Model magnetic fields of CP stars with large rotation periods

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Abstract. It is pointed out to data contradicting to the hypothesis of loss of rotation moment in presence of magnetic fields for CP stars.

There are difficulties to explain the slow rotation of CP stars. More probable prove the hypotheses:

1) The loss of the rotation moment took place under the influence of the magnetic field just before the "pre main sequence"-phase of evolution,
2) The small rotation moment was taken from protostellar clouds.

The only property of CP stars is in favor of the hypothesis of deceleration – the smaller the mass the greater the difference between their average velocity *v*sin*i* and normal stars (Fig.1)

On the other hand, there is another property – the lower velocity of CP stars the greater their proportions among normal stars (Fig.2). The latter property supports the hypothesis that the lower the initial rotation velocity of a star is when it forms, the greater the probability would be to become a chemically peculiar one. It has turned out that this property is common to chemically peculiar stars – with a magnetic field and without one. It has been suggested [1] that the cause of the slow rotation of CP stars should be searched for at the very initial stages of formation (this is also the reason for the division into CP magnetic, CP nonmagnetic and normal stars) because Ae/Be Herbig stars do not possess any magnetic field of sufficient strength [1].

In accordance with the statement in [2], the closeness of the dipole and rotational axes (small angles β between them) must be a serious condition for deceleration of CP stars. It is only in this case that conditions arise under which the loss of the moment of rotation is effective. To clear this up, we investigate in the present paper magnetic configurations of several slow rotating Cp stars ($P > 25^d$) for which phase relationships of variation of the effective B_e and the mean surface B_s magnetic fields are known. For the modeling we used the methods of "magnetic charges" that we have developed [3 – 5]. Table 1 presents the summary of our results of modeling slow rotators, which shows that they have no predominant orientation of the magnetic dipole with respect to the rotational axis, that is, there is no domination of small angles β as predicted by Stępień [2] (i is the inclination angle of the star, B_e is the magnetic field at the magnetic poles). It turned out that the magnetic field structure in two of the investigated stars is best described by the central dipole model, four of them show a noticeable displacement of the dipole from the center by Δr along the dipole axis (in units of radius of the star). The displacement can be both towards the positive and negative charges, i.e. the magnetic field is asymmetric about the magnetic equator. The physics of this phenomenon is not clear yet. The angles β between the rotational axis and the dipole axis in all the cases proved to be considerable, apart from HD2435. It is known from literature data that the quantity of photometric variability ΔV of the investigated stars is rather large, although in the case of small β the variability must be practically imperceptible. One more argument against the magnetic deceleration is that the relationship between the average surface magnetic field of slow rotators and the rotation period proves to be opposite to the expected one (Fig.3), and the "slowest" star γEqu has a rather weak magnetic field. It is not improbable that the magnetic field played an important role only in the diminishing of the moment of rotation of the protostellar clouds.

It can be seen from the Table that in some cases the dipole is shifted along the axis by a considerable value up to Δr = 0.24 the radius of the star, which seems to be quite noteworthy. It is not quite clear yet to what extent the magnetic field configuration of CP stars is asymmetric in reality and to what degree the field measurements are distorted by the influence of inhomogeneous distribution of chemical elements. In the stars considered the mean value of β = 56°, which approximately corresponds to the mean value that must be in the case of arbitrary orientation of dipoles. The basic conclusions are:

1) The fact that the axes of rotation and of the dipole are not parallel is one of the indications that the deceleration at the "pre-main sequence" stages is absent and it verifies the hypothesis of an initial slow rotation of CP stars as the result of the small moment of rotation for protostellar clouds.
2) The absence of sufficiently strong magnetic fields in Ae/Be Herbig stars [1,8] also poses difficulties for the hypothesis of "magnetic" deceleration at "pre-main sequence" stages of evolution.
3) The known considerable photometric variability of the investigated CP stars is also an argument against the closeness of the axes.
4) The axes of the magnetic field dipoles in slow rotators are oriented randomly with respect to the rotational axes, as in the case of fast rotators.
5) The inverse relationship $B_s(P)$ contradict to the assumption that the magnetic field is involved in the deceleration.
6) The same relation between the relative number of chemically peculiar stars and nonmagnetic stars is inconsistent with the assumption that the magnetic field is involved in the deceleration.
7) The loss of the moment of rotation with the magnetic field involved could hardly occur at "pre-main sequence" evolutionary stages, the slow rotation is most likely due to its origin from protostellar clouds.

References

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Table 1
Results of modeling magnetic fields of CP stars with large rotation periods.

Star	*P*,days	*i*	*β*	Δ*r*	B_p,Gauss	Author
2453	547	14°	80°	0.00	±6560	[5]
12288	35	24	66	0.00	±13400	[5]
9996	8000	89	10	0.00	±8100	our last results
201601	3800	34	85.5	0.00:	±6210	[8]
116458	4600	75	12	0.07	+9510 - 6220	[6]
126515	12300	22	86	0.24	-45800 +11100	[6]
187474	5000	86	24	0.10	+18500 -11420	[7]
200311	8600	30	86	0.08	+1850 -11420	[5]

Average: 47° 56°

i - inclination of the star
β - angle between the dipole axis and axis of rotation
Δ*r* - value of the dipole shift from the star center (partial radius)
B_p - magnetic field at the poles

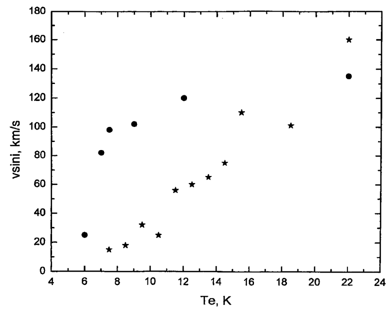

Fig. 1. Average values of the rotation velocity *v*sin*i* for normal stars with different temperatures (circles) and chemically peculiar stars (asterisks)

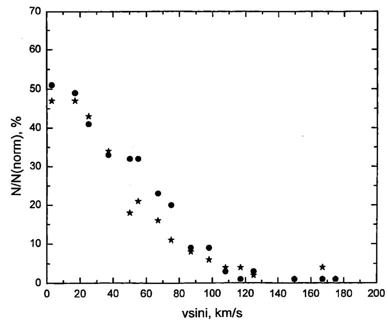

Fig.2. Relative amount of CP stars with different rotation velocities with magnetic field (circles) and without field (asterisks)

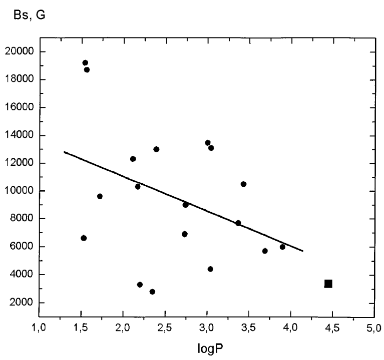

Fig.3 Dependence of the average surface magnetic field of CP stars on their period of rotation. In a case of "magnetic" braking the period would be longer the stronger the magnetic field. The angular coefficient is 2.2 σ after the formula

$$B_s = (16526 \pm 3426) + (-2710 \pm 1220)\ \log P.$$