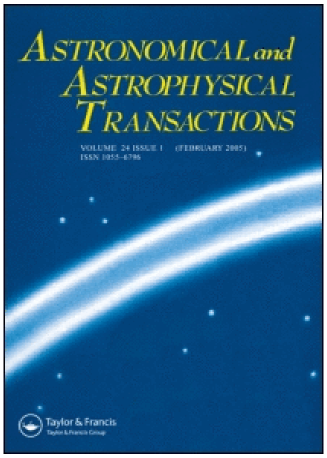

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Distribution of turbulent plasma in the galaxy

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It is shown that the level of plasma turbulence strongly depends on a direction in the Galaxy. It is obtained that there are nearly three orders of magnitude larger in the directions of the central portions of the Galaxy at low latitudes IbI < 2° and longitudes IlI < 60°, than at latitudes IbI > 10°. In the galactic arms the highest values of level of turbulence are near supernova remnants located in the regions with large electron densities. We show that the typical radius of the strong turbulence region around supernova remnants is ≅ 35 pc. Within this region the level of plasma turbulence is approximately 10 times larger, than on its edges. It is concluded that presence of supernova explosions in the medium with large density is necessary for existence of strong turbulence in interstellar plasma.

Keywords: Interstellar medium; Pulsars; Supernova remnants

1. Introduction

Pynzar' and Shishov [1] suggested the use of the ratio $\tau/(\mathrm{DM}^2)$ as a parameter describing interstellar turbulent plasma, where τ is the pulsar pulse broadening time due to interstellar scattering and DM is a dispersion measure. The parameter $\tau/(\mathrm{DM})^2$ characterizes a relative level of the turbulent fluctuations:

$$\tau/(\mathrm{DM})^2 \propto \langle \Delta \mathrm{N_e^2} \rangle / \langle \mathrm{N_e} \rangle^2, \quad (1)$$

where $\langle \Delta \mathrm{N_e^2} \rangle$ is a mean square of the electron density fluctuation and $\langle \mathrm{N_e} \rangle^2$ is the square of the mean value of the electron density in the direction of the pulsar. Using parameter $\tau/(\mathrm{DM})^2$ we investigate the relative level of turbulence of interstellar plasma in the different directions in the Galaxy.

2. Dependeces of the parameter $\tau/(\mathrm{DM})^2$ on dispersion measure, pulsar ages and angular distance between pulsar and nearest supernova remnant

In this work we used the data on the pulse broadening time τ at frequency 1 GHz, dispersion DM, pulsar ages t, pulsar galactic coordinates (l and b) taken from pulsar catalog [2] and

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galactic coordinates of supernova remnants taken from Green's catalog [3]. The data on τ are also taken from papers [4, 5]. For 89 pulsars we have defined values of τ using pulsar pulse profiles measured at 1374, 1396 and 1400 MHz published in papers [6–9]. Using the power low $\tau \propto \nu^{-4}$ obtained in paper [5], we scaled all values of τ to a frequency $\nu = 1$ GHz.

Figure 1 shows the parameter $\tau/(\mathrm{DM})^2$ as a function of dispersion measure DM. The data for pulsars located in various directions in the Galaxy are denoted by different symbols. We see, that values of the parameter $\tau/(\mathrm{DM})^2$ for DM $< 50\,\mathrm{pc/cm}^{-3}$ do not depend on DM. This data corresponds to pulsars with galactic latitudes IbI $> 10°$ and all longitudes (open and filled squares), to pulsars with latitudes $2 <$ IbI $\leq 10°$ and longitudes l = 55°–280° (filled triangles), to some pulsars with latitudes $2° <$ IbI $\leq 10°$ and longitudes l = 280°-55° (open triangles) and to a few pulsars located near the galactic plane between arms and in the anti-centre (open and filled circles). For DM $> 50\,\mathrm{pc/cm}^{-3}$

$$\tau/(\mathrm{DM})^2 \propto (\mathrm{DM})^{2.5}, \tag{2}$$

This data corresponds to pulsars located in the directions of the central regions of the Galaxy at low latitudes IbI $\leq 10°$ and longitudes l = 280°–0°–55° (open circles, open stars and open triangles) and to some pulsars located in the directions l = 55°–280° and IbI $\leq 10°$ (filled circles, filled triangles and filled stars). With decrease of latitude IbI $\leq 2°$ (filled circles, open circles and open stars) values of parameter $\tau/(\mathrm{DM})^2$ increase very strong, especially for pulsars, located in the directions of central regions of the Galaxy (open circles and open stars).

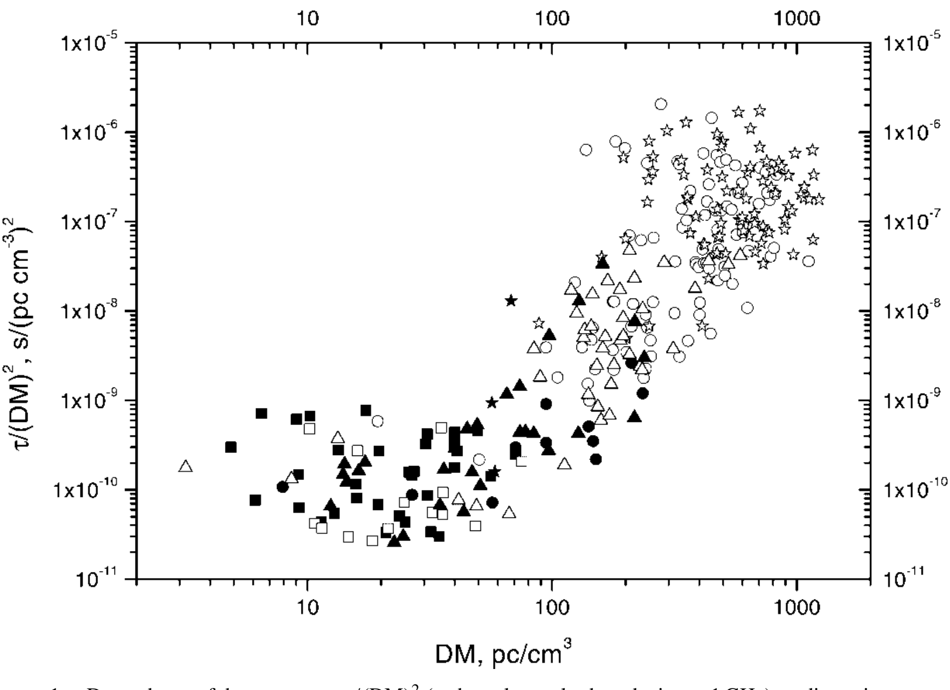

Figure 1. Dependence of the parameter $\tau/(\mathrm{DM})^2$ (τ-the pulsar pulse broadening at 1 GHz) on dispersion measure DM. Filled symbols correspond to pulsars located in the directions of longitudes l = 55°–280°, open symbols to pulsars with longitudes l = 280°–0°–55°. Squares correspond to pulsars at latitudes IbI $> 10°$, triangles to pulsars at latitudes $2° <$ IbI $\leq 10°$, circles to pulsars at IbI $\leq 2°$ and stars to pulsars located from nearest supernova remnants at angular distances $\varphi \leq 0.6°$.

We see that the data in figure 1 for pulsars located in the directions of the nearest vicinities of the supernova remnants (open stars) are mainly at the top of this dependence. It indicates that there is a high level of turbulence near the supernova remnants. This is consistent with the statement of Pynzar' and Shishov [10, 11] about existence of a ionized gas regions around supernova remnants (fossil Stromgren zones).

Figure 2 shows the parameter $\tau/(\mathrm{DM})^2$ as a function of an angular distance between pulsar and nearest supernova remnant φ. It is seen, that lower boundary of this dependence is located highly at small values φ, then it sharply falls down at $\varphi \cong 0.35°$ and in the future smoothly falls with increase φ. We suggest, that this value of φ corresponds to average angular radius of Stromgren zone of supernova remnant. The level of plasma turbulence is approximately 10 times greater within of this region, than on edge of it and 30 times greater, than at an angular distance of 1° from its centre (figure 2).

The age of pulsar should be proportional to its linear distance to supernova remnant, if pulsar and supernova remnant were born in the same supernova explosion. In this connection, it is interesting to consider dependence of the parameter $\tau/(\mathrm{DM})^2$ on the pulsar ages. This dependence is shown in figure 3.

It is seen, that the lower boundary of this dependence is located highly at small values t, then it sharply falls down at $t \cong 1.2 \cdot 10^5$ years and in the further it remains approximately at a constant level with increase t. We think, that this value t corresponds to average time of an exit of a pulsar from a Stromgren zone surrounding the supernova remnant. The level of plasma turbulence is approximately one order of magnitude larger for pulsars with ages $t \leq 2 \cdot 10^5$ years (filled circles in figure 3), than for more old pulsars (open circles).

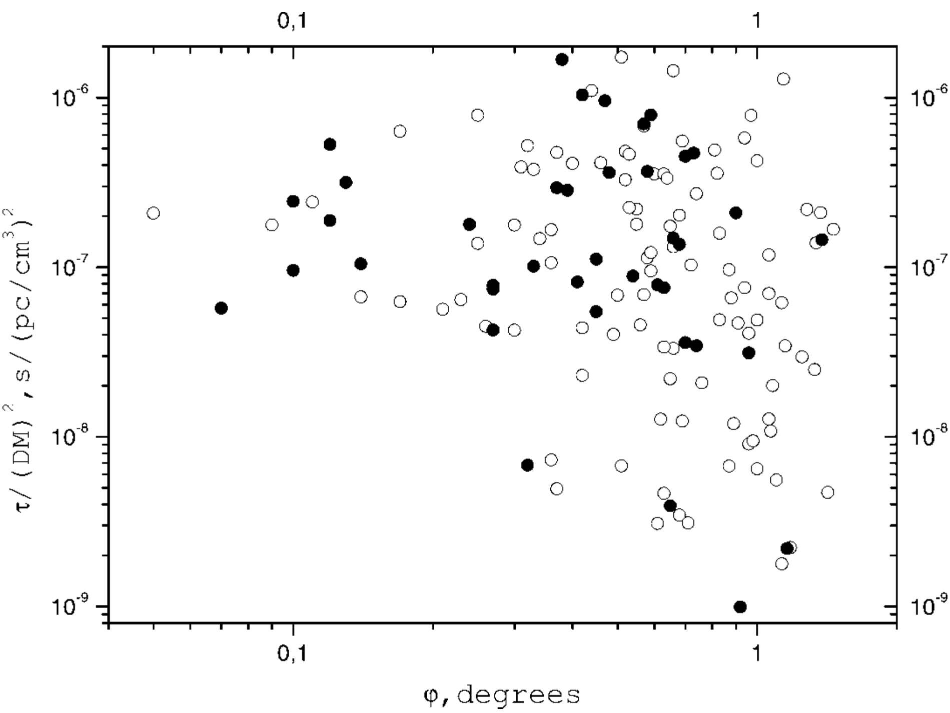

Figure 2. Dependence of the parameter $\tau/(\mathrm{DM})^2$ on angular distance between pulsar and nearest supernova remnant φ. The data correspond to pulsars located in directions of longitudes $l = 280°–0°–55°$ and of latitudes $|b| \leq 2°$. Filled circles correspond to pulsars with ages $t \leq 2 \cdot 10^5$ years and open circles to pulsars with $t > 2 \cdot 10^5$ years.

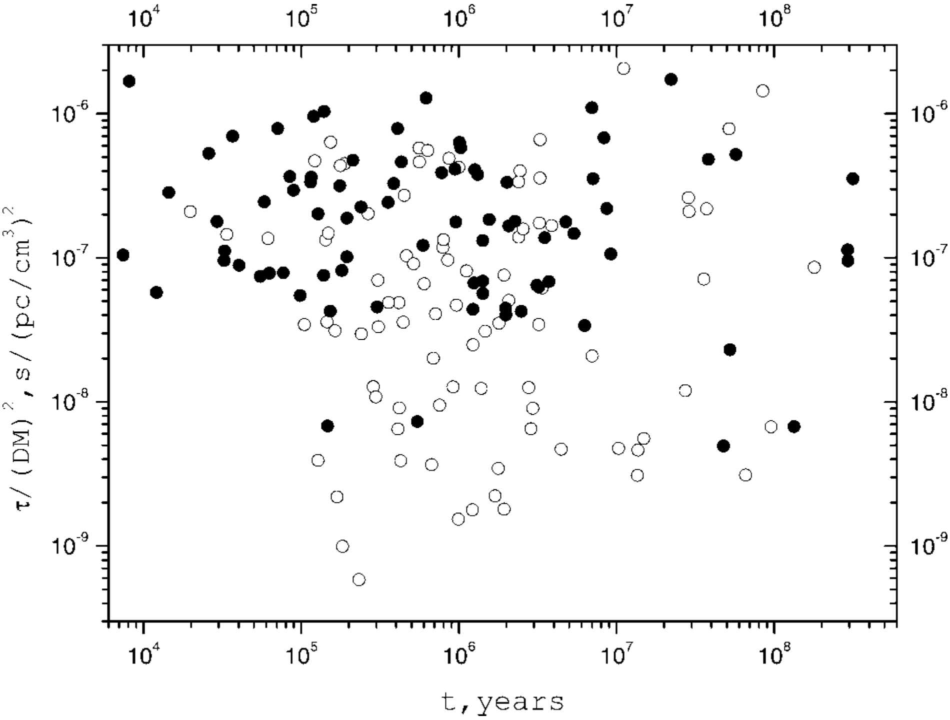

Figure 3. Dependence of the parameter $\tau/(\mathrm{DM})^2$ on ages of pulsars t. The data correspond to pulsars located in directions of longitudes l = 280°–0°–55° and of latitudes IbI ≤ 2°. Filled circles correspond to pulsars located at angular distances from nearest supernova remnants $\varphi \leq 0.6°$, open circles to pulsars at $\varphi > 0.6°$.

3. Discussion and conclusion

As we can see in figure 3 there is a striking concentration of pulsars nearest to supernova remnants (filled circles) to a small values of ages ($t < 2 \cdot 10^5$ years) and to high values of parameter $\tau/(\mathrm{DM})^2$. It means that these pulsars are located within Stromgren zones, surrounding supernova remnants. However, we also see many old pulsars near supernova remnants (open circles in figure 2 and filled circles in figure 3). We think that these pulsars have very small velocities therefore they remain within the Stromgren zone for a long time. It is also possible, that some of these old pulsars are seen in projection against supernova remnants. Using dependences $\tau/(\mathrm{DM})^2$ on φ and t (figures 2 and 3), we can estimate sizes of Stromgren zones around of the supernova remnants. With the median value of the distance to the supernova remnants of ≅6 kpc[3] and $\varphi \cong 0.35°$ (figure 2) we obtain for average radius of Stromgren zone of supernova remnant $R \cong 35$ pc. Using average value of velocity for a pulsars of 300 km/s [12] and $t \cong 1.2 \cdot 10^5$ years we obtain $R \cong 36$ pc. Pynzar' and Shishov [10, 11] have received $R = 30$ pc absolutely other method. We see, that three completely different methods give close results.

From the above results the following picture of distribution of turbulent plasma in the Galaxy appears. Outside of the Galaxy arms (at high galactic latitudes and in a plane of the Galaxy between arms and in anti-centre) the level of plasma turbulence is very low and it does not depend on DM and galactic coordinates. In the galactic arms the level of plasma turbulence is 2–3 orders of magnitude larger, than outside of arms (figure 1) and it increases with increase DM as $(\mathrm{DM})^{2.5}$. In the galactic arms there are regions of strong and moderate turbulence. The strong turbulence exists around the type II supernova remnants (within Stromgren zone of supernova). Inside of these regions the level of plasma turbulence is approximately one order larger, than outside of them. However in the directions of latitudes IbI $> 2°$ for all the longitudes and even in the galactic plane towards the anti-centre of the Galaxy, where electron density is low, the level of plasma turbulence is also low even near supernova remnants (figure 1 filled stars). Thus, we come to the conclusion that the presence of supernovae explosions and the medium with large electron densities is necessary for the existence of a high level of turbulence in the interstellar plasma.

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