B type stars. The catalog consists of figures, which display individual B_e measurements and error bars, and phase curves approximated either by a sine wave, or by a double wave.

The catalog presents lists the following parameters of the magnetic phase curves: coefficients B_0, B_1, and B_2 of the harmonic expansion of $B_e(\phi)$, the period P (in days) and the Julian Day of zero phase T_0, and the coefficient r defined by Stibbs (1950).

Acknowledgements

Our research is based on data compiled and posted in the SIMBAD, ADS, and CDS databases. We acknowledge support from the Polish Committee for Scientific Research grant No. 1 P03D 001 26.

References

Babcock, H.W., Burd, S. 1952, *ApJ* 116, 8
Bohlender D.A.,Brown D.N.,Landstreet J.D., Thompson I.B. 1987, *ApJ* 323, 325
Bohlender D.A.,Landstrret J.D.,Thompson I.B. 1993, *A&A* 269, 355
Borra E.F. & Landstreet J.D. 1979, *ApJ* 228, 809
Bychkov, V.D., Bychkova, L.V., Madej, J. 2004,*A&A* in press
Mathys G. 1991, *A&ASS* 89, 121
Mathys G. & Hubrig S. 1997, *A&SS* 124, 475
Preston G.W. 1967, *ApJ* 150, 547
Stibbs, D.W. 1950, *MNRAS* 110, 395
Wade G.A.,Donati J.-F.,Landstreet J.D.and Shorlin S.L.S. 2000, *MNRAS* 313, 851

https://doi.org/10.1017/S174392130500949X Published online by Cambridge University Press