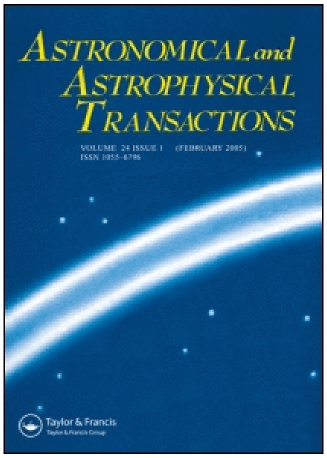

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EFFECTS OF THE BACKGROUND RADIATION ON RADIO PULSAR AND SUPERNOVA REMNANT SEARCHES AND THE BIRTH RATES OF THESE OBJECTS

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In different directions of the Galaxy the Galactic background radio radiation and radiation of star formation regions which include a large number of OB associations have different influences on radio pulsar (PSR) and supernova remnant (SNR) searches. In this work we analyse the effects of these background radiations on the observations of PSRs at 1400 MHz and SNRs at 1000 MHz. In the interval $l = 0 \pm 60°$ the PSRs with flux $F_{1400} > 0.2$ mJy and the SNRs with surface brightness $\Sigma > 10^{-21}$ W m^{-2} Hz^{-1} sr^{-1} are observable for all values of l and b up to distances of 6–7 kpc. All the SNRs with $\Sigma > 3 \times 10^{-22}$ Wm^{-2} Hz^{-1} sr^{-1} can be observed in the interval $60° < l < 300°$. We have examined samples of PSRs and SNRs to estimate the birth rates of these objects in the region up to 3.2 kpc from the Sun and also in the Galaxy. The birth rate of PSRs is about 1 in 125–200 years and the birth rate of SNRs is about 1 in 65 years in our galaxy.

KEYWORDS: radio background, radio pulsar, supernova remnant, star formation region

1 INTRODUCTION

According to Lorimer *et al.* (1993), radio pulsars (PSRs) are formed once every 125–250 years in the Galaxy and the lower limit for the mass of the stars which form PSRs at the end of their evolution is about (6–8)$M_\odot$. By examining the historical supernova remnants (SNRs), Strom (1994) found that a supernova explosion occurs every 13–25 years in the Galaxy and the lower limit for the mass of the progenitors of these SNRs is about $5M_\odot$. There is a large difference between the birth rate of PSRs given by Lorimer *et al.* (1993) and the formation rate of supernovae given by Strom (1994). Assuming the lower limit for the mass of the progenitors, which end their evolution with supernova explosion, to be $5M_\odot$ or $8M_\odot$ leads to a difference of a factor of 3 in the rate of supernovae, if we use the initial mass function (IMF) of Blaha and Humphreys (1989). Even for different galaxies and star formation regions (SFRs) we can use a simple IMF with a power about 2.3–3 (Schaerer, 2003). Does the formation of PSRs

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predominantly depend on some other parameters because the lower limit for the progenitor mass are close to each other in these two cases?

It is known that in Sb-type galaxies the average rate of supernova explosion is about 1–2 in 100 years. The supernova rate in our Galaxy must be a similar value as our galaxy also is Sb type (van den Bergh and Tammann, 1991). Recent statistical investigations of average supernova rate in Sb-type galaxies show that the rate of supernova Ia is 0.4 ± 0.2 in 100 years and the rate of supernova II together with supernova Ib and supernova Ic is about 1.5 ± 1.0 per century in Sb-type galaxies and also in our galaxy (Capellaro *et al.*, 1999; Capellaro and Turatto, 2001). So, finding the birth rates of PSRs and SNRs is an actual and important problem in astrophysics. In this work, we shall examine and try to solve this problem.

2 EFFECTS OF THE BACKGROUND RADIATION ON SUPERNOVA REMNANT AND PULSAR SEARCHES

It is known that the background radio radiation increases when the line of sight becomes closer to the Galactic centre direction and the Galactic plane. Distribution of the temperature which characterizes the background radiation at 400 MHz is known (Haslam *et al.*, 1982; Sunyaev, 1986). When we compare the intensity (temperature) of the background radiation with the structure of the Galactic arms (Georgelin and Georgelin, 1976; Paladini *et al.*, 2003), the effect of giant H II regions located in SFRs is seen.

In the last 7–8 years, the Galactic plane (especially the southern hemisphere) and particularly the Galactic central directions were observed at 1400 MHz and a large number of new PSRs were found (Australia Telescope National Facility, 2003). As a result of these searches, today the number of known PSRs with measured 1400 MHz flux is larger than the number of known PSRs with measured 400 MHz flux.

Below, we shall discuss the effect of the background radiation and the effects of different SFRs (which include many O-type stars, OB associations and young open clusters) on the PSR search at 1400 MHz and on the SNR search at 1000 MHz. It should be noted that the searches for PSRs at 400 MHz have a high sensitivity only in the Arecibo window ($40° < l < 65°$; $|b| \leqslant 2.5°$ (Hulse and Taylor, 1975)). It is necessary to note that the possibility of observing far-away PSRs in the Galactic central directions also depends on the pulse period, the dispersion measure and the frequency.

We have examined the SNRs with observed surface brightness which have various different values of l and b. SNRs G3.8 + 0.3 and G354.8 − 0.8 are the dimmest among the SNRs which are the closest to the Galactic centre direction (in the range $l = 0 \pm 10°$ and $|b| < 2°$). The Σ values of these two SNRs are $1.86 \times 10^{-21}\,\mathrm{Wm^{-2}\,Hz^{-1}sr^{-1}}$ and $1.17 \times 10^{-21}\,\mathrm{Wm^{-2}\,Hz^{-1}sr^{-1}}$ respectively. The SNRs G6.4 + 4.0 and G358.0 + 3.8 (which have slightly larger $|b|$ values) have considerably small Σ values of $2.04 \times 10^{-22}\,\mathrm{Wm^{-2}\,Hz^{-1}\,sr^{-1}}$ and $1.56 \times 10^{-22}\,\mathrm{Wm^{-2}\,Hz^{-1}\,sr^{-1}}$ respectively. Observational data of SNRs show that it is possible to observe such low-Σ SNRs with $60° < l < 300°$ (*i.e.* far away from the Galactic centre) and even with $|b| < 2°$. Among the observed SNRs, only two of them, G156.2 + 5.7 and G182.4 + 4.3, have $\Sigma < 10^{-22}\,\mathrm{Wm^{-2}\,Hz^{-1}\,sr^{-1}}$ (Green, 2004). The distribution of the SNRs in different longitude intervals with respect to Σ show that the longitude interval which is the most affected by the background radiation is $l = 0 \pm 40°$. So, the effect of the background radiation on the SNR search in the Galactic anticentre and central directions except $l \approx 0 \pm 40°$ can surely be neglected for the SNRs with $\Sigma \geqslant 3 \times 10^{-22}\,\mathrm{Wm^{-2}\,Hz^{-1}\,sr^{-1}}$. On the other hand, only about 20% of all the SNRs given by Green (2004) have $\Sigma < 10^{-21}\,\mathrm{Wm^{-2}\,Hz^{-1}\,sr^{-1}}$. For the SNRs in the anticentre directions, even if the Σ values are small, the flux values ($F \sim \Sigma \times \theta^2$, where θ is the angular size of the SNR) can be larger compared with the flux values of the SNRs in the Galactic central directions in most of the cases, because the SNRs in the anticentre directions have, in general, smaller distances and larger angular sizes.

Among the known PSRs (Australia Telescope National Facility, 2003) in the interval $l = 0 \pm 10°$ and $|b| < 2°$, PSR J1728-3733 ($l = 350°.8$; $b = -1°.66$) has the lowest flux at 1400 MHz: $F_{1400} = 0.19$ mJy. Other low-flux PSRs are PSR J1804-2228 ($l = 7°.72$, $b = -0°.4$) with $F_{1400} = 0.2$ mJy and both PSR 1736-3511 ($l = 353°.6$, $b = -1°.6$) and PSR J1751-2516 ($l = 3°.85$, $b = 0°.69$) with $F_{1400} = 0.22$ mJy. So, the background radiation practically cannot hide PSRs in the surveys of approximately the last 10 years if $F_{1400} > 0.2$ mJy (similar to the case of SNRs with $\Sigma > 10^{-21}$ Wm^{-2} Hz^{-1} sr^{-1}).

The $|z|$–l diagram of the PSRs with $|l| < 70°$, $|b| < 2°$, dispersion measure (DM) less than 800 pc cm^{-3} and $F_{1400} < 0.5$ mJy is represented in Figure 1. Since the electron density strongly depends on the longitude value, as the direction becomes far away from the Galactic centre direction the PSRs (in such directions), which have the same DM value as the PSRs in the Galactic centre direction, are located at larger distances. This leads to the possibility that the $|z|$ values the larger for the same $|b|$ values. For the same DM value of two different PSRs, the smaller distance value belongs to the PSR that is closer to the Galactic centre direction. As seen from Figure 1, although the distances of the PSRs in the interval $l = 0 \pm 20°$ are somewhat less, the average $|z|$ value is larger and this shows that the average $|b|$ value of these PSRs is larger. This is also a result of the effect of the background radiation.

The background radiation is strong (*i.e.* has peaks in the distribution of the background temperature with respect to the Galactic longitude) in the regions $l \approx 10$–$30°$ and $l \approx 330$–$340°$, because the number of H II regions in these intervals is large (Haslam *et al.*, 1982; Sunyaev, 1986; Georgelin and Georgelin, 1976; Paladini *et al.*, 2003). Since this is related to the fact that the number of massive stars is large in these intervals, here the formation rates of SNRs and PSRs must also be high. In general, this statement is true, but it is necessary to take into

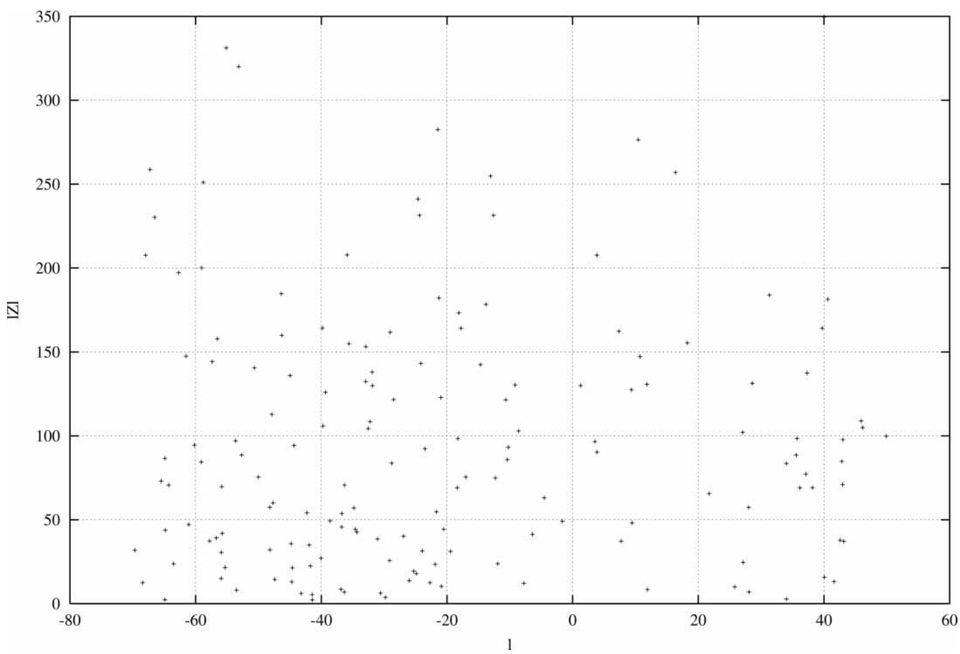

Figure 1. **$|z|$ Versus longitude diagram of PSRs with $|b| < 2°$, $F_{1400} < 0.5$ mJy, $-70° < l < 55°$ and a DM of less than 800 pc cm^{-3}.**

consideration that the SNR search in the Galaxy has been made with roughly the same sensitivity (*i.e.* the sensitivities of the telescopes are comparable) but not necessarily with the same precision in all directions (*i.e.* some parts of the Galaxy have been searched more precisely than other parts).

In order that the probabilities of observing the PSRs with roughly the same flux values and the SNRs with roughly the same Σ values are approximately the same for the whole Galactic plane and in order not to reduce the number of objects in the samples too much, we have considered only the PSRs with $F_{1400} \geqslant 0.2$ mJy and the SNRs with Σ (at 1 GHz) $\geqslant 10^{-21}$ Wm^{-2} Hz^{-1} sr^{-1}.

3 DISCUSSION AND CONCLUSIONS

Observational data on PSRs (Australia Telescope National Facility, 2003; Guseinov *et al.*, 2004) and SNRs (Green, 2004) show that even in the Galactic central directions ($l = 0 \pm 10°$, $|b| < 2°$) all the SNRs with $\Sigma > 10^{-21}$ Wm^{-2} Hz^{-1} sr^{-1} and the PSRs with $F_{1400} > 0.2$ mJy are observable up to distances of 6–7 kpc. The background radiation is strongly dependent on the Galactic latitude, but the SNRs with $\Sigma > 1.5 \times 10^{-22}$ Wm^{-2} Hz^{-1} sr^{-1} in the same longitude interval can be observed if $|b| > 4°$. The observational data also show that the SNRs in the interval $60° < l < 300°$ can easily be observed for all values of b if $\Sigma > 3 \times 10^{-22}$ Wm^{-2} Hz^{-1} sr^{-1}.

In the Galaxy, the total number of the observed SNRs with $\Sigma > 3 \times 10^{-22}$ Wm^{-2} Hz^{-1} sr^{-1} and $d < 3.2$ kpc in the interval $60° < l < 300°$ is 33 (Guseinov *et al.*, 2003a). It is seen from PSR–SNR associations that the ages of the SNRs which are genetically connected to PSRs do not exceed 3×10^4 years in general (Kaspi and Helfand, 2002). Since the SNRs in the regions that we examined have less surface brightness values on average, we can assume that the ages of these SNRs may exceed 3×10^4 years but are not greater than 5×10^4 years in general. There are 23 SNRs with $\Sigma > 10^{-21}$ Wm^{-2} Hz^{-1} sr^{-1} located at $d \leqslant 3.2$ kpc from the Sun, among which 14 of them are in the sector under consideration. If we assume that the ratio of the number of the SNRs with 3×10^{-22} Wm^{-2} Hz^{-1} sr^{-1} $< \Sigma \leqslant 10^{-21}$ Wm^{-2} Hz^{-1} sr^{-1} to the number of the bright SNRs in the central region ($l = 0 \pm 60°$) is approximately equal to the same ratio of the SNRs in the region $60° < l < 300°$, then we can use the ratio for the Galactic anticentre directions to find the number of dim SNRs in the Galactic central directions. In this case, the number of the SNRs with $\Sigma > 3 \times 10^{-22}$ Wm^{-2} Hz^{-1} sr^{-1} and ages of 5×10^4 years or less in the region up to 3.2 kpc from the Sun is 54. If we assume that the radius of the Galaxy is about 12 kpc and that the average number density of the SNRs in the whole Galaxy is the same as the number density of the SNRs within 3.2 kpc around the Sun, then the number of the SNRs having ages less than 5×10^4 years must be about 800 in the Galaxy. (Since the distribution of SNRs in the Galaxy is not homogeneous and the distribution of their number density with respect to Galactic radius is not known well, we cannot estimate the number of the SNRs considerably better than this.) From these data, the formation rate of SNRs turns out to be about one in 65 years which is approximately the same as the supernova explosion rate (van den Bergh and Tammann, 1991; Capellaro *et al.*, 1999; Capellaro and Turatto, 2001). We can use the same approach to estimate the birth rate of PSRs.

There are 48 PSRs with $\tau \leqslant 10^6$ years located at $d \leqslant 3.2$ kpc around the Sun (Guseinov *et al.*, 2004). If we assume that the distribution of the PSRs in the Galaxy is roughly similar to the distribution of the SNRs given above, then the number of PSRs with $\tau \leqslant 10^6$ years must be about 700 in the Galaxy. If we further assume the beaming fraction to be about 0.35 for the PSRs with $\tau \leqslant 10^6$ year (Lyne and Graham-Smith, 1998), then the number of the PSRs turns out to be about 2000. We can estimate the total number of PSRs knowing that about

75% of the PSRs around the Sun have $L_{1400} > 3$ mJy kpc^2 and using the luminosity function of Guseinov *et al.* (2003c): the number of PSRs with $\tau \leqslant 10^6$ years must be about 4.5×10^3 in the Galaxy. Using this result the birth rate of PSRs is found to be 1 in 220 years, but the PSRs with magnetic fields greater than 10^{13} G (about 20% of all PSRs) may enter the death belt and turn off in less than 10^6 years. Taking this fact also into account, the birth rate of PSRs can roughly be assumed to be one in 200 years. On the other hand, according to Tauris and Manchester (1998) the average value of the beaming fraction for PSRs with $\tau \leqslant 10^6$ years is about 0.22. In this case, the birth rate of PSRs must be about 1 in 125 years. Since the value of the beaming fraction is not known well, the birth rate of PSRs with $L_{1400} > 0.3$ mJy kpc^2 (*i.e.* almost all radio PSRs) is 1 in 125–200 years.

Our estimate of PSR birth rate is comparable with the birth rate estimate given by Lorimer *et al.* (1993). Strom (1994) has found the supernova explosion rate from the data of historical supernovae; this is a less reliable way, because the number of data is small and some of the data are not reliable. On the other hand, the rate of supernova in the Galaxy considering a region of about 3.5 kpc from the Sun was probably larger for the last 2000 years compared with the average supernova rate in the Galaxy. More reliable estimates of the birth rates have been given by van den Bergh and Tammann (1991), by Capellaro and Turatto (2001) and in this work.

The difference between the PSR birth rate and the supernova explosion rate can be explained by the formation of different types of neutron star, mainly dim isolated thermal neutron stars (Guseinov *et al.*, 2003b). If we used the luminosity function of Lorimer *et al.* (1993) or Allakhverdiev *et al.* (1997) instead of the luminosity function given by Guseinov *et al.* (2003c), then the birth rate of PSRs would be slightly larger.

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