ABOUT THE GLOBAL MAGNETIC FIELDS OF STARS

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ABSTRACT. We present a review of observations of the stellar longitudinal (effective) magnetic field (B_e) and its properties. This paper also discusses contemporary views on the origin, evolution and structure of B_e.

Key words: Stars: magnetic field

1. Introduction

At present there are collected direct measurements of the longitudinal (effective) magnetic fields in 1873 stars of various spectral types. The total number of the magnetic field B_e measurements amounts to 24124. In the following text we shall refer to B_e as the magnetic field for brevity.

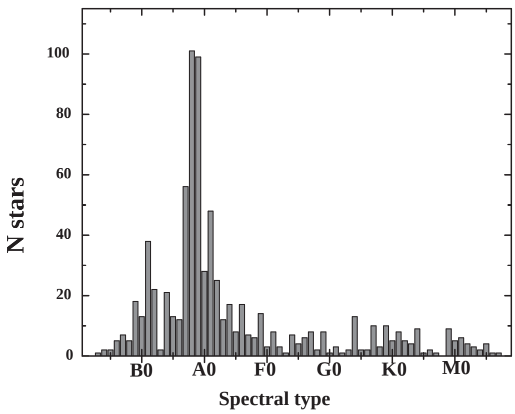

Figure 1: Number distribution of stars with measured longitudinal magnetic fields B_e vs. spectral type.

The dominant part of existing observations (for over 900 objects) was obtained for CP stars.

2. Observational data

We list here the most obvious advantages of the above progress:

1. There is accumulated a large set of B_e measurements.
2. In some cases new magnetic measurements were obtained from spectra of relatively low resolution.
3. Those data were accumulated during a long time period (over 60 years), which actually allows one to study the long-period magnetic behavior of some objects.

Table 1: Principal methods of B_e measurements:

Method	N measurements
Phot.	5375
Elc.	6991
LSD and WDLS	4083
BS	1544
FORS1/2	2540

"Phot." stands for the photographic method (Babcock 1947a,b, 1958 and many others). This method is now obsolete and is not used.

The "Elc." method is an analogue of the photographic method, but a CCD matrix is used as the receiver of light. Previously CCD matrix replaced a photographic plate in classical spectrometers. Currently echelle spectrometers are routinely used due to limited size of CCD matrices. This method is still sometimes applied.

"LSD and WDLS": It is a well known method, cf. Donati et al. (1997), Wade et al. (2000) and many other papers. This is a precise method, which was actively in recent years and has yielded many new results.

"BS" denotes the average surface field of stars. Such a number of measurements does not imply that "BS" was measured for high number of stars. For some slowly rotating CP stars BS was measured many times.

FORS1/2 stands for the low-resolution spectropolarimeter at the ESO Very Large Telescope.

"H-line" denotes B_e measurements observed in hydrogen lines (Borra and Landstreet 1980, Bychkov et al, 1988 and many other papers).

3. Stars with known magnetic phase curves

There exist 218 stars with measured phase curves of their longitudinal (effective) magnetic field B_e. In that

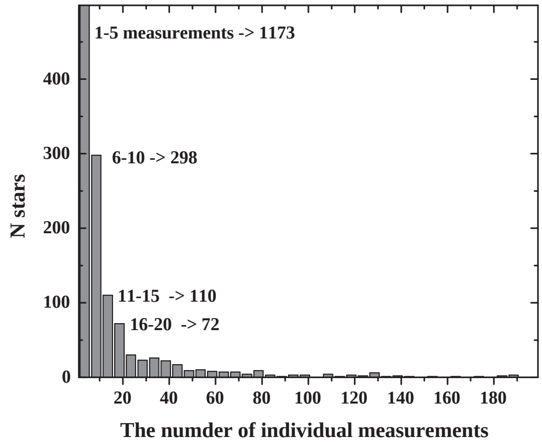

Figure 2: Number of individual B_e measurements. bychdoc

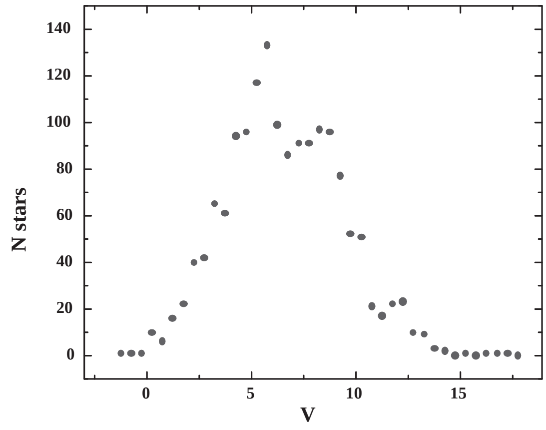

Figure 3: Distribution of magnetic stars vs. apparent stellar magnitude.

Table 2: Number of stars for which magnetic phase curves were determined vs. the most important types.

All stars with mag. phase curves	218
mCP stars	172
Ae/Be Herbig stars	7
Be stars	7
Supermassive Of?	3
Normal early B stars	5
Flare stars	3
TTS (T Tau type)	2
var. Beta Cep type	6
SPBS	3
var. BY Dra type	4
var. RS CVn type	1
Semi-regular var.	1
DA	1
var.pulsating stars	2
HPMS (high proper motions stars)	3
var.Ori type	2

group, 172 objects are classified as magnetic chemically peculiar stars. Remaining objects are stars of various spectral types, from the most massive hot Of?p supergiants to low-mass red dwarfs and stars with planets.

Some stars were simultaneously put into two different classes. For example, HD 96446 belongs to both the He-r and β Cep classes and HD 97048 belongs to both the TTS and Ae/Be Herbig classes. The binary system DT Vir consists of two companions: UV+RS (Flare + RS CVn type stars). Therefore, the distribution of stars between classes had to be arbitrary or redundant in some cases.

For example, Fig.5 shows the magnetic phase curve for mCp stars β CrB. Periodic variability of the magnetic field of stars was described in more detail by Bychkov et al. (2005, 2013).

We selected the following most important conclusions about the magnetic activity among stars of various types.

- 1. New class of magnetised objects was recently discovered – supermassive hot stars, type Ofp?. These stars show periodic variations of the longitudinal magnetic field. Amplitudes of magnetic phase curves (MPC) reach several hundred G. Of?p stars apparently are slow rotators. Configuration of their magnetic field is represented by an oblique rotator.

- 2. Magnetic fields were found among chemically normal early B stars. MPC's were obtained for 3 stars of this type. In one object, HD 149438, MPC shows complicated double wave shape, displayed also by some mCP stars.

- 3. Magnetic field and its behaviour was best investigated in the group of mCP stars. Longitudinal magnetic fields B_e have simple dipole configuration in majority of mCP stars (in 86 % objects). Rotational magnetic phase curves often display simple harmonic shape with amplitudes reaching 10 kG. Remaining 14 % of investigated mCP stars display more complex phase curves being a superposition of two sine waves and have either dipole or more complex structure of their global magnetic fields. Amplitudes of rotational B_e variation essentially do not differ from those in “sine-wave” mCP stars.

- 4. Solar-type stars have global magnetic fields of low strength, seldom approaching few dozens of G.

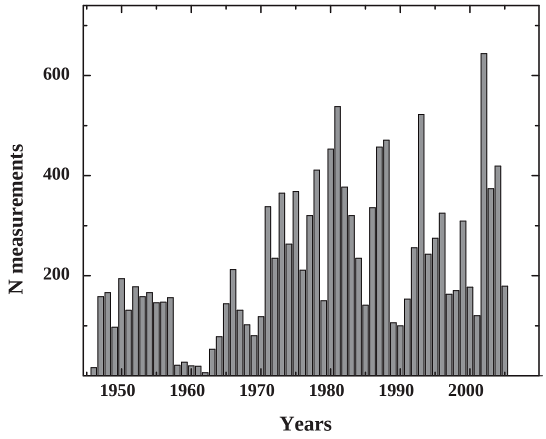

Figure 4: Number of B_e measurements obtained in various years.

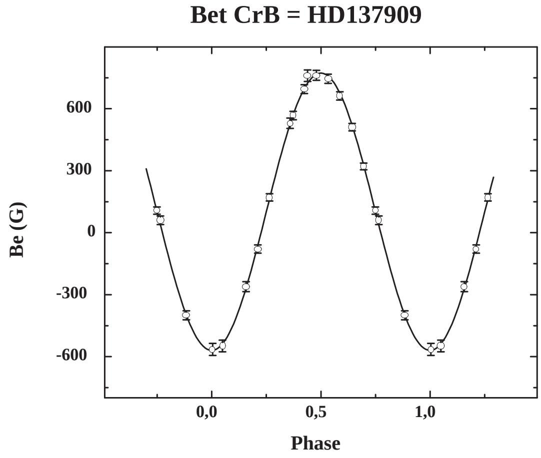

Figure 5: Magnetic rotational phase curve of the mCp star β CrB (HD 137909) for the accurate rotational period derived by Wade et al. (2000).

Measuring of such low-intensity fields meets with many methodologicacl difficulties. Therefore, we can only suppose, that in some investigated stars (in ξ Boo A, for example) magnetic phase curves appear as simple harmonic waves. Very significant progress in measuring of magnetic fields in stars was achieved using the ZDI method (magnetic cartography of the surface). More credible considerations require higher number of investigated stars and still higher accuracy of magnetic field observations. Moreover, it is known that magnetic properties of solar-type stars vary periodically in time scale from few years to several dozens of years.

- 5. Ae/Be Herbig stars usually exhibit magnetic rotational phase curves of a purely harmonic shape with amplitudes reaching several hundred G.

- 6. Magnetic phase curves of pulsating β Cep stars vary with the period of rotation. MPC show a complicated structure with low amplitudes of dozens G. Closely related slowly pulsating B stars (SPB) also display longitudinal magnetic field varying with the period of rotation. MPC show a simple harmonic shape with amplitudes reaching several dozens G.

- 7. T Tau stars have magnetic fields of complex structure, display also complex magnetic phase curves with amplitudes approaching several hundred G. Undoubtedly, fields of such a strength have to strongly influence accretion of matter onto stars.

- 8. Late-type stars – M dwarfs have global magnetic fields of complex structure. Magnetic rotational phase curves only roughly can be approximated by a superposition of two waves. This was also directly confirmed by recent observations using the ZDI method. Amplitudes of variations of the integrated longitudinal magnetic fields reach several hundred G. Some stars present an amazing feature, stepwise creation or anihilation of the global magnetic field and related B_e variations.

- 9. HD 189733 – this is a typical dwarf of spectral class K2V, where a giant planet, "hot Jupiter" was found. Central star in the system is a solar-like object. The star possesses magnetic field which is typical for its spectral class, and its longitudinal component varies with the amplitude of several G.

4. mCp stars

Magnetic fields of stars are best studied for mCp stars. One of major problems for these stars is the relations between their magnetic field and the chemical composition. We proposed a way to clarify this problem (Bychkov et al. 2009). We defined relative magnetization (MA) for different types of chemically peculiarity comparing distributions of their occurrence with the observed $< B_e >$. Example of such a distribution for stars of Si peculiarity is shown in Fig. 6. Number distribution of CP stars vs. $T_{\rm eff}$ for all different types of chemical peculiarity was shown in Fig. 7. Magnetization "MA" for various subclasses of CP stars vs. $T_{\rm eff}$ was shown in Fig. 8. Reduction of "MA" with the reduction of $T_{\rm eff}$ is apparent there for H-r, He-w and Si stars. Such a reduction of "MA" supports the fossil theory of the magnetic field origin in those stars. If the age of a star is high, then its mass is lower and "MA" also is lower. But we see sharp rise of

"MA" about $T_{\rm eff} = 10000\ K^o$. Therefore, we raise the assumption that the dynamo mechanism joins at this point on the $T_{\rm eff}$ scale.

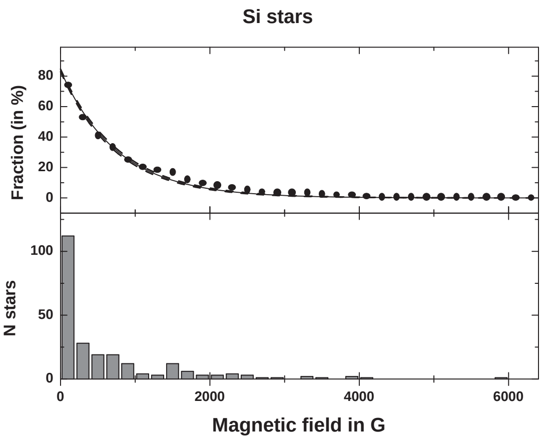

Figure 6: Integrated distribution function $N_{Int}(B)$ in percent (upper panel), and the number distribution function $N(B)$ (lower panel) for stars of Si peculiarity type.

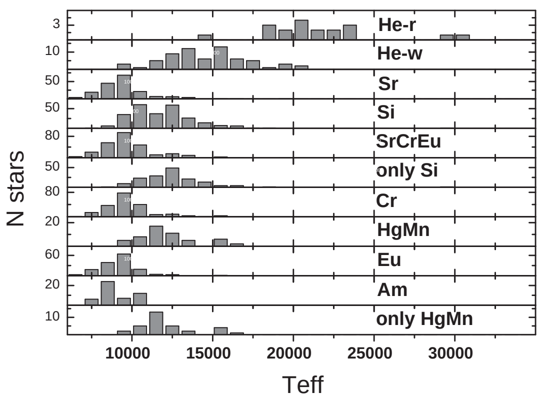

Figure 7: Number distribution of CP stars vs. $T_{\rm eff}$ for various types of chemical peculiarity.

Summary

In recent years significant progress was attained in the study of stellar magnetism. While previously one could measure and discuss behaviour of the stellar magnetic field only in mCP stars, white dwarfs and the Sun, currently we can measure and collect data on the magnetic field for many more types of stars ranging from supermassive hot giants to fully convective cold dwarfs of low mass. One can note significant contribution of the MiMeS collaboration which has discovered a new class of magnetic objects, supermassive hot giants Ofp? type and other magnetised hot stars. These discoveries significantly extended our knowledge about magnetism of hot stars and in future will give rise to our understanding of processes in stellar atmospheres and circumstellar space.

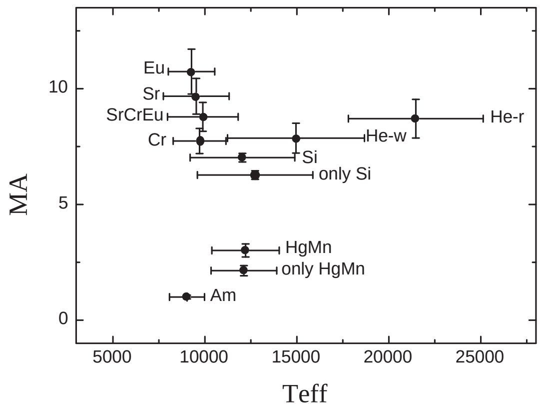

Figure 8: Magnetization (MA) for various subclasses of CP stars. Bars define the range of $T_{\rm eff}$ and MA occupied by a given subclass.

One can expect that rapid accumulation of new observational data will allow one to study in detail the variability of stellar magnetic field in stars both of different spectral types and evolutionary stages. We share the conviction that the magnetic field and its evolution is a crucial agent of stellar physics.

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