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Chemical composition and magnetic fields of Ap stars

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Abstract. We analyzed properties of 352 chemically peculiar A and B stars in the catalog of averaged quadratic effective magnetic fields, including Am, ApSi, He-weak, He-rich, HgMn, ApSrCrEu, and all ApSr type stars. It is shown quantitatively that both the integrated number distribution function and the distribution function of all chemically peculiar (CP) stars *vs.* averaged magnetic field strength are well approximated by decreasing exponential functions, at least, above about 100 G. Relations of this type hold also for most of the analyzed subclasses of chemical peculiarity. We have also found that the strength of the intrinsic surface magnetism depends on the chemical peculiarity class.

1 Introduction

In the present paper we analyze magnetic properties of Ap stars which were collected in the newest catalog of averaged quadratic stellar effective magnetic fields, $\langle B_e \rangle$ (Bychkov et al. 2003; see also our previous poster). The catalog contains magnetic and spectral data on 596 main sequence and giant stars.

The quantity $\langle B_e \rangle$ was defined as

$$\langle B_e \rangle \quad = \quad \left(\frac{1}{n} \sum_{i=1}^{n} B_{ei}^2 \right)^{1/2} , \qquad (1)$$

where B_{ei} denotes the i-th measurement of the effective magnetic field, and n is the total number of observations for a given star. This quantity, $\langle B_e \rangle$, is a measure of the field strength in the atmosphere of a given star.

We extracted a sample of 352 chemically peculiar A and B stars, which are split into Am, ApSi, He-weak, He-rich, HgMn, ApSrCrEu, and all ApSr subclasses.

2 Distribution of averaged effective magnetic fields

Let us substitute $B = \langle B_e \rangle$ for brevity. For the given set of magnetic stars we define two different relations. They present dependence of the number distribution function $N(B)$, and its integral over B, on the average quadratic effective magnetic field B of magnetic stars.

For each subclass of Ap stars, we have divided the range of the quadratic averaged magnetic field $\langle B_e \rangle$ from zero to the maximum field in this group into as many as 40 bins of equal length (80 bins for Si stars), Note that the quantity $N(B)\,dB$ gives the number of stars in the given group having the average quadratic effective magnetic field B in the range $[B, B + dB]$.

Table 1: Best fit parameters

Peculiarity	N	$a_1(\%)$	$a_2(G)$	30%	50%	70%
all Ap	352	97.2	789.2	928	525	259
Sr all	167	106.9	1081.2	1360	819	448
Sr only	126	108.6	1018.1	1310	790	447
Am	44	95.3	110.5	127	71	34
He-rich	19	97.2	916.1	1080	609	301
He-weak	60	116.0	717.9	970	604	363
Hg & Mn	39	74.9	515.7	471	208	34
HgMn only	19	75.2	350.1	322	143	25
Si	159	102.0	906.1	1110	646	341

3 Integrated distribution function

We define the integrated distribution function as

$$N_{Int}(B) = N_{tot} - \int_0^B N(B')\, dB' \,, \tag{2}$$

where N_{tot} denotes the total number of stars belonging to that group.

We drew a striking conclusion that all the corresponding functions $N_{Int}(B)$ are well approximated by the exponential function normalized to unity at $B = 0$

$$N_{Int}(B)/N_{tot} = \frac{a_1}{100\%} \exp\left(-B/a_2\right) . \tag{3}$$

Coefficients a_1 (in %) and a_2 (in G) depend on the class of chemical peculiarity. Function $N_{Int}(B)$ describes the probability that upon investigating a new star of this particular chemical peculiarity, its $\langle B_e \rangle$ will be higher than the value of B.

4 The distribution fuction

The distribution function can immediately be obtained from N_{Int} by the relation

$$N(B) = -\frac{dN_{Int}}{dB} \,. \tag{4}$$

The function $N(B)$ is therefore also an exponential function with the above analytic approximation

$$N(B) = N_{tot} \frac{a_1}{100\%} a_2^{-1} \exp\left(-B/a_2\right) . \tag{5}$$

If one attempts to construct the distribution function in a direct way, based on the tabulated data, then this function would exhibit serious noise due to the limited number of data points.

The distribution function $N(B)$ is the first derivative of N_{Int}, and obviously all numerical distortions of the latter involve fluctuations of the derivative.

5 Best fit parameters

Table 1 presents parameters a_1 and a_2 determined by fitting exponential curves to corresponding histograms.

Table 2: Strength of the intrinsic surface magnetism

Peculiarity	N	30%	50%	70%	average
Sr all	167	10.7	11.5	13.2	11.8
Sr only	126	10.3	11.1	13.1	11.5
Si	159	8.7	9.1	10.0	9.3
He-weak	60	7.6	8.5	10.7	8.9
He-rich	19	8.5	8.6	8.9	8.7
Hg & Mn	39	3.7	2.9	1.0	2.5
HgMn only	19	2.5	2.0	0.7	1.7
Am	44	1.0	1.0	1.0	1.0

Some of Ap stars exhibit a few different peculiarity types simultaneously, and they are counted in more than one row of Table 1.

Columns 3–4 of Table 1 present the best fit coefficients a_1 and a_2 for all the analyzed subclasses. The last three columns present the fixed values of magnetic field intensity $\langle B_e \rangle^{fix}$ (in G). The stars with $\langle B_e \rangle \geq \langle B_e \rangle^{fix}$ are found to account for 30%, 50%, and 70% of the total number of stars belonging to this peculiarity type.

6 Magnetism of Ap stars

Let us assume for Am stars that the value of $\langle B_e \rangle^{fix}$ is unity, when it corresponds to 30%, 50%, and 70%, of the total number of Am stars, respectively. Am stars were chosen as the reference subclass, since they exhibit the lowest surface magnetic fields.

Table 2 presents analogous values of $\langle B_e \rangle^{fix}$ for other subclasses of chemical peculiarity, and the corresponding averages. We draw the following quantitative conclusion. The most "magnetic" are Sr-type stars in a sense that they exhibit the exponential surface distribution function reaching the strongest surface quadratic effective magnetic fields $\langle B_e \rangle$. Si, He-weak, and He-rich stars are less magnetic. Distinctly less magnetic are Hg & Mn, HgMn only, and Am type stars.

7 Sample distribution functions

Figures 1–2 display the exemplary integrated distribution functions $N_{Int}(B)$, see upper panels. They describe the probability that upon investigating a new star of this chemical peculiarity, its $\langle B_e \rangle$ will be higher than the value of B. That relation is given by a series of dots in the figures.

The lower panels of both figures present corresponding distribution functions $N(B)$, which were derived from the catalog of Bychkov et al. (2003). One can see that the shapes of both functions are similar to decreasing exponents. However, there exist substantial deviations of $N(B)$ from exponent in the case of less numerous or less "magnetic" subclasses.

8 Summary

We have determined for the first time that the relation between the number of occurrences N_{Int} of magnetic fields higher than the specified $\langle B_e \rangle$ is given by the decreasing exponential function, at least, starting from the minimum value of $\langle B_e \rangle \approx 100$ G. Such a relation is found to hold for all analyzed subclasses: Am, Si, He-weak, He-rich, HgMn, SrCrEu, and all Sr type stars. We determined and listed values of the parameters a_1 and a_2 for each subclass, see Table 1.

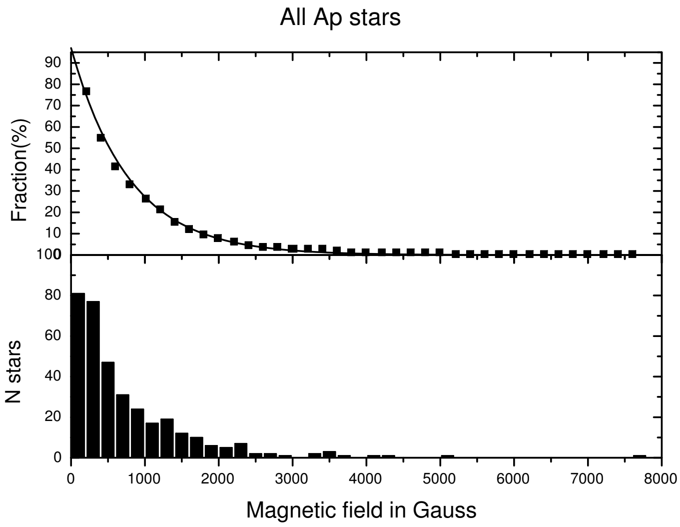

Figure 1: *Integrated distribution function* $N_{Int}(B)$ *in percent (upper panel), and the number distribution function* $N(B)$ *(lower panel) for all Ap stars.*

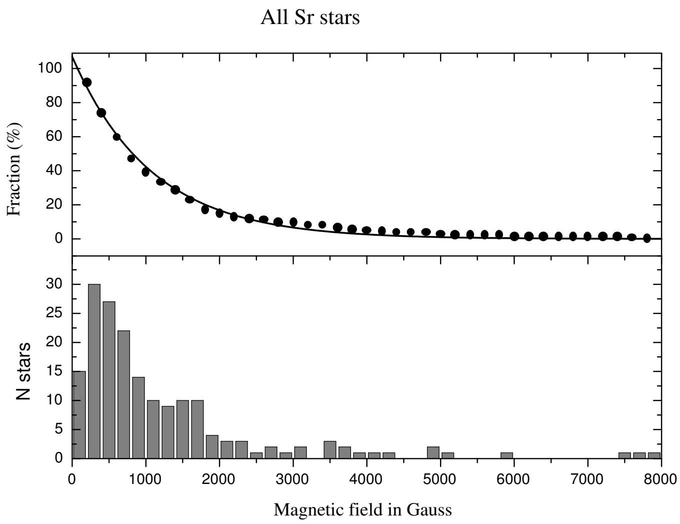

Figure 2: *The same for all Sr type stars, also those with mixed peculiarities.*

We also argue that the strength of intrinsic surface magnetism of Ap stars depends on the chemical peculiarity class. While it is the weakest for Am stars, its strength increases for HgMn, and further He-rich and He-weak stars. On this scale Si and Sr stars exhibit the strongest effects of magnetism among Ap stars.

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The catalog has been published in Astron. Astrophys 407, pp.631-642 (2003). Table A.1 and its references are available only in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/407/631 .