# PROBLEMS OF MAGNETIC FIELD ORIGIN AND EVOLUTION IN CHEMICALLY PECULIAR STARS

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ABSTRACT. Some problems of origin and evolution of magnetic fields in CP stars are considered. The arguments are presented in favour of an assumption that CP stars originate before the Main Sequence and that now they are in stable state. It is shown that Magnetic fields generate most probably by means of dynamo- effect.

There are many available observational data at present for an attemp to throw a light upon the problem of origin and evolution of the magnetic fields of CP stars. The main hypotheses to which a serious attention is paid now are the hypotheses of the relic field and the dynamo field each of them having positive and negative features. We do not hope at the nearest time to give a definite answer on the question how a magnetic field originates and what occurs with it after, but, however, analysing the available data it is possible to elucidate which of these hypotheses is the most probable one.

Klochkova and Kopylov (1984a, 1986a, 1986b) and Glagolevskij, Klochkova and Kopylov (1984, 1986, 1987) have shown that neither the surface abundance (the degree of peculiarity P for the main chemical elements) nor the mean magnetic field $<B_e>$ change at the period when CP stars are on the Main Sequence (Fig. 1 and 2 a). From the Fig. 2b one may suppose that at t moment CP stars have acquired magnetic fields either due to contraction of the magnetized clouds in the course of their generation or due to dynamo process. The stars with large masses (M) evolve faster and reach a zero age sequence ("0" in Fig. 2b) at $t \approx 10^5 - 10^6$ years, and the stars with small masses at $t \approx 10^6 - 10^7$ years; after this they continue to evolve with different rate, of course, across the Main Sequence (with the radius increase) and reach the upper boundary of the Main Sequence - III. The dependences shown in Fig. 1 and 2a attribute on an average to stars of V luminosity class, so in the case of a large change of $<B_e>$ in a time there would be noticed some variation of $<B_e>$-(log t) dependence. (The star ages are determined by Glagolevskij (1987) using Iben tracks, the mean ages of different type stars are given in Table 3). From Fig. 1 and 2a it is seen that on the lower boundary of the Main Sequence the values of the chemical anomalies and the magnetic fields have the same

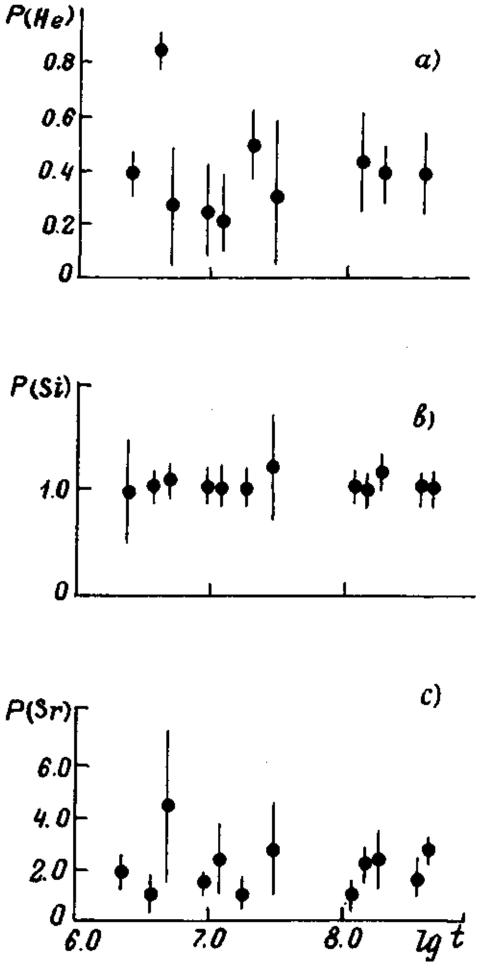


Fig. 1. The mean values of peculiarity degrees He, Cr, Sr in stars of different ages obtained by Klochkova and Kopylov (1981).

quantity as at the following stages of evolution. It is quite obvious that both are acquired by stars before the Main Sequence. The fact of (HgMn) HD 29647 star discovery in the region of star formation in Taurus, which is, evidently, on evolution stage before the Main Sequence (Straizys et al., 1982) confirms this assumption. As it was supposed in papers of Klochkova, Kopylov (1984a, 1986a, 1986b), Glagolevskij et al. (1984, 1986, 1987) the magnetic field and chemical abundance did not change further. It is probably that either the magnetic field is constantly being "fed" by dynamo process or the atmosphere conditions are so stable that a field is dissipating only ohmically on the time scale of

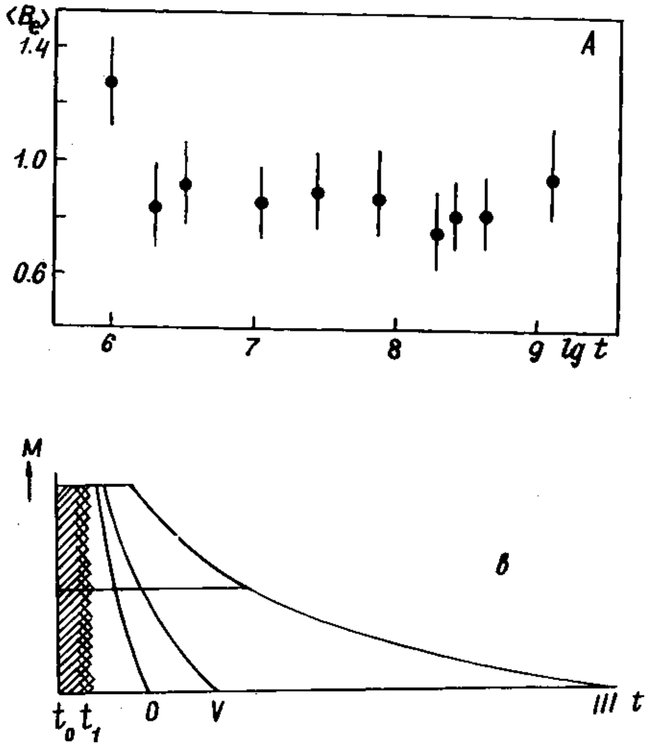


Fig. 2.

$10^9 - 10^{10}$ years as it follows from the theory and the diffusion processes are in equilibrium with those of destruction of chemical element concentration regions. In this connection it is interesting to see the behaviour of a field when CP stars are in the course of evolution across the Main Sequence when radii of stars grow 1.5-2 times from the moment of their appearance on the zero age sequence to the moment of their going to the upper boundary of the Main Sequence. In the condition of the magnetic flow preservation the field value on a surface must decrease proportionally to $R^{-2}$. Glagolevskij et al. (1986, 1987), North and Cramer, (1984), Glagolevskij and Chunakova, (1984) have shown that there exist some signs of such field decrease. We studied again this problem on the basis of our more exact, as we think, data. The Fig. 3 shows the diagram which

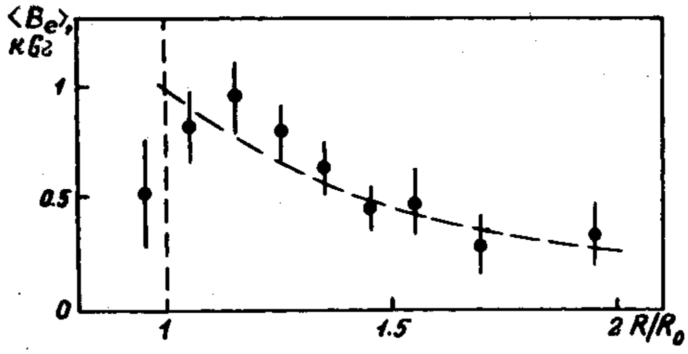


Fig. 3.

demonstrates dependence of the mean magnetic field $<B_e>$ for CP stars upon their relative radius $R/R_§$, ($R_0$ is the radius of the star on the zero age of the Main Sequence and R is its radius at the present time). For construction of the considered dependence we took the root-mean-square value of the magnetic field from Glagolevskij et al.(1986), the radius w**as** calculated from the balometric values M that were received from the parameter $\beta$ of the multicolour Geneva photometry (Houck and Mermilliod, 1980). The procedure of determination of these parameters is reported by Glagolevskij,(1987).

The slope of the dependence in Fig. 3 is close to the law $R^{-2}$, marked by the dashed line and this does not contradict the assumption that the surface field of CP stars changes in time only due to the radius increase, but not due to dissipation. The left part of the dependence in Fig. 3 as if demonstrates the field increase near the zero age of the Main Sequence, but the absence of the same increase on the dependence $<B_e>$-(log t) in Fig. 2a and 4 brings us to an assumption that this is caused by "diffusivity" of the low boundary part of the Hain Sequence **and** by errors arisen due to small amount of stars, presented in the first point of Fig. 3.

The Fig. 4 shows $<B^e>^0$ (log t) dependence where all the field values are corrected for the effect of radius increase, i. e. each star after the correction has such a magnetic field $<B_e>_0$ that was on the initial Main Sequence.
From this Figure we can see that the field does not change in time and the line of regression is as follows:

$$<B_e>_0 = -0.046 \log t + 1.65,$$

where a coefficient a = -0.0461 0.0S3. From this Figure we can make an assumption that, first, the star appears on the Main

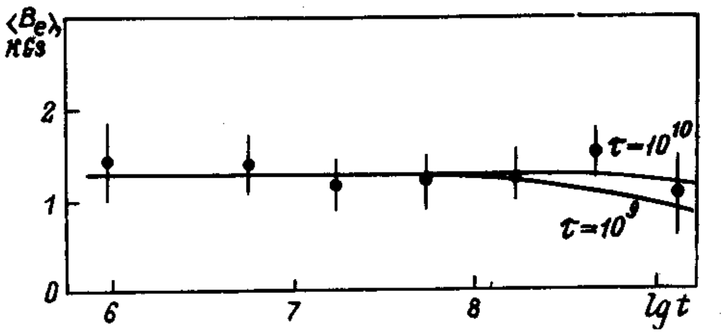


Fig.4.

Sequence with a field already and, second, a magnetic flux while being on the Main Sequence does not change. For convincingness of the last assertion we devided ail 167 stars into two nearly equal parts with a boundary at $T_e$ = 13000 K. The "hot" group of stars evolves on an average more than an order faster than the "cool" one ($\overline{\log t}$ = 6.5 for a "hot" group and $\overline{\log t}$ = 7.7 for a "cool" one). The dependences $\langle B_e \rangle_e$ $(R/R_\odot)$ were constructed for these two groups . They are shown in Fig. 5. It is not noticeable that the "cool"

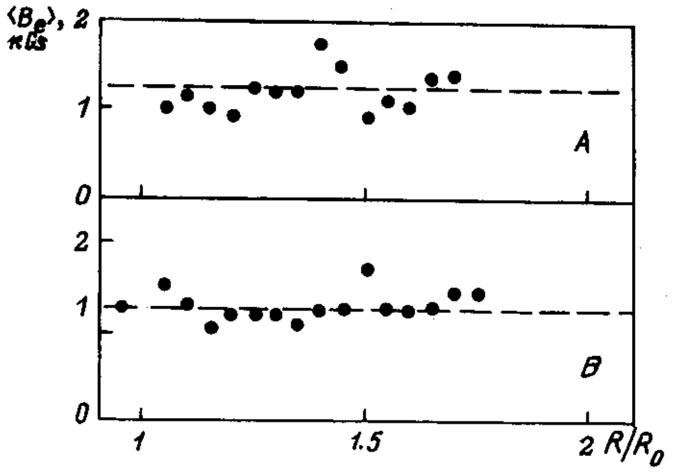


Fig.5.

group was losing additionally a field at the expense of some dissipation mechanism and differed from the "hot" one by fore of the dependence.

For simultaneous preservation of both magnetic flux and chemical abundance anomalies in the upper atmosphere layers during the whole time when CP stars are on the Main Sequence the extremely stable atmosphere is necessary. A very important question in the problem of origin and evolution of magnetic fields is the loss of angular momentum of CP stars which was studied by Glagolevskij (1987). Some authors tried to find the source of breaking at the period when the stars were on the Main Sequence, but there arose some definite difficulties (necessary conditions for breaking were not found). The problem may be essentially simplified if we suppose that the angular momentum loss had occurred at the period before the Main Sequence (Glagolevskij, 1985a, 1987; Klochkova and Kopylov, 1984b, 1985). The dependence of the mean value of the rotation period P (P is taken from the catalogue of Catalano and Renson, 1984) for stars of principle peculiarity type upon their mean ages log t is shown in Fig. 6. The Figure presents also analogous dependence for normal stars for which P = 50.6 R/V, and

$$V = V \sin i/(\overline{(\sin i)^2})^{1/2} = V \sin i/0.7.$$

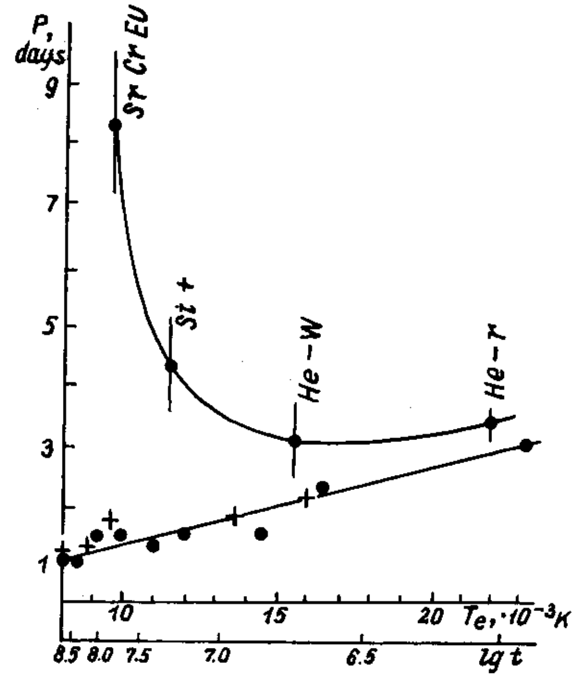


Fig. 6

V sin i data are taken from the catalogue of Uesugi and Fucuda (1970) and also from the paper of Klochkova and Kopylov (1986a). From the Figure it can be seen that the fastly evolved massive CP stars differ from the normal stars less than the slowly and long-devolved small-massive stars.This fact may indicate that the young CP stars have no time for breaking. A comparison of normal and peculiar stars according to their speed of rotation velocity change occurred due to the radius increase, when they are evolving across the Main Sequence, have shown that the peculiar stars break not faster than the normal ones (Glagolevskij, 1987). This is one more argument in favour of the assumption about the rotation moment loss by CP stars before the Main Sequence. A study of P distribution has shown that this distribution is maxvellian (Glagolevskij, 1987) and in the first approximation is characterized by Deutsch's formulae (Deutch, 1970).

$$f(p) = (4/\sqrt{\pi})p^2 \exp(-p^2).$$

Distribution of CP stars of the main peculiarity types within the error limits may be considered as maxvellian as well, both the maximum positions of these distributions and their forms being dependent upon the mean age log t (Glagolevskij, 1987). Maxima P(max) and average values of P (for distributions of stars of the main peculiarity types according to their periods) depending upon $t_0$- the mean ages of CP stars of the main peculiarity types on the initial Main Sequence appeared to be as follows:

**Table 1**

| Type | He-r | He-w | Si + | SrCrEu |
|---|---|---|---|---|
| P(max) | 1.10 | 1.15 | 1.50 | 2.00 |
| $t_0$, years | $6.0 \cdot 10^5$ | $2.0 \cdot 10^6$ | $6.0 \cdot 10^6$ | $8.5 \cdot 10^6$ |
| $\bar{P}$, days | 3.4 | 3.1 | 4.3 | 8.4 |

In this Table we give $t_0$ since we assume that the breaking occurs uniformly up to the star ariving onto the initial Main Sequence. This is a very rough assumption, but the details of the breaking conditions are quite unknown for us. The dependences P(max) ($t_0$) and $\bar{P}$ ($t_0$) are shown in Fig. 7 from which it follows that the breaking has an exponential character

$$\bar{P} = 2.7 \cdot e^{t/9 \cdot 10^6} \qquad P\,(max) = 0.97 \cdot e^{t/13 \cdot 10^6}$$

In both cases the time of breaking $\tau$ appeared to be close to the value ~ $10^7$ years. It should be noted that this is rather a rough

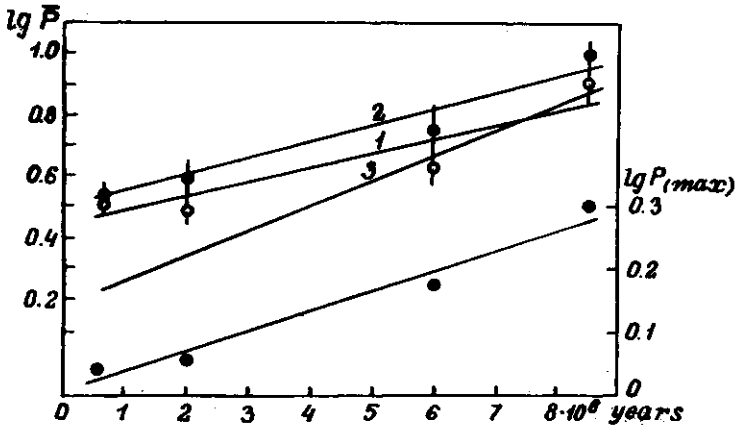


**Fig. 7**

estimation, since it is clear that the breaking was not uniform during the period "before the Main Sequence". It is unknown what was the reason for changing the structure and the field value at the period when the star was entering the initial Main Sequence. If one assumes the simpliest case that a star field is relic, then at the period whin the star structure and its radius change or at the period of accretion or loss loss, the field can not remain constant.

Some mechanisms of breaking are supposed: a hydromagnetic one (Fleck, 1980), mass loss with a magnetic field participation (Strittmatter and Norris, 1971; Mestel, 1972), accretion with magnetic field participation (Havnes and Conti, 1971; Mestel, 1975; Bychkov and Fabrika, 1987). However, the first is hardly an effective one. One of the **Bain** conclusions of this mechanism theory is that the breaking time is strongly dependent upon the dipole orientation. If the angle of dipole axis to the rotational axis $\chi \sim 90°$, then the breaking time is $\tau \sim 10^6$ years, and if $\chi \sim 0°$, then $\tau \pm 10^9$ years. We compared the mean periods of stellar rotation with small and large angles $\chi$ , **which were** calculated using methods described by Glagolevskij (1985b).

**Table 2**

| Angle range | P days | $\pm\sigma$ | number of stars |
|---|---|---|---|
| $\chi < 45°$ | 8.4 | 1.0 | 7 |
| $\chi > 45°$ | 5.1 | 0.6 | 33 |

From this Table we see that there exists a correlation of periods for these groups of stars but rather an opposite than the expected one, though the difference is not more than $3\sigma$ . Therefore, the dipole orientation does not cause the breaking process and thus, Flack's hypothesis is not in agreement with our assumption. North (1984) has come to the same conclusion about the small role of this mechanism otherwise. Accretion and mass loss mechanisms are in great dependence upon the following facts: which of them occurred at the period of maximum magnetic field, their duration and activity.

There is a possibility to find the exponential parameters for $\bar{P}$ values with a higher accuracy. For this purpose we corrected the log $\bar{P}$(t) dependence (see the curve 2 in Fig. 7) for the influence of analogous dependence for normal stars and obtained the straight line 1 in Fig. 7. If the field did not influence the rotation periods of CP stars, then the log P(t) dependence was the same as that one observed now in normal stars. Having introduced these corrections we obtain the breaking effect with magnetic field participation as if in a "purer conditions". The new exponential curve looks like

$$\bar{P} = 3.1 \cdot e^{t/8 \cdot 10^6}$$

Thus, the $P_0$ and $\tau$ parameters did not change essentially. However, this formula is true if $P_0$ periods of all the stars are similar, that is hardly probable. What was a real $P_0$ period is unknown. If we suppose that $P_0$ for CP stars of each peculiarity group are equal to the mean periods of normal stars with the same temperatures, then we obtain four exponential curves for He-r, He-w, Si+ and SrCrEu - stars with $P_0$ equal to $2^d.85$, $2^d.05$, $1^d.60$, $1^d.35$, and $\tau$ equal to $3.7 \cdot 10^6$, $4.8 \cdot 10^6$, $6.0 \cdot 10^6$ , $4.6 \cdot 10^6$ years, respectively. The last values are 1.5 - 2 times lower than the preceding values ($8 \cdot 10^6$ years). With the help of these data we have found for each star the values of periods at $t_0$ moment. The results are plotted in Fig. 8 from which it is seen that the main amount of stars are concentrating now within $P \approx 1 - 1.5$ days and only some of them are on the right.

They are breaked, probably, stronger due to more favourable conditions, that is due to more accelerated tempo of mass loss or their field configuration was nearer to the dipole one, or due their being in a "tail" of maxwellian distribution P and etc.

The observed log <$B_e$><log P> dependence from the paper by Glagolevskij (1985a) which demonstrates the well known right $B \propto P$ correlation and the new calculated dependence after reducing of all P to $P_0$ are presented in Fig. 9. We see that maximum has shifted from $P \sim 8 - 9^d$ to $P \sim 2^d.5$ and the curve became more symmetrical and an impression about the existence of right $B \propto P$

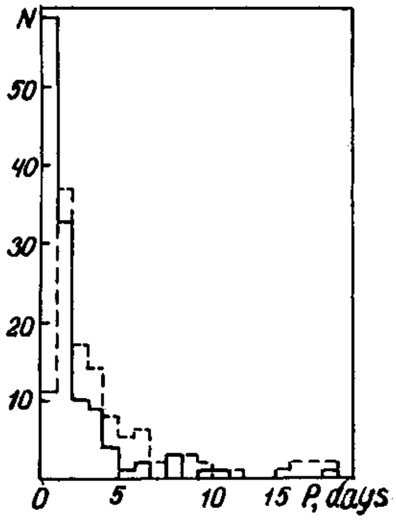


Fig. 8.

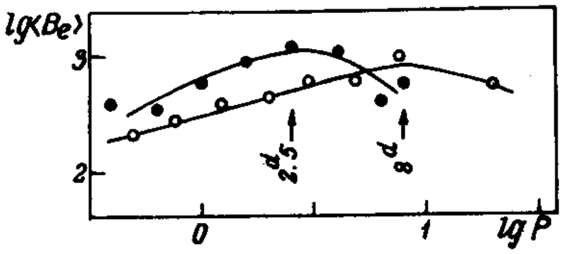


Fig. 9.

correlation had disappeared. Due to the fact that at the initial period (near $t_0$) the young stars had rather narrow range of rotation velocities, it is difficult to expect the significant influence of the supposed correlation as result of dynamo $B \propto \Omega$ (Mestel,1975) action on the generated magnetic field value. At the period of breaking stars with a stronger field are decelerated and, apparently, only this effect influences the $B \propto P$ dependence and provides the known right correlation (Glagolevskij, 1985a; Landstreet et al., 1975; Mestel, 1977). If the field is relic then the breaking process with the help of the magnetic field will lead also to the right correlation.

Mestel and Moss (1977) supposed that the right $B \propto P$ correlation can appear due to influence of the supposed meridional circulation which "hides" the field inside the star, the activity being in great dependence upon the rotation velocity ( P smaller).

However, no signs of meridional circulation existence were observed, this is only an assumption. As it is shown above, it is doubtful that there is a field dissipation more rapid than the ohmical one. This is the first difficulty of the meridional circulation. The second one is that one of the main assumption of the hypothesis for meridional circulation is the necessity of $B(\chi)$ dependence existence. It appeares because circulation must reduce the dipole axis to $\chi \sim 90°$ and simultaneously weaken the field on the surface which is being carried inside the star. Our calculations of these angles using the data of Glagolevskij et al. (1986) gave the following results:

| $\chi$ | $< 45^0$ | $> 45^0$ |
|---|---|---|
| $\bar{B}_s$, kGs | 3.2 | 6.1 |

Thus, the correlation of $\bar{B}_s(\chi)$ is inverse to the expected one. The same effect can be well seen from the following data:

Table 3.

| Main types | He-r | He-w | Si + | SrCrEu |
|---|---|---|---|---|
| $\chi$ | $56^0$ | $62^0$ | $55^0$ | $51^0$ |
| $\pm\sigma$ | $5^0$ | $4^0$ | $4^0$ | $3^0$ |
| $\overline{\lg t}$ | 6.2 | 6.8 | 7.5 | 8.4 |

From the Table it can be seen that the dipole orientation relative to the rotational axis is independent upon the star age (the $\chi$ angles of all type stars are equal to the mean value at ordinary dipole orientation). These data show well that there are no indications of meridional circulation existence in CP stars and it is the second uncertainty of this hypothesis. Therefore, the right B ↔ P correlation occurs only due to the breaking effect. Thus, there is a sufficient amount of data in favour of the assumption that CP stars generate before the Main Sequence.

Let us discuss two most probable, from the modern point of view, mechanisms of magnetic field generation - relic and dynamo ones. Against the assumption that CP stars have a relic nature of the field are the following facts:

1). It is unknown yet why only 10% of stars preserve their magnetic fields and the rest ones are losing them completely. It is naturally to assume that a field can preserve itself to great or small degree depending upon the ambipolar diffusion intensity, but not disappear at all.

2). Among the double systems there are practically no pairs with both CP -components; more often one of the components it a normal star. If we assume relic nature of the field, then both components must be magnetic ones since they are generated from the same cloud.

3). Glagolevskij, (1985b) and other authors have shown that the greatest part of magnetic fields have dipoles oriented at large angle to the rotation axis. It is easily explained with the help of dynamo mechanism, but it is not clear from the viewpoint of the relic field.

4). At present there are known at least two stars which clearly show the quadrupole configuration of the field and which can be generated only by dynamo mechanism.

5). The lack of close binaries (Lebedev, 1987) with CP-component indicates most of all in favour of the field generation by dynamo mechanism, but not by its contraction with the magnetized gas. We may suppose that tidal forces of a close component disturbed the conditions of the field generation and disturbed also the diffusion conditions indignating their surface layers. From the view point of relic field it is impossible to interpret why generation of close pairs from the magnetized gas is more difficult than that of wide pairs.

There are the uncertainties of the relic field hypothesis. At the same time it should be noted that in case of dynamo a small amount of stars having a magnetic field seems to be natural if remember that for generation it is necessary to take into account the following conditions: 1) the lack of nonstationary processes which disturb the homogeneity of ciclonic vortexes and disturb the earlier generated field; 2) the lack of differential rotation (Radler,1986) rather weak field dissipation and etc.

The observations show that on the early evolution stages the stars are unstable in a lot of cases and, probably, they are just the future normal stars. What can one suppose on behaviour of a magnetic star after its field generation? The cool CP stars appear on the Main Sequence for $10^6$ -$10^7$ years and the hot ones for $10^5$ -$10^6$ years. It is evidently that this time is quite enough for the field to be acquired, breaked and enrich the upper atmosphere layers by heavy chemical elements. Concentration of chemical elements could occur not earlier than the time when the atmosphere became quite stable and accretion and mass loss processes stopped. Just the high stability of the upper layers (if consider the diffusion hypothesis) can provide the field and chemical abundance stability. In first approximation a coincidence of regions of peculiar element concentration with the magnetic poles leads to an assumption that a magnetic field influences the diffusion processes, for example, it helps the ions to drive along the force lines. Then in the quite unturbulent atmosphere the magnetic field is distroyed only by ohmic mechanism and, therefore, magnetic flow dissipation in time on the Main Sequence is not noticeable. The battarey mechanisms, of course, generate toroidal magnetic field, but it does not transform into the poloidal field duo to the lack of meridional circulation streams.

The uncertainty of the dynamo hypothetic is the fact that in accordance with the papers of Larson (1969) the stars with mass more than $2M_{\odot}$ have no convective phase. Therefore, there are no conditions for the field generation. A large amount of uncertainties against the hypothesis of relic field leads to an assumption that either Larson is not right or the field generates by the unknown mechanism.

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