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Magnetic CP stars in our Galaxy

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Abstract. A review of the modern state of the problem is presented. Spatial distribution of CP stars in the Galaxy is considered, it is shown that concentration of CP stars increases toward the Galaxy plane and toward the center of the Local System. Kinematics was studied: it was demonstrated that magnetic stars rotate in synchronism with other nearby stars of the Local System around the center of the Galaxy. Rotation velocities, inclination angles between the axis of rotation and the line of sight, photometric indices Δa, ages and masses of magnetic stars depending on galactic longitude and latitude are analyzed, stars in the clusters of different age and binary systems are under investigation.

1 Introduction

A considerable body of unquestionable evidence of magnetic fields existing in both separate cosmic objects and in stellar systems have been obtained by astronomers during the last half a century. In particular, the structure of the magnetic field of the Galaxy have been studied well enough, magnetic fields of hundreds of stars and in the interstellar medium have been found and studied.

However, the main question — how the magnetic field in our Galaxy (as a whole and in separate objects) is formed and supported, how it evolves — has been unclear in many aspects up to now. In our opinion, the fundamental cause of this difficulty is the fact that data obtained from the observations very often lack information that can be used for magnetic field analysis. Usually, such data can be obtained from spectropolarimetric observations, which are considerably rare, because they need a special complicated instrumentation far from existing at all telescopes. Moreover, many physical effects perfectly observed in magnetic field in the ground-based laboratories, cannot be measured in space because of low sensitivity of facilities and because it is impossible to make experiments with astronomical objects.

For example, the question if there exists any connection between magnetic field parameters of separate objects and the structure of the magnetic field in different local regions of the Galaxy, has been not risen up to now, whereas such an investigation could give important information about the processes of formation and evolution of magnetic fields in our stellar system.

The deficit of information about cosmic magnetism presently analyzable is caused not only by difficulties and labour intensity of magnetic field observations, but also by the fact that the interpretation of data is often ambiguous and depends on the model. The existing technique for the study of magnetic fields is far from being perfect, it permits us to find only strong, regular and large-scale fields of simple configuration. Studied objects must be bright enough for spectropolarimetric observations with high resolution and high photometric accuracy. Search for such objects is one of urgent directions in the problem of the stellar magnetism study.

In this context attention is paid to the so-called chemically peculiar (CP) stars of the Main Sequence. They are numerous enough, the fullest catalog (Renson et al., 1991a) contains information about more than 6600 such objects of different types.

2 CP stars in the local part of the Galaxy

2.1 Some general parameters of CP stars

A detailed review of physical parameters and chemical composition of atmospheres of CP stars was published by Romanyuk (2007). In this paper information about different-type chemically peculiar stars is presented: frequency of occurrence, duplicity, rotation, magnetic fields, variability, luminosity, anomalies of chemical composition, etc.

In the present review we restrict ourselves only to a discussion of some basic parameters and distinctive features of these Main Sequence objects.

Unique feature of CP stars is their anomalous abundances (sometimes higher or lower by a few orders) of certain specific chemical elements (for example, such as helium, chromium, strontium, silicon, rare-earth elements etc.). The frequency of occurrence of CP stars is about 15% – 20% of Main Sequence stars in the B2 – F0 spectral range.

CP stars can be divided into two large subclasses: magnetic and non-magnetic. The magnetic subclass contains approximately 3000 so-called Ap/Bp stars presented in the catalog by Renson et al. (1991b). Magnetic field was first discovered in 1947 by Babcock (1958) in the Ap star 78 Vir.

Apparently all Ap/Bp stars possess regular large-scale magnetic fields, however practical spectropolarimetric observations to search for such fields were made only for a small part (approximately 10%) of them. First of all it depends on the fact, that magnetic measurements need very large expenditure of observing time at big telescopes. Besides one needs to use special equipment — analyzers of circular polarization and high resolution spectrographs.

For this reason, magnetic field measurements are not widespread. For illustration, during the last 60 years passed from Babcock's discovery, direct Zeeman observations of 800 Ap/Bp stars were made; magnetic fields were found in 350 of them. Even using the world's largest telescopes it has been possible to study only the brightest stars up to recent time. For example, in 1983, at the end of photographic era in astronomy Didelon (1983) published a catalog containing information on about 130 magnetic CP stars, only 4 of them were fainter than the 8th magnitude. Most of them were brighter than magnitude 6.5.

Since, the typical absolute magnitude (M_v) for most of the objects indicated above (excluding a small group of stars with anomalous helium lines), occupied the interval from -1 (Si anomalies) to $+1$ (SrCrEu anomalies), this means, that most of the observed magnetic stars are located in the nearest neighborhood of the Sun, at the distances closer than 100–200 pc. Therefore the formulation of the problem of searching for any connections with the magnetic field of the Galaxy 20 years ago was too untimely.

However, the development of observational techniques, growing sizes of telescopes, improvement of spectrograph and detector parameters make it possible to study magnetic fields in fainter and more distant stars. Already in 2000, 212 magnetic CP stars were presented in the catalog by Romanyuk (2000), 30 of them are fainter than the 8th magnitude.

All new found magnetic stars in the XXI century were observed in two observatories: 1) at the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) using the 6 m telescope BTA and 2) at the European Southern Observatory in Chile, using the 3.6 m and the 8 m telescopes. 75 new magnetic CP stars were found with the 6 m telescope during 2000 – 2006, and 50 of them fainter than the 8th magnitude (Kudryavtsev et al. 2006). Bagnulo et al. (2006) found 41 new magnetic stars in open clusters using observations in Chile, 28 of them are fainter than the 8th magnitude. At the same country, using the 8 m telescope VLT, the magnetic field of the faintest star of 12.9 magnitude was measured.

Thus, progress is evident: now approximately 350 magnetic CP stars are known and more than 100 of them are fainter than 8th magnitude. The region of the Galaxy with observed magnetic stars is extended: up to 200 – 300 pc for typical SrCrEu stars, up to 300 – 400 pc for silicon stars and

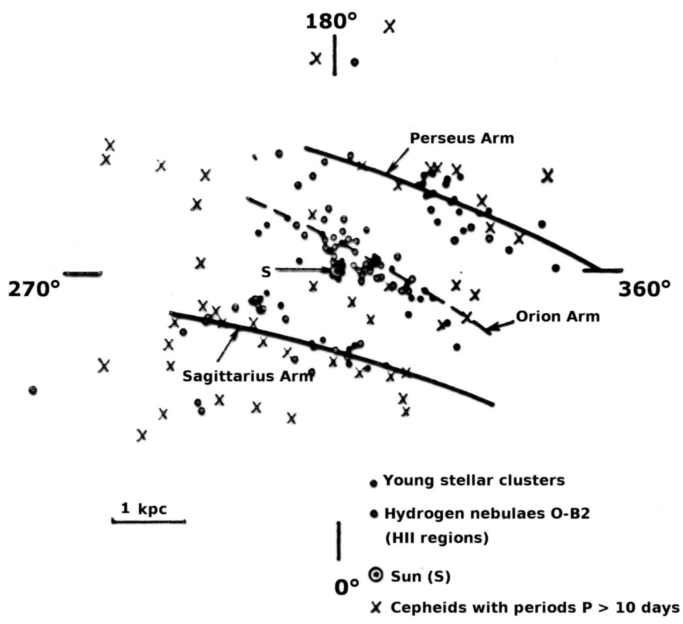

Figure 1. Local part of the Galaxy.

up to 500 – 600 pc for helium stars.

But is this information sufficient to search for any connections between topology and orientation of magnetic fields of individual stars and the magnetic field of the Galaxy?

2.2 Local part of the Galaxy

Consider first our local region of the Galaxy. The Sun locates near the median plane of the Galaxy at a distance of approximately 8 kpc from center of the system and about 20 pc toward to the north of the galactic plane.

Three regions of concentration of young objects exist in the solar neighborhood. In one of them, the so-called Orion arm, the Sun is located. The second is observed in the direction opposite to the center of the Galaxy at a distance of 1.5 kpc (Perseus arm), the third one locates in the direction towards the center of the Galaxy at a distance of about 1.2 kpc (Sagittarius arm).

The Orion arm is believed to be a small branch of large spiral arm, which is often observed in other galaxies ("Fizika Kosmosa" 1986) (see Fig. 1).

The plane of concentration of nearby stars does not coincide with the plane of the galactic equator. As far back as 1879, Gould (Agekian 1962) found a tilt of 17 degrees of the plane of largest concentration of stars brighter than 4th magnitude to the plane of the Galaxy. For fainter stars this inclination decreases, it reduces to 9 degree for stars brighter than 9th magnitude and is lower for fainter stars.

The described phenomenon may be considered as evidence of existence of the Local System, the main plane of which is oblate and does not coincide with the plane of the Galaxy. The study of stellar density in the region around the Sun shows an essential increase of the density in the direction with the galactic longitude from $l = 230°$ to $l = 260°$, up to distances of 300 – 400 pc. This scale is considered as approximate characteristics of the size of the Local System (Agekian 1962). It is essential that increasing density takes place mainly due to B and partially A stars' contribution to general density. It is presently accepted that Local System have sizes 200 × 500 pc, their center is located at a distance of 100 – 150 pc from the Sun in the direction $l = 275°$, $b = +12°$.

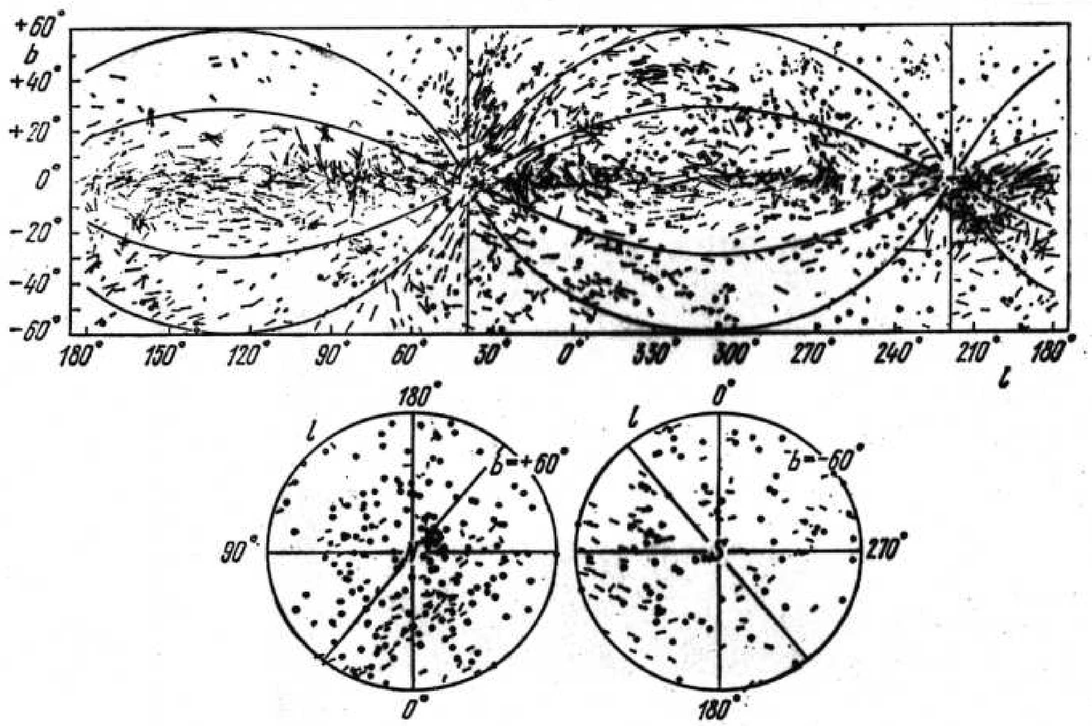

Figure 2. Distribution of polarization in our Galaxy.

A radio-astronomical study shows that emission from the Galaxy is linearly polarized. The generally accepted explanation is that polarization arises from the light scattering on interstellar dust. It is oriented predominantly under the influence of magnetic field. The maps of galactic polarization show clearly that polarization in the Galaxy is directed along the spiral arms. Thus we have evidence that: 1) common magnetic field in the Galaxy exists; 2) it is directed along the spiral arms.

For illustration, we demonstrate the distribution of polarization versus galactic coordinates l and b in Fig. 2 (Spoelstra 1977).

Comparison of Fig. 1 and Fig. 2 shows that there are "zero points" towards the galactic longitudes $l = 40°$ and $l = 220°$ where the sign of polarization reverses.

2.3 Spatial distribution of CP stars

2.3.1 General pattern

Let us consider location and kinematics of CP stars in the local part of our Galaxy. For this purpose, we use our data and information from different astronomical catalogs. The spatial distribution of 6600 CP stars from the catalog of Renson et al. (1991a) is demonstrated in Fig. 3.

Extremely faint objects from the catalog are 12–13 magnitude stars, i.e. they are located at distances of about 1 kpc. However, most of the catalog objects are brighter and nearer stars, belonging to the Local System.

It is seen in Fig. 3 that the distribution of CP stars on galactic coordinates is non-uniform: 1) evident concentration toward the plane of the Galaxy is observed along galactic latitude b; 2) highest concentration along galactic longitude l is seen towards the center of the Local System, the lowest concentration — towards the anti-center of it.

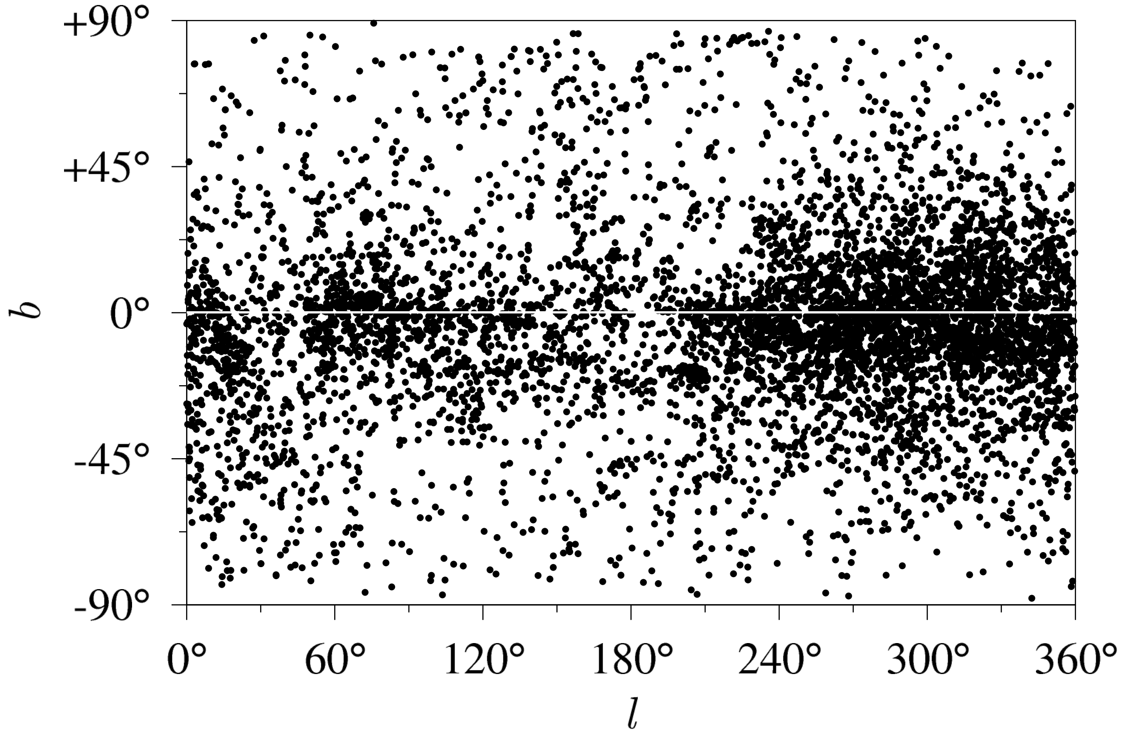

Figure 3. Distribution of CP stars from the catalog of Renson et al. (1991a) versus galactic coordinates l and b

The median of the distribution lays along galactic latitude $b = -3.5°$, which reflects the fact that the Sun is located somewhat higher (to the north) above the plane of the Galaxy.

Thus, we can see that the spatial distribution of CP stars from the catalog of Renson et al. (1991a) is sensitive to morphology of the local part of the Galaxy. That is why a search for any features in the distribution of magnetic stars depending on the morphology of the magnetic field in the Local System acquire a sense.

In order to be able to connect parameters of individual stars with the structure of the Galaxy and the morphology of its magnetic field, it is needed to make numerous measurements of magnetic fields of stars in the whole region of the Local System and even beyond its boundaries up to distances of 1 kpc. It is not realistic to study all 6600 stars with anomalous chemical composition (and brightness up to 12 magnitude) because it demands too much observing time at world's major telescopes.

For this reason special approaches were developed to search for new magnetic stars. An effective procedure has been developed and employed at the 6-m telescope for such investigations (see, for example, Kudryavtsev et al., 2006). Main criterion for selection of magnetic star candidates for the program of observation with BTA is the existence of strong anomalies in energy distribution in their continuous spectra.

It is important that the development of new techniques make it possible to largely increase the number of stellar groups of different age, in which one can observe magnetic stars (70 clusters and associations, Bagnulo et al. (2006)). Comparative analysis of magnetic field parameters in young and old objects may be of importance for understanding the process of origin and evolution of stellar magnetic fields.

2.3.2 Distribution of CP stars of different peculiarity types

Consider, whether there are any differences in the distribution of chemically peculiar stars in the Galaxy depending on the peculiarity type?

Since in further statements we will take interest in various relations with magnetic fields, we restrict ourselves only to comparison with the spatial distribution of unique potentially magnetic subclasses of Ap/Bp stars: 1) stars with anomalous helium lines, 2) stars with anomalous silicon lines, 3) stars with strongly enhanced lines of strontium, chromium and europium. Data on the objects were taken from the catalog of Renson et al. (1991b). The results of this analysis are demonstrated in Fig. 4.

Stars with anomalous helium lines (He-rich, He-weak) show conspicuous concentration towards the galactic plane. There are relatively not numerous young and hot B stars, an essential part of them are members of open stellar clusters and associations. Any predominant concentration along galactic longitude is not seen (Fig.4, upper panel).

Stars with anomalous silicon lines (Si and Si+ types) can be easily selected during spectral classification of stars, therefore they are found in a great number. These are late B and early A stars, members of clusters and field stars are present among them. Si- and Si+-type stars show an essential concentration towards the plane of the Galaxy and non-uniform distribution in azimuth: the number of them towards galactic longitude $l = 275^\circ$ is many times higher than in opposite direction (Fig.4, middle panel).

The oldest and coolest (late A and F) stars of SrCrEu type show an essentially lower concentration toward the galactic plane in comparison with silicon stars (as it was expected). Higher concentration towards the center of the Local System (galactic longitude $l = 275^\circ$) is preserved, but it is not seen as pronounced as for silicon stars (Fig.4, lower panel).

Thus, we can see that the distribution of Ap/Bp stars of different types in our local part of the Galaxy is different. In general, it corresponds to the spatial distribution of normal stars with the same temperatures and spectral classes in the Local System.

3 CP stars with measured magnetic fields in the Galaxy

3.1 Introduction

The overwhelming majority (more than 90%) of stars classified as chemically peculiar are very poorly studied. As a rule, only peculiarity types, magnitudes and colors are known. However, it is possible to select a small part of them, at this moment about 350 magnetic Ap/Bp stars. Magnetic fields can to be studied only by using high-quality observational data. Reduction of spectropolarimetric data permits not only magnetic field parameters, but also radial velocities, physical parameters and chemical composition of atmospheres to be defined. Thus, magnetic Ap/Bp stars are usually well-studied. As a rule, these are bright (usually brighter than 10th magnitude) and relatively near objects. Let us consider their location in the Local System in more detail and make analysis: if there exist any dependence of physical parameters and kinematic on their galactic coordinates.

The main sources of data on magnetic Ap/Bp stars are the catalog by Romanyuk (2000), and original papers (Kudryavtsev et al. 2006 and Bagnulo et al. 2006). Common parameters of the considered objects were adopted from the database SIMBAD.

Of course, the authors of the present review understand that 350 objects is a too small number for detailed investigation of their spatial characteristics. It is apparent that should be continued intensive searches for new magnetic CP stars. But we cannot expect high (if only few times) increases in the number of magnetic Ap/Bp stars in the nearest 10 years. Thus, to assess the present day state of the problem is very important for selection of optimal strategy of investigation in this scientific direction. Our review serves for this purpose.

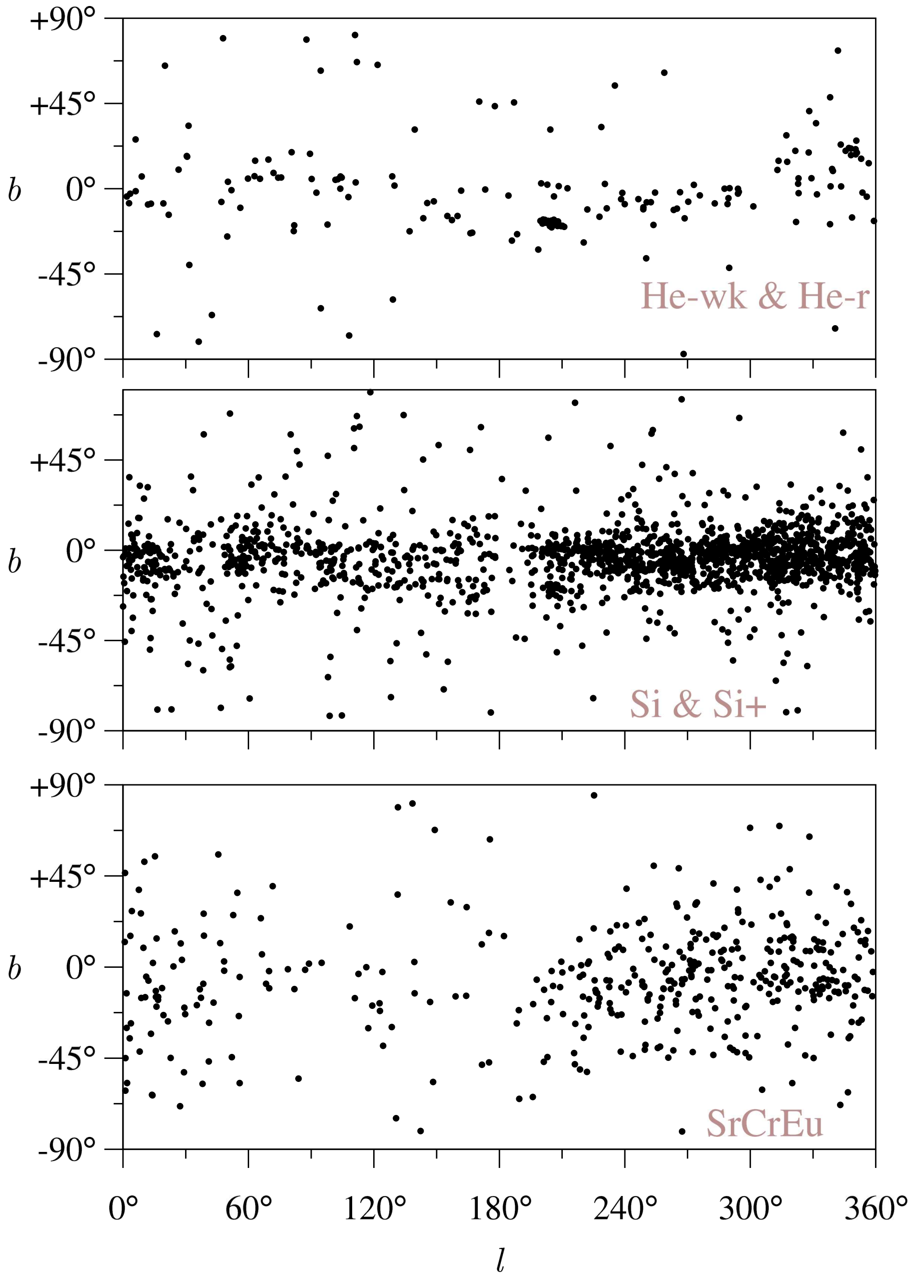

Figure 4. Distribution of CP stars from catalog of Renson et al. (1991b) versus galactic coordinates l and b depending on peculiarity type

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3.2 Spatial distribution

Hereafter we will consider only Ap/Bp stars with measured magnetic fields. Since, only less than 50 magnetic stars with anomalous helium lines are known and most of them are members of clusters, we will not demonstrate the spatial distribution of individual objects of this type in the Local System.

The distribution of magnetic silicon and SrCrEu stars versus galactic longitude l and latitude b is shown in Fig. 5.

An analysis of Fig.5 shows that concentration of magnetic silicon stars towards the galactic plane is more pronounced than in cooler magnetic SrCrEu stars. The same is observed for all CP stars presented in Fig.4. Separate zones where magnetic stars are actually absent are observed in the plane of galactic coordinates, for example the zone with $l = 240 - 360°$ and $b < -20°$ for SrCrEu stars (Fig. 5, lower panel).

Note, that the location of the center of the Local System ($l = 275°$, $b = +12°$) corresponds to the region with equatorial coordinates $\alpha = 10^h18^m$ and $\delta = -42°$.

Such a feature is difficult to explain. Most probably, the effect of observational selection manifests itself. As we mentioned above, magnetic field observations were performed earlier and made now only in a few observatories of the world, mainly located in the Northern hemisphere of the Earth. That is why, mainly observations of southern stars, in particular, towards the direction of the center of the Local System are deficient.

Note, that a considerable part of magnetic observations using different telescopes located in Chile were made by J. Landstreet and his colleagues with a Balmer-line magnetometer. They were concerned mainly with searching for magnetic fields in fast rotating stars with anomalous lines of helium and silicon (see, for instance, Borra et al., 1983; Bohlender et al., 1987; Bohlender et al., 1993). Magnetic fields were found in no less than 50 such objects. Now approximately the same number of magnetic silicon stars are known in both the northern and southern sky.

Searches for magnetic fields in cool SrCrEu stars were made by G. Mathys and his colleagues at ESO, using the study of Zeeman splitting of spectral lines. They found a smaller number of new magnetic stars than those discovered in observatories at the Northern hemisphere. Since G.Mathys made magnetic observations in a single observatory, the seasonal variations of weather conditions or particular character of telescope time allocation at ESO can, in principle, produce an effect of false non-uniform distribution of SrCrEu magnetic stars along galactic longitude l (Fig. 5, lower panel).

We suppose that effects of observational selection may affect significantly the number of objects that we observed in different directions, therefore it is too early to make any conclusions concerning the existence of real features of the distribution of magnetic CP stars in the Local System. HIPPARCOS parallaxes (ESA 1997) were measured for approximately 200 magnetic CP stars, which permits a three-dimensional picture of their distribution in the Galaxy to be derived.

For illustration, the location of the sample of magnetic CP stars with measured parallaxes in our local region in the Cartesian coordinate system (X, Y, Z) is demonstrated in Fig.6.

It is well known that HIPPARCOS parallaxes permit us to measure reliable distance only for stars located closer than 300 pc. For more distant objects the errors in distance determinations are too large, which should be borne in mind when examining Fig.6. For instance, the long chain of objects toward $l = 210°$ (or $X = -500$, $Y = -300$), presented by stars from the association Ori OB1, is unreal, it is due to the low accuracy of parallax determination.

Thus, one can conclude that relatively nearby magnetic CP stars with measured parallaxes do not demonstrate on the whole any conspicuous features in their spatial distribution in the Local System.

3.3 Radial velocities

We will consider the kinematics of the objects studied using radial velocities and proper motions.

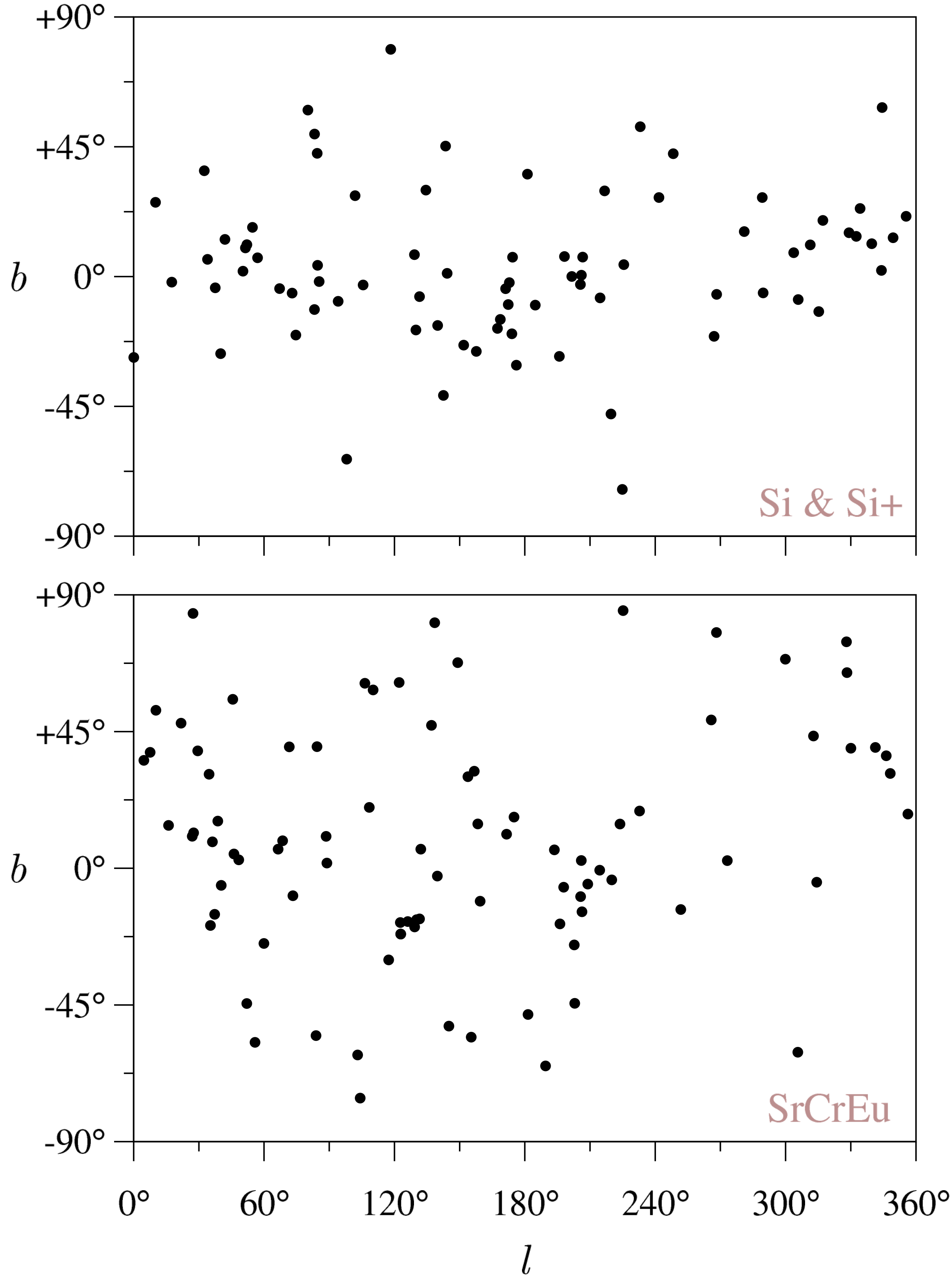

Figure 5. Distribution of magnetic CP stars with anomalies of Si and SrCrEu versus galactic coordinates.

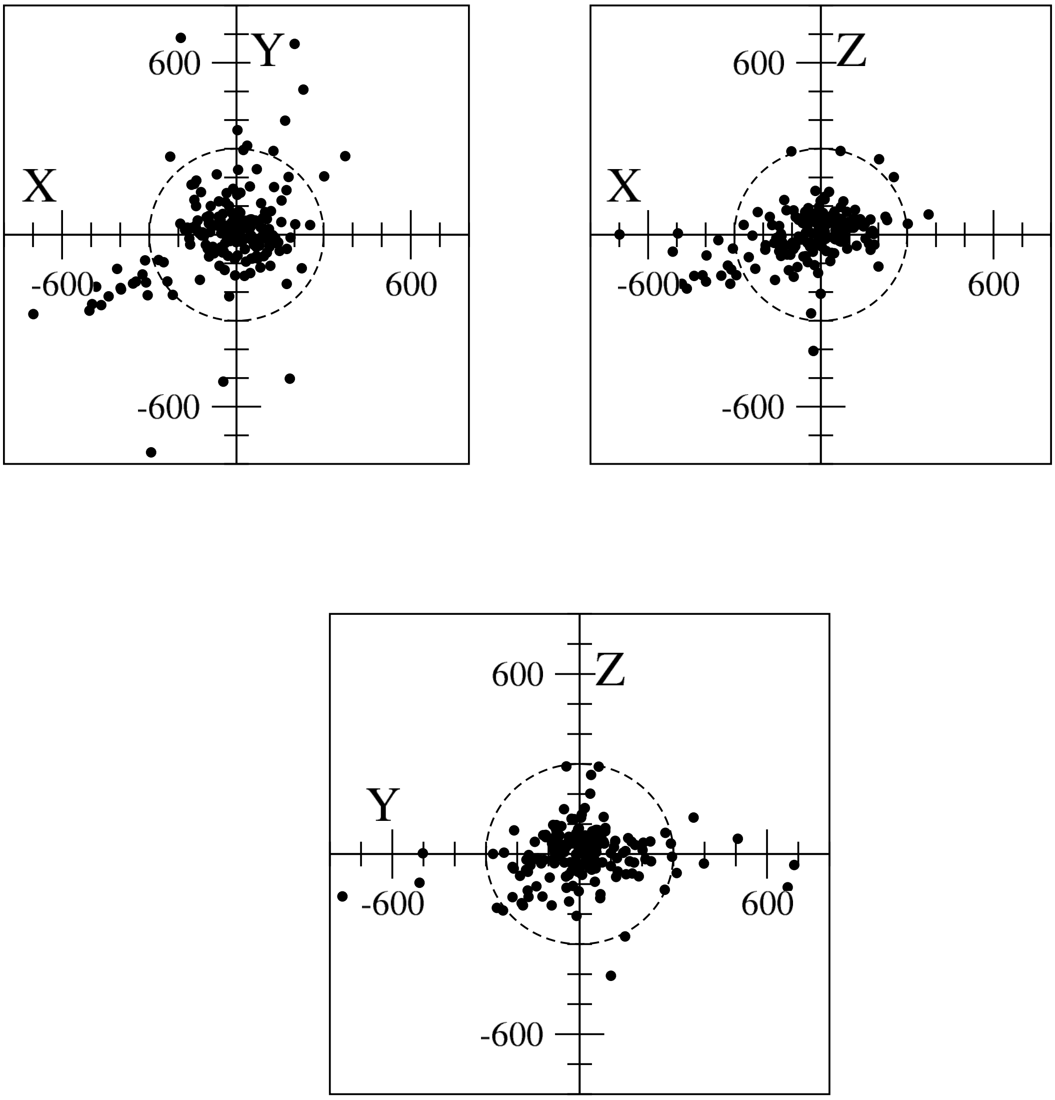

Figure 6. Distribution of magnetic CP stars in solar neighborhood.

Radial velocities were measured for 193 magnetic CP stars. We use information taken from the database SIMBAD, and the new data from our paper (Kudryavtsev et al., 2007). Radial velocities of stars reduced to the system of galactic coordinates l and b are presented in Fig.7. Radial velocities are designated by circles of different diameters, the approaching and receding objects are represented by different tints.

On can clearly see peculiar movement of the Sun to the apex $l = 210°$, $b = +22°$ with a velocity of $V = +20$ km/s relative to our sample. It is seen that there is not a single magnetic CP star whose radial velocity is strongly different from others. An analysis of proper motions leads to the same conclusion. This means that the kinematics of magnetic stars in the observed local part of the Galaxy is the same. They rotate in synchronism with other stars of the Local System around the center of the Galaxy.

Thus, the data on the spatial distribution and kinematics of magnetic CP stars give evidence that these are not alien objects, but they are an integral part of the Local System. They formed and evolved in it.

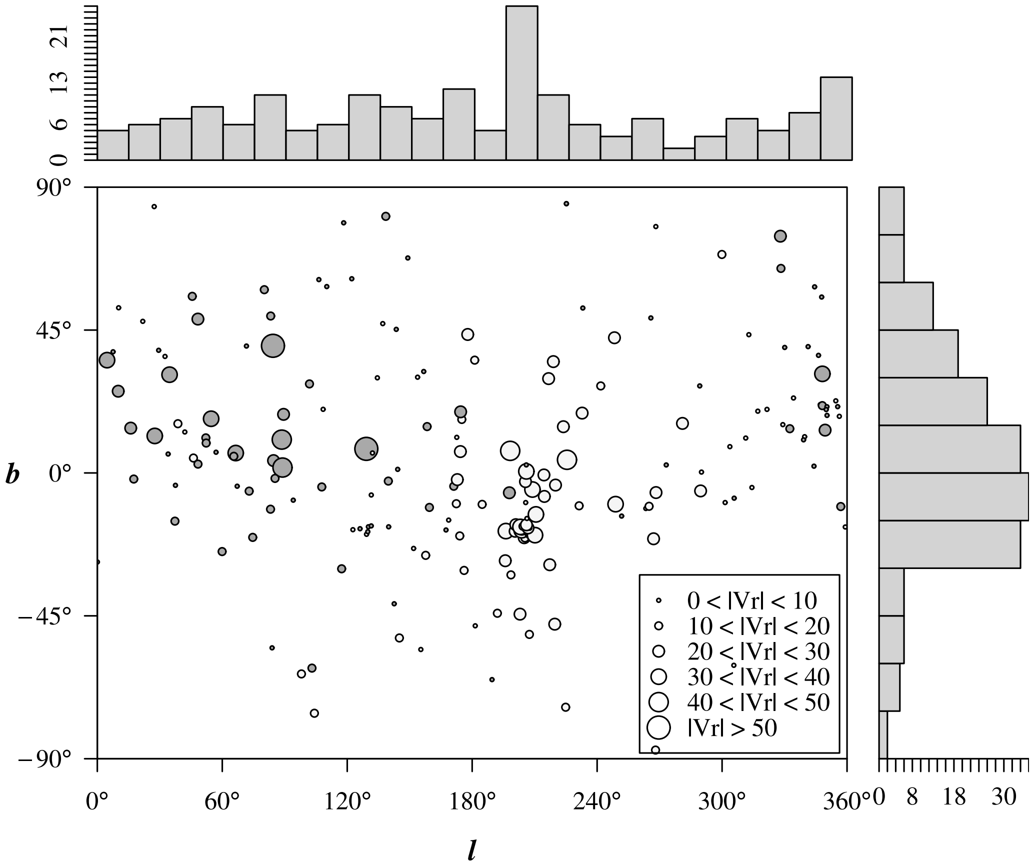

Figure 7. Distribution of magnetic CP stars with different radial velocities in the system of galactic coordinates l and b (filled circles are for receding stars, and open circles — for approaching).

3.4 Rotation velocities

Let us analyze, whether the velocities of axial rotation of magnetic stars located in different regions of the Local System are equal.

Since the value of the equatorial rotation velocity v_e has been determined only for a relatively small number of stars with a known rotation period, we will use and compare the data on the projection of the rotation velocity onto the line of sight $v_e \sin i$.

Most of the data on $v_e \sin i$ values for magnetic CP stars were compiled by Romanyuk (2004) in his Thesis, new data were obtained by Kudryavtsev et al. (2007). The distribution of 200 magnetic stars with different $v_e \sin i$ values in the plane of galactic coordinates (l, b) is present in Fig. 8.

In this figure the diameter of the circle is proportional to value of a projection of rotation velocity of a star onto the line of sight $v_e \sin i$. In the lower part of Fig.8 two histograms are presented; they demonstrate the distribution function for stars with measured $v_e \sin i$ northward ($b > 0°$) and southward ($b < 0°$) from the plane of the Galaxy.

An analysis of this figure shows that in Northern part of the Local System magnetic stars with $v_e \sin i > 50$ km/s are not observed, whereas in the Southern region they make up a considerable part of the sample.

Consider how differs the average values of rotation velocities $\langle v_e \sin i \rangle$ in the Northern and Southern parts of the Local System (see Table 1).

Assuming the distribution $v_e \sin i$ values to be random and applying Student's distribution cri-

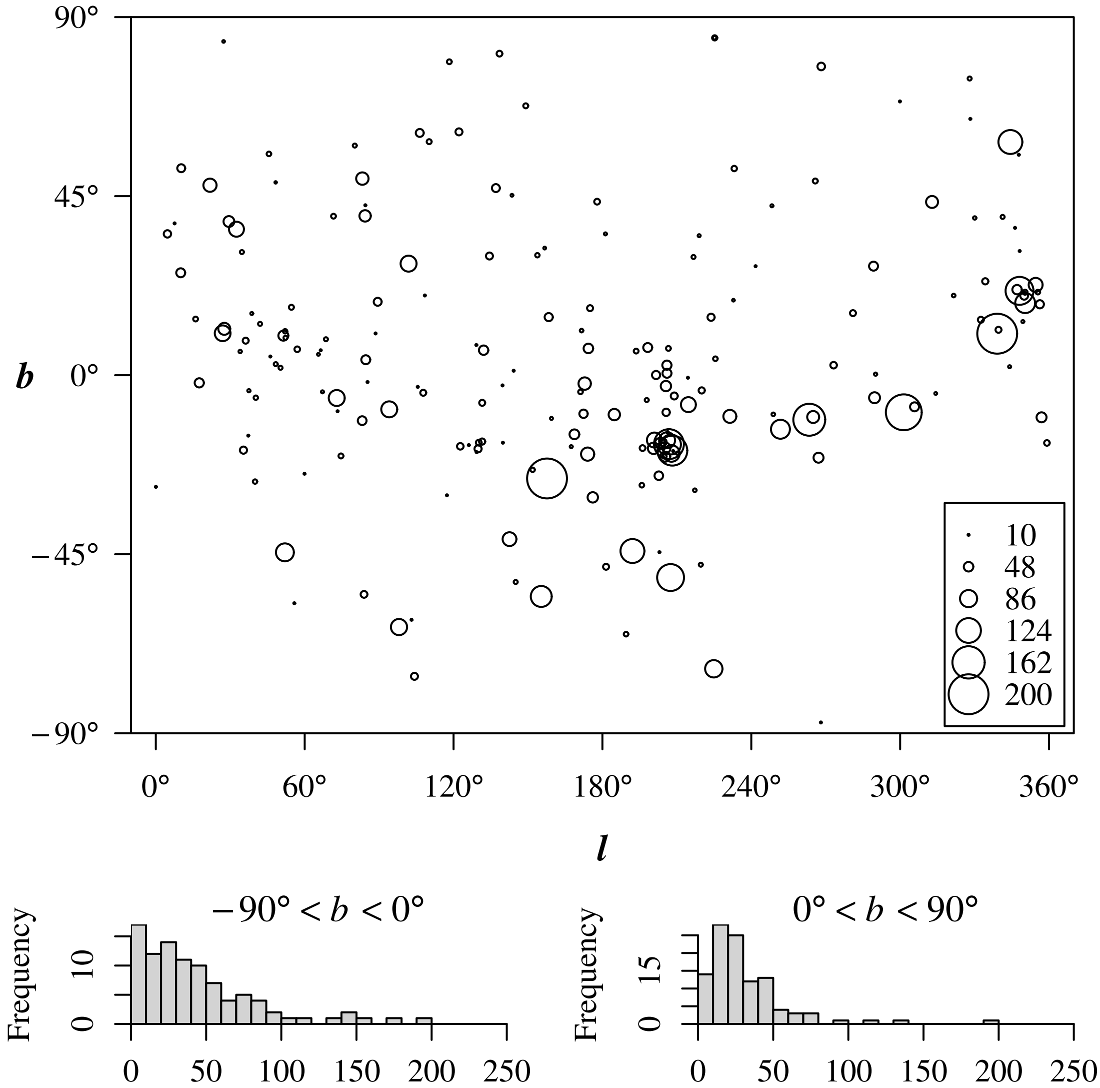

Figure 8. Distribution of magnetic CP stars with different rotation velocities in the Galaxy

teria for comparison of average values, we find the t criterion to be equal 2.64. With a high degree of probability it means that the differences between two samples are not occasional. The same picture (faster rotation of Southern objects) is observed for stars located in high galactic latitudes ($b > 45°$).

Similar results, presented in Tables 1 and 2 make improbable an occasional cause of appearance of the differences indicated above. Thus, from data available it follows that rotation velocities of magnetic CP stars located in the Southern hemisphere of the Local System are 1.5 times higher than in the Northern.

It seems to us that observational selection may has played an important role in the appearance of such an effect. It is rather difficult to determine it numerically, therefore we will make only a rough estimation.

As we wrote above, when analyzing the spatial distribution of different type magnetic stars, magnetic field measurements are relatively rare, especially in the Southern hemisphere. Various techniques were used in different observatories and different type of stars were studied. In particular, a relatively large number of magnetic stars newly discovered using Chilean telescopes are fast rotators with anomalous lines of helium and silicon. Observations were made using a Balmer

Table 1. Average values of $v_e \sin i$ in the Local System.

Hemisphere	$\langle v_e \sin i \rangle$ km/s	Number of stars
$b \geqslant 0^\circ$	33.2 ± 5.3	106
$b < 0^\circ$	46.3 ± 6.4	94

Table 2. Average values of $v_e \sin i$ of high latitude stars in the Local System

Hemisphere	$\langle v_e \sin i \rangle$ km/s	Number of stars
$b \geqslant +45^\circ$	30.9 ± 4.9	25
$b \leqslant -45^\circ$	46.2 ± 6.4	13

magnetometer (Borra et al., 1983; Bohlender et al., 1987; Bohlender et al., 1993). This technique increases the relative number of stars known as fast rotators in the Southern hemisphere.

Magnetic field observations mainly using lines of metals were made in the Northern hemisphere with large spectrographs and analyzers of circular polarization. Preferences in such observation have been made for stars with sharp and narrow lines in spectra. For example, such technique was used by Babcock (1958) and by our group using the 6 m telescope (Kudryavtsev et al., 2006). Certainly, a numerical estimate of this effect is needed.

3.5 Inclination angles i between rotation axis and line of sight

3.5.1 Magnetic stars in the Local System: general case

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In the case of magnetic CP stars we are afforded a unique opportunity: it makes possible to determine a very important parameter, the spatial orientation of the rotation axis for a star in the Galaxy (to be more correct — inclination angle i between the rotation axes and the line of sight in the plane perpendicular to picture plane). Note that now we cannot distinguish between different directions of the rotation axes in the picture plane.

For magnetic CP stars it is possible to determine angle i because one can find rotation parameters of a star by two independent ways: from the Doppler broadening of spectral lines it is possible to determine the $v_e \sin i$ value, and given the period of rotation of a star P and its radius R (which is possible to estimate from temperature and/or spectral class), it is easily to find the velocity of equatorial rotation v_e using the known formula (R in solar units, P in days):

$$v_e = 50.6 \frac{R}{P}, \tag{1}$$

and then the $\sin i$ value.

There is not any reason for distribution of angles i to have predominant directions in the Galaxy as a whole. The random distribution was confirmed repeatedly (for example, Stepien 1989 or Abt 2001). For instance, Abt (2001) found on the basis of $v_e \sin i$ and rotation period determinations for 102 Ap stars that rotation axes are oriented in a random manner within the measurement error. Abt found no relationship of the orientation of axes either with galactic longitude or galactic latitude.

In the study reported here we were interested in the point if there exist any selected regions in our Galaxy where spatially close magnetic stars have the similar orientations of rotation axes.

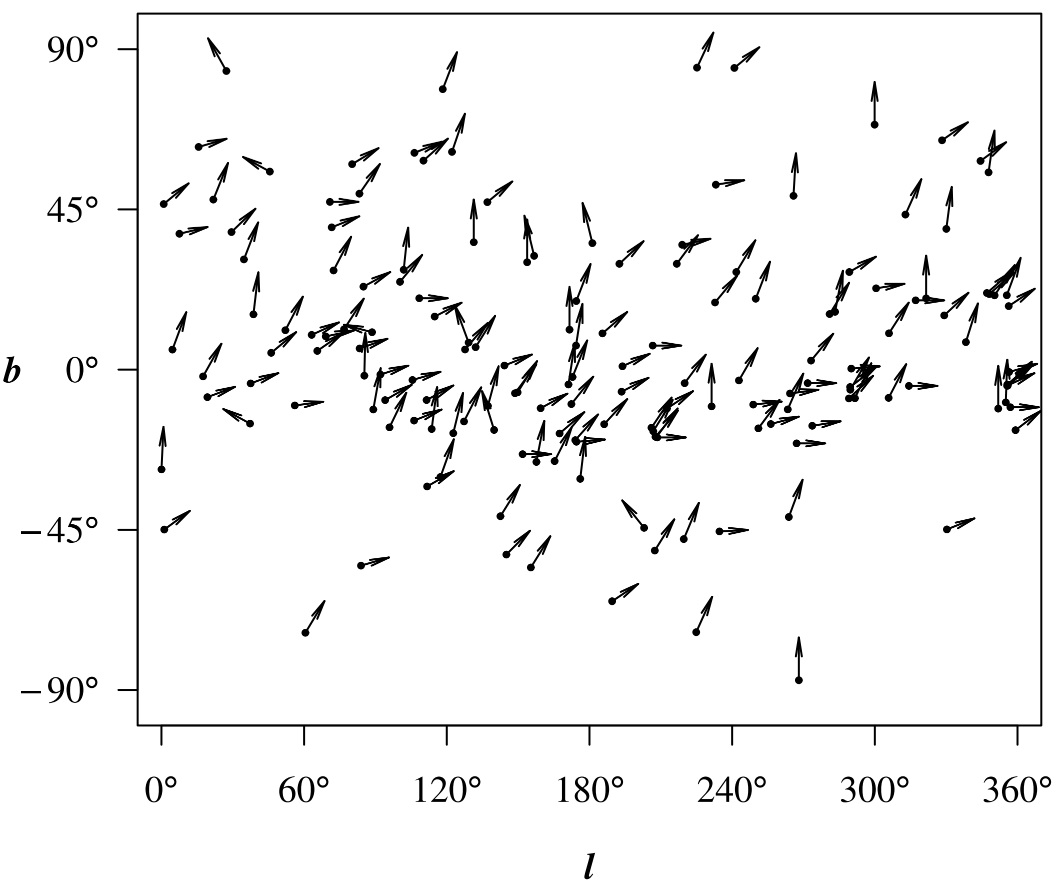

Figure 9. Distribution of inclination angles i for magnetic CP stars in the Galaxy (in the plane perpendicular to the picture plane).

The question what stars are close remains undecided. We will analyze data available from literature and will make a conclusion pertaining the real distances between closest CP stars. Taking into account our previous study (Kudryavtsev and Romanyuk, 2001), we suppose that they must not exceed a few tens of parsecs.

We found in literature data on 160 CP stars (members of clusters and field stars) with determined inclination angle i. The principal source of information is the paper by Kopylov (1987). Data on inclination of axes for other stars, not considered in this paper, were collected by Romanyuk (2004). Inclination angles of all found objects are displayed in Fig.9.

There is a certain complication in demonstration of the distribution of angles i because they are determined in the plane perpendicular to the picture plane. Angle i is equal to 0° when rotational axis is parallel to the line of sight (parallel to the direction of galactic longitude l in Fig.9), and $i = 90^\circ$ when the rotation axis of a star is perpendicular to it (parallel to the direction of galactic latitude b in Fig.9). Certainly, angles $i = 0^\circ$ and 180° are displayed identically.

The positions of stars in the galactic coordinate system l and b are marked by dots in Fig.9, the directions of rotation axes (emphasize: in the plane perpendicular to the picture plane) are shown by arrows.

A review of Fig.9 shows, at a first sight, that some predominant alignment of rotation axes at an angle of about 45° is observed. But this is due to large selection effects.

The main difficulty is as follows. Knowing the equatorial velocity v_e of a star (determined using formula (1)) and its projection onto the line of sight $v_e \sin i$ (which is determined from the Doppler broadening of lines), one can not find directly angle i, but only the $\sin i$ value. Therefore, if one does not take into account any additional arguments, one cannot distinguish to which quadrant the angle i belongs. The majority of authors prefer the first quadrant($0° < i < 90°$), and because of this visual illusion arises. However, over the last years papers have appeared (for example, by J. Landstreet and his team) in which magnetic models of stars were derived. Parameters of these models are angle i and angle β between rotational and dipole axes. The approach applied by these authors leads to deriving angle $i > 90°$ for some stars.

We will not discuss in this review if such an approach is realistic, we only note that the number of stars with angle $i > 90°$ is extremely small, which is apparent from Fig. 9.

Besides, the accuracy of determination of angle i is very low, especially for slowly rotating CP stars. It is common, that 2–3 different estimates of angles i for the same stars but made by different authors differ by a few tens of degrees.

Thus, we can consider the situation with determination of angles i to be unsatisfactory. For this reason, we cannot make a definite conclusion if there exist obvious predominant orientation of rotation axes of magnetic CP stars in the Local System and any relationship with its magnetic field structure.

Does there exist a certain predominant collective orientation of rotation axes of close magnetic stars located in more compact regions of the Galaxy (for instance, in stellar clusters)? How are the rotational axes of binary stars oriented in space? These questions will be considered below.

3.5.2 Magnetic CP stars in open clusters

The point of the possible predominant collective spatial orientation of nearby stars is of certain interest: according to modern idea, group formation of stars takes place and their further evolution depending on their masses. It was proved that rotation velocities of magnetic CP stars is three-fold lower than those for normal Main Sequence stars (for example, Romanyuk 2004). Question of angular momentum loss is active discusses in literature (for example, Stepien 2000).

Since 80s of the XX century a variety of investigations of magnetic stars in clusters of different age have been performed. Note here the series of papers presented by I.M. Kopylov and his group (for instance, Klochkova, Kopylov 1986, Glagolevskij et al. 1987). It was shown that peculiarity types, rotation velocities and magnetic fields do not change during the main sequence lifetime of stars. However, spatial orientation of rotational axes of magnetic stars – members of clusters was not considered before. We will attempt to fill the gap.

Formulation of the problem makes sense because earlier we (Romanyuk, Kudryavtsev 2001, Kudryavtsev, Romanyuk 2003) found evidence that in some cases relatively close stars (for instance, 53 Cam and 49 Cam, as well as 3 stars in Scorpius–Centaurus association) have similar physical characteristics, chemical composition and morphology of magnetic field.

It is most reasonably to search for close magnetic stars among members of clusters. Using the paper by Kopylov (1987) and data from our catalog (Romanyuk 2004), we selected 4 stellar groups or clusters (Pleiades group, Ursa Majoris Stream, Orion OB1 and Scorpius-Centaurus associations) if only 5 CP stars with determined i values exist in each of them.

Some general information making possible to estimate the spatial orientation of the rotational axis, distances between stars, magnetic field parameters and peculiarity type is presented in 3. For each group in its columns are presented: the name of the star, angle i, galactic coordinates l and b, parallax π (in milliarcseconds, using HIPPARCOS data), extreme values of the longitudinal magnetic field and peculiarity type.

It is seen from Table 3 that Pleiades group and UMa stream occupy a large space in the plane of galactic coordinates, while Orion and Scorpius-Centaurus associations are essentially more space-saving.

Table 3. Orientation, location and some parameters of CP stars, members of clusters

HD name	$l°$	$b°$	$i°$	π, mas	B_{extr}, G	pec
			Pleiades group			
11503	142.548	−41.201	47	15.96	$-900/+410$	SiCr
25823	167.428	−17.959	30	6.60	$-100/+1200$	Si
27309	174.044	−19.828	37	10.32	$-1200/-200$	Si
74521	216.711	+29.711	42	8.00	$-200/+1400$	SiCr
220825	83.917	−55.083	11	20.12	$-400/+200$	CrSr
			UMa stream			
15144	189.53	−65.08	24	15.24	$-1100/-530$	SrCr
112185	122.18	+61.16	63	40.30	$-50/+150$	Cr
118022	328.27	+64.41	25	17.79	$-1800/-200$	SrCr
148112	29.46	+38.63	19	13.87	$-250/-90$	SrCrEu
152107	71.61	+39.96	15	18.62	$+500/+2000$	SrCr
209515	94.08	−8.58	21	6.16	$-270/+560$	SiMn
			Ori OB1			
36916	207.76	−18.88	38	2.88	$-640/-615$	He-wk
37017	208.18	−18.96	42	2.68	$-2300/-300$	He-r
37058	208.52	−19.07	0		$-800/+1000$	He-wk
37479	206.82	−17.32	47		$-1650/+3500$	He-r
37776	206.07	−16.34	45 (90?)	1.96	$-2000/+1000$	He-r
			Sco-Cen			
103192	103192	+27.41	21	8.93	$-250/-100$	Si
122532	122532	+19.45	0	5.91	$-900/+900$	Si
125823	125823	+20.02	90,5	7.79	$-440/+370$	He-wk
130880	130880	+15.21	32	7.90	$-4400/+1920$	Si
142301	142301	+21.51	35	7.16	$-4100/+1600$	He-wk
142990	142990	+21.20	30	6.68	$-2500/+600$	He-wk
144334	144334	+20.85	45	6.70	$-1400/+500$	He-wk
147010	147010	+20.88	61	6.98	$-4500/-2500$	SiSr

We will search for close magnetic stars in these clusters (the distances between stars must not exceed tens of parsecs) and compare orientation of rotational axes and their other characteristics. Analyze each of the clusters separately.

Pleiades group. This group occupies almost the whole hemisphere towards the anticenter of the Local System. The cluster is nearby, stars locate at distances from 50 to 150 pc from the Sun. The directions of the rotational axes of 5 magnetic CP stars with known i values are shown in Fig. 10.

It is seen from Fig.10 that predominant orientation of the rotational axes exists, the scattering is low. As follows from Table 3, the average angle $i = 33 \pm 6$ degrees.

We analyzed above various disadvantages of the technique, which can give rise to a false opinion concerning the existence of the predominant alignment, therefore we will not dwell here on this problem.

We calculated distances between all CP stars in Pleiades group from Table 3. We found that the closest to each other are two pairs of stars from this cluster. The distance between HD 25823 and HD 27309 in the first pair is 56 pc, and HD 11503 and HD 220825 in the second pair is 40 pc. It

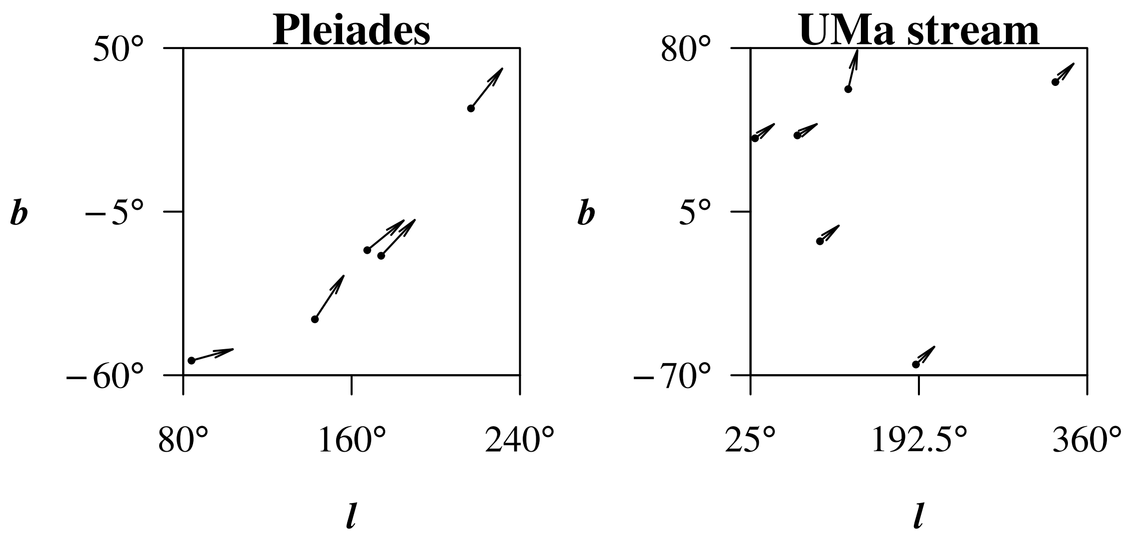

Figure 10. Orientation of rotation axes (angles i) in individual magnetic stars from Pleiades group and UMa stream (in the plane perpendicular to the picture plane).

follows from Table 3 that both stars from the first pair are silicon stars and they have approximately similar magnetic field strength.

HD 11503 and HD 220825 locate closer to the Sun, they have chromium anomalies and approximately similar but weaker (than in the first pair) magnetic fields. Thus, we have a good ground to believe these stars to be close enough and similar.

Compare all found physical parameters for the two pair of stars: HD 25823 and HD 27309 as well as HD 11503 and HD 220825, which we have managed to determine by ourselves or to find in literature.

Data on radial velocities V_r (in km/s), proper motions μ_α and μ_δ (mas/year), rotation $v \sin i$ (km/s), rotation periods P (days), duplicity and effective temperatures T_{eff} were taken from the catalog by Romanyuk (2004), and rest of them — distances d (in pc), absolute magnitude M_v, logarithm of luminosity $\log L$, masses M, logarithm of age $\log t$ and fractional age τ — were adopted from the paper by Kochukhov and Bagnulo (2006). The data are presented in Table 4.

An analysis of Tables 3 and 4 shows that even close CP stars in Pleiades group are located sufficiently far from each other, the distance between the closest of them is from 40 to 60 pc.

A comparison of the kinematics and physical parameters of the pair of stars HD 25823 – HD 27309 shows following: both stars have approximately the same temperatures, peculiarity types, magnetic field strengths and orientation of rotational axes with the respect to the line of sight; however their rotation and radial velocities, masses and luminosities strongly differs. According to Kochukhov and Bagnulo (2006) ages t for them are about the same, but fractional ages τ are largely different: HD 25823 has already stayed more than 2/3 of its life on the Main Sequence, while HD 27309 finishes only the first 1/3. HD 25823 is a spectral binary with an orbital period of 7.23 days, which coincides with the rotation period. There is no information on the duplicity of HD 27309.

For the stars HD 11503 and HD 220825 (the second pair) we can see approximately the same radial velocities and proper motions, temperatures (both are cooler by 3000 degrees than the stars of the first pair), rotation periods and ages $logt$. Rotation velocities $v \sin i$ and fractional ages τ are different. HD 11503 is a well known binary star ADS 1507 A (γ Ari A), while there is no information on the duplicity of HD 220825.

Table 4. Kinematics and physical parameters of close CP stars in Pleiades group

	HD 25823	HD 27309	HD 11503	HD 220825
V_r, km/s	-2.0	$+12.4$	-0.6	-3.2
μ_α, mas/y	22.13	29.77	79.43	85.60
μ_δ, mas/y	-50.18	-41.39	-99.10	-94.43
$v \sin i$, km/s	15	66	69	34
P	7.227^d	1.569^d	1.60920^d	1.412^d
duplicity	sp. bin	no data	ADS 1507 A	no data
T_{eff}, K	12900	12260	9850	9100
d, pc	151 ± 19	96 ± 7	62 ± 3	49 ± 1
M_v	-0.63 ± 0.28	0.40 ± 0.16	0.60 ± 0.12	1.45 ± 0.09
$\log L$	2.50 ± 0.12	2.01 ± 0.07	1.78 ± 0.05	1.35 ± 0.04
M	3.80 ± 0.19	3.04 ± 0.09	2.57 ± 0.06	2.07 ± 0.04
$\log t$	8.13	8.07	8.47	8.57
τ	0.72	0.34	0.55	0.37

According to Klochkova and Kopylov (1986) the age of Pleiades group is $\log t = 7.5$, which is in a good agreement with the age of the two stars from the first pair, determined by Kochukhov and Bagnulo (2006). The age of the stars from the second pair is half an order of magnitude higher. So, we can conclude: the difference between the stars inside each pair in Pleiades group is smaller than between the stars in different pairs.

Ursa Majoris Stream. It is seen from Table 3 that UMa stream contains stars distributed all over the sky. Actually, it means that our Solar system is located inside this cluster (see Fig. 11 and right part of Fig. 10). This group contains cooler stars, than the group considered before.

In Table 3 we found 3 closest stars in UMa stream: HD 148112, HD 152107 and HD 112185. The distance between HD 148112 and HD 152107 is 39 pc, between HD 152107 and HD 112185 it is 37 pc and between HD 148112 and HD 112185 of is 63 pc.

By analogy with Table 4 construct Table 5. All symbols are the same.

According to Klochkova and Kopylov (1986), the age of UMa stream is $\log$ t=8.6, which is in an excellent agreement with the data presented by Kochukhov and Bagnulo (2006) for 3 stars from Table 4.

Let us analyze the results presented in Tables 3 and 5. A comparison of the pair HD 148112 – HD 152107 shows that both stars have nearly the same temperatures, peculiarity types, inclination angles i (between the rotational axis and the line of sight) and rotation periods. Kinematics, luminosities and masses differ insignificantly. Both stars are multiple: HD 148112 is a binary (ADS 10054 AB = CCDM J16254+1402AB), HD 152107 is a triple system (ADS 10227 ABC = CCDM J16492+4559ABC). In both cases peculiar are the primary components, which are substantially brighter than the secondary.

According to Kochukhov and Bagnulo (2006), ages t are approximately the same for both of them while fractional ages τ differ rather significantly.

There are no essential differences in the pair HD 152107 – HD 112185. The main of them: HD 112185 (well known star ϵ UMa) is twice as close to the Sun (at a distance of 24 pc) as HD 152107, therefore kinematic parameters (proper motions and radial velocities) are different. Temperatures, projections of rotation velocities onto the line of sight, rotation periods and ages t are very close. But luminosities, masses and fractional ages τ largely differ. HD 112185 is finishing

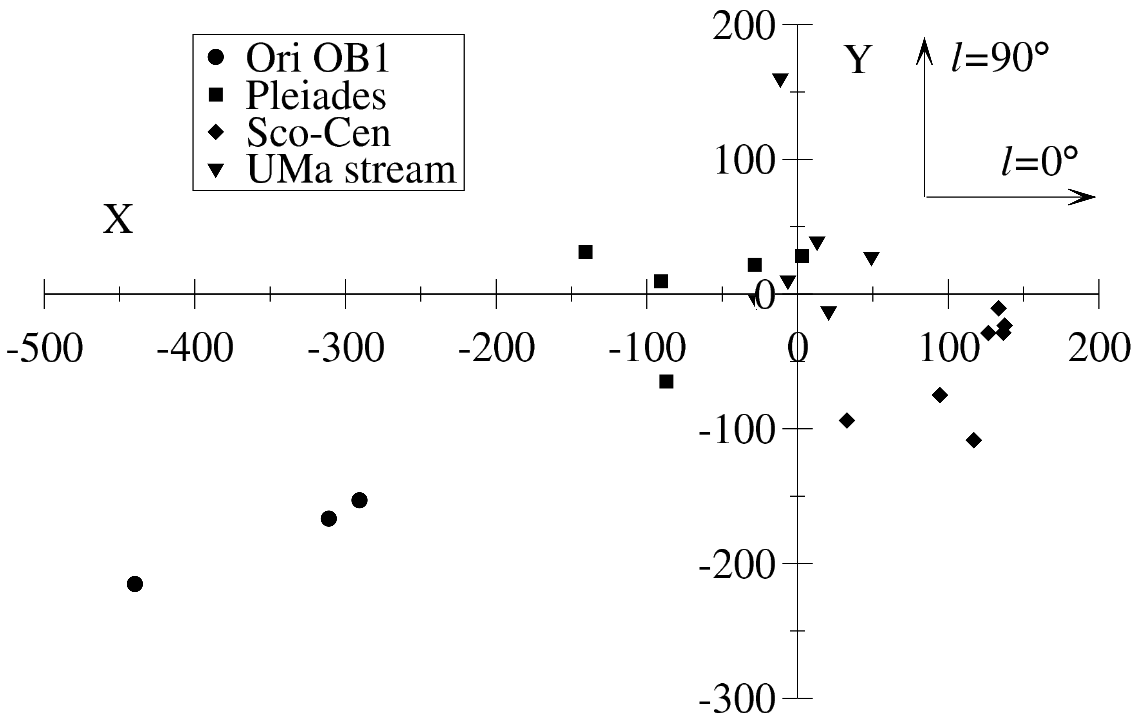

Figure 11. Distribution of selected CP stars–members of open clusters in the plane of galactic coordinates.

its evolution on the Main Sequence, while HD 152107 has evolved only half of its Main Sequence lifetime. No data on the duplicity of HD 112185 are available.

In general, we can conclude that parameters of close stars in UMa stream are essentially more alike than in the previous case of Pleiades group.

Orion OB1 The open cluster in Orion is reach in young hot stars. It occupies a rather compact area with a size of only a few square degrees in the galactic system of coordinates. Five magnetic CP stars with measured angle i are presented in Table 3. All of them belong to the subclass of chemically peculiar stars with anomalous helium lines.

Unfortunately, the cluster in Orion is far away and therefore the distances to the stars are determined with large errors: no parallax measurements for 2 stars out of 5. Information about physical parameters, kinematics and ages of these stars was collected by Romanyuk (2004).

Inclination angles i for the Orion stars are presented in Fig. 12.

Physical parameters of the 5 CP stars in Orion are presented in Table 6. The symbols are the same as in Table 4, but R — radius of a star (in solar radius units) — is added.

We can see that 4 objects out of 5 have a period of about 1 day, while that of HD 37058 is about 15 days. Lines in the spectrum of this star are not broadened, most probably angle i is small.

HD 37017 and HD 37479 are binary stars, information of multiplicity of HD 36916, HD 37058 and HD 37776 is absent.

According to Klochkova and Kopylov (1986) the CP stars in Orion have the following ages: in Ori OB1a $\log t = 7.3$, in Ori OB1b — $\log t = 6.6$, in B Ori OB1c — $\log t = 6.4$ and in Ori OB1d — $\log t < 6.0$.

We cannot determine reliable distances between the stars in Orion now, this is the subject of future studies. Note once more: this cluster is reach enough by peculiar stars in anomalous helium lines. In the paper by Klochkova and Kopylov (1986) data on 35 of such stars in Orion were presented.

Table 5. Kinematics and physical parameters of 3 close CP stars in UMA stream

	HD 148112	HD 152107	HD 112185
V_r, km/s	−5.9	−1.0	−9.3
μ_α, mas/y	39.39	22.78	111.74
μ_δ,mas/y	−59.89	−51.37	−8.99
$v \sin i$, km/s	54	24	35
P	3.043^d	3.858^d	5.0887^d
uplicity	ADS 10054 AB	ADS 10227 ABC	no data
T_{eff}, K	9250	8800	8900
d, pc	72 ± 4	53 ± 1	24 ± 0
M_v	0.20 ± 0.15	1.21 ± 0.07	-0.21 ± 0.04
$\log L$	1.87 ± 0.06	1.43 ± 0.03	2.01 ± 0.02
M	2.60 ± 0.08	2.10 ± 0.04	2.76 ± 0.03
$\log t$	8.63	8.74	8.61
τ	0.81	0.58	0.94

Table 6. Physical parameters of five CP stars in Orion

	HD 36916	HD 37017	HD 37058	HD 37479	HD 37776
V_r, km/s	+10.7	+29.0	+22.8	+29.0	+27.0
$v \sin i$, km/s	100	150	0	150	80
	150	80			
P	1.565^d	0.901^d	14.6^d	1.191^d	1.539^d
T_{eff}, K	12950	20450	19600	22500	23050
d, pc	298	692			603
M_v	−0.9	−2.2			−2.2
$R/R_\odot$	3.0	4.8	4.7	5.7	5.5

A detailed investigation each of them and their comparative analysis are seen to be important for clearing the details of the process of group formation of the stars.

Scorpius-Centaurus The young stellar cluster in Scorpius-Centaurus is reach also in CP stars (more than 30 such objects). V.G. Klochkova and I.M. Kopylov for many years were concerned with the study of peculiar stars of the northern part of this cluster amenable to observations with the 6 m telescope. In particular, they estimated the ages of CP stars in the region of Upper Scorpius: core — $\log t = 6.6$, inner zone — $\log t = 6.7$, eastern zone — $\log t = 7.0$, western zone —$\log t = 7.1$ (Klochkova, Kopylov 1986).

Using data from Table 3 we can find that the stars closest to one another are three He-weak stars: HD 142301, HD 142990 and HD 144334. They occupy a zone of a few square degrees in the plane of galactic coordinates, and the distances to them are approximately equal.

Similarly to Table 3, the parameters of these 3 stars are listed in Table 7.

We calculated the distances between these stars. The distance between HD142990 and HD142301 is 10.3 pc, between HD144334 and HD142301 — 12.3 pc, and between HD144334 and HD142990 — 5.5 pc. The stars occupy a volume of diameter less than 20 pc. HD 142990 and HD 144334 are particularly close.

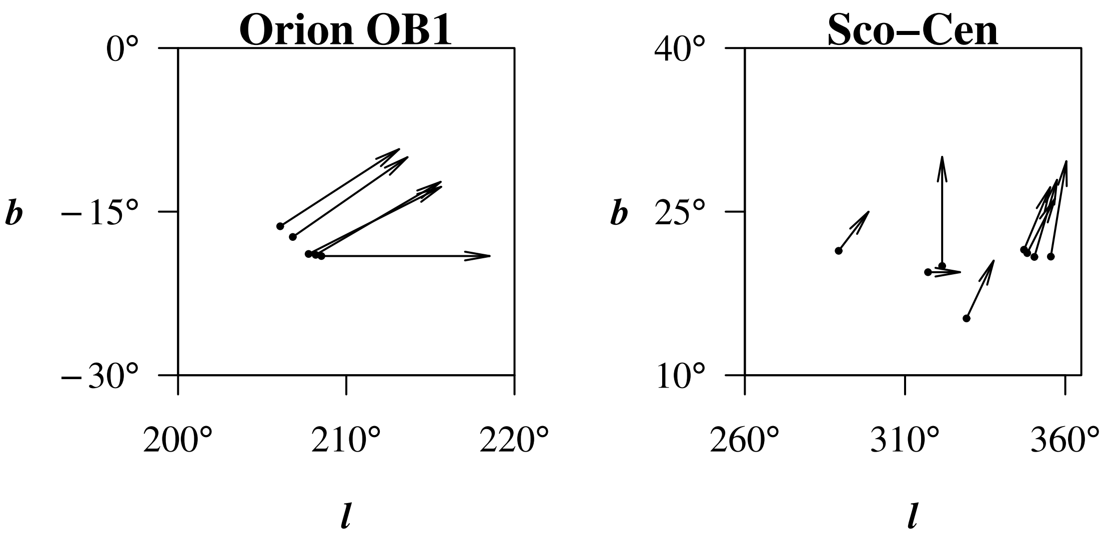

Figure 12. Orientation of inclination angles i of separate CP stars–members of association Ori OB1 and cluster Sco–Cen (in the plane perpendicular to the picture plane).

From Tables 3 and 7 it follows that all the 3 stars are very similar: they have approximately the same spectral classes, temperatures, rotation periods, peculiarity types, inclination angles of rotational axes to the line of sight, kinematics (both radial velocities and proper motions). Masses and luminosities are not much different. The three stars are single stars, no information on their duplicity is available.

The ages $\log t$ differ by half an order of magnitude, fractional ages τ are less different: all the stars evolved less than 1/3 of their Main Sequence lifetime. Greatly different is the projection of rotation velocity onto the line of sight $v \sin i$ for HD 142990. However, it is not improbable that this effect may be due to the large magnetic broadening of line profiles in strong magnetic field and, possibly, in magnetic fields of complex structure. This idea needs checking.

Putting an end to the discussion of properties of magnetic CP stars in open clusters it should be noted, that these stars do not form groups in some separate regions of these systems. The distances between known CP stars exceed, as usual, a few tens of parsecs. Only in the Scorpius–Centaurus cluster we have found objects really close enough.

At present we can observe only rare isolated cases where close stars have close physical parameters. For this reason it is needed to formulate an observational problem with the purpose of reliable determination of physical parameters of magnetic stars (in the first place — in Orion and Scorpius–Centaurus), including the magnetic field structure, orientation of the rotational axis to the line of sight i, and inclination angle β between the dipole and the rotational axes.

3.6 Binary magnetic CP stars

An evident new question arises — how are rotational axes of components of binary systems oriented, one of which (or both) is a magnetic CP star?

The deficit of double systems among magnetic stars is well known, (see, for example, the review by Romanyuk (2007)). Nevertheless, actually all brightest and best studied magnetic CP stars are either optical or spectral binaries: α^2 CVn, β CrB, 52 Her, γ Equ, 53 Cam and others.

Carrier et al. (2002) presented information about 74 magnetic binary stars, 53 binaries are described in our catalog of magnetic CP stars (Romanyuk, 2004). Peculiar are primary components, all secondary components belong to the Main Sequence, no special cases (for instance, white dwarfs)

Table 7. Kinematics and physical parameters of close CP stars in Scorpius–Centaurus cluster

	HD 142301	HD 142990	HD 144334
V_r, km/s	-8.7	-11.1	-6.6
μ_α, mas/y	-12.29	-11.41	-10.98
μ_δ,mas/y	-25.45	-24.06	-29.18
$v \sin i$, km/s	47	140	25
P	1.459^d	0.979^d	1.495^d
duplicity	no	no	no
T_{eff}, K	17300	17800	15150
d, pc	139 ± 23	149 ± 18	149 ± 19
M_v	-0.24 ± 0.37	-0.74 ± 0.27	-0.29 ± 0.27
$\log L$	2.53 ± 0.15	2.78 ± 0.11	$2.50 + -0.12$
M	4.30 ± 0.21	4.87 ± 0.20	4.08 ± 0.17
$\log t$	7.21	7.54	7.72
τ	0.11	0.34	0.33

were found.

Our search for data from literature shows that at the present time there is no system with a magnetic CP component studied to a degree allowing the spatial orientation of both components to be found. This problem is to be resolved in the future.

Below, in Table 8 we propose a list of binary CP stars for first priority detailed investigation.

It is obvious that one needs to consider bispectrum binaries, in which if only one of the components is magnetic CP star while second would be such that high quality data could be obtained for a detailed study, including construction of models and estimation of physical parameters.

Most of the data were taken from the "Catalog of the observed periods of Ap and Bp stars" (Catalano, Renson 1998) and from the paper by Leone and Catanzaro (1999).

Table 8. Bispectrum optical binary magnetic stars

HD number	ADS number	Comments
BD +40°175 AB	ADS 693 AB	Second component — magnetic CP star weaker by 0.5 magnitude at a distance of 3.7″ (Elkin 1999).
HD 11503/2	ADS 1507 A	"HD 11502a, companion (HD 11503) at 8″ often confused with the Ap star, the luminosity being about the same. HD 11502b (Δm less than 0.1"), (Catalano, Renson 1998).
HD 12447	ADS 1615 A	companion (Am star at 2") $\Delta m = 0.9$", companion A ($m_v = 4.33$) — Ap star, companion B ($m_v = 5.23$) — Am star at a distance of 3.6″ (Catalano, Renson 1998).

Table 8. Bispectrum optical binary magnetic stars (continued)

HD number	ADS number	Comments
HD 15089 Aa	ADS 1860 A	triple system, companions at $2''$ ($\Delta m = 2.9$, orbital period 840 years) and at $7''$ ($\Delta m = 3.8$), close HD 15089 Ab companion at $0.1''$, revol. in 52.4 years (Catalano, Renson 1998).
HD 15144 Aa	ADS 1849 A	companion at $12''$, $\Delta m = 3.1$ spectral binary, $P = 2.9978^d$ (Babcock 1958), $\sin i = 0.15$ (Catalano, Renson 1998 and orbit from (Leone, Catanzaro 1999)
HD 36485	ADS 4134 C	δ Ori C. The system consists of 4 stars: the primary component A = HR 1852 = HD 36486 is a spectral binary with $V = 2.23$, component B locates at a distance of $33''$ from A and has a magnitude of 14.0^m. Component C (with enhanced helium lines) = HR 1851 = HD 36485 locates at a distance of $51.7''$ from A and have a magnitude of 6.85. HD 36485 is also binary (Bohlender et al. 1987). Orbital elements are available (Leone, Catanzaro 1999).
HD 108662 (17 Com A)	ADS 8568 A	Magnetic Ap star. Multiple system. A — primary component. Component B — Am star at a distance of $145''$ from A.
HD 108651 (17 Com B)	ADS 8568 BC	Component B — spectral binary system (includes the components CCDM J12289+2554BC) (Babcock 1958).
HD 112413 (α^2 CVn)	ADS 8706A	Optical binary. Component A — famous magnetic CP star. Component B — on the distance $15''$ — F star. The distance and kinematics of components are as follows: comp. A — $\pi = 29.60$ mas, $\mu_\alpha = -233.43$ mas/y, $\mu_\delta = 54.98$ mas/y, $V_r = -3.3$ km/s.
HD 112412 (α^1 CVn)	ADS 8706 B	Comp. B — $\pi = 39.95$ mas, $\mu_\alpha = -203.89$ mas/y, $\mu_\delta = 88.34$ mas/y, $V_r = -3.1$ km/s (ESA 1997).
HD 130559 (μ Lib A)	ADS 9396 A	Component A — 5.4 magnetic Ap star, visual binary with companion (A6p) of a 6.3 magnitude at a distance of $1.6''$ (Babcock 1958). Probably, component B is also a magnetic star.

Table 8. Bispectrum optical binary magnetic stars (continued)

HD number	ADS number	Comments
HD 145501 (ν Sco BC)	ADS 9951 CD	CCDM J16120-1928CD — Binary or multiple star. Component B = sp.B8p, component C = sp. B9III. CD = visual binary (separation 2″). Component D is by 0.7^m weaker than C (Borra et al. 1983).
HD 145502 (ν Sco A)	ADS 9951 AB	Component A = B2 star at a distance of 40″. Spectral binary. Magnetic star – HD 145501.
HD 165475 (HR 6758)	ADS 11056 A	Component A — a typical A star with wide lines Peculiar star — component B, of approximately the same magnitude at a distance of 7″ from A.
HD 165474	ADS 11056 B	(Babcock 1958)

Thus, we propose 11 binary systems with a magnetic CP component for a detailed investigation. This problem needs to be considered in more detail in future studies.

3.7 Δa photometry

The photometric index Δa was introduced by Maitzen (1976), it is a characteristic of anomalies in energy distribution of magnetic CP stars, in particular, continuum depression at a wavelength 5200 Å. The index Δa correlates in a certain degree with the magnetic field strength on the star's surface (Kudryavtsev et al. 2006), therefore it can be used for indirect estimations of the field parameters.

The distribution of stars with different Δa values versus the galactic coordinates is shown in Fig.13, the source of data is the Thesis by Romanyuk (2004).

It is seen from Fig.13 that most of the data were obtained for stars of the northern part of the Galaxy. It seems, that an essential contribution is introduced by instrumentation selection, which we discussed repeatedly above. No systematic features in the distribution of Δa values versus galactic longitude l in Fig.13 are seen.

Let us consider numerically if there are any differences in the distribution of stars with different Δa versus galactic latitude b. For an analysis we divided all the sample into 3 zones in the Galaxy: northern ($b > 30°$), central($-30° < b < 30°$) and southern ($b < -30°$). The average indices Δa in the zones are presented in Table 9.

Table 9. Distribution of CP stars with different Δa indices with galactic latitude b

	$\langle \Delta a \rangle$	Number of stars
$b > +30°$	0.034 ± 0.003	29
$-30° < b < +30°$	0.037 ± 0.003	70
$b < -30°$	0.029 ± 0.003	18

It follows from Table 9 that most CP stars with known Δa indices are accumulated in the plane of the Galaxy. No significant difference across the galactic latitude is observed.

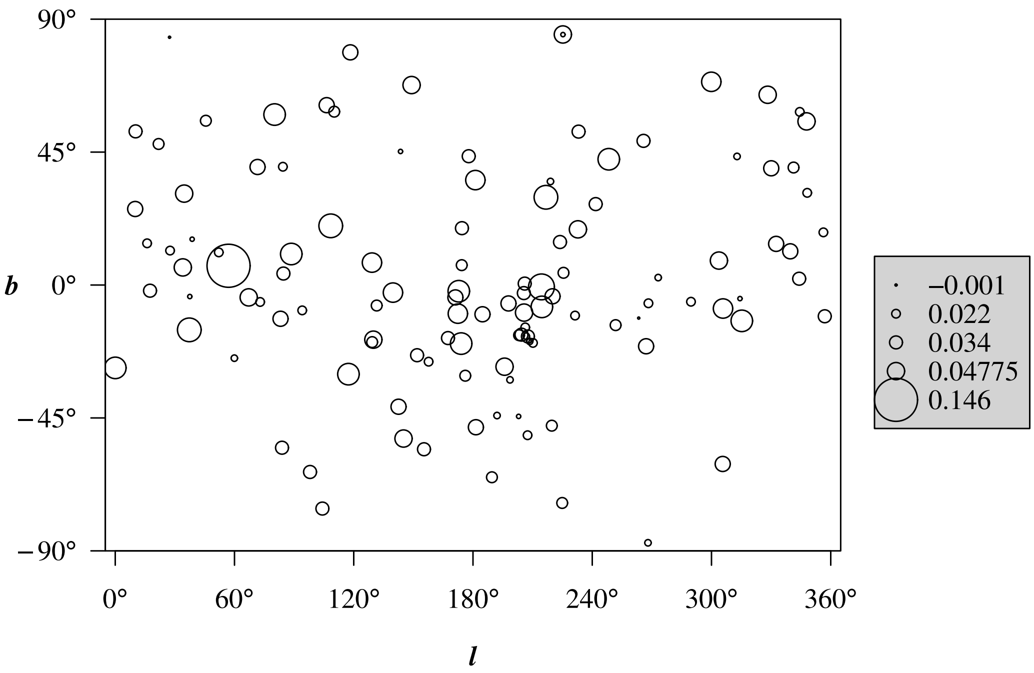

Figure 13. Distribution of Δa indices of magnetic stars along galactic coordinates.

3.8 Age

Consider the age distribution of CP stars in the Local System. It will be recalled once again that these objects belong to the Main Sequence. The age designated as t is the chronological age, it shows how many years a star lives on the Main Sequence. τ is fractional age — the fraction of the Main Sequence lifetime completed. Ages ($\log t$) and fractional ages (τ) for a large sample of stars are presented in the paper by Kochukhov and Bagnulo (2006). We have already used the results of this paper when making an analysis of magnetic CP stars in stellar clusters.

Consider now, if there are any systematic regularities in the distribution of stars versus age in the Local System. We will make the same analysis as for indices Δa. The distribution of stars of different age $\log t$ versus galactic coordinates is presented in Fig.14.

There is no pronounced peculiarities in the distribution of $\log t$ versus galactic longitude. By analogy with the study of Δa distribution, divide the region of the Local System into 3 zones across the galactic latitude b and find an average $\log t$ for stars in them.

Results are presented in Table 10.

Table 10. Distribution of CP stars with different ages $\log t$ versus galactic latitude

	$\langle \log t \rangle$	Number of stars
$b > +30°$	8.61 ± 0.05	33
$-30° < b < +30°$	8.11 ± 0.08	66
$b < -30°$	8.23 ± 0.14	17

The differences are clearly seen. To the north of the plane of the Galaxy, considerably older stars are observed. We consider this as a result of different distribution of Si and SrCrEu stars across galactic latitude: Si stars concentrate towards the galactic equator much more largely, and therefore

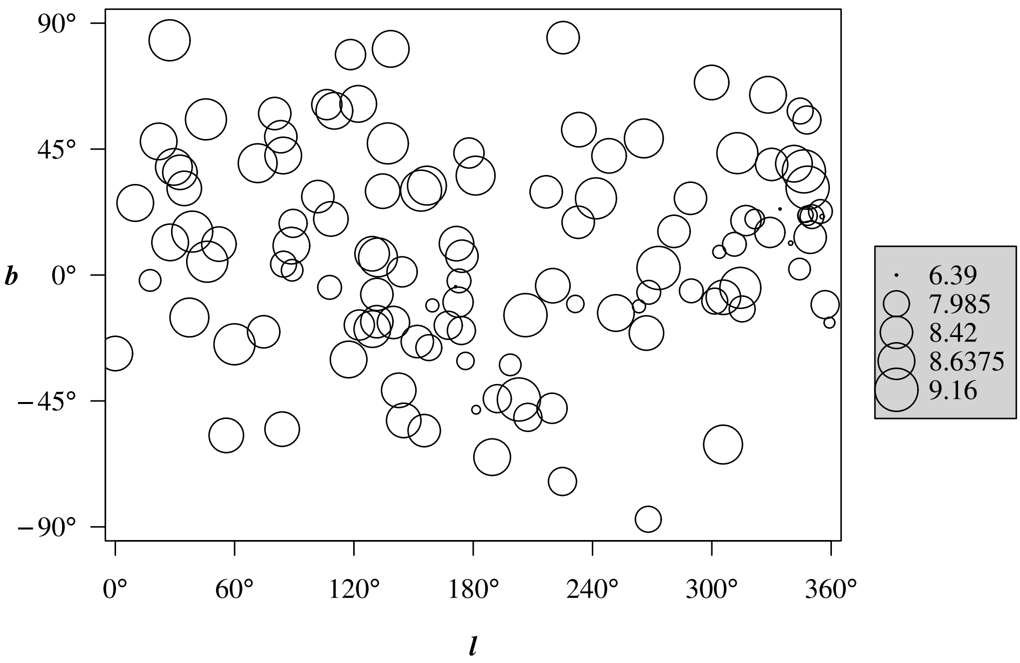

Figure 14. The distribution of stars of different age ($\log t$) versus galactic coordinates.

we can observe mainly older SrCrEu stars in the high galactic latitudes. A very small number of data was obtained in the southern part of the Galaxy ($b < -30°$) and the contribution of observational selection is large. In particular, as we mentioned above, J. Landstreet and his colleagues in Chilean observatories studied mainly hot helium and silicon CP stars using the Balmer-line magnetometer.

Table 11 and Fig. 15 are constructed by analogy with Table 10 and Fig. 14, using fractional age τ instead of age $\log t$.

Table 11. Distribution of CP stars with different fractional ages τ versus galactic latitude

	$\langle\tau\rangle$	Number of stars
$b > +30°$	0.61 ± 0.04	33
$-30° < b < +30°$	0.50 ± 0.03	66
$b < -30°$	0.49 ± 0.06	17

The same picture is seen from Table 11: high latitude stars ($b > 30°$) have spent more time of its evolution on the Main Sequence in comparison with stars of the equatorial zone of the Galaxy.

3.9 Masses of magnetic CP stars

We made the same analysis for the mass distribution of magnetic CP stars, using the data from the paper by Kochukhov and Bagnulo (2006). Results are presented in Fig.15 and in Table 12.

It is seen that masses of north high latitude stars ($b > +30°$) and stars from the plane of the Galaxy are the same within errors of estimation. Southern stars show unexpectedly low masses. Probably, this is a result of low statistics and observational selection. This point should be studied in more details.

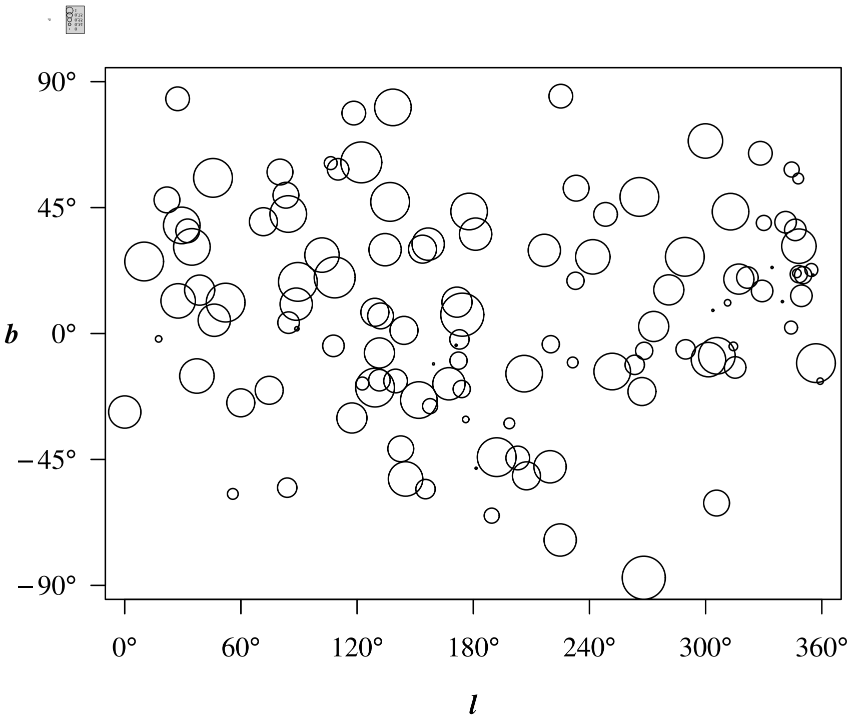

Figure 15. Distribution of CP stars of different fractional ages (τ) across galactic coordinates.

Table 12. Distribution of CP stars of different masses across galactic latitude b

	$\langle M/M_{\odot}\rangle$	Number of stars
$b > +30°$	2.88 ± 0.24	33
$-30° < b < +30°$	3.07 ± 0.13	66
$b < -30°$	2.38 ± 0.08	17

4 CONCLUSIONS

We have made a review of magnetic CP stars in our Galaxy. The spatial distribution of CP stars in the Local System has been considered. It is shown that the majority of them are located at the distances less than 1 kpc. The distribution is non-uniform: the accumulation of CP stars grows towards the galactic plane and towards the center of the Local System. Stars with anomalous helium and silicon lines show a higher concentration towards the galactic plane than SrCrEu stars.

A study of radial velocities and proper motions shows that magnetic CP stars rotate in synchronism with other nearby stars of Local System around the galactic center. These data give evidence that magnetic CP stars were formed in the Local System and evolve in it.

Rotation velocities of stars located in the southern hemisphere of the Galaxy are 1.5 times higher then those in its northern hemisphere. An important role in the appearance of such a false effect may be plaid by observational selection.

The inclination angles between the rotational axes and the line of sight are distributed randomly. However, for some spatially close cluster stars evidence of collective predominant orientation of rotational axes exists.

We propose a list of binary systems in which if only one component is a magnetic star for a detailed study.

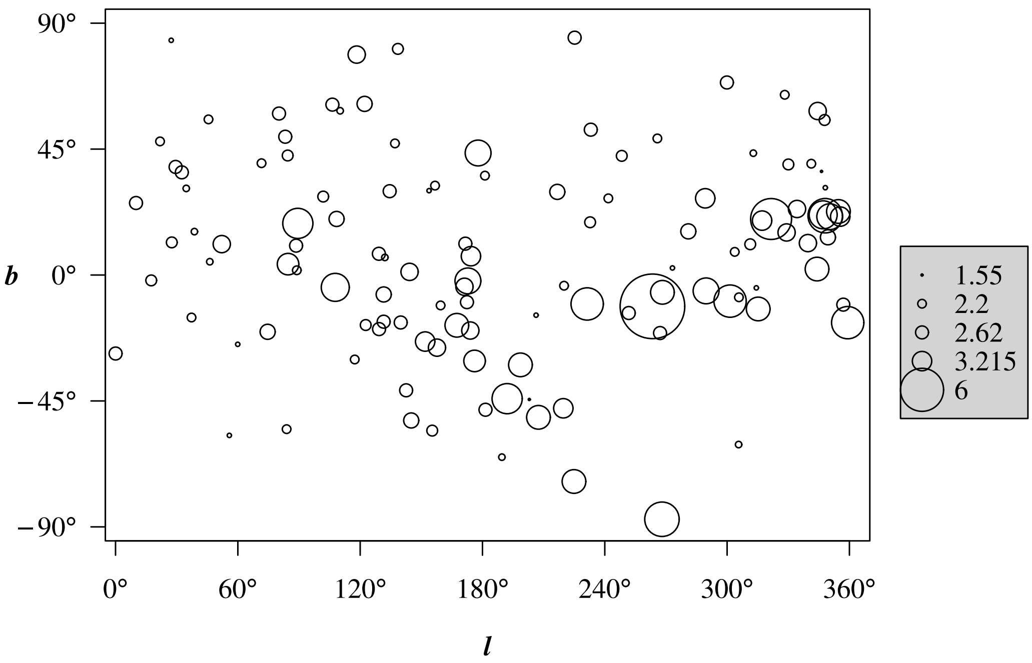

Figure 16. Distribution of CP stars with different masses versus galactic coordinates.

We demonstrated, that photometric indices Δa and masses of magnetic stars do not depend on galactic latitudes, young helium and silicon stars show high concentration to the plane of the Galaxy, while older stars (both, chronological and evolution ages) spread up to the high galactic latitudes.

Neither location of magnetic star in the Local System nor their kinematics show any anomalies or features to distinguish them from normal stars of the Main Sequence. It means that they did not come from anywhere, but they are an intrinsic part of the Local System. Magnetic stars in open clusters do not show any concentration within them, they spread over a cluster.

Certainly, the existing number of magnetic CP stars is too small for construction of reliable statistical distributions. To search for a connection between magnetic field of single stars and the structure of magnetic field of the Galaxy requires to find if only 500 new magnetic CP stars, mainly brighter than 10–12 magnitude, preferably in different clusters. It is needed to construct magnetic models of these objects and compare them with configuration of magnetic field in different local parts of the Galaxy. This is a very important observational project, requiring cooperative efforts of astronomers from different countries.

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