Magnetic Field in some Selected Directions of the Galaxy: Sagittarius Spiral Arm

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Abstract

Faraday rotation data on 180 pulsars are used in a detail study of the magnetic field in the direction of galactic longitude $40° < l < 70°$, including the Sagittarius spiral arm region. The highly regular magnetic field in northern hemisphere of galaxy is directed to the Sun, when the magnetic field of southern hemisphere is directed from the Sun. We propose that the Sagittarius spiral arm lies mainly to the north of the Galactic plane, while the magnetic field with opposite direction below this plane is the field of the halo of the southern hemisphere of the Galaxy.

Keywords: *magnetic fields – Galaxy: general*

1. Introduction

The study of the magnetic fields of galaxies and, in particular, of our Galaxy has a great importance for explaining many dynamical and active processes taking place in these objects. The presence of the magnetic field of the Galaxy can explain the transportation of cosmic rays through the interstellar medium Fermi (1949), as well as synchrotron background radiation in the Galaxy Kiepenheuer (1950). The magnetic field of the Galaxy was studied using observational data of various types, such as interstellar polarization of starlight, Zeeman splitting of spectral lines of HI and different molecules in the radio range, data on Faraday rotation of extragalactic radio sources and pulsars. It is known that pulsars, for which numerous and diverse observational data were obtained, can be considered probes for studying the interstellar medium. In particular, data on dispersion measures (DM), which practically are known for all known pulsars, and about measures of Faraday rotation (RM) (more than 1300 pulsars) are very important for studying the magnetic field of the Galaxy. These data are directly derived from observations of pulsars. Theoretically they are expressed by the electron density ne in the interstellar medium through which the polarized radio emission of the pulsar passes and the projection of the magnetic field B_L (in Gauss) in this medium, using the following formulas:

$$RM = d\psi/d(\lambda^2) = \alpha \int n_e B_L dL, (\alpha = 8.1 * 10^5), \quad (1)$$

$$t_2 - t_1 = (2\pi e^2/m) * (1/\omega_2^2 - 1/\omega_1^2) * DM, \quad (2)$$

$$DM = \int n_e dL, \quad (3)$$

where dψ – is the difference of plane of polarization in different wavelength λ.
t –is the time of receiving the radio signal from pulsar.
ω – is the frequency of radio wave.

In these formulas, integration is carried out over the entire traversed path L of radiation (in parsecs) from the pulsar to the observer. Formula 1 makes it possible to determine the distance of a pulsar with the

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known electron density distribution in the Galaxy, and formula 2 together with formula 1 makes possible to determine the average component of the tension of interstellar magnetic field $< B_l >$ on the line of sight in micro gauss (μG).

$$< B_l >= (1/\alpha) * RM/DM = 1.23 * RM/DM, \quad (4)$$

Rotayion measure and dispersion measure data were used to study the structure and magnitude of the magnetic field of the Galaxy, since the seventies of the last century, when the rotation measures were known for only 3-4 tens of pulsars Manchester (1974). As the amount of RM data increases, more detailed studies have been carried out and various models have been proposed for the plane component of the Galactic magnetic field, as well as for the magnetic field in the Halo of the Galaxy. In particular, in Andreasyan & Makarov (1988, 1989a,b), where the model of the two-component magnetic field of our Galaxy was proposed, for the first time it was shown that the data on the rotation measures of pulsars and extragalactic radio sources are in good agreement with the model when the magnetic field of the plane component of the spiral arms is imbedded in the magnetic field of the Galactic halo with the dipole configuration, which is deformed due to the differential rotation of Galaxy.

It should be noted that in works studying the plane component of Galactic magnetic field are discussed mainly three models: 1) a bisymmetric spiral (BSS), in which the magnetic field in neighbor spiral arms has opposite directions; 2) an axially symmetric (ASS) structure with two changes in the direction of the field inside the solar circle; 3) concentric circular model.

There are also works in which it is shown that none of these models correspond to observational data better than the other Noutsos et al. (2008). We begin more detail investigation of separate regoins of Galaxy.

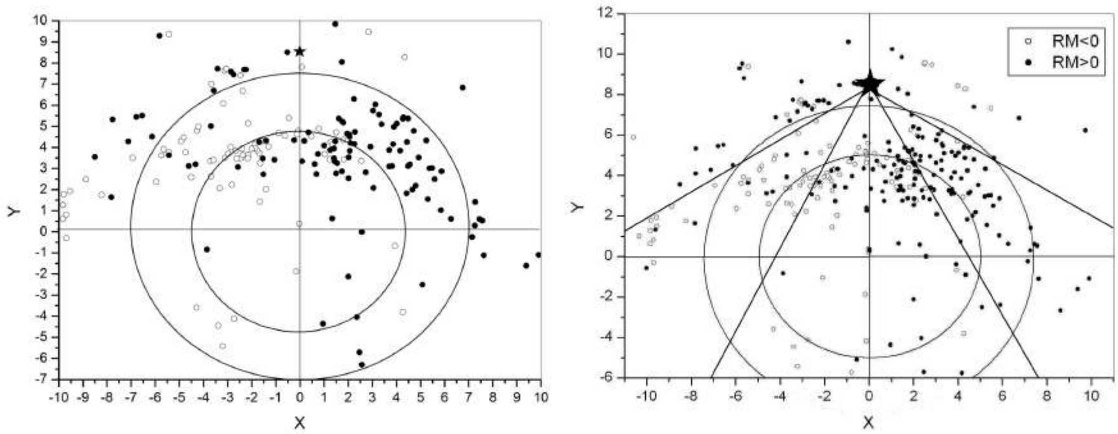

Figure 1. Distribution of rotation measures of pulsars in the plane of the Galaxy. (a) Black circles denote pulsars in which $RM > 300 rad/m^2$ (the projection of the magnetic field on the line of sight is directed toward the observer), white circles - in which $RM < -300 rad/m^2$; (b) The distribution of rotation measures of pulsars with $|RM| > 200 rad/m^2$

2. Sagittarius spiral arm region.

In Andreasyan et al. (2020) using pulsars rotation measure data was studied the magnetic field in the plane of Galaxy. It was shown, that distribution of signs of large ($| RM |> 200 rad/m^2$) rotation measures of pulsars are in good agreement with the concentric ring model with the anticlockwise direction of magnetic field in the galactocentric ring with radius $5\,kpc < R < 7\,kpc$ and reversal of direction at the radius 7 kpc (Fig.1a;b).

On the fig1b with black lines there are also divided two regions with about $40° < l < 70°$ and $290° < l < 320°$ (l-is Galactic longitude). In the first region, that includes the Sagittarius spiral arm we have mainly pulsars with $RM > 200 rad/m^2$, while in the second region there are mainly pulsars with $RM < -200 rad/m^2$. It is interesting, that this picture is greatly distorted when we ad pulsars with $|RM| < 200 rad/m^2$. The study of 3-dimensional distribution of rotation measure signs of pulsars may gave some explanation of this phenomenon.

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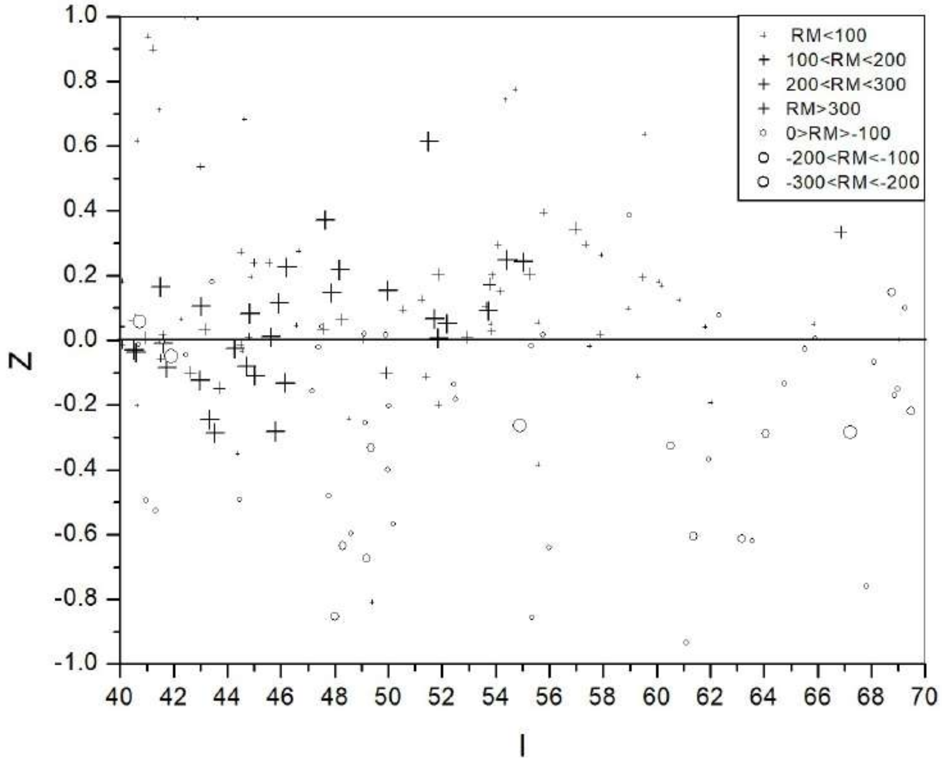

Figure 2. The distribution of RM for the pulsars in the region of galactic longitude $40° < l < 70°$. Z - is the distance of pulsar from the Galactic plane in kpc. The simbols "+" with different sizes indicate pulsars with positive sign and of RM, and the open circles – for the pulsars with negative sign of RM.

In this paper we study the magnetic field of first region more detail using the RM data of 180 pulsars. The data of pulsars were used for the study of Z dependence of rotation measure signs (Z is the distance of pulsar from the Galactic plane). In fig.2 we bring the distribution of RM signs for pulsars in the region with galactic longitude $40° < l < 70°$, which includes the Saggitarius spiral arm. The figure shows that in the Southern hemisphere of Galaxy (where $Z < 0$) the rotation measures are mostly negative, and in the Northern hemisphere they are mostly positive. Moreover, the magnitudes of positive rotation measures in the Northern hemisphere are much larger than the absolute magnitudes of negative rotation measures in the southern hemisphere, where $|RM| < 200 rad/m^2$. Three pulsars of Southern Hemisphere with $Z > 0.2$ kpc and positive RM has distances more than 10 kpc from the Sun, and are located outside of the Sagittarius arm (in the Perseus arm region). All of this can be easily explained if if we assume that Sagittarius' arm is located not symmetrically to the Galactic plane and is mostly located in the Northern hemisphere. The magnetic field of this spiral arm is directed toward the Sun. This direction coincides with the direction of the magnetic field of the Northern Hemisphere Halo Andreasyan & Makarov (1988). The negative rotation measures in the Southern hemisphere are mainly due to the magnetic field of Southern hemisphere halo which is directed opposite to the field of Northern Hemisphere halo and to the Sagittarius spiral arm field.

It must be mentioned that there is an assumption that pulsars are correlated with the spiral arms of the galaxy Kramer et al. (2003) and are born as a result of the evolution of O-stars, galactic distribution of which is well known Bronfman et al. (2000). These stars are highly concentrated in the galactic plane, and in particular O-B stars are distributed asymmetrically relative to the plane of the galaxy, which phenomena is known as the Gould Belt. (See, for example, Biazzo et al. (2012)). According to Gould belt plane of symmetry in the distribution of O-B stars is inclined relative to the plane of the galaxy, and in the direction of the galactic longitude $l = 0° - 180°$ O-B stars are distributed above the plane of the Galaxy (mainly located in the Northern hemisphere of Galaxy). Such an asymmetric distribution has also gas-dust component of the Galaxy Kulikovskij (1985). Above we have shown that the regular magnetic field in the Sagittarius spiral arm region in the direction of the Galactic longitude of about $40° - 70°$ is also distributed asymmetrically relative to the plane of the galaxy, or probably, spiral arm is located mainly in the Northern hemisphere of the Galaxy. This result fits very well into the picture of the Gould Belt phenomenon.

In fig.3 we bring the rotation measure distribution of pulsars in the abowe mentioned region, but in coordinates of the pulsar distance from the Sun (d) and the distance of pulsar from the Galactic plane.

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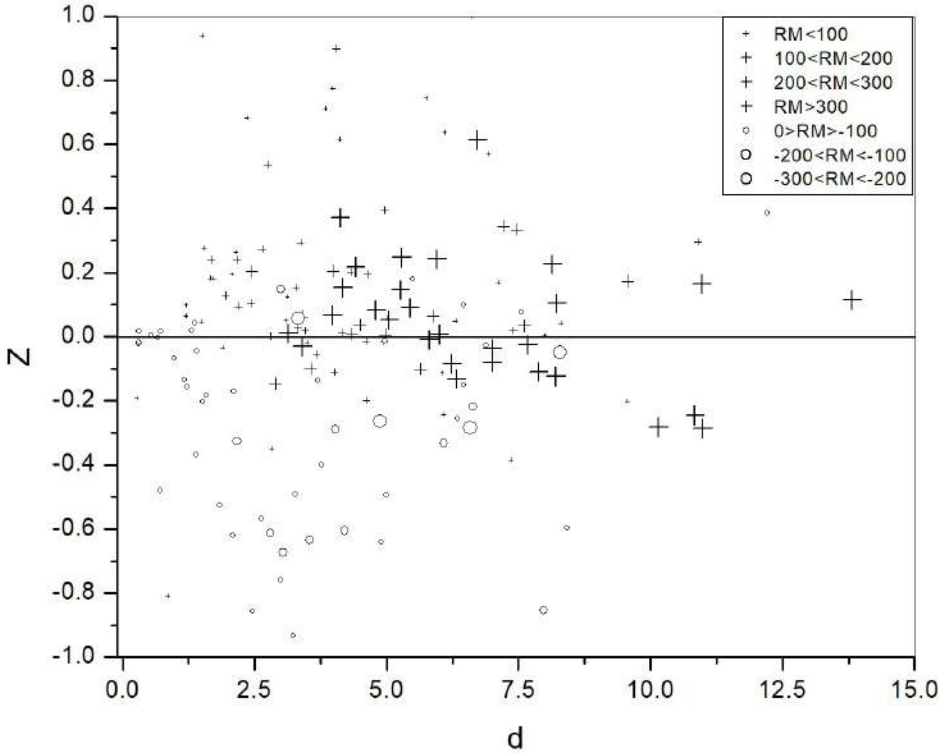

Figure 3. The distribution of RM for the pulsars in the region of galactic longitude 40°< l <70°. d - is the distance of pulsar from the Sun in kpc, and Z - is the distance of pulsar from the Galactic plane in kpc. The simbols "+" and open circles indicate the same as in the fig.2.

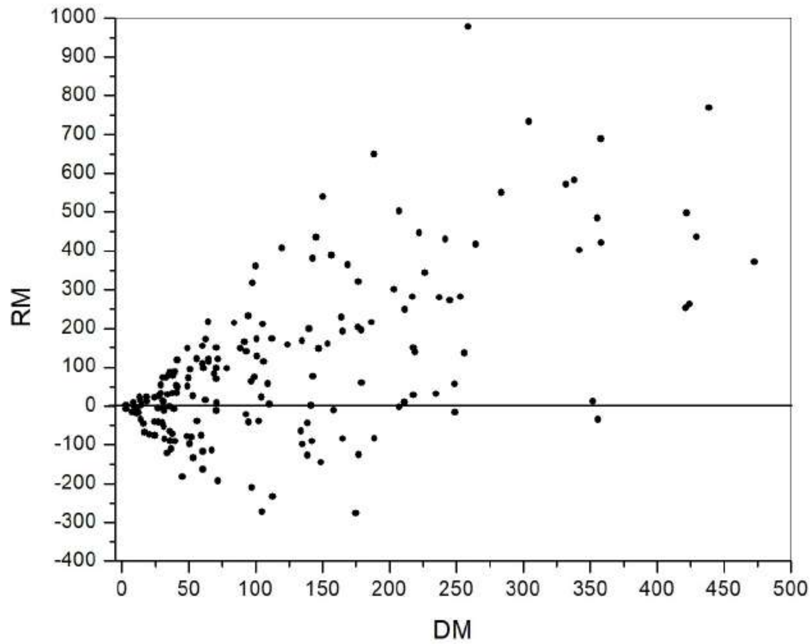

Figure 4. The distribution of pulsars of region 40°< l <70° in coordinates of rotation measures RM and dispersion measures DM.

From the fig.3 we see that, as in the fig.2, pulsars with positive sign of RM mainly are located in the northern hemisphere of Galaxy, and pulsars with negative sign of RM are located in the region southern of the plane of about $Z < -0.2$ kpc. Figure confirms the findings of the previous figure, that 3 pulsars with positive rotation measures and located at $Z < -0.2$ kpc are in the distances more than 10 kpc from the Sun. The negative rotation measures of some Northern hemisphere pulsars at a distance of about $d < 1$ kpc from the Sun are due to the influence of the magnetic field of local Orion arm and also of the interarm space Andreasyan & Makarov (1989a,b).

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In fig. 4 we bring the distribution of pulsars of this region in coordinates of rotation measures RM and dispersion measures DM. It can be seen from the figure that the magnitudes of positive rotation measures increase up to the values of $DM \sim 250 - 300$, while the absolute magnitudes of the negative values increase up to the value of $DM \sim 50$ that corresponds to the inter arm distance between the local Orion arm and Sagittarius spiral arm of Galaxy. As discussed above, some of these negative RM values can be due to the magnetic field of Orion's arm and interarm space that probably is the continuation of the magnetic field of Southern hemisphere halo.

Using the formulae 4 it was estimated the value of the strength of the average magnetic field in the Northern hemisphere that include the Sagittarius spiral arm region. It is $< B > \sim 2.5$ microGauss.

3. Conclusion.

Faraday rotation data of 180 pulsars are used in a detail study of the magnetic field in the direction of galactic longitude $40° < l < 70°$, that includes the Sagittarius spiral arm region. We propose that the region of regular magnetic field in the Sagittarius spiral arm at the direction of the Galactic longitude of about $40° - 70°$ is distributed asymmetrically relative to the plane of the galaxy, or probably, spiral arm is located mainly in the Northern hemisphere of the Galaxy, while the magnetic field with opposite direction below this plane is the field of the Halo of the Southern hemisphere of the Galaxy.

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