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脉冲星与超新星遗迹成协的候选体

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摘要: 从所有已被提出和发现的 230 多颗超新星遗迹和 1300 多颗脉冲星中，总结出一个共 50 对脉冲星与超新星遗迹成协候选体的样本. 其中至少 20 对因为环绕脉冲星的脉冲星风云已被探测到，其成协性应该是真实的. 结合近来的观测结果，对导致这种成协对缺失现象的各种因素进行了讨论，尤其深入地讨论了这个样本中有代表性的 3 个很可能成协的脉冲星与超新星遗迹对.

关 键 词: 天体物理学；成协；综述；脉冲星；超新星遗迹；统计

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Candidates for Pulsar/Supernova Remnant Associations

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Abstract: We list a sample of 50 pairs of pulsar (PSR) and supernova remnant (SNR) associations which have been suggested from over 230 SNRs and 1300 PSRs. At least 20 pairs of them are real because the pulsar wind nebulae around the PSRs have been detected. We analyze factors which may result in the deficit of associations. Considering recent observational progress, we simply discuss reality of the 50 pairs cataloged associations and the possibility to detect more PSR/SNR associations. We give a detailed discussion aimed at three pairs of likely PSR/SNR associations PSR J1811−1925/SNR G11.2−0.3, PSR J1932+2020/ SNR G55.0+0.3 and PSR J1706/SNR G343.1−2.3 in our sample.

Key words: astrophysics; associations; review; pulsar; supernova remnant; statistics

1 Introduction

Pulsars (PSRs) have been understood to be neutron stars born rotating rapidly (10—100 ms). Strong evidence supports that most of neutron stars are created in supernova explosions involving massive stars, which give rise to expanding supernova remnants (SNRs). The study of

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young PSRs and their SNRs may enrich our knowledge about the periods, magnetic fields and velocities of PSRs at their birth, and give independent age and distance estimates for PSRs. Young PSRs associated with SNRs usually lose their rotational kinetic energy at a rapid rate, and deposit this energy into their surroundings in the form of a magnetized relativistic particle wind. This wind can interact with the ambient medium to produce an observable PSR wind nebula (PWN), the study of which can provide information on both the PSR's wind and surrounding environment [1]. For a little older PSR/SNR system, after the associated SNRs have dissolved into the interstellar medium, the PSR still moves as an isolated PSR through the interstellar medium, and can form a PWN bow shock system.

2 Analysis

2.1 Factors Causing Deficit in PSR/SNR Associations

Although at present over 230 SNRs and over 1300 radio PSRs [2] and two dozen PWN [3] have been known in the Milky Way, there are only about 50 pairs of traceable associations of PSR/SNR in the literature. The deficit in associations may be caused by the following:

(1) Selection effects associated with detecting each type of object can partly account for the deficit in associations [4].

(2) The shorter radiative lifetime of most of SNRs results in longer lived PSRs losing associated SNRs. Most PSRs have a radiative lifetime (10^3—10^4 kyr), much larger than the age <10 kyr of a SNR in the Sedov phase. Therefore PSRs will remain visible long after the associated SNRs have dissolved into the interstellar medium. A typical example of such a system is the Guitar Nebula around PSR B2224+65 which has been detected both in Hα [5] and in X-rays [6], but which has no associated SNR. However, the discovery of a long radiative lifetime SNR G55.0+0.3 ($\sim 10^6$ yr) implies that the radiative lifetime of some SNRs could be much longer than previously suggested.

(3) There is mounting evidence that a significant fraction of SNRs may be associated with objects (e.g., Anomalous X-Ray Pulsars (AXPs) and Soft Gamma-Ray Repeaters (SGRs), and Radio Quiet Neutron Stars (RQNSs)) with very different properties from traditional radio PSRs. However, in the absence of detectable pulsations, canonical radio PSRs can be distinguished from AXPs, SGRs and RQNSs by the presence of an extended synchrotron nebula, powered by the energetic relativistic wind [7].

(4) The large difference of rate (>5) between supernova and PSRs leads to the conclusion that a rather large fraction of PSRs don't probably originate from supernova explosions which certainly produce SNRs.

(5) The sensitivity limits of present telescopes hinders us to detect weak pulses of compact sources embedded within associated SNRs or faint SNRs around young PSRs in existing X-ray and radio observations. The discoveries of three extremely weak young radio-emitting PSRs with 1—2 orders of magnitude lower luminosity than any young PSRs previously known highlight the

vexing issue of the true luminosity distribution of particularly young PSRs [8]. Gaensler *et al.* [9] has recently observed a PWN around vela-like PSR B1823-13 but not seen the association SNR which is probably too faint.

(6) PSR characteristic ages can be poor age estimators for some PSRs. On the one hand, by studying PSR B1757−24/SNR G5.4−1.2 system, Gaensler and Frail's [10] conclusion that thearacteristic age of a PSR greatly underestimate the true age of the PSR may explain the fact that many PSRs with small characteristic ages have no associated SNRs. On the other hand, the reverse conclusion holds for some other PSRs: SNR G296.5+10 (PKS 1209−51/52) with an age of 7 kyr convincingly associates with PSR 1E 1207.4−5209 with characteristic age of (340±140) kyr [11]. Also, PSR J1811-1925/SNR G11.2−0.3 association is younger, by a factor of ~12, than characteristic age of PSR J1811−1925 [12]; AXP 1E2259+586 with characteristic age 226 kyr is certainly associated with the young SNR CTB 109 with age ~3—21 kyr [13].

(7) An assumption that the neutron star birth-place should locate at the geometrical centre of the associated SNR limits the search radius for possible PSR/SNR associations. Bock and Gvaramadze [14] claimed that SNRs can be products of an off-centre supernova explosion in a preexisting bubble created by the wind of a moving massive star. A cavity supernova explosion of a moving star results in a considerable offset of the neutron star birth-place from the geometrical centre of the SNR. This can therefore enlarge the circle of possible PSR/SNR associations. According to the hypothesis, in SNR G 315.4−2.3 (MSH 14−63), Gvaramadze and Vikhlinin [15] has recently found a possible young "ordinary" PSR whose photon index and non-thermal luminosity are almost the same as those of the Vela PSR and the PSR J0205+6449 in the SNR 3C 58.

2.2 Criteria to Confirm the Association

Associations between PSRs and SNRs are usually judged on criteria such as agreement in ages and distances and whether the transverse velocity derived for the PSR is reasonable. This method is difficult to some degrees, because an independent measure of the age and distance of both SNRs and PSRs is usually difficult and inexact. A simple method taken by many authors to judge the relation is to check if a PSR and an adjacent SNR lie along similar lines of sight. The method has to be carefully considered because they are possibly physically unrelated. A very powerful method of confirming an association is the observing interaction between PSR and SNR, because when a PSR is still inside its parent SNR, the high pressure of the surrounding plasma can confine the PSR's relativistic wind generating synchrotron emission observable as a PWN. However, young PSRs are rare, and cases where such interaction is apparent are rarer still. Frail and Scharringhausen [16] have concluded that only young PSRs with high rotational energy losses produce an observable radio nebula. About twelve radio PWNs are known unambiguously around PSRs (B0531+21, B1509−58, B0540−69, B0833−45, B1757−24, B1853+01, B1951+32, B0906−49, B1643−43, B1706−44, J1811−1925, J1846−0258). At other than radio wavelengths, in particular X-rays, there are more than ten detections of PWNs around PSRs who are associated with SNRs in our galaxy and in the Large Magellanic Cloud (LMC). As we have known that there are at least two morphological types of PWNs: those with so-called filled-center morphology, in which the PWN is confined by the gas pressure of the surrounding medium (e.g., the Crab), and those with a bow-shock morphology, where the PWN is confined by ram pressure resulting from the PSR's motion with respect to its environment (e.g., PSR J1758−24/G5.4−1.2 [17]).

There are many methods to measure distances and ages of both SNRs and PSRs. We summarize nine methods to measure distance and six for age.

For distance:

(1) Distance from the surface brightness-diameter relationderived by Clark and Caswell [18];
(2) Kinematic-optical distance [19];
(3) HI absorption distance [20];
(4) Proper motion plus optical expansion;
(5) Association with distance-known objects (e.g., IC443/S249);
(6) X-ray observations as distance indicates [21];
(7) Low-frequency radio absorption [22];
(8) Parallax measurements for PSR distance [20,23];
(9) Dispersion measurements for distances of PSRs [24].

For age:

(1) The spin-down age for PSRs, which is a basic method of estimating PSR's age;
(2) The dynamical age for the SNRs [25];
(3) The SNR age estimated by the surface brightness-age relation [26];
(4) The SNR age derived from the different evolution stage of SNR evolution model [27];
(5) The PSR age calculated by the known PSR proper motion [28];
(6) The SNR age based on the expansion velocity of associated Hα filement [29].

Most authors take advantage of the surface brightness-diameter relation to estimate the SNRs' distance. However, the technique is probably the most disputed method of distance determination for SNRs. There have been many statistical studies which show that there is no evidence for a working brightness-diameter relation [30]. The observations of HI emission and absorption towards PSRs together with a rotation curve or velocity field for the Galaxy allow the derivation of lower and/or upper distance limits, depending on the distribution of HI in the line of sight [31]. A widely-used distance measure to a PSR is from its dispersion measure, based on the Galactic electron density distribution model due to Taylor and Cordes [24]. But the Taylor and Cordes model, which lacks fine structure (i.e., small-scale clumps), likely underestimates the electron density and, hence, overestimates the distance for this line of sight [32].

3 Results and Discussion

3.1 50 Pairs of Suggested PSR/SNR Associations

By searching the literature published until the end of 2003, we found 50 claimed pairs of PSR/SNR associations (see Table 1). In Table 1, SNRs are classified as plerions (P), which show

Table 1 Present Sample of Associations Between Known SNRs and PSRs or Neutral Stars

SNR (other name)	Type	Distance /kpc	Age /kyr	Evidence and PSR	Distance /kpc	Char Age (real) /kyr	Period /ms	Reference
G5.4−1 2 (Milen 56)	S	4.3–5.3	14	PWN J1758−24	3.5–5.0	15.5 (39–170)	125	[10]
G6.4−0 1 (W28)	C	1.6-3.6	35-150	J1801−23	9 4±2.4	<58.3	412	[33]
G8 7−0.1 (W30)	S?	5-6	~16	J1803−2137	3.9 5.3	15.8	134	[17 34]
G11 2−0 3	C	~5	~2	PWN J1811−1925	?	24 (~2)	65	[12, 35]
G16 8−1.1	?	?	?	B1822-14	~3 5	200	279	[36]
G23 3−0.3 (W41)	S	4.8	<50	B1830−08	4 5	148	85	[37]
G24 7+0.6	C	4.4	12	B1832−06	6.3	120	?	[37]
G27.4−0.0 (Kes 73)	S	6.0–7.5	~2	AXP 1E 1841−045	?	4.7 (<10)	11800	[38]
G29.6+0 1	S	<20	<8	AXP J1845−0258	8.5–15.0	? (~10)	7000	[38]
G29 7−0 3 (Kes 75)	C	9-21	~1	PWN J1846−0258	?	0.725 (0.98–1 77)	300	[39, 40]
G34 7−0 4 (W44,3C392)	P	2.5	>10	PWN Γ-ray? B1853+01	3.3	20.3	267	[41, 42]
G42.8+0 6	S	10±3	a few 10	J1907+0918	7 7	38	226	[4, 43]
G54 1+0.3	P?	3.2–8.0	1 5-6 0	PWN J1930+1852	~12	2 9 (1 5 6 0)	136	[8, 44]
G55 0+0.3 (G55 2+0.5)	S	14	<1500 2300	J1932+2020	9.14	1100	268	[45]
G57.3+1.2	S?	5.4±1 9	40-290	B1930+22	6.6±2i.0	39 8	144	[46]
G69.0+2.7 (CTB 80)	C	2	77	PWN Γ-ray B1951+32	2.4±0.2	107 (64±18)	39 5	[28, 47]
G106.3+2 7	?	0.8?	?	PWN J2229+6114	0.8?	10.5	51 6	[48, 49]
G109 1−1 0 (CTB109)	S	2 5–3.5	~10	AXP 1E2259+586	4.6-5.1	100–200 (<10)	6979	[50]
G114.3+0.3	S	1 6–3.8	a few 10	PWN B2334+61	~1.4	40.9	495	[51 52]
G130.7+3 1 (3C58)	P	3 2	0.82	PWN J0205+6449	3.2	5 4	65	[8]
G160.9+2.6 (HB9)	S	1.1–4.0	a few 100	B0458+46	1.8	1813	639	[53]
N49	S	50	5–16	AXP and SGR J0526−66	50	2 (~6.6)	8040	[38, 54]
G180.0−1 7 (S147)	S	0.8–1.6	80-200	PWN J0538+2817	1 2	600	143	[55, 56]
G184.6−5.8 (Crab SNR)	P	2	0.94	PWN Γ-ray B0531+21	2	1.3	33	[57]
N157B (SNR 0538−691)	P	51	~5	PWN X-ray J0537−69	51?	~5	16	[58]
SNR 0540−693 (N158A)	C	55	0.8–1 1	PWN B0540−69	49.4	1 67	50	[59]
G189 1+3.0 (IC 443,3C157)	S	1.5	30	PWN? B0611+22	4.7	~80	335	[60]
G205 5+0.5	S	0.8-1.6	30-150	B0656+14	0.2–0.8	110 8	385	[61]
G263.9−3 3 (Vela SNR)	C	0.22–0.28	5–29	PWN Γ-ray B0833−45	0 24-0.37	11 2 (10)	89	[23, 62]
G284 3−1 8 (MSH 10−53)	S	3.0±0.6	~10	J1016−5857	7–12	21 or 16	107/128	[63]
G290.1−0.8 (MSH 11−61A)	S	6.9–12.0	10–20	J1105−6107	7	63	63	[64]
G292.0+1.8 (MSH 11−54)	C	3.6–5.5	2.40–2.85	PWN J1124−5916	?	2.9	135	[8, 65]
G292.2−0.5	S	~5?	2.9?	J1119−6127	>30	1.6	408	[32, 66]
G296.5+10.0 (PKS 1209−51/52)	S	1.3–3.9	3–21	RQNS 1E 1207 4−5209	2	340±140	424	[67, 68]
G296.8−0.3 (1156-62)	S	9.6±0.6	2–10	J1157−6224	~10	1600	401	[69]
G308.8−0 1	S	4 0–6.9	<32.5	PWN ? J1341−6220	15	12	193	[70]
G320.4−1.2 (MSH 15−52)	C	3 8–6.6	6–20	PWN Γ-ray B1509−58	4.4	1 7	150	[71, 72]
G332.4−0.4 (RCW 103)	S	2 7 6 5	1–8	J1617−5055	6.1–6.9	8.1	69	[73]
G332.4+0.1 (Kes 32)	S	3 7	~5	B1610−50	5–15	7.45	231.6	[74]
G335.2+0 1	S	6.5	?	J1627−4845	5.1–8.5	2700	612	[75]
G341.2+0.9	C	8.3 9.7	?	PWN B1643−43	6.9	32 6	232	[76, 77]
G343.1−2.3 (MSH 17−41)	S	~3	5–6	PWN Γ-ray B1706−44	1.8–3.6	17 5	102	[14, 78]
G351 7+0.8	S	?	?	J1721−3532	~4.8	178	?	[79]
G354.1+0.1	C?	4 7-5.6	?	B1727−33	4 2	26	139	[77]
G0 9+0 1	C	~10	1–7	PWN CXOU J1747−2809 ?	?	(<2 7)	80 190	[80]
G10 0−0.3 (W 31)	?	14.5	?	SGR 1806−20	?	?	7500	[38]
G111 7−2 1 (Cassiopeia A)	S	3 4	0.340	CXO J2323+5848	?	?	?	[81]
G266 2−1 2 (RX J0852.0−4622)	S	0.25-1 0	?	RQNS AX 0851 9−4617 4	?	?	?	[82, 83]
G337.0−0 1 (CTB 33)	S	11	?	SGR 1627−41	11	?	?	[84, 85]
G346.5−0 1 ?	?	5 5-11 0	?	AXP J1708−4009	?	? (<10)	10999	[38]

a filled-center, flat-spectrum nebula presumably powered by a compact object; shell (S), which show basically empty shells of emission; and composites (C), which show a shell in addition to a center plerion. The '?' represents an uncertain state or no data available.

3.2 Reality of 50 Pairs Cataloged Associations

Although we give 50 pairs claimed associations in our sample, parts of them are worth of suspicion for weaker criteria [38,96,97]. For example, PSR B1822−14 is suggested to associate with SNR G16.8−1.1 due to their close position, because there are less available data on the association. Based on a simple model-free statistical analysis of around 30 pairs proposed PSR/SNR associations, Lorimer *et al.*[88] concluded that at most 17 associations are likely to be real. Eight pairs associations given by Lorimer *et al.* have been cataloged into our sample, but we mention that Gaensler and Frail [10] suggested that one of the eight pairs, PSR B1757−24/SNR G5.4−1.2, has to change the age extremely from 1.55 to 170 kyr if the association is real. However, at least 20 pairs of our sample are likely real because the strongest supporting evidence, the PWN around the PSRs, have been detected. From the observational point of view, along with new appearing evidence some PSR/SNR associations in our sample will be continuously either confirmed or debated.

3.3 The Possibility and Reasonableness to Detect New PSR/SNR Association

Recent observational progress suggests that PSR/SNR associations may be older than previously documented by an order of magnitude, that the characteristic age of a PSR may be different from its true age by at least one order of magnitude, and that neutron star birth-place may have a considerable offset from the geometrical centre of its associated SNR. Therefore it is possible and reasonable to search new PSR/SNR associations on a larger scale. Such PSR/SNR association candidates may be located in a circular area with centre at geometrical centre of a SNR with known distance, and with radius equaling sum of the half-radius of a SNR plus its associated PSR moving a distance during the SNR present lifetime (if unavailable, assuming 10 kyr, because the age of a SNR in Sedov phase is smaller than 10 kyr) and at typical transverse velocity of 500 km/s [89] . The previous search for PSRs in SNRs or SNRs around young PSRs by many authors [52,59,61,75,77,88,90] can help to select PSR/SNR association candidates. Actually, some unconfirmed candidates (e.g., PSRs with large characteristic age at a large radius, which were considered not to associate with SNRs in previous studies) are worth to be studied further.

3.4 Three Pairs of Special PSR/SNR Associations

(1) SNR G11.2−0.3 / PSR J1811−1925

G11.2−0.3 is a remarkably spherical young SNR with age ~2 kyr nearing the onset of the Sedov phase based on nonequilibrium ionization modeling of the spectrum of the shell [91]. The distance ~5 kpc to G11.2−0.3 has been measured reasonably well from HI measurements [92]. The Chandra X-ray Observatory imaging observations of G11.2−0.3 [12] reveals the morphology of the PWN. Roberts *et al.* [35] have measured the X-ray spectrum of various components of the shell and PWN of G11.2−0.3 and compared them with the radio spectrum and morphology, and concluded that the shell temperature and hard X-ray structure are consistent with age ~2 kyr remnant. A 65 ms X-ray and radio PSR with characteristic age 24 kyr is located within 8″ of the geometric center of the SNR shell [93]. Its characteristic age is much greater than the apparent age of the SNR and that inferred from its remarkably central position within the remnant given any reasonable transverse velocity [12] . The simplest explanation for this apparent age discrepancy is that the initial spin period of the PSR is very near the current spin period. This provides strong confirming evidence that the system is younger, by a factor of ~12, than the characteristic age of the PSR. The age discrepancy suggests that PSR characteristic ages can be poor age estimators for young PSRs.

(2) SNR G55.0+0.3/ PSR J1932+2020

G55.0+0.3 is among the faintest SNRs known. From analysis of HI data, Matthews *et al.* [45] estimated that the SNR's kinematic distance is 14 kpc, yielding a radius of approximately 70 pc, making it one of the largest known SNRs, and that the SNR's age upper limit is $(1.9\pm0.4)\times10^3$ kyr due to the remnant being in the radiative phase. The SNR age exceeds the conventional limits on observable SNR lifetimes in the literature by a factor of 5 (the average age of the currently known SNR population is about 60 kyr [17]), implying that the radiative lifetimes of SNRs could be much longer than previously suggested. PSR J1932+2020 lies at an angular distance of only 1.3 times the radius of the SNR. Its characteristic age is 1.1×10^3 kyr [94], and its DM distance is approximately 9 kpc, with an uncertainty of 25%. This proposed SNR/PSR association is older than any previously documented by an order of magnitude. This maybe implies that some weaker SNRs may be found around a few of older PSRs in the future.

(3) SNR G343.1−2.3/ PSR B1706−44

McAdam *et al.*[95] first proposed the association; then Nicastro *et al.*[86] questioned it due to distance inconsistencies, a lack of morphological signatures of interaction between the PSR and SNR, and scintillation measurements indicating a transverse velocity for the PSR at least 20 times smaller than that required if the PSR originated in the geometric center of SNR G343.1−2.3 about 17 kyr ago. But Dodson and Golap [78] and Bock and Gvaramadze [14] insisted that the association is probably real based on their new evidence and a reasonable assumption that both the PSR and the SNR are the remnants of a supernova (SN) which exploded within a mushroom-like cavity (created by the SN progenitor wind breaking out of the parent molecular cloud). The fact that both convincing radio and X-ray PWNs have been found supports the association [76,78].

PSR B1706−44 with a characteristic age of 17.5 kyr is one of a very small number (six) of radio PSRs to have been detected as a pulsed γ-ray source [96]. Its DM distance is (1.8 ± 0.5) kpc, and HI distance is in the range of 1.8—3.8 kpc [97]. McAdam *et al.* [95] estimated the distance of 3 kpc for the remnant, derived from the surface brightness-diameter relationship, and the approximate age of 5—6 kyr, derived on the basis of the Sedov-Taylor solution.

3.5 Individual SNR/AXP or SGR or RQNS Association

There has been a growing recognition of diversity in the neutron star population, i.e., the

RQNSs detected in the X-ray only; the AXPs, which are characterized by soft X-ray pulsations and cannot be powered by rotational energy or by accretion of matter from a binary companion star; the SGRs, whose rotational and radiative properties are strikingly similar to the AXP but emit at γ-ray energies. Recently a few observations supported a close relationship (perhaps evolutionary) between AXPs and SGRs, with both being magnetars [98,99]. Four of the known six AXPs and three of the known five SGRs have been claimed to have the associated SNRs. AXPs are characterized by spin periods in the range of 5 to 12 s, steady spin-down (10^{-11} s/s). SGRs have spin periods in the range of 5 to 8 s but somewhat smaller characteristic ages than the AXPs, less than a few thousand years [38].

4 Conclusions

We have given a sample containing 50 pairs claimed PSR/SNR associations so far. The present sample of PSR/SNR associations is still small comparing with the number of found PSRs and SNRs, it is difficult for us to summarize any reliable statistical results on typical features of PSR/SNR associations at present. Based on the recently observational progress, we think that it is possible and reasonable to give and observe a bigger sample of PSR/SNR association candidates and find more PSR/SNR associations in the work in the future.

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