The Galaxy distribution of pulsars

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Abstract

We investigated the distribution of pulsars in our Galaxy. Special attention was paid to Galaxy distribution of millisecond pulsars. We study also the difference of physical properties of millisecond and normal pulsars as well as the differences in physical properties of millisecond pulsars in Globular clusters and these objects in the Galaxy field.

Keywords: *Pulsar, distribution of pulsars, millisecond pulsars*

1. Introduction

The study of the distribution of pulsars in the Galaxy is of great importance for understanding many aspects of their birth and evolution, such as: estimating the birth rate of pulsars, the distribution of the velocity obtained by a pulsar at its birth in the process of an asymmetric supernova explosion, etc., as well as for constructing a model of the Galaxy (Manchester & Taylor, 1980, Taylor & Cordes, 1993). At present, more than 3800 pulsars have been found, which are mainly concentrated near the plane of our Galaxy, and a small part is located in some Galactic globular clusters and in nearby extragalactic objects, such as the Magellan Clouds. Pulsar data are presented in the ATNF Pulsar Catalogue. This catalog contains both purely observational pulsar data such as period of pulsation P_0, the first-time derivative of period P_1, flux density in different wavelength, and data obtained using observational data and pulsar or Galaxy theoretical models (characteristic age, pulsar magnetic field, distances of pulsars etc.).

As noted above, in addition to the Galactic pulsars, the ATNF pulsar catalog also contains pulsars located in the Magellan Clouds. Since we will study the Galactic distribution of pulsars, all pulsars located outside our Galaxy were excluded from consideration. The main classification of pulsars is based on the pullsation periods P_0. Pulsars are divided into two groups: millisecond and normal pulsars. However, pulsars can also be divided by the wavelength range of radiation. These are X-ray pulsars (XRS), pulsars that also have gamma-ray radiation (GRS), optical radiation and pulsars that radiate only in radio wavelength.

2. The distribution of pulsation periods of pulsars

The distribution of millisecond pulsars in the Galaxy and their radiation mechanism differ greatly from the distribution and radiation mechanism of ordinary pulsars (e.g. Faucher-Giguère & Kaspi, 2006). In this paper, we study the Galactic distribution of different types of pulsars. In order to determine the pulsar period P_0 using which millisecond pulsars will be divided from the others, a distribution of the pulsars was constructed by the pulsation period.

Figure 1 shows the distribution of radio pulsars by period P_0. The $\lg(P_0)$ values are shown on the abscissa, and the number of pulsars is shown on the ordinate. It is clear from the figure that the graph actually shows two different groups of objects with different distributions that have their maxima at values of approximately $\lg(P_0)$ = -2.4, and $\lg(P_0)$ = -0.3. The minimum of the distribution between these groups falls approximately at the value $\lg(P_0)$ = -1.7, which corresponds to P_0 = 20 millisecond. This value of the P_0 period was chosen to divide the pulsars into two subtypes: if $P_0 < 20$ msec. - millisecond pulsars and if $P_0 \geq 20$ msec. - ordinary pulsars. Of course, the choice of the value $P_0 = 20$ msec to divide pulsars into two

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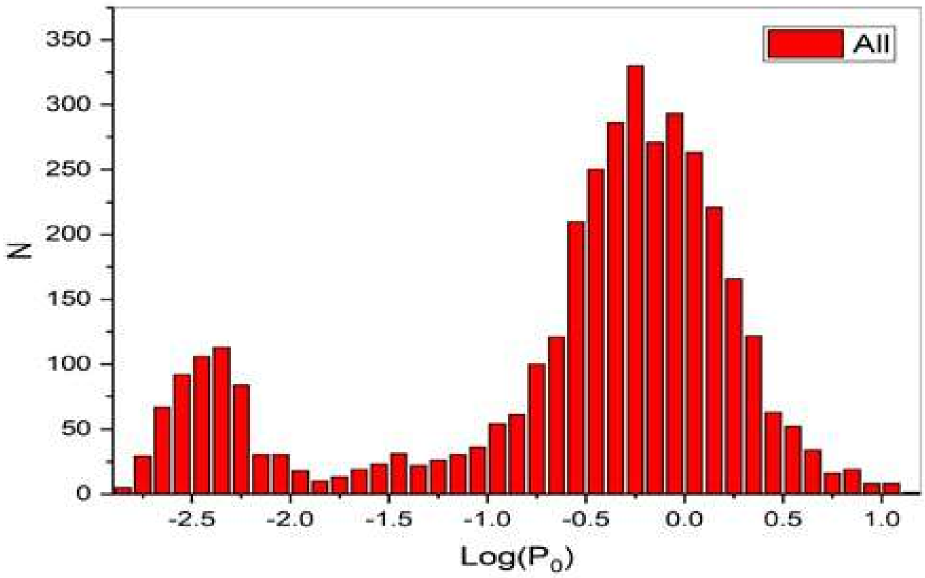

Figure 1. Distribution of pulsars by pulsation period

subtypes is somewhat arbitrary, but it is obvious that pulsars of these subtypes are completely different in their radiation mechanism and in their Galactic distribution (Faucher-Giguère & Kaspi, 2006).

In Fig.2 for comparison with each other we bring the distributions of pulsation period for the pulsars located in Galactic globular clusters (GC), for XRS and GRS pulsars.

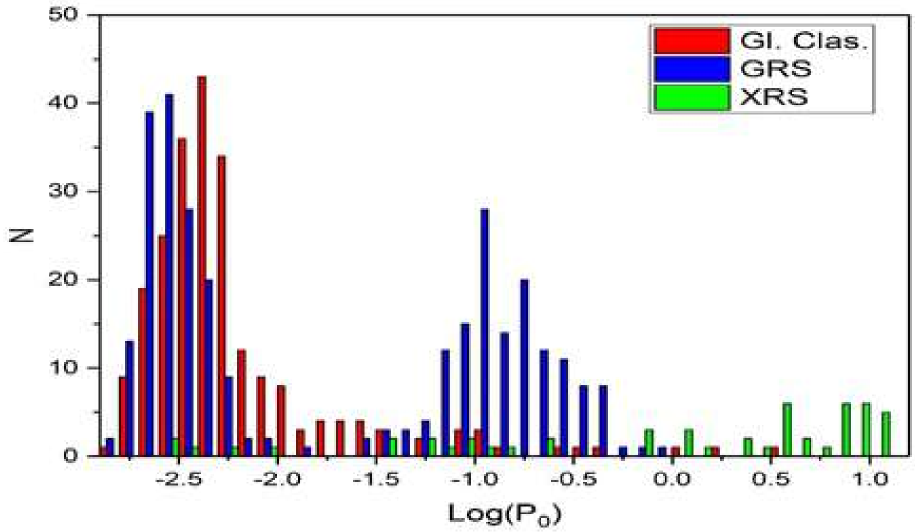

Figure 2. the distribution of periods of pulsation for different types of pulsars.

From Figure 2 we see large differences in the distribution of periods of pulsation for different types of pulsars. Pulsars located in Galactic globular clusters (GC) are mainly millisecond pulsars with the maximum of distribution $\lg(P_0)$ = -2.3. The Galaxy field pulsars that radiate also in gamma-ray (GRS pulsars) are divided into two groups. These are millisecond pulsars with the maximum of distribution $\lg(P_0)$ = -2.6 (less than for GC pulsars) and pulsars with relatively large periods. The maximum of distribution for these pulsars is $\lg(P_0)$ = -1.0 that is much less than for ordinary pulsars for which, as was said above $\lg(P_0)$ = -0.3. It should be noted that there are almost no pulsars among the GRS pulsars that have periods greater than this value. The XRS pulsars that are located in the Galaxy field mainly have large periods of pulsation (with periods of several seconds, $\lg(P_0)$ ¿0.0). Of course, there are XRS pulsars that are located in globular clusters (GC), or radiate also in the gamma-ray wavelength. For these XRS pulsars, the distribution corresponds to the distributions of GC and GRS pulsars.

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3. Distribution of normal radio pulsars relative to the plane of the Galaxy.

The study of the distribution of pulsars relative to the plane of the Galaxy is very important in many aspects: a) to find out what population the pulsars belong to, b) what stars are parent stars for pulsars, c) what spatial velocities pulsars receive at birth as a result of a supernova explosion, etc. There is an assumption that pulsars correlate well with the spiral arms of the Galaxy (Kramer et al., 2003) and are born as a result of the evolution of O-B stars, the Galactic distribution of which is well known (Bronfman et al., 2000). These stars are strongly concentrated near the plane of the Galaxy.

In Fig.3 we bring the distribution of Absolute values of distances from the Galactic plane.

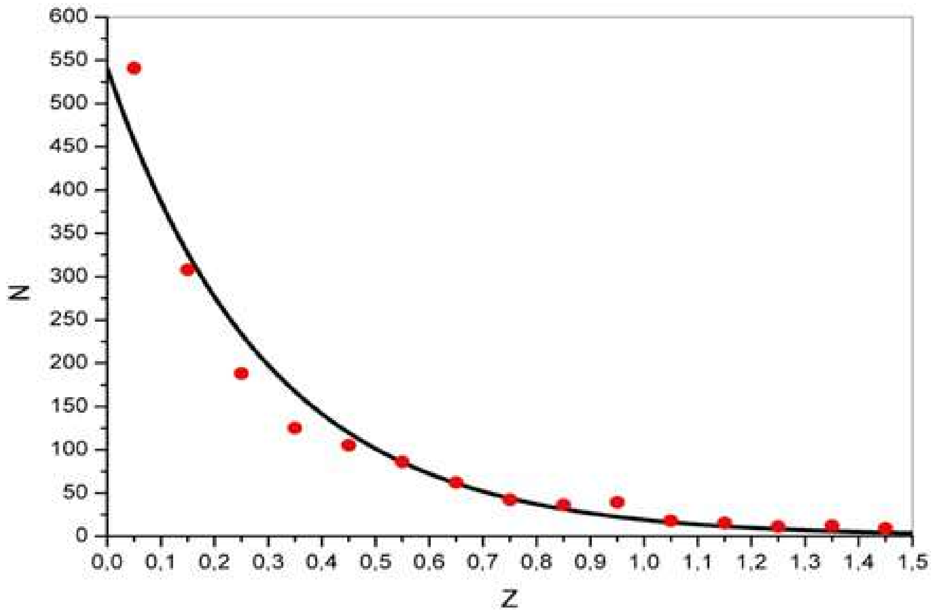

Figure 3. Distribution of absolute values of pulsar distances from the Galactic plane.

Fig. 3 shows an approximation of the distribution function N($|h|$) by the exponential function

$$N(|h|) = N_0 e^{-|h|/H}, \quad (1)$$

where N_0 is the number of pulsars in the Galactic plane, h is the distance from the Galactic plane and H is the characteristic distance. The normalized distribution function $\phi(|h|)$ has the form

$$\phi(|h|) = (1/H)e^{-|h|/H}, \quad (2)$$

from which it follows that the characteristic distance H can be defined as the average value of the absolute values of the pulsar distances $< |h| >$ from the Galactic plane.

$$H =< |h| >, \quad (3)$$

The characteristic distance value H=0.451 kpc for normal pulsars with $|h| < 1.5$ kpc and with ages less than 100 milion years. Since it is accepted that pulsars are born near the plane of the Galaxy and move away from it due to the speed obtained as a result of a supernova explosion, the characteristic distance from the plane of the Galaxy should increase as the age of the pulsar increases. The ATNF pulsar catalog contains values of the characteristic age τ of pulsars, which is determined from observational data using the formula

$$\tau = P_0/(2P_1), \quad (4)$$

Table 1 presents the values of the characteristic distances H (in parsecs) from the Galactic plane for different age groups of pulsars (in years), obtained by formula (3).

The table clearly shows that the characteristic distances H increase with the age of the pulsars. This corresponds to the generally accepted assumption that pulsars are born near the Galactic plane and propagate in the Galaxy with the velocities obtained during the outburst of the parent supernova. The obtained result can be used to study the distribution of these velocities (e.g. Arshakyan, 1994, Huang et al., 1985).

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Table 1.

	$\tau < 10^6$	$10^6 < \tau < 10^7$	$10^7 < \tau < 10^8$
H	182	395	580
N	340	665	675

4. Distribution of pulsars in the plane of the Galaxy

In many works (e.g. Yusifov & Küçük, 2004) it was shown that in the central part of the Galaxy the density of pulsars is much less than in the ring with the diameter $R \approx 3-4$ kpc from the center of the Galaxy (R is the Galactocentric distance), where the density reaches its maximum. At Galactocentric distances greater than 4 kpc the density of pulsars decreases and at the distances of the Sun $R_0 = 8.5$ kpc it is approximately equal to the central density. It should be noted that at distances $R \approx 3-4$ kpc from the center of the Galaxy the electron density ne also reaches its maximum in the model used by Taylor and Cordes to determine the distances of pulsars (Cordes, 2004, Taylor & Cordes, 1993). In this section the distribution of pulsars relative to the center of the Galaxy will be studied using more numerous data and a different processing method than in previous works. Data from normal pulsars located near the plane of the Galaxy in the layer -1.5 kpc $\leq$ h $\leq$ +1.5 kpc were used. Using data on the distances of pulsars di from the Sun, the Galactocentric distances R_i were determined by the formula

$$R_i = [R_0^2 + d_i0^2 – R_0 d_{i0} Cos(l_i)]^{1/2}, \quad (5)$$

where $d_{i0} = d_i$ $\text{Sin}(b_i)$ is designated. d_{i0} is the projection of the distance of a given pulsar onto the plane of the Galaxy, (l_i, b_i) are the Galactic coordinates of pulsars. We will study the dependence of the pulsar density on the Galactocentric distance in the direction of the center of the Galaxy. In the plane of the Galaxy, regions were identified in which pulsars had approximately the same distances from the center of the Galaxy. Then, from each region, those pulsars that were approximately equally distant from the Sun were selected.

The number of pulsars in these regions, the area of the region, and the density of pulsars in each region were calculated. Data on these regions are given in Table 2, where the first line shows the distance of the region from the center of the Galaxy, the second line shows the number of pulsars in the region, the third line shows the area of the region in kpc^2, and the fourth line shows the average density of pulsars.

Table 2.

R	1	2	3	4	5	6	7	8	9	10	11	12	13
N	35	52	120	127	80	56	50	37	45	20	15	20	10
S	1.53	2.25	2.63	2.82	2.86	2.74	2.47	1.95	3.14	2.17	3.10	3.91	4.68
Q	22.9	23.1	45.6	45.0	28.0	20.4	20.2	19.0	14.3	9.2	4.8	5.1	2.1

Using the results of this calculation was constructed the distribution of the observed density of pulsars as a function of distance from the center of the Galaxy. Then using the luminosity function of nearby pulsars was constructed the true distribution of pulsars from the center of the Galaxy. As a result, it was confirmed that the early obtained result that the maximum of the pulsar density distribution occurs at a distance of approximately 4 kpc from the center of the Galaxy.

5. Conclusion

In conclusion, we note that the following results were obtained in this work.

There are large differences in the distribution of periods of pulsation for different types of pulsars. Pulsars located in Galactic globular clusters (GC) are mainly millisecond pulsars with the maximum of distribution lg(P_0) = -2.3. The Galaxy field pulsars that radiate also in gamma rays (GRS pulsars) are divided into two groups, the millisecond pulsars with the maximum of distribution lg(P_0) = -2.6 (less than for GC pulsars), and pulsars with relatively large periods. The maximum of distribution for these pulsars is lg(P_0) = -1.0 that is much less than for ordinary pulsars for which the maximum is near to lg(P_0) = -0.3. The XRS pulsars that are located in the Galaxy field mainly have large periods of pulsation (with periods of several seconds, lg(P_0) $>$ 0.0).

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The characteristic distances H of the pulsars from the plane of Galaxy increase with the age of the pulsars. This corresponds to the generally accepted assumption that pulsars are born near the Galactic plane and propagate in the Galaxy with the velocities obtained during the outburst of the parent supernova.

In the central part of the Galaxy the density of pulsars is less than in the ring with diameter R=4 kpc from the center of the Galaxy where the density reaches its maximum. At Galactocentric distances greater than 4 kpc the density of pulsars decreases and at the distances of the Sun $R_0 = 8.5$ kpc it is approximately equal to the central density.

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