The Lower Limit for Masses of Progenitors of Supernova Remnants and Radio Pulsars

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Abstract
We examined correlations between young radio pulsars (PSRs), Supernova remnants (SNRs) which have different surface brightness values and young star formation regions (SFRs). Angular correlation of PSRs with SFRs is reliable up to 4 kpc and considerably strong up to 3 kpc from the Sun. On average this correlation is stronger for Galactic anticenter directions compared to Galactic central directions. Angular correlation of SNRs with SFRs is weaker and depends on the surface brightness of the SNR. Spatial correlation of PSRs with SFRs is also stronger than spatial correlation of SNRs with SFRs. Dim SNRs show weak spatial correlation with SFRs. These investigations and analysis of various data show that the lower limit for masses of progenitors of PSRs is about 9 M_☉ and of SNRs (or supernovae) is about 7 M_☉.

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1 Introduction

Although the problem of masses of the progenitors (on the main sequence) of radio pulsars (PSRs) and Supernova remnants (SNRs) has been discussed for many years, there are still open questions. It is not well known under which circumstances a neutron star (NS) is born during a Supernova (SN) explosion. Actually, PSRs and in general NSs do exist in SNRs which are formed as a result of SN explosions with energies $10^{49}$-$10^{51}$ erg, in some cases even with energies $<10^{49}$ erg (e.g. Crab) and with energies $>10^{51}$ erg (e.g. Cas A). How can we determine the lower limit for masses of NS and PSR progenitors and masses of the stars for which the evolution ends with SN explosion (excluding the accretion induced collapse)?

It was claimed that PSRs are formed once every 150 years and the lower limit for masses of the stars which form PSRs at the end of their evolution is about $5 M_\odot$. On the other hand, by examining the historical SNRs it was claimed that a SN occurs every 6 years and the lower limit for the mass of the progenitors is also about $5 M_\odot$. Does the formation of PSRs predominantly depend on some other parameters as the lower limit for the progenitor mass is $5 M_\odot$ in both cases?

In principle, the lower limit for masses of the progenitors of the stars, which experience SN explosion and possibly form PSRs and in general NSs, may be equal to the higher limit for masses of the progenitors of single white dwarfs (WDs). According to a theoretical calculation, the higher limit for masses of the progenitors of WDs is about $7-8 M_\odot$. This higher limit was also given as $6-11 M_\odot$. Today, there is no observational data showing that mass of the progenitor of a WD can be $>6-7 M_\odot$; this result comes from the investigations of WDs in young open clusters (OCs). WD 0349+247, which has a mass of $\sim 1 M_\odot$ in the OC Pleiades, has a progenitor with a mass of $\sim 6 M_\odot$.

Now, lets briefly look at the perspective to find the higher mass limit for progenitors of WDs in OCs. For a star with $7 M_\odot$ the lifetime is $\sim 4 \times 10^7$ yrs, but the uncertainties in cooling times (i.e. ages) of WDs with high temperatures ($\sim 30000$ K) are greater than the lifetime of the progenitor (only such WDs are observable at large distances). If we take into account the distance of the young OC NGC 2168 (870 pc), we can see how difficult it is to find the upper limit for the mass from the observations of WDs in this and other distant OCs. One must add up the errors in determinations
of temperatures and masses of WDs with the errors in WD cooling models. So, it is more reliable, but not easier, to search for planetary nebulae and their stellar remnants in young OCs with turn-off masses $\sim 6-8 \, M_\odot^{12}$. By this way we get rid of the difficulties mentioned above. We can assume that the mass of the progenitor is equal to the turn-off mass for the stars in the OC, since the lifetime of planetary nebulae is very short ($\sim 10^4$-$10^5$ yrs).

Assuming the lower limit for the mass of progenitors of SN to be 5 or 8 $M_\odot$ leads to a difference of a factor of 3 in the formation rate of SNRs, if we use the initial mass function (IMF) of Blaha & Humphreys $^{13}$. In the Solar neighbourhood the uncertainty in the IMF up to $\sim 15$-$16 \, M_\odot$ is not large. Even for different galaxies and star formation regions (SFRs) we may use a simple IMF, similar to the one given by Salpeter $^{14}$, with a value of power about $2.3$–$3^{15}$.

The problem mentioned above is an actual one and it is essential to try to find reliable ways to understand the differences in the birth rates of SNR, PSR and NS. But there are some difficulties: there are significant uncertainties in the data because of taking large volumes and long time intervals into account in order to find a statistical result, but even if we try to increase the number of the statistical data by this way, we can not have enough number of them to be used in order to obtain reliable results in statistical investigations. So, one must use all the possible independent ways to solve the problem. In fact, neither of these ways leads to a reliable result by itself because of small number of data even if it leads to a result which is actually true. On the other hand, we can compare the results of these independent ways and try to find a reliable result. So, we can determine the lower limit for the mass of progenitors of PSRs, NSs and SNRs in this way; we will use independent data such as the upper limit for masses of the progenitors of single WDs, formation rates of SNe based on IMF and observationally found SN rate for Sb type galaxies together with the relations between the locations of young PSRs, SNRs, young SFRs and OB associations in the Galaxy.
2 Connections of SFRs to PSRs and SNRs: the general view

Average space velocity of PSRs is about 250-300 km/s \(^{16,17}\) so that, PSRs with large ages can go very far away from their birth sites (i.e. from OB associations and partly from SFRs). Since we want to examine the relations of PSRs and SNRs with their birth sites, we will take into account only the PSRs which have characteristic ages \(\tau \leq 10^6\) yrs. On average, PSRs with such ages can not go more than 200 pc far away from the Galactic plane. There are 259 PSRs with \(\tau \leq 10^6\) yrs, \(|b| < 5^\circ\), and \(F_{1400} \geq 0.2\) mJy values \(^{18}\). Sixty of these PSRs are located within 4 kpc around the Sun \(^{19}\). Below, we will use this sample of PSRs.

About 75\% of O-type stars are members of OB-associations, whereas, only about 58\% of the stars earlier than B3-type (i.e. the stars with masses \(\geq 9\) M\(_{\odot}\)) are members of OB-associations \(^{20}\). On the other hand, in the region with a radius of 110 pc in the Solar neighbourhood, there are 6 stars having masses \(> 9\) M\(_{\odot}\) \(^{21}\). It is known that massive stars which are not members of OB-associations and OCs are located in SFRs. The Sun is also located in a SFR and there is a surrounding environment with young OCs (Perseus, Pleiades, o Vela and Carina) which contain 6-7 M\(_{\odot}\) stars in its near neighbourhood. A bit farther away, at a distance of 180 pc, there is OB-association SCO OB2. Because of these facts, we can assume that \(\geq 50\%\) of the stars with masses \(7\) M\(_{\odot}\) \(< M < 9\) M\(_{\odot}\) and most of the stars which have masses \(\geq 9\) M\(_{\odot}\) are located in SFRs. The SFRs are actually much wider than OB-associations \(^{22}\).

In spite of the considerable influence of HII regions on lifetimes of SNRs, the distributions of PSRs and SNRs must be correlated with the distributions of SFRs. In addition to this, if the lower limits for the mass of the progenitors of these objects are considerably different from each other, then there will be a weak correlation between PSRs and SNRs.

Distance versus Galactic longitude diagram of the PSRs with characteristic ages \(\tau \leq 10^6\) yr and \(|b| < 5^\circ\) is displayed in Figure 1. By comparing Figure 1 with the Galactic arms and the distribution of HII regions \(^{23}\) we see that in general the distribution of such young PSRs is in accordance with the Galactic arm structure. Despite the fact that there is no arm nor subparts of an arm in the Galactic longitude interval \(l = 270^\circ \pm 10^\circ\) \(^{23}\), PSRs are
located densely in these directions, particularly at 5-6 kpc. In actuality, Vela I-IV associations are located in these directions that there is a large SFR in this direction. Among these OB-associations the nearest one, Vela OB2, has a distance of ∼0.5 kpc and the most distant one, Vela OB1, is located at ∼2 kpc \(^{24,25}\). In these directions, there are many young OCs at different distances \(^{26,27}\) and there are many red supergiants at 5-6 kpc \(^{28}\). As seen from Figure 1, the number of PSRs is also large in the intervals \(d=2-3\) kpc and \(d=6-10\) kpc in the direction \(l=300^\circ\). In this direction, first the Carina arm and then both the Carina arm and a subpart of it are cut at about the same distance values. There is a large region which does not contain any PSR in this direction at distances ∼3-4 kpc (see Figure 1) and this shows that there is actually no SFR between the arms Carina and Sagittarius. As seen in Figure 1, there are many young PSRs roughly in the interval \(275^\circ < l < 325^\circ\) at about 10-15 kpc. This shows that another arm or a large subpart of Carina arm is passing through this region. The number of PSRs being large in the interval \(l = 25^\circ ± 5^\circ\) (Figure 1) fits well to the distributions of the giant HII regions \(^{23}\).

In Figure 2, distance versus Galactic longitude diagram of 208 SNRs which have \(|b|<5^\circ\) is represented (the distance values were taken from Guseinov et al. \(^{29}\)). When we compare Figure 2 with the arm structures and the distribution of the HII regions, we see that the SNRs and O-type stars do not show clustering likewise.

### 3 Angular correlations between the PSRs, SNRs and the SFRs with many massive stars

Let’s now examine the relations between the places of young PSRs, SNRs and SFRs around the Sun. As known, depending on the distance (beyond ∼3 kpc) the selection effect in finding O-type stars and their associations in the Galactic central directions becomes very significant. But considering the fact that the numbers of the SNRs and the PSRs are small, first we will take into account only 29 bright SNRs with \(\Sigma>10^{-21}\) Wm\(^{-2}\)Hz\(^{-1}\)sr\(^{-1}\) and \(d\leq4\) kpc, and 60 PSRs with \(\tau\leq10^6\) yr, \(|b|<5^\circ\), \(F_{1400}\geq0.2\) mJy and \(d\leq4\) kpc. Today, the SNRs with such surface brightness values and the PSRs with such fluxes are directly observable also in the Galactic central directions \(^{30}\). The
number of PSRs in this sample is small in spite of the existence of ∼900 PSRs with measured $F_{1400}$ values. The flux values of nearby PSRs are known, but, independent of the flux value, there are only 60 PSRs satisfying the criteria $d \leq 4$ kpc, $|b| < 5^\circ$ and $\tau \leq 10^6$ yr. Below, we will examine projections of the PSRs and the SNRs in our sample on the SFRs.

Among the PSRs in our sample some of them have projections on the SFRs 24,25,31,32,33 which include many massive stars (i.e. O-type stars and supergiants). Numbers of such PSRs are given in Table 1. Forty-eight PSRs are located in the Galactic central directions. Six out of 9 SFRs given in Table 1 are also in the Galactic central directions. We have chosen the Galactic latitude $|b|$ intervals for each SFR considering the minimum and the maximum latitude values of the OB-associations (and the OCs) for each region. Only 17 of the PSRs in our sample (6 of which have ages $\leq 10^5$ yr that there is no difference in the ages of the PSRs which are projected on the SFRs and which are not) have projections on 6 of the SFRs in the Galactic central directions given in Table 1. As seen from Table 1, 12 out of 17 PSRs which are in the interval $-9^\circ < l < 14^\circ$ are projected on the SFRs. The number of SNRs which have projections on the SFRs in the central directions is 3 (Table 1). On the other hand, the number of bright SNRs in the Galactic central directions is 20 in our sample. From these data, the portions of the PSRs and the SNRs which are projected on the SFRs are 0.35 and 0.15, respectively, whereas the ratio of the total area of these SFRs to the area of the sky with $l = 0^\circ \pm 90^\circ$ and $|b| \leq 5^\circ$ is 0.13. So, most of the PSRs are born in SFRs, whereas, the SNRs seem to have weaker connections with SFRs. But the value of the angular correlation must be more because of a selection effect which we can not take into account quantitatively; it is well known that the number density of even very young objects increases in the central direction. The maxima of the number density distributions are within ∼3-4 kpc of the Galactic center. Therefore, there exist many SFRs (which we did not take into account) in the region up to 4 kpc from the Sun in the Galactic central directions. A similar effect, but in smaller degree, exists also in the directions $60^\circ < l < 300^\circ$.

There are totally 29 SNRs which are located within 4 kpc around the Sun in the Galactic longitude interval $60^\circ < l < 300^\circ$ with surface brightness values $\Sigma > 3 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$ (here we can neglect the influence of the background radiation 30). Numbers of the SNRs with $\Sigma > 3 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$ projected on the SFRs in this longitude interval are also
shown in Table 1.

Ten of the PSRs are projected on the 5 SFRs (see Table 1) and the total number of PSRs included in our sample in these directions is 19. Eight out of the 29 SNRs with $\Sigma > 3 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$ in the directions $60^\circ < l < 300^\circ$ have projections on these 5 SFRs. Therefore, the ratios of the numbers of the PSRs and the SNRs projected on these SFRs to the numbers of the PSRs and the SNRs in the interval $60^\circ < l < 300^\circ$ respectively are 0.53 and 0.30. The ratio of the total area of the SFRs in these directions to the area of the sky with $60^\circ < l < 300^\circ$ and $|b| \leq 5^\circ$ is 0.21. Therefore, the number of PSRs projected on the SFRs in these directions is considerably larger than the expected number of chance projections, but the number of the SNRs projected on the SFRs is a bit larger than the expected number of chance projections. Since Vela SNR and PSR has $b = -2.74^\circ$, they do not seem to be projected on SFR. A similar situation also arises for Cas A. But these objects have relations with SFRs, therefore, we have included them in the statistics.

It is necessary to note that the HII regions in each large SFR have no effect on the searches of the PSRs and the SNRs in our sample, but the effect of HII regions on the SNRs is not only related to the background. The SNRs which are born at the end of evolution of massive stars expand in HII regions and they have short lifetimes. On the other hand, the southern hemisphere was not searched so well compared to other regions. Although, there are 13 PSRs projected on the last 4 SFRs shown in Table 1, there is no SNR projected on these SFRs.

As seen from Table 1, SFRs are formed by OB-associations and OCs (e.g. SGR OB1 forms the first SFR in Table 1, whereas, the second SFR contain 3 OB associations, namely, CYG OB3, CYG OB1 and CYG OB9). The sum of longitude intervals of OB associations (and OCs) is close to the sum of the longitude intervals of SFRs in which they are included (see Table 1). We have not taken into account the overlapping parts, so that, the difference between the sum of angular sizes of OB associations and of the SFRs arises from the latitude intervals. Therefore, the sum of areas of SFRs may be up to 2-3 times more than the sum of areas of OB associations (the Vela being a special case). On the other hand, since progenitor stars and especially PSRs with $d < 4$ kpc may change their positions more than $1^\circ$, it is difficult to expect that angular correlation between SNRs, PSRs and some of the OB associations can give an additional result. The PSR which has projection on
the second SFR (see Table 1) is also projected on the OB association CYG OB9 which contain a considerably small number of massive (O-type stars and in general the stars with $M > 7 М_☉$) stars compared to the other 2 OB associations in the SFR. Among the 5 SNRs which have projections on the third SFR, 2 of them are projected on CAS OB5 and one of them is projected on CAS OB4. Also one of the PSRs is projected on CAS OB5. None of the SNRs nor PSRs has a projection on PER OB1 in which the number of massive stars is several times more compared to each of the other OB associations in the SFR. It is necessary to take into consideration that, in this direction, in the intervals $128^\circ < l < 155^\circ$ and $|b| < 6^\circ$, there are only 2 SNRs and 4 PSRs (independent of any parameters).

Among the 4-5 SNRs in our sample which have projections on the OB associations given in Table 1, SNR G116.9+0.2 (CTB1) has the lowest surface brightness ($\Sigma = 1.17 \times 10^{-21} \text{ Wm}^{-2} \text{Hz}^{-1} \text{sr}^{-1}$) and this SNR has a projection on CAS OB5 association. This SNR is expanding in a supercavity and since it is located at 3.5 kpc it has no genetic connection with CAS OB5. SNR G78.2+2.1 may be expanding in a cavity. SNR 89.0+4.7 (HB 21) has a connection with CYG OB7 (not included as a SFR in our work). The last one is SNR G120.1+1.4 (Tycho). The distances of the last 3 SNRs are comparable with the distances of the related OB associations, so that, they can be physically connected to Cas OB4. All of these 3 SNRs have $\Sigma > 3 \times 10^{-21} \text{ Wm}^{-2} \text{Hz}^{-1} \text{sr}^{-1}$, so that, the small sizes and ages are in agreement with the conclusions of Lozinskaya and Tagieva.

4 Spatial correlation of PSRs and SNRs with SFRs around the Sun at distances up to 3 kpc

In Figure 3, spatial distributions of the OB associations for the regions $d \leq 3$ kpc, $60^\circ < l < 300^\circ$ and $d \leq 2.5$ kpc, $l=0^\circ \pm 60^\circ$ are displayed. All the PSRs with $\tau \leq 10^6$ yr and $F_{1400} > 0.2$ mJy in the same regions are also represented in this figure. Since the number of the PSRs is small, the boundaries of the SFRs are determined roughly, and the uncertainties in the distance values are comparable with sizes of the SFRs, it is not easy to find an exact value for the portion of the PSRs genetically connected to the SFRs. In the figure,
there are 20 PSRs in the interval \(60^\circ < l < 300^\circ\). We can roughly assume that about 11-13 of these PSRs (i.e. \(\sim 55\%-65\%\) of them) are genetically connected to SFRs. The total number of PSRs shown in Figure 3 is 31; 16-18 of them can be assumed to have genetic connections with the SFRs. Please note that there is Persei arm in the direction \(l\sim 120^\circ\) at about 3 kpc and there are many HII regions there. So, the PSRs in this region must have connections with SFRs. All of these show that about 55-60\% of the PSRs are connected to SFRs. On the other hand, projections of the SFRs on the plane of the Galaxy in this region occupy approximately 30\% of the area of the region under consideration (Figure 3).

In Figure 4, spatial distributions of the same OB associations, the SNRs with \(3 \times 10^{-22} < \Sigma \leq 10^{-21}\) Wm\(^{-2}\)Hz\(^{-1}\)sr\(^{-1}\) and the SNRs with \(\Sigma > 10^{-21}\) Wm\(^{-2}\)Hz\(^{-1}\)sr\(^{-1}\) in the same regions at the same distances of the PSRs are displayed. It is seen that out of the 17 bright SNRs 9 of them are genetically connected to the SFRs. The historical SNRs Tycho, Cas A and SN1181 are located at distances a little more than 3 kpc (Figure 4). We do not show the locations of OB associations beyond 3 kpc, but it is known that all of these SNRs are located in SFRs. If we exclude these 3 remnants, fraction of the SNRs which have connections with SFRs will be 6 out of 14. Out of the 9 dim SNRs only 3-4 of them may be connected to the SFRs. There are also 10 SNRs with \(\Sigma < 3 \times 10^{-22}\) Wm\(^{-2}\)Hz\(^{-1}\)sr\(^{-1}\) located in the considered region \((60^\circ < l < 300^\circ)\). These 10 SNRs were all observed in the interval \(60^\circ < l < 240^\circ\) because this interval was observed more precisely and with high sensitivity. Among these 10 SNRs, 3-4 of them may be connected to SFRs. As seen from Figure 4, about 30-45\% of the SNRs in our sample can have genetic connections with SFRs. But we must also take into account short lifetime of the SNRs in HII regions. Therefore, the fraction of SNRs which have connections with SFRs must be about 45\%. Please note that the connections would be \(\sim 30\%\) for the chance distribution of these objects.

5 Discussion and Conclusions

Observational data of PSRs\(^{18}\) and SNRs\(^{39}\) show that even in the Galactic central directions \((l=0^\circ\pm 10^\circ, |b|<2^\circ)\) all the SNRs with \(\Sigma>10^{-21}\) Wm\(^{-2}\)Hz\(^{-1}\)sr\(^{-1}\) and the PSRs with \(F_{1400}>0.2\) mJy are observable. Also, the SNRs in the interval \(60^\circ < l < 300^\circ\), for all values of b, can be easily observed if \(\Sigma>3 \times 10^{-22}\)
Wm$^{-2}$Hz$^{-1}$sr$^{-1}$.

We have taken this into account and in Section 3 we have examined the angular correlations between the PSRs with $\tau \leq 10^6$ yr, $|b|<5^\circ$, $F_{1400} \geq 0.2$ mJy, the SNRs which have $\Sigma > 10^{-21}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$, $|b|<5^\circ$ and $\Sigma > 3 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$, $|b|<5^\circ$, and the SFRs rich in O-type stars, which are located up to 4 kpc. The correlation of the PSRs in the Galactic central directions ($l=0^\circ \pm 90^\circ$) with the SFRs is strong. The probability of chance projection of the PSRs in our sample on the SFRs in these directions is 13%, but in actuality the percentage of the ones which have projections is not smaller than 35% if we take into account high space velocities of PSRs. In the Galactic longitude interval $60^\circ < l < 300^\circ$ the probability of chance projection is 21%, but actually $\geq 53\%$ of the PSRs are projected on the SFRs.

The angular correlation of the SNRs in the Galactic central directions with the SFRs is 15%, whereas, the chance projection is 13%, but number of the statistical data is very small. The probability of projection on the SNRs for the SNRs with $\Sigma > 3 \times 10^{-22}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$ and $|b|<5^\circ$ in the interval $60^\circ < l < 300^\circ$ is 30%, i.e. 1.4 times larger than the distribution by chance. Although PSRs and SNRs are born due to SN explosions, there is no angular correlation for the spatial distributions of young PSRs and the SNRs in our sample, either. This must be the result of different precisions and sensitivities of the PSR and SNR searches in different directions of the Galaxy as well as short lifetimes of the SNRs which are born at the end of the evolution of O-type stars. For example in the sector $270^\circ < l < 360^\circ$ there is a large number of PSRs and a small number of SNRs, while in the region $60^\circ < l < 90^\circ$ number of SNRs is large (see Figures 3 and 4). Another reason can be that the average mass of progenitors of PSRs is a bit larger than the masses of progenitors of SNRs.

We have considered the same correlation also for the PSRs and the SNRs in our sample and the SFRs all of which are located up to 3 kpc. We have found the value of 45%, instead of 35% found for the PSRs with $d \leq 4$ kpc in the central directions. For the interval $60^\circ < l < 300^\circ$, we have found the percentage of the PSRs which have projections on the SFRs to be 64% instead of 53% which was found for $d \leq 4$ kpc case. On the other hand, for the SNRs in the Galactic central directions, instead of the value of 15% found for $d \leq 4$ kpc case, we have found the value of 18%. For the SNRs in the interval $60^\circ < l < 300^\circ$ we have found a value of 22% instead of the value of 30% found for the $d \leq 4$ kpc case. So, we can assume that the actual
projections of young PSRs on the SFRs is about 3 times larger than the chance projections. If we consider the short lifetime of SNRs in HII regions, then the actual projections of the SNRs on the SFRs will be about 1.5 times more than the chance projections.

The increase of the correlation under the diminishing of the volume should be considered normal. The PSRs and SNRs in our sample can be observed easily up to 4 kpc, but it is difficult to observe O-type stars beyond 2-3 kpc, especially the OB associations in the central directions. Therefore, the most distant PSRs and SNRs actually may have projections on the SFRs which were not observed. Existence of such an effect must show itself also for O-type stars, but weakly. The diminishing of the percentage of the SNRs, which have projections on the SFRs, at smaller distances show that the SNRs actually have weaker correlation with young SFRs compared to the PSRs.

Is the angular correlation of the O-type stars given in Cruz-Gonzalez et al. 40 with the SFRs in the region $60^\circ < l < 300^\circ$ much different compared to the correlation with the PSRs? There are 309 O-type stars in the directions of these SFRs and the total number of O-type stars in this region is 455, so that, the angular correlation is 68%. This is possibly an underestimated value because we do not put a limit for the distances of O-type stars as we have put for the SFRs. But still this value is a bit larger than the correlation of the PSRs located less than 3 kpc and significantly larger than the correlation of the PSRs with $d \leq 4$ kpc. This shows that PSRs have, in general, progenitors with masses $>9$ M$_\odot$ (i.e. earlier than B3V-type stars). It is necessary to remember that about 75% of O-type stars are members of OB associations, whereas, only about 58% of the stars earlier than B3-type are members of OB associations 20.

We have tried to find relations between the spatial distributions of the SFRs on the basis of the OB associations classified by Melnik & Efremov 24 and of the PSRs with characteristic ages $\tau \leq 10^6$ yr and $F_{1400} > 0.2$ mJy, of the SNRs with $\Sigma > 10^{-21}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$, and of the SNRs with $3 \times 10^{-22} < \Sigma < 10^{-21}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$. We have compared the spatial distributions for the interval $60^\circ < l < 300^\circ$ up to 3 kpc from the Sun, taking into account that OB associations were identified better in this angular interval. On the other hand, for the region $l = \pm 60^\circ$ in the central direction, we have considered the correlations of the objects located up to 2.5 kpc. We attempt to take into account the uncertainties in the distance values of these objects and the high space velocities of PSRs. Naturally, the errors in the determination of sizes
of the SFRs together with the numbers of the PSRs and SNRs being small make the uncertainties larger. This does not change the reliability of whether there is a correlation or not, but has some effect on the quantitative value of the correlation. About 55-60% of the young PSRs and about 45-55% of the SNRs with $\Sigma < 10^{-21}$ Wm$^{-2}$Hz$^{-1}$sr$^{-1}$ are genetically connected to the SFRs, whereas only about 30-40% of the dimmer SNRs have connections with the SFRs. As seen from Figures 3 and 4, sum of the areas of the SFRs is about 30% of the total area chosen, so that, the connections between these objects must be $\sim 30\%$ under chance distributions.

Actually, there are some O-type stars, other than the ones in the SFRs shown in Figure 3, included in the catalogue of Cruz-Gonzalez et al. 40, particularly around Crab PSR. Taking this and especially the discussions in this section into account, we can say that most of the progenitors of PSRs and in general of NSs are more massive (like the progenitors of most of the bright SNRs) compared to the progenitors of dim SNRs. This is also supported by a comparison of the distance versus longitude distributions of young PSRs and SNRs (Figures 1 and 2) with the distribution of HII regions and the Galactic arm structures 23.

Only SNR Tycho among the 6 historical SNRs (age $\leq 1000$ yr) is probably a member of an OB association. But if all of the progenitors of SNe had masses $> 9$ M$_{\odot}$, then most of the SNRs and PSRs would be born (but not necessarily located) in or near OB associations. Although, SNRs Cas A and SN1181 are not members of OB associations, they are located in SFRs. None of the other historical SNRs (Kepler, Crab and SN1006) was found to be in OB association nor in or close to SFR, even if they were searched in all wavelength bands.

According to Ankay et al. 30, on average, one SN explosion occurs every 65 yr and one PSR is formed every 300 yr in the Galaxy. On the other hand, the upper limit for masses of the progenitors of WDs is $\sim 7$ M$_{\odot}$. This value is also the lower limit for masses of the progenitors of SNe, if the lower limit and the upper limit do not overlap. If we use this value of lower limit together with the IMF, we find the formation rate of SNe to be $\sim 1-2$ in 100 years, which is in accordance with the observations 41. If the lower limit for masses of the progenitors of SNe were less than $\sim 7$ M$_{\odot}$, then the formation rate of SNe would be higher and there would not be spatial correlation between the SNRs and the SFRs. Please note that the SFRs considered in this work include OB associations and very young OCs which contain O-type stars.
Since lifetimes of the stars with masses $<7 \, M_\odot$ are large, we do not expect spatial correlation between such stars and the SFRs used in this work. So, we can say that the lower limit mass for the progenitors of SNe and SNRs is $\sim 7 \, M_\odot$. From the spatial correlation of young PSRs with the SFRs we see that the lower limit for masses of the progenitors of PSRs must be $\sim 9 \, M_\odot$. The difference between the lower limits for the masses of progenitors of SNe and PSRs ($\sim 7 \, M_\odot$ and $\sim 9 \, M_\odot$ respectively) does not correspond to the ratio of the birth rates of these objects which is about 4.5\textsuperscript{30}. So, we can expect some additional conditions for the formation of PSRs, possibly an idea similar to the one claimed by Iben & Tutukov\textsuperscript{6}.

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Table 1  Clusters of OB associations and young (<10^8 yr) OCs and the numbers of SNRs and PSRs in our sample which are projected on the chosen clusters

| Name       | ∆l(°)  | ∆b(°)  | d(kpc) | Age  | # of O stars | # of SNRs | # of PSRs |
|------------|--------|--------|--------|------|--------------|----------|----------|
| SGR OB1    | 4-14   | -2.6  - +1.4 | 1.5   | 6.0-6.6  | 15  | 2  | 4  |
| CYG OB3    | 71-73.8| +1.2  - +3.4  |       |       |    |    |    |
| CYG OB1    | 73-79  | -0.6  - +2.84 | 1.2-2 | 6.0-7.2 | 42  | 1  | 0  |
| CYG OB9    | 77-79  | +0.8  - +2.2  |       |       |    |    |    |
| CEP OB1    | 98-109.3| -3.1  - +1.3  |       |       |    |    |    |
| CAS OB2    | 109-114.1| -1.7  - +3.1  |       |       |    |    |    |
| CAS OB5    | 114.9-118| -2.4  - +1.3  |       |       |    |    |    |
| CAS OB4    | 118-122| -2.7  - +2.3  |       |       |    |    |    |
| CAS OB7    | 121.5-125.2| -0.9  - +2.6  | 1.6-4  | 6.0-7.6 | ~80 | 5  | 5  |
| CAS OB8    | 128-131| -4    - +2    |       |       |    |    |    |
| PER OB1    | 132-138| -5    - +2    |       |       |    |    |    |
| CAS OB6    | 132-142| -3.7  - +2.3  |       |       |    |    |    |
| 10 OCs     | 231-242| -5.5  - +2    | 1.6-4  | 6.0-7.4 | 10  | 0  | 2  |
| PUP OB1    | 242-246| -1    - +2    |       |       |    |    |    |
| VELA OB2   | 262-268| -2.7  - +1.4  |       |       |    |    |    |
| VELA OB4   | 262-268| -2.7  - +1.4  | 0.6-2  | 6.0-8.0 | 9   | 1  | 1  |
| VELA OB1   | 262-268| -2.7  - +1.4  |       |       |    |    |    |
| CAR OB1    | 284.2-286.3| -2.2  - +0.9  |       |       |    |    |    |
| 9 OCs      | 286-289.6| -1    - -0.2  | 2-3.1  | 6.0-7.7 | 84  | 0  | 2  |
| CAR OB2    | 289.2-291.2| -0.6  - +1.6  |       |       |    |    |    |
| CRU OB1    | 293.5-295.9| -2.4  - +0.1  |       |       |    |    |    |
| CEN OB1    | 301-306.3| -1.6  - +3.2  | 2.2-2.5| 6.3-7.5 | 11  | 0  | 1  |
| ARA OB1a   | 335.3-336.8| -1.6  - -1.2  | 1.1-2.8| 6.0-7.4 | 44  | 0  | 2  |
| 13 OCs     | 338-346| -3    - +1.6  |       |       |    |    |    |
| 7 OCs      | 351-360| -2.4  - +1.4  | 1.3-1.7| 6.8-8.0 | 11  | 0  | 8  |
Figure 1: Distance versus longitude diagram for 259 PSRs with |b|<5° and log τ≤6.
Figure 2: Distance vs. longitude diagram for all the 208 SNRs with $|b| < 5^\circ$. 
Figure 3: Distributions of young PSRs and OB-associations in the Galaxy up to 2.5 kpc in the central directions and up to 3 kpc in the anticenter directions. PSRs with $10^5 < \tau \leq 10^6$ yr are displayed with sign (X) and PSRs with $\tau \leq 10^5$ yr are shown with sign (+). Small circles represent OB associations. Three large circles have radii 1 kpc, 2 kpc and 3 kpc, respectively, and the Sun is located at the center.
Figure 4: Distributions of SNRs and OB-associations in the Galaxy up to 2.5 kpc in the central directions and up to 3 kpc in the anticenter directions. SNRs with $\Sigma \geq 10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}\text{sr}^{-1}$ are displayed with sign (X) and SNRs with $3 \times 10^{-22} \leq \Sigma < 10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}\text{sr}^{-1}$ are shown with sign (*). Small circles represent OB associations. Three large circles have radii 1 kpc, 2 kpc and 3 kpc, respectively, and the Sun is located at the center.