Observed variations of the global longitudinal magnetic fields of stars.

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Abstract Actually there exist 218 stars with measured phase curves of the longitudinal (effective) magnetic field $B_e$. In that group 172 objects are classified as magnetic chemically peculiar stars (mCP). Remaining objects are stars of various spectral types, from the most massive hot Of? supergiants to low mass red dwarfs and stars with planets. This paper aims to review briefly properties of the observed magnetic field in various types of stars.

1. Introduction

Probably all stars developed global magnetic fields, and their longitudinal field $B_e$ is variable (again probably) mostly with the period of rotation. Strength of global fields generally is not high and yet could not be measured in most objects. At present we observe rapid progress in the field of instrumentation and methods of magnetic field measurements. All those improvements allowed one to investigate and observe variability of magnetic fields in Of? stars which are very difficult to measure Wade et al. \cite{9},\cite{10}. Investigation of Of? objects is extremely important for the study of the origin of global magnetic fields.

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 with 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 in some objects.

Some stars were simultaneously put into two different classes. For example, HD 96446 belongs to He-r and $\beta$ Cep classes and HD 97048 belongs to TTS and Ae/Be Herbig types. 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 not unique in some cases.
Table 1. Number of objects for which we determined magnetic phase curves vs. the most important types.

| Category                        | Number |
|---------------------------------|--------|
| All stars with mag. phase curves| 218    |
| mCP stars                       | 172    |
| Ae/Be Herbig stars              | 7      |
| Be stars                        | 7      |
| Super massive 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      |

Fig. 1 shows the discrete distribution of star number vs. spectral class in our sample of magnetized stars with well known phase curves. Dominant fraction of those stars is located in the spectral range from early B to F type, i.e. in the spectral region containing mCP stars.

At present direct observations of the longitudinal magnetic field were obtained for ca. 1900 stars. Only for 218 stars the number of available observations allowed us to determine magnetic phase curves (MPC) and their parameters.

Actually we prepare a new extended catalog of the magnetic phase curves for stars on basis of the above data.

2. Conclusions

We selected the following, most important conclusions on the magnetic activity among stars of various types:

1. New class of magnetised objects was recently discovered – supermassive
Figure 1. Figure shows the number distribution of stars with known $B_c(\phi)$ phase curves vs. spectral type (left panel), magnetic phase curves of the Of?p star HD191612 with the rotational period 537.6 following Wade et al. [9] (center panel), for normal B star HD149438 with the rotational period 41.033 days following Donati et al. [3] (right panel).

Figure 2. Magnetic phase curves for the mCP-star $\beta$ CrB (HD 137909) for the high accuracy rotational period by Wade et al. [5] (left panel), for the mCP star HD 32633 obtained from high accuracy observations by Silvester et al. [7] (center panel), and Ae/Be Herbig star HD101412 with the rotational period 42.076 (right panel).

hot stars type Of?. Amplitudes of magnetic phase curves (MPC) reach several hundred G. Of? 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 MPC 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 G. Measuring of such low-intensity fields meets with many methodical difficulties. Therefore, we can only suppose, that in some investigated stars (in ξ Boo A, for example) MPC’s 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).
5. Ae/Be Herbig stars usually exhibit MPC’s of purely harmonic shape with amplitudes reaching several hundred G.
6. MPC’s of pulsating β Cep stars varies with the period of rotation. MPC shows 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 shows a simple harmonic shape with amplitudes reaching several dozens G.
7. T Tau stars have magnetic fields of complex structure, they also display complex MPC’s 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 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.

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 Of? type and other magnetised hot stars. Variations of global longitudinal magnetic fields are described by average curves and define movements of matter close to stars. It influences physical processes and evolution of stars.

Acknowledgements. We acknowledge support from the Polish Ministry of Science and Higher Education grant No. N N203 511638 and the Russian grant “Leading Scientific School” N4308-2012.2.

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