MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
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About the periodic variation of the stellar magnetic fields

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Abstract. In this work, a general description of the observed variability of magnetic fields in stars of various spectral types is presented. Average magnetic phase curves (MPC) and their parameters are presented in three catalogs. As a result, there are currently medium magnetic phase curves for 415 stars, 258 of which are Ap/Bp stars. Such a large number of Ap/Bp stars allows you to judge not only the parameters variability, the structure of the global magnetic field, but also opens up the possibility of finding the reason explaining the super slow rotation of some of them.

Keywords: stars: magnetic fields, variability

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1 Introduction

Magnetic fields play an important role in the physics and evolution of stars. For stars with a sufficient number of B_e measurements and for which the magnetic variability period P_{mag} is known, we obtained average magnetic phase curves (MPC). About 10% OBA stars have fairly strong magnetic fields (Grunhut et al. 2017; Sikora et al. 2019) reaching several thousand gauss in intensity. According to Bychkov et al. (2021a) 75% stars have magnetic harmonic phase curves, and 25% stars have two-wave phase curves. The magnetic fields of hot stars are generally stable throughout the entire period of studies (about 75 years). Only some of them are suspected of slight variability of the MCP parameters (magnetic phase curves) (Bychkov et al. 2021a). Examples of single-wave and double-wave MCP are shown in Fig. 1a, b. All MCPs and their parameters are presented by Bychkov et al. (2005, 2021a).

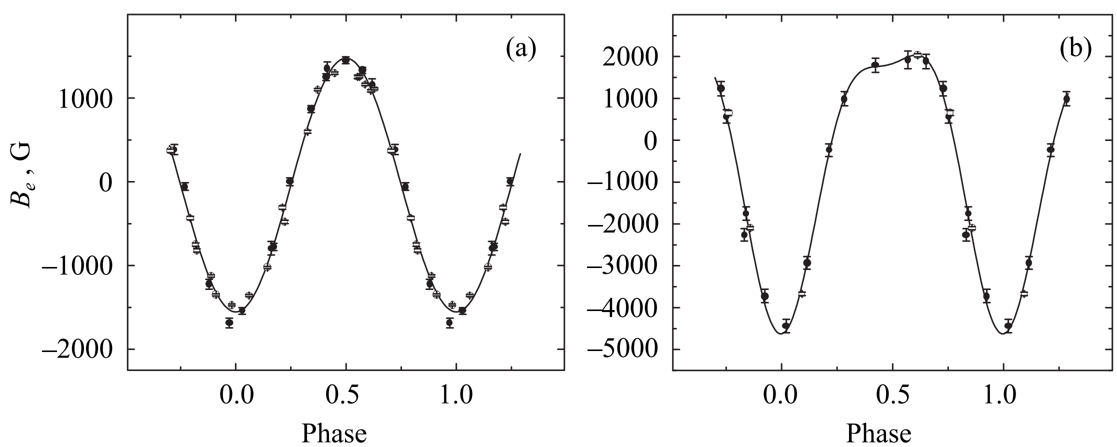

Fig. 1. Examples of single-wave MPC for the star HD 62140 F0pSrEu type (Bychkov et al. 2021a) (a) and double sine wave MPC for the star HD 133880 B8IVpSi (Bychkov et al. 2021a) (b).

2 Types of stars for which MPCs were obtained

Table 1 shows the number of stars by spectral type with famous MPCs.

3 MPC hot stars

Ap/Bp stars have photometric variability due to the presence of relatively cold spots on their surface. Photometric variability provides an excellent opportunity to esti-

Table 1. Number of stars in various classes with known magnetic phase curves.

Type	Number	Type	Number
Ap/Bp	258	Stars hosting planets	8
Var. β Cep	18	Normal chem. comp. stars	6
Slowly Pulsating B stars	9	Be stars	6
High Proper Motion stars	14	Var. δ Sct	3
Var. δ Cep	2	Semi-regular var. pulsating	3
Multiple stars	19	Flare stars	17
Pulsating stars	6	Ae/Be Herbig stars	10
Var. BY Dra	12	T Tau stars	6
Var. Ori type	5	Pre-main sequence	3
Rotationally var. stars	20	EB, Algol + BY Dr	1
Var. RS CVn	2	Blue supergiant star	2
Wolf-Rayet star	2		

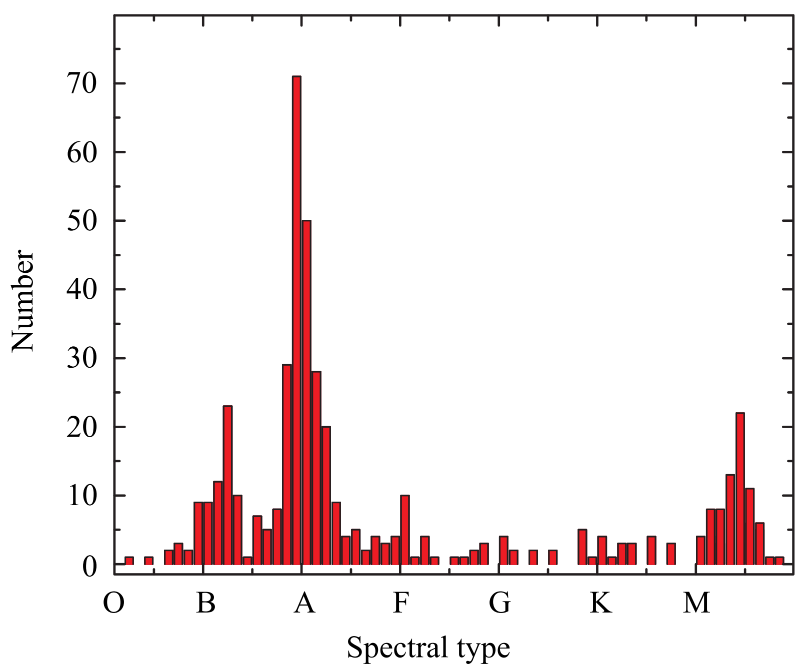

Fig. 2. Number of stars with known MPCs depending on spectral type. 43 objects are included (red dwarfs from M0 to M6), whose magnetic behavior was investigated by Donati et al. (2023).

mate the rotation period of these stars with high accuracy (Saar et al. 1986; Metlova et al. 2014; Renson & Catalano 2001), and many others. This has become especially important with the advent of high-precision photometry from the Kepler, TESS, Gaia and other space missions (Balona et al. 2019; David-Uraz et al. 2019; Sikora et al. 2019). Thanks to Labadie-Bartz et al. (2023) and a number of other researchers it was possible to determine the periods of mCP stars with high accuracy. The possibilities of high-precision space photometry have appeared recently. This limits the search and precise determination of periods longer than 50 days (Mathys et al. 2024). One of the most interesting features of magnetic Ap stars is their slow rotation. On average, Ap stars rotate 4–5 times slower than the same normal stars (Abt & Morrell 1995; Glagolevskij 2021). It is believed that they acquired slow rotation before entering the main sequence. Currently, 24 Ap/Bp stars with rotation periods of more than 100 days are known to have MPC. The possibility of the existence of rotation periods of hundreds and even thousands of years was indicated by Mathys (2017). This is confirmed by Metlova et al. (2014); Bychkov et al. (2016); Hubrig et al. (2018); Giarrusso et al. (2022) and a number of others. The main difficulty in obtaining the MCP for such stars is long-term magnetic monitoring which sometimes lasts for decades.

4 Global magnetic fields of late stars

Stars of late spectral classes have strong surface magnetic fields reaching 3.8 kG. This was first shown for the dwarf M3 AD Leo (Saar & Linsky 1985; Saar et al. 1986). How strongly the MPC parameters vary on such stars was shown by Donati et al. (2008); Bychkov et al. (2021a). A huge contribution to the study of the magnetic behavior of such objects was made by the SPIRou near-infrared magnetic measurement program, carried out at the CHFT (Canada-France-Hawaii Telescope) (Donati et al. 2023). During this survey, 6700 magnetic field estimates were obtained for 43 red dwarfs in the spectral range from M0 to M5.5 in the time interval 2019–2022 with an average accuracy of about 4 G (the error range was from 1 G to 15 G depending on the object). The number of estimates obtained for one object ranged from 50 to 247 and on average was about 150.

It has been convincingly shown that the magnetic phase curves of these stars vary greatly with time. In a first approximation, they can be represented as a superposition of two harmonic dependencies with close periods. It seems that there are two (or more) dipoles, whose axes (respectively, magnetic poles) are spaced apart in latitude. Due to the differential rotation of the star's atmosphere, these dipoles rotate with close but different periods. It is possible that the intensity itself of these magnetic "spots" varies. This will further complicate the observed variability. The observed

MF intensities vary from units to tens of gauss. The rotation periods of these objects vary from several to hundreds of days (Donati et al. 2023). As an example, the MCP for GJ 1289 (spectral class M4Ve) with the main period of 73.66 days is given in Fig. 3, which clearly shows how the phase dependence of the magnetic field varies from period to period.

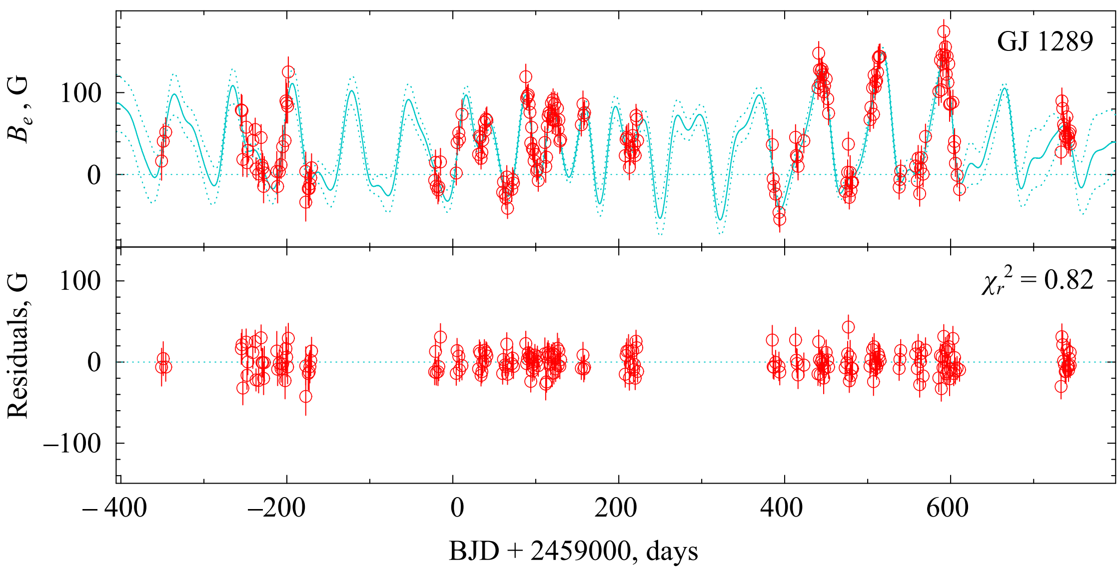

Fig. 3. As an example, magnetic monitoring of the red dwarf GJ 1289 (spectral class M4Ve) is shown, obtained by Donati et al. (2023) with the period of 73.66 days. Red dots indicate magnetic field estimates depending on the time of acquisition. A total of 204 estimates were obtained a little over 3 years. This is more than 15 periods. The solid curve plotted in blue in the figure is an approximation curve describing the magnetic behavior of GJ 1289. The two curves marked with dots indicate the accuracy of the approximation.

5 Summary

The created catalogs serve to present and summarize the observational material of the variability of stellar magnetic fields of different types. This allows us to reasonably judge the origin and evolution of stellar magnetic fields, test hypotheses and conduct statistical analysis, study the mechanism of "magnetic braking" of stellar rotation and much more.

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