Magnetic Field Function for Early-Type Stars

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We present a model describing the magnetic field function for early-type stars. The model relies on population synthesis to generate the ensemble of magnetic stars on the upper main sequence. It also includes the capabilities for statistical simulations and parameter estimation necessary for analysis of real data. Our model was able to reproduce the empirical magnetic field distributions for OBA stars. We estimated the model parameters, found constraints on dissipation of stellar magnetic fields and explored the hypothesis that magnetic properties of early-type stars (2–60 $M_\odot$) might be described by a single magnetic field function.

1 Introduction

Magnetic stars on the upper main sequence (upper MS) are particularly interesting for research. All of the theories proposed to explain the origin of the large-scale magnetic fields are closely related to our understanding of early stages of the pre-MS evolution and formation of intermediate-mass and massive stars [12]. Moreover, although these stars are the progenitors of isolated pulsars, their magnetic properties are not interrelated directly, but strongly suggest the evolution of the magnetic fields between the zero-age main sequence (ZAMS) and supernova explosion [7].

Potentially, a lot of information that might be vital for our understanding of stellar magnetism should be gained from the study of the distributions of the stellar magnetic fields. The great increase in the number of known magnetic stars [5, 13] that happened over the last decades, including the discovery of the magnetic O-type stars, provides us with the opportunity to study such distributions even for different groups of OBA stars [8]. It also opened the possibility to check some of the early hypotheses about properties of the stellar magnetic fields in the light of recently acquired data.

For these purposes, we model the magnetic field function for early-type stars. We create a tool that would be useful for analysis of the empirical magnetic field distributions. Our model is based on population synthesis to account for the diversities in stellar parameters that always will exist in real samples of magnetic stars. It is also able to simulate the magnetic field distribution for a sample of a given size and, what is important, to estimate the magnitude of its possible variations.

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2 The model

The population synthesis begins with the initial ensemble containing stars that are randomly generated assuming the standard initial mass function [9] and a constant birth-rate. The temporal evolution of the ensemble is computed with the SSE code [6] implemented within the AMUSE environment for astrophysical simulations [10]. The evolution time is set to be large enough for the ensemble to achieve stationarity for a number of MS stars.

The magnetic fields corresponding to ZAMS stars are generated, assuming the lognormal distribution for the initial net magnetic flux, which is defined by the mean logarithm of the net magnetic flux $\langle \log \Phi \rangle$ and its deviation Δ. The evolution of stellar magnetic fields on the MS is represented by the exponential decay of the magnetic flux [8]. The process is described by the dissipation parameter τ_d that coincides with the relative time-scale for the decay, expressed in terms of a stellar MS lifetime. The ensemble generation is accomplished when the root-mean-square (rms) magnetic fields $\mathcal{B}$ for all objects in the ensemble of magnetic stars are finally computed.

The ensemble is then used to obtain the magnetic field function and its appearance for the sample of a given size. This involves random sampling and raw statistical methods for estimating of the mean distribution and limits for its possible variations (Fig. 1).

3 Empirical magnetic field distributions

We obtained the magnetic field distributions for BA, OB and O-type stars using data from different sources [2, 4, 11], and applied our model for their analysis.

We find that the empirical magnetic field distributions for BA and OB stars are very similar. They both reveal the same regular shape, typical of the lognormal distribution. In particular, the distribution for BA stars can be fitted by the

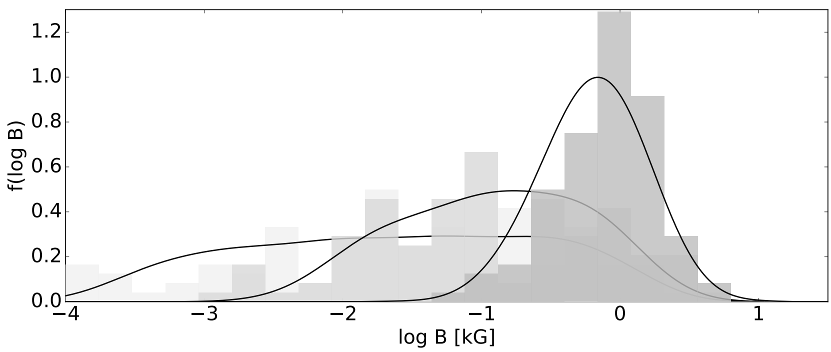

Figure 1: Magnetic field function for early-type stars calculated with our model. Black lines correspond to different values of the dissipation parameter τ_d: 0.15 (left curve), 0.3 (central curve) and ∞ (right curve). The gray histograms show the distribution for the same parameters, but for samples of $\sim$100 stars.

Table 1: Best-fit parameters obtained from the simultaneous approximation of the magnetic field distribution functions for BA, OB and O-type stars. The confidence intervals were obtained by using the C-statistics introduced by Cash [3]

Model	$\langle \log \Phi \rangle$, G cm^2	Δ	$\tau_{\rm d}$
I	$26.86^{+0.07}_{-0.21}$	$0.55^{+0.09}_{-0.13}$	∞
II	$27.23^{+0.11}_{-0.12}$	$0.38^{+0.1}_{-0.13}$	0.5

lognormal distribution with the mean $\langle \log \mathcal{B} \rangle \approx 0.5$ and the standard deviation $\sigma = 0.5$. It is inconsistent with the hypothesis of a "magnetic threshold" proposed by Aurière et al. [1] to explain the lack of stars with $B_d \lesssim 300$ G (or $\mathcal{B} \lesssim 60$ G), appeared in their sample. We found no peculiarities or other indications supporting this conjecture. A similar issue was also reported for OB stars in [5].

Also, we suppose that dissipation of the stellar magnetic fields is not very fast, otherwise we would expect very different appearances of the empirical distributions (Fig. 1). Our analysis shows that only for $\tau_{\rm d} \gtrsim 0.5$ it is possible to achieve the best agreement between the model and empirical distributions. This implies that the time-scales for magnetic field dissipation are at least comparable with the stellar MS lifetimes.

The sample of O-type stars consists of 11 stars only. Such a small size makes it difficult to draw reliable conclusions about the intrinsic magnetic field function. However, we assumed that the empirical distribution for O-type stars might also be drawn from the same magnetic field function as for BA and OB stars. Applying the procedure of simultaneous fitting, we were able to describe all of the empirical distributions with a single model (see Table 1). Therefore, it is not unlikely that magnetic properties of upper MS stars (with $M > 2$–$60\,\mathrm{M}_\odot$) are defined by a common magnetic field function.

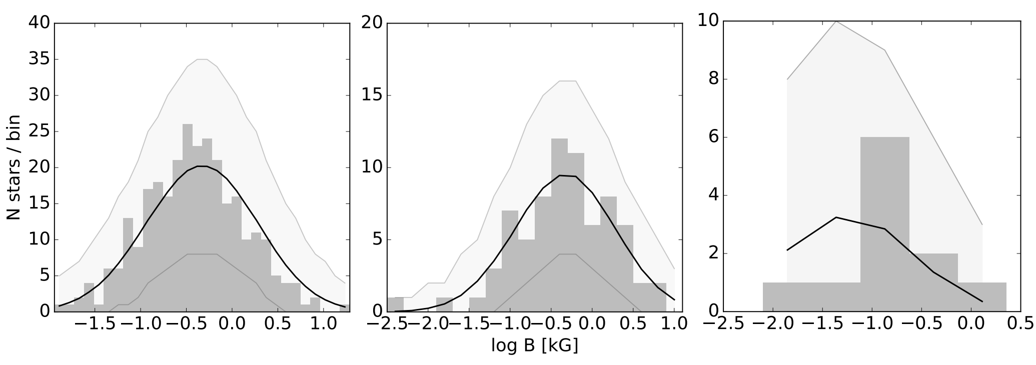

Figure 2: Simultaneous fitting of the magnetic field distributions for BA, OB and O-type stars (from left to right). The gray histograms represent the empirical data, while the black lines show the mean model distribution. The gray filled area corresponds to the 95% confidence limits for possible variations.

4 Conclusions

- We built a model describing distribution of magnetic fields for early-type stars and applied model for analysis of the empirical data.
- The empirical magnetic field distribution for BA and OB stars are very similar and both can be fitted by a lognormal distribution.
- It is possible to reproduce all of the empirical distributions with a single magnetic field function (Table 1).
- The estimated constraint on the dissipation parameter is $\tau_d \leq 0.5$, are in accordance with estimations by Kholtygin et al. [8].
- The empirical distributions for OBA stars provide with no evidence supporting the hypothesis of a "magnetic desert" [1].

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