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POSSIBLE MASSES OF PROGENITORS OF DIFFERENT TYPE NEUTRON STARS

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An attempt to establish the mass of progenitors of different types of neutron stars having different degrees of activity by examining of the environments of supernova remnants connected to these neutron stars is done. It is found that there is no reliable relation between the mass of the progenitor star and the degree of activity (or passivity) of the neutron star. The S-type supernova remnants without point sources located in less dense media and their progenitors may be less massive stars compared to the progenitors of the neutron stars considered here.

1. Introduction

What does the type (or the activity) of a neutron star depend on? The activity depends on parameters of neutron stars. The most important ones among these parameters are magnetic field, spin period, and maybe mass of the neutron star. These parameters must depend on the mass of the progenitor star and it is important to know, whether the progenitor was single star or entered into binary system. If progenitor was in binary system, then the masses and the separation of the two components must be important [1]. Number of the neutron stars in binary systems is very small, and as the binary parameters change at SN explosion, so it is difficult to check if the pulsar phenomenon depends on the progenitor star being in a close binary system or not.

Today, various different types of single neutron stars having very different physical properties are known; these are classical PSR-s, dim radio quiet neutron stars (DRQNSs) which are the type of neutron stars having very low luminosity in the X-ray band and have no detected radio radiation, anomalous X-ray pulsars (AXPs) and soft gamma repeaters (SGR-s) (see [2] for review). Do the neutron stars with different physical properties have progenitors with different masses? This question was asked before in [3]. In this work, we examine the environments of the SNRs connected to different types of neutron stars and also of the S-type SNRs in which no sign of any kind of neutron star is seen. We discuss masses of the progenitors of these SNRs and neutron stars. We have approached the problem through 4 independent ways: we have examined surface brightness (Σ) - radius, Σ - age, and radius-age graphs as well as the observational data about density in the shock fronts and in the ambient media of the supernova remnants. We have also examined the environments of C- and S- type supernova remnants in which no point source has been observed.

2. Environments of SNRs and the types of the point sources connected to these SNRs

In Table 1, data of various types of neutron stars and SNRs are listed. The data of PSRs are taken from [4], and the data of AXPs and DRQNSs are taken from [5]. In this table, names of the point sources in the SNRs, ages, radio luminosities (at 1400 MHz) of these neutron stars and their distances are represented. In Table 2, data of the SNRs, which the neutron stars represented in Table 1 are connected to, as well as data of some nearby S- and C-type SNRs (without observed point sources and for which information about the environments, ages, explosion energies are available) are listed.

The data of the SNRs are taken from [6] and [7]. In this table, Galactic coordinates, names, morphological types in radio and X-ray bands, radio surface brightness, diameter, and distance values of the SNRs as well as the OB-associations in which they are located and distances of these OB associations are given. In Table 2, explosion energies, ages, density in the shock waves of the SNRs, and data about the surrounding medium are also represented [7].

Various data about the density in the medium around SN explosion sites and in the shells of the SNR-s are given in Table 2. By examining these and some additional data we can get some information about the progenitor masses. Then we can check if there is a relation between progenitor masses and the types (different activity or total passivity) of neutron stars. For some of the SNRs average values of number density of particles in front of and just behind the shock front in the shell are given in Table 2 in the first part of the 12th column. In the same column, after the density of the shock wave, the existence of HI clouds around SNRs are represented (the densities of these clouds are also given, if available). If there is a bubble around the SNR it is also written (also its density if possible). In Table 2, we have listed only those SNRs which have reliable distance, age and density values and after carefully examining PSR-SNR connections we have selected reliable pairs (Table 1).

Three of the AXPs are connected to Galactic SNRs, whereas none of the SGRs were found to have reliable connections with Galactic SNRs. SGR 0526-66 may be connected to a SNR in LMC [7]. In [3] it is claimed that the SNRs connected to AXPs (and also SGRs) are located in a dense medium. They present a figure (SNR age versus SNR radius) to show that the media of the SNRs connected to AXPs and SGRs are denser than the media of all the other SNRs, on average. Theoretically found average constant density lines are also included in this figure to show the evolution of the SNRs (with the same explosion energy) evolving in different media which have different (constant) densities [3].

The SNRs which are at the same age have different radius values depending on the density of the medium [8]. In actuality, it is known that the explosion energy values vary in a wide range, about 3 orders of magnitude (e.g. kinetic energy of Crab SNR is ~ 10^{49} erg, [9], whereas kinetic energy of Cas A SNR is $>10^{51}$ erg, [10]. In the Galaxy, the interstellar medium is inhomogeneous and has a cloudy structure. The observational parameters of SNRs strongly depend on the characteristics of the surrounding matter.

Table 1. Data of the Point Sources of the SNRs

Source Type	Point Source Name	*l,b (*SNR*)*	Characteristic Age (kyr)	Log $L_{1400\ MHz}$	d (kpc)	Progenitor Star
Radio Pulsars and Single Strong X-Ray Pulsars	J 1801-2451 R	5,27-0,9	15	1,05	4,5	
	J 1803-2137 R,X	8,7-0,1	16	2,25	3,5	O8-B1
	J 1811-1926 X	11,2-0,3	24		5	O
	J 1846-0258 X	29,7-0,3	0,72		5,7	O
	J 1856+0113 R	34,7-0,4	20	0,89	2,8	O
	J 1930+1852 R,X	54,1+0,3	2,9	0,17	5	
	J 1952+3252 R,X	69,0+2,7	107	0,6	2	
	J 2229+6114 R,X	106,3+2,7	10	0,97	5,5	
	J 2337+6151 R,X	114,3+0,3	41	1,04	2,8	O9-B3
	J 0205+6449 R,X	130.7+3,1 Nit.	5,38	-0,3	3,2	O8-B1
	J 0534+2200 R,O,X,G	184,6-5,8	1	1,75	2	
	J 0835-4510 R,O,X,G	263,9-3,3	20	2,31	0,45	
	J 1124-5916 R,X	292,0+1,8 Ox.	2,9	0,46	6	O8-B1
	J 1119-6127 R	292,2-0,5	1,6	1,65	7,5	B2-B3
	J 1341-6220 R	308,8-0,1	12	2,11	8	
	J 1513-5908 R,O,X,G	320,4-1,2	1,7	1,25	4,2	B0-B2
	J 1646-4346 R	341,2+0,9	40	1,67	6,8	
DRQNSs	RX J 2020.2+4026	78,2+2,1		<-0,1	1,5	O8-B1
	CXO J 2323+5848	111,7-2,1 Ox.		<1,18	3	massive O
	RX J 0007.0+7302	119.5+10 Ox.		<-0,2	1,4	B1-B3
	RX J 0832-4300	260,4-3,4 Ox.	7,9	<0,08	2	O
	1E 1207.4-5209	296,5+10	11, ~10	<-0,4 (4800MHz)	1,8	B1-B3
	1E 161348-5055	332,4-0,4	8,1, 8	<0,1 (1500 MHz)	3,7	O
	CXOU J 0617+2221	189,1+3,0		<2 (327 MHz)	1,5	
AXPs	AXP 1E 1841-045	27,4+0,0	4,7	<1,5	6,5	O
	AXP J 1845-0258	29,6+0,1	5--8		11	O
	AXP 1E 2259+586	109,1-1,0	200	<0,3	5	B0-B2

Notes:

R=Radio Pulsation, O=Optical Pulsation, X=X-Ray Pulsation

G=Gamma-ray Pulsation, T= Thermal X-Ray Radiation

CXOU J 0617+2221: DRQNS candidate

All of these should be taken into account while analyzing possible masses of progenitors of neutron stars and density of the matter in the environments of SNRs. Following [3], we have constructed similar SNR radius versus age diagrams including the average (constant) density lines as presented in [3]. Figure 1, SNR radius vs. age diagram for S- and C-type SNRs which are connected to PSRs and single strong X-ray pulsars is displayed using the ages of SNRs (see Table 2) and the characteristic ages of pulsars (see Table 1), separately. In Figure 2, SNR radius vs. age diagram for the SNRs which are connected to AXPs and DRQNSs is displayed, again using the ages of SNRs (see Table 2) and the characteristic ages of AXPs and DRQNSs (see Table 1), separately. In Figure 3, SNR radius vs. SNR age diagram for S- and C-type SNRs (for which no point source has been observed) is displayed.

3. Reliability of the positions of the SNRs in the Age-Radius diagram

Positions of the SNRs connected to PSRs and single strong X-ray pulsars are represented in figure 1. F-type SNRs are included in Table 1, but we did not show the positions of them in the figures; we want to examine the ambient medium of the SNRs through which the SNR's shell expands. The uncertainty in the age values of SNRs are represented with error bars in Figure 1. The real age of PSRs is given as

$$\tau = \frac{P}{(n-1)\dot{P}}\left(1-\left(\frac{P}{\dot{P}}\right)^{n-1}\right)$$

where P and $\dot{P}$ are the spin period and time derivative of the spin period, and n is the braking index. For $n = 3$ and $P_0 << P$, τ is the characteristic age which is close to the real age of the PSR. For all of the SNRs in figure 1, characteristic ages of the pulsars connected to them are known and the positions of the SNRs using the τ values are shown in figure 1 by (+) sign.

Table 2. Data of the SNRs

Type	*l,b*	Name	Type (Radio)	Type (X-Ray)	Σ	d	R	OB	d_{OB}	E_0	Age	Density
					(10^{-22})	(kpc)	(pc)	assoc.	(kpc)	(10^{51} erg)	(kyr)	(cm^{-3})
Radio Pulsars and Single Strong X-Ray Pulsars	5.27+0.9		F									
	8.7+0.1	W30	S		59	3,5	22,9			1--4	30	0,03
	11.2+0.3		C		2069	5	2,9			<0,24	2	MC,MS
	29.7-0.3	Kes75	C		1672	6,7	2,9				1	
	34.7-0.4	W44	C	C	366	2,8	12,5			~10	10--20	1-6, MC
	54.1+0.3		F	F	334	5	1,2					
	69.0+2.7	CTB80	?		28	2	23,3			10		
	106.3+2.7		?	C	6	5,5	30,4			0,7	<100	in HI bubble, MC
	114.3+0.3		S		2	2,8	28,7	CasOB5	2,3		10—20	0,1, low
	Nit.130.7+3.1	3C58	F		1104	3,2	2,9			0,2-0,4	0,8	
	184.6-5.8	Crab	F		44720	2	1,8			0,1-0,3	1	low
	263.9-3.3	Vela	C		40	0,45	16,7			10--20	11	high
	Ox.292.0+1.8	MSH 11-54	C	C?	235	6	7,2				<1,6	
	292.2-0.5		S		35	7,5	18,9			10		
	308.8-0.1		C?		38	8	28,5					
	320.4-1.2	RCW89	C		74	4,2	21,4			10--20	1,7	very high
	341.2+0.9		C		6	6,8	18,5					
DRQNSs	78.2+2.1	DR 4	S		142	1,5	13,1	CygOB1	1,3		5—10	in cavity, MC, >1
	Ox.111.7-2.1	Cas A	S		163744	3	2,2			30	0,32	high
	Ox.119.5+10	CTA1	S	C	7	1,4	18,4			0,3	15	0,01-0,02, H1 cl. 0,5-1,MC
	260.4-3.4	Puppis A	S		65	2	16				3,4	0,4-3, cl,100-180
	296.5+10	PKS 1209	S		12	1,8	20,1			>0,2-2	10	0,1-0,2, H1cl~10
	332.4-0.4	RCW 103	S		421	3,7	5,4				1—3	MS,MC>1000
	189.1+3.0	IC 443	C		119	1,5	9,8	Gem1	1,5		1—5	10-20, cl.100, MC 10000
AXPs	27.4+0.0	4C 0471	S		564	6,5	3,7				2	low
	29.6+0.1		S		90	11	8,1				<8	
	109.1-1.0	CTB 109	S		38	5	20,4			10-100	3~10	0,25, cl. 20
Without Point Sources	0.9+0.1		C		423	8	9,3				1--7	<0,001, MC
	6.4-0.1	W28	C	C	265	2,5	17,5			4~10	~50	0,1-0,23, MC~10000, MS
	42.8+0.6		S	C	8	6	21				10	low
	74.0-8.5	Gyg.Loop	S		9	0,8	22,3			0,17	5--10	H1 Cloud 4
	116.5+1.1		S		4	3,5	35,3				10--40	low
	132.7+1.3	HB 3	S	C	11	2,3	26,8			3,1	21	high
	315.4-2.3	RCW 86	S		42	2,7	16,5	CirOB1	2,5	6--7	9,5	0,2-0,3, in cloud
	326.3-1.8	MSH15-56	C		151	2	11			~10	10	0,1, medium
	327.1-1.1		C		33	6,5	17			~13	7	
	327.6+14	SN 1006	S		32	2	8,8			10	1	0,02, 0.1, 0,4

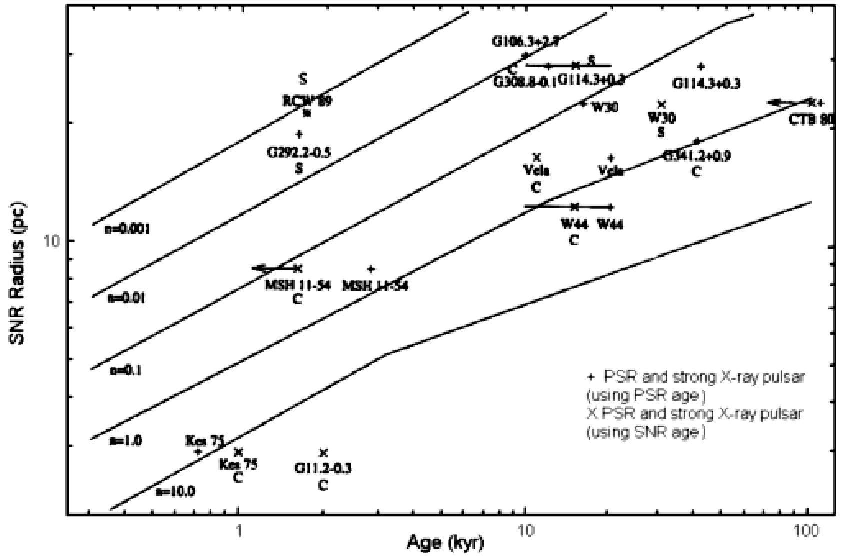

Fig.1. SNR –s connected to PSRs and single strong X-ray pulsars

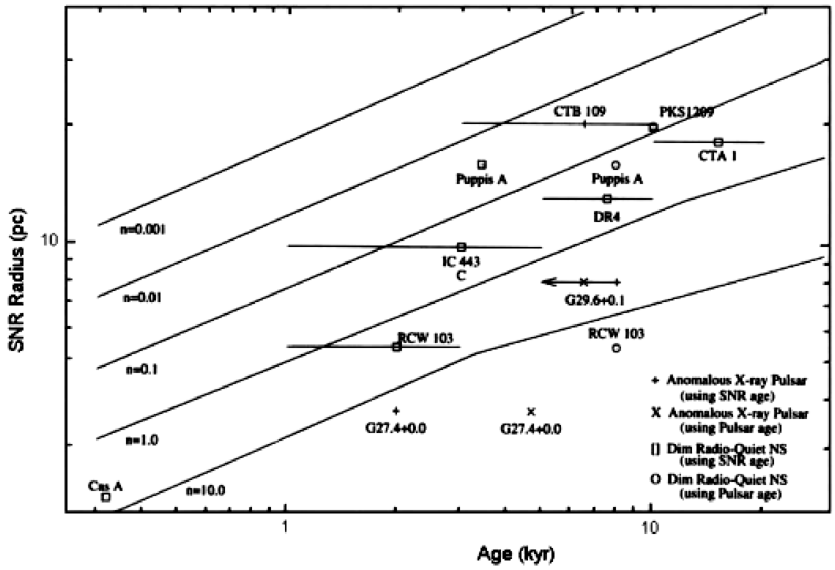

Fig.2. SNR-s connected to AXP-s and DRONS-s.

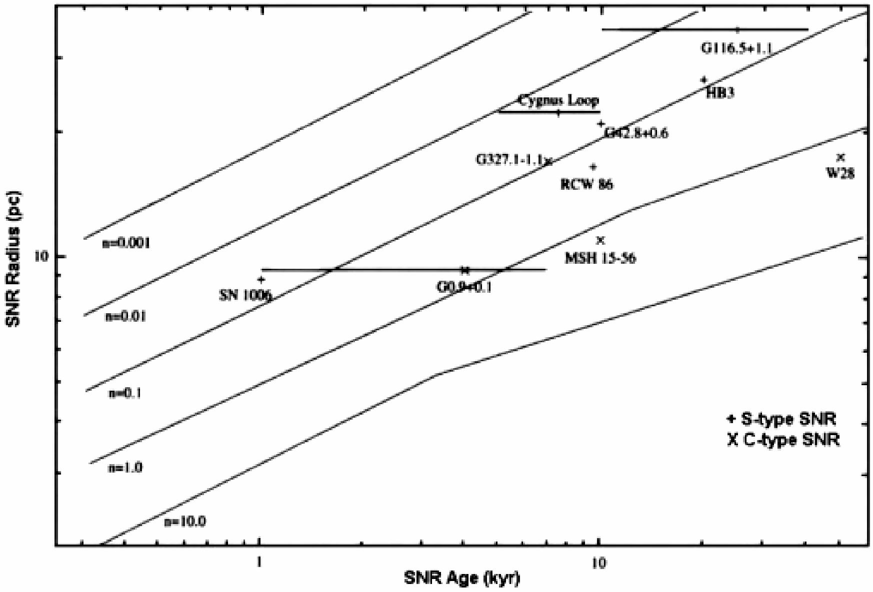

Fig.3. The S- and C-type SNR-s without point sources.

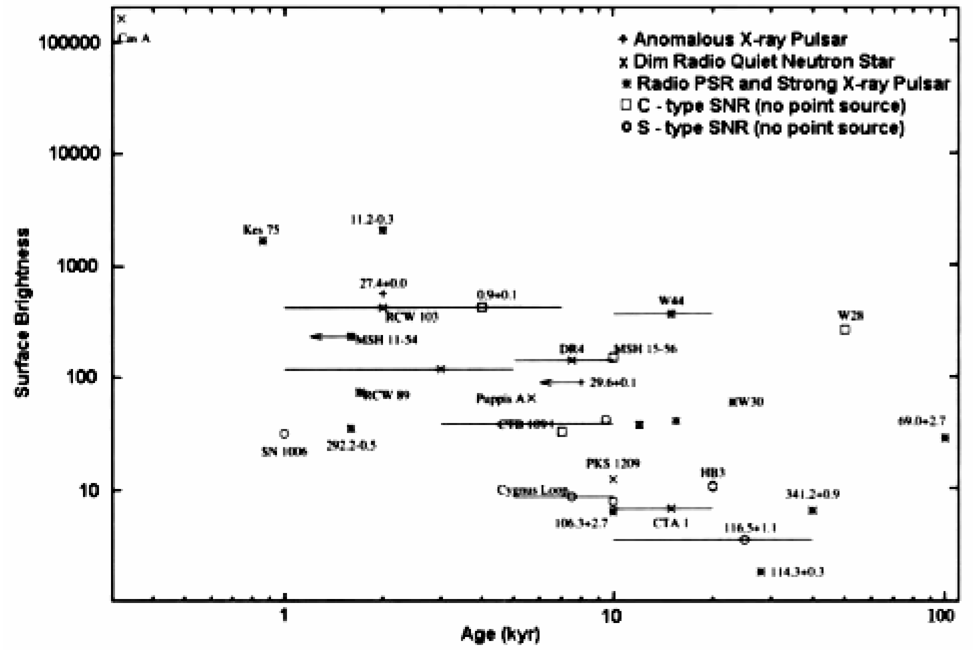

Fig.4. Surface Brigthness - Age

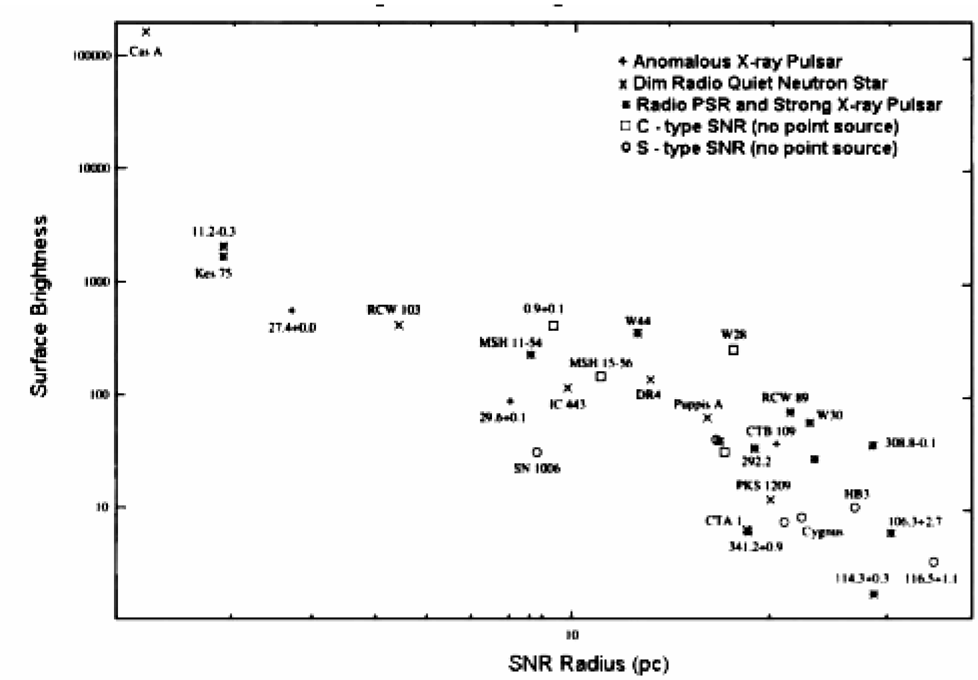

Fig.5. Surface Brigthness-Radius

Examining only the radius vs. age diagrams using an average value of explosion energy and constant density values for the ambient media does not give us enough information about densities of the ambient media. We have also constructed surface brightness (Σ) vs. age (Figure 4) and Σ vs. radius diagrams (Figure 5) of the SNRs in order to get more information about the densities. We have also collected observational density values of the ambient media of the SNRs (see Table 2) and we have compared these density values with the positions of the SNRs in Figures 1-5.

Although, independent age measurements are not available for all the SNRs, we have also shown the positions of the SNRs using the SNR's age (if it is known) by (X) sign in Figure 1.

When we take into account the morphological types in the radio band (see Table 2) of the SNRs given in Figure 1, we see that, in general, the C-type SNRs are evolving in a denser medium compared to the S-type SNRs. On the other hand, when we compare the density values corresponding to the positions of the SNRs in Figure 1 (i.e. the position of the SNR with respect to the constant density lines for expansion in a homogeneous medium) with the observationally found density values given in Table 2, we see that there are considerably large differences. It must be noted that, the observed density values correspond to the actual density values of the shell and the ambient medium depending on the diameter value of the SNR. The density values of the shell and the ambient medium change, because the medium is not homogeneous. The density values also change with respect to the diameter if the progenitor is an O-type star; in such a case, the SNR (during its initial phase) expands inside an HII region formed by the O-type progenitor or inside a bubble, i.e. in a low-density medium. So, if the SNR is expanding inside a HII region, i.e. in a low density medium, it does not necessarily mean that the surrounding medium is not dense. If the SNR is in a star formation region where molecular clouds, OB associations are present, then the SNR will be in a dense medium and this may be an evidence for the progenitor being a massive star.

3.1 The SNRs connected to PSRs and single strong X-ray pulsars

As seen from Figure 1, SNRs Kes 75 and G11.2-0.3 are expanding through the densest media. There is no observational density data available for Kes 75 (Table 2). The SNR G11.2-0.3 is seen to be in a region in which there are molecular clouds and this SNR interacts with these clouds. In Figures 4 and 5, Σ-age and Σ-radius graphs for all the S- and C-type SNRs given in Table 2 are shown. As seen from these figures, SNRs Kes 75 and particularly G11.2-0.3 are expanding in dense media the progenitors of these SNRs may be O-type stars.

The positions of SNR W44 in Figures 1, 4 and 5, and the observational density of W44 given in Table 2 show that this SNR is expanding in a dense medium. So, the progenitor of SNR W44 and PSR J1856+0113 (which is connected to this SNR) may be an O-type star. As displayed in Figure 1, C-type SNR MSH 11-54 is expanding in a less dense medium compared to the media of the SNRs discussed above. The age of the PSR connected to this SNR is greater than the age of SNR MSH 11-54 (see Tables 1 and 2) and the uncertainty in the PSR's age is less than the uncertainty in the SNR's age. If the PSR and the SNR are connected genetically having an age of 2.9 kyr then, there is no contradiction between the positions of this remnant in Figure 2 and Figures 4, 5. There is no observational data directly available about the density of the ambient medium of MSH 11-54 (Table 2). SNR MSH 11-54 is an Oxygen-rich SNR; the progenitor of MSH 11-54 may be an O8-B1 type star.

As seen from Figure 1, the SNR RCW 89 is expanding in a very low density medium. On the other hand, observational data show that this SNR is in a very dense medium (Table 2). What is the reason for this contradiction? As seen in Table 2, the explosion energy of this SNR exceeds 10^{51} erg. So the progenitor may be B0-B2 type star. SNR G292.2-0.5 is situated in a very low density medium (Fig.1). There is no observational data about the density. PSR J1119-6127 is projected on the center of this SNR that the connection between the PSR and the SNR is most probably true [11]. Progenitor of this pair may be a B2-B3 type star in a low density environment. From Figure 1, we can conclude that SNR G114.3+0.3 is expanding in a low density medium and this is roughly in agreement with the observational density data given in Table 2. The positions of this remnant in Figures 4 and 5 also give evidence for this SNR to be expanding in a very low-density medium. The progenitor of this SNR may be an O9-B3 type star.

The position of SNR W30 in Figures 4 and 5 is in accordance with the position of this SNR in Figure 1, but contradicts with the observational low density value given in Table 2. It is not possible to get rid of the contradiction by changing the distance and age values of this remnant. We can suppose that either the actual density of the ambient medium of W30 is larger than the observed density value (Table 2) or the explosion energy of this SNR is higher than the value given in Table 2. Progenitor of the pair W30-J1803-2137 may be an O8-B1 type star.

3.2 The SNRs connected to AXPs and DRQNSs

In Figure 2, radius-age diagram of the SNRs connected to AXPs and DRQNSs is represented. Observed density data on SNR G27.4+0.0 and the positions of this SNR and SNR G29.6+0.1 in Figures 2, 4 and 5, show that the progenitors of these AXP-SNR pairs may be O-type stars. Among the AXP - SNR pairs, the most well examined one is 1E 2259+586 - SNR G109.1-1.0 (CTB 109) pair. As seen from Figure 2, this SNR (similar to Puppis A) is in a less dense medium compared to all the other SNRs which are connected to AXPs and DRQNSs. On the other hand, the ambient density of this SNR given in Table 2 and the positions of this remnant in Figures 4 and 5 do not confirm this result. If we take into account large energy of supernova explosion we can confidently say that the progenitor is a B0-B2 type star.

Next we will examine the SNRs connected to DRQNSs. Among the SNRs which are connected to DRQNSs, the densest ambient medium belongs to SNR RCW 103 as seen in Figure 2. The density in the ambient media of this SNR given in Table 2 and the data of this remnant shown in Figures 4 and confirm this result; SNR RCW 103 is expanding in a dense medium that its progenitor may be an O-type star. As seen in Figure 2, the next densest medium is the one in which SNR DR4 (which is connected to a DRQNS) is located. Again, the density data of this remnant given in Table 2 and the location of this remnant shown in Figures 4 and 5 do not contradict with this result. As seen in Table 1, this SNR is associated with Cyg OB1 that its progenitor may be an O8-B1 type star. Next we will examine the SNRs (connected to DRQNSs) which are in less dense ambient media. The age of SNR G260.4-3.4 (Puppis A) is 3.4 kyr, whereas, DRQNS RX J0822-4300, which is connected to Puppis A, has a characteristic age of 7.9 kyr. In Figures 4 and 5, we have adopted an average age value of 5.7 kyr for this remnant. There is a contradiction between the position of Puppis A in Figure 2 and value of the ambient medium density given in Table 2 (and also the positions of the remnant in Figures 4 and 5). It must be noted that Puppis A is an Oxygen-rich SNR like SNRs CasA and CTA 1. Cas A is in a dense medium and the thrown out mass was calculated to be ~4 solar mass [12]. As seen from the figures, the progenitor of SNR CTA 1 may be a massive B-type star. The density of the ambient medium of SNR Puppis A is in between the densities of the ambient media of SNRs Cas A and CTA 1, so the progenitor of Puppis A may be an O-type star. Since, the SNRs connected to AXPs are not in less dense media compared to Puppis A, in principle we can assume that the progenitors of AXPs and DRQNSs are often O-type stars.

3.3 The SNRs without observed point sources

Now let us examine the S- and C-type SNRs for which no point source has been observed (Table 2). As most of the PSRs are connected to C-type SNRs (in most of the cases PSRs create pulsar wind nebula), the C-type SNRs for which no point source has been observed most probably include

PSRs. As seen from Figure 3, C-type SNR W28 has the largest ambient density. The ambient density value of W28 in Table 2 and the positions of the SNR in Figures 4 and 5 confirm this result.

Similar to W28, the C-type SNR MSH 15-56 is in a dense ambient medium as seen from Figure 3. Its ambient density data (Table 2) and its positions in Figures 4 and 5 show that this SNR is in a medium which has a density value a bit less than the density in the ambient medium of W28. Progenitors of W28 and MSH 15-56 may be massive O-type stars. The third densest ambient medium may belong to SNR G0.9+0.1 (see Figure 3). So, we can confidently say that this SNR has large explosion energy and is expanding in a HII region which was created by its progenitor. This fact supports the idea that the progenitor of this SNR may be an O-type star.

As seen in Figure 3, the SNRs expanding in less dense media are SN1006, Cygnus Loop and G116.5+1.1 which are S-type SNRs. The positions of these 3 SNRs in Figures 4 and 5 also confirm this result. From Figures 3, 4 and 5, after examining the ambient media of S- and C-type SNRs (in which no point source has yet been found) we see that, on average, the C-type SNRs are expanding in denser media compared to the S-type SNRs.

4 Discussion and Conclusions

As is well known, average density values of the media, presence and sizes of HII regions, and the masses of OB stars are related with each other. Therefore, examining the average density of the media around the SNRs, the density in the shock wave, chemical abundances of the SNRs, and the existences of the OB associations in the regions of the SNRs we may roughly estimate the types of the progenitor stars. Possible types of the progenitor stars of the SNRs which contain neutron stars are given in the last column of Table 1.The progenitors of all the SNRs (except the S-type SNRs without point sources) discussed above are expected often to be O-type stars with different masses. At the end of their evolution massive B-type stars often must give birth to S-type SNRs in which it is difficult to detect point sources in radio and X-ray bands even if these SNRs are located at small distances. Since, the number of F-type SNRs is small and as F-type SNRs do not have shells (i.e. we can not put them in our figures for comparison), we can not discuss the density of their ambient media. But we know that the ambient medium of the Crab PSR has a low density and nearby the PSR there is no young open cluster. Therefore, the progenitor of Crab PSR may be a massive B-type star, rather than an O-type star.

Our investigations show that the type of activity (or passivity) of a neutron star practically does not or slightly depends on the mass of the progenitor star on the main sequence. So, it is necessary to examine the idea of connection of the type of activity to the parameters of binary systems (similar to the idea of the connection of the origin of PSRs to close binary systems as claimed in [1].

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MÜXTƏLİF TİPLİ NEYTRON ULDUZLARIN ƏCDADLARININ MÜMKÜN KÜTLƏLƏRİ

Müxtəlif aktivliyə malik neytron ulduzları ilə genetik bağlı olan ifrat yeni ulduz qaliqlarini əhatə edən mühiti analiz edərək, neytron ulduzların əcdadları olan ulduzların kütlələrini təyin etməyə cəhd göstərilmişdir. Göstərilmisdir ki, əcdad kütlələri ilə neytron ulduzların aktivliyi arasinda etibarlı bir asılılıq yoxdur. İçində nöqtəvi mənbə olmayan S- tipli ifrat yeni ulduz qalıqları daha seyrək mühitdə yerləşmişlər və onlarin əcdadlarının kütlələri baxılan neytron ulduzlarınsın əcdadlarının kütləsindən az ola bilər.

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ВОЗМОЖНЫЕ МАССЫ ПРЕДШЕСТВЕННИКОВ НЕЙТРОНЫХ ЗВЕЗД РАЗНОГО ТИПА

Анализируя окружающую среду остатков сверхновых, связанных с нейтронными звездами, сделана попытка установить массу предшественников нейтронных звезд различных типов, имеющих разные степени активности. Установлено, что не существует надежной зависимости между массами предшественников и степенью активности (или пассивности) нейтронных звезд. Остатки сверхновых S-типа, не содержащие точечные источники, находятся в менее плотной среде, и их предшественники могут быть менее массивными, чем предшественники остальных типов нейтронных звезд.

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