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New Pulsar/Supernova Remnant Associations

W.M. Goss, D.A. Frail *National Radio Astronomy Observatory, Socorro, NM, USA*

J. B. Z. Whiteoak *School of Physics, University of Sydney, Sydney, Australia*

1. Introduction

In recent years numerous claims have been made of new pulsar/supernova remnant associations. The list of potential associations has grown to the point where there are as many as perhaps 17. This is a far cry from the early decades of pulsar astronomy when only the Crab and Vela pulsars had associated remnants. Progress in this field is in large part due to advances in high frequency pulsar surveys (Clifton et al. 1992, Johnston et al. 1992) and low frequency radio imaging efforts (Cornwell 1993).

It is impossible to overstate the importance of these associations in studying the origin and evolution of neutron stars. Through the study of young pulsars and their supernova remnants we can gain information about the periods, magnetic fields, and velocities of pulsars at their birth. The supernova remnant provides an independent age and distance estimate for the system and acts as a probe of the ambient gas (density, filling factor, pressure, etc.) (Shull, Fesen & Saken 1989). In a recent paper Frail, Goss & Whiteoak (1994) presented evidence for three new pulsar/supernova remnant associations based on VLA observations and drew some general conclusions from a study of all associations with characteristic ages τ_c <60,000 yrs. The purpose of this paper is to summarize those results and to discuss the implications of their findings.

2. New Associations

2.1 *PSR 1643–43 and G341.2+0.9*

PSR1643–43 has a period P of 232 msec, a characteristic age τ_c of 32.6 kyrs and a dispersion measure based distance of 6.9 kpc (Johnston et al. 1994). A 20-cm image toward PSR 1643–43 (Fig. 1) shows that it lies in an extended (22′ × 16′) radio source which is assigned the galactic source name G 341.2+0.9. Comparison with data at 90 cm shows that G 341.2+0.9 is a non-thermal source and likely a

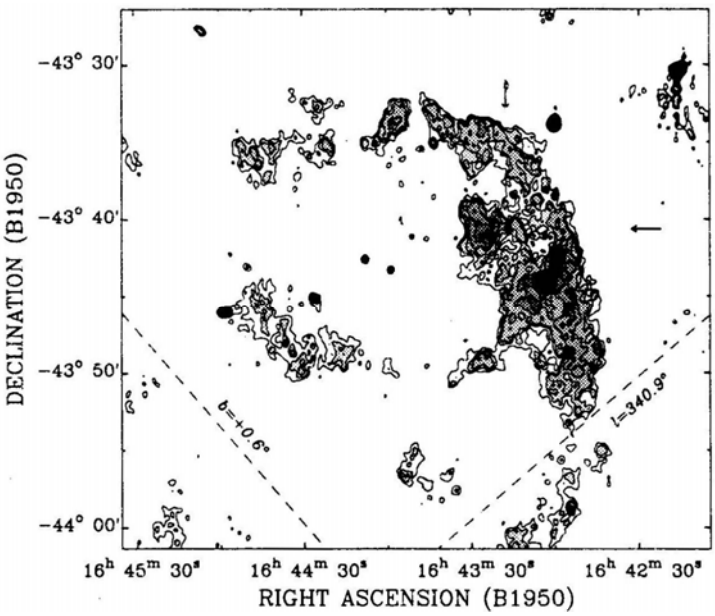

Figure 1: The PSR1643–43 and G 341.2+0.9 association. The position of the pulsar is indicated by the arrows.

supernova remnant with a Σ-D distance between 8.3-9.7 kpc (Milne 1979, Clark & Caswell 1976, Allakhverdiyev et al. 1983). In addition to the shell-type emission which brightens on the side closest to PSR1643–43, there is diffuse emission in the immediate vicinity of PSR 1643–43. This includes a 4′ nebulosity just east of the pulsar which is joined to the pulsar by a “bridge” of emission. The appearance of this structure is consistent with an implied westward motion of the pulsar.

Frail et al. (1994) argue that the similar distances of the pulsar and the supernova remnant and the morphological evidence, are strong indicators that a real physical association exists between this supernova remnant and the pulsar.

2.2 *PSR 1706–44 and G 343.1–2.3*

PSR 1706–44 has a period of 102 msec, a characteristic age of 17.5 kyrs and a dispersion measure based distance of 1.8 kpc (Johnston et al. 1994). McAdam, Osborne & Parkinson (1993) have claimed that a faint arc of radio emission, on which PSR 1706–44 is superimposed, is a supernova remnant and that the two objects were physically associated. New data by Frail et al. (1994) raise some questions about the validity of the association. PSR 1706–44 is indeed found on the edge of the non-thermal shell of G 343.1–2.3, 23′ south-east of the geometric center, but a higher resolution image at 20 cm (Fig. 2) shows a 4′ diameter radio "halo" surrounding PSR 1706–44.

If the pulsar originated at the center of G 343.1–2.3 and traveled to its current position, then a cometary nebula pointing back to the center might be expected, much like that surrounding PSR 1757–23 outside G 5.4–1.2 (Frail & Kulkarni 1991). Furthermore there is no clear signs of an interaction between PSR 1706–44 and G 343.1–2.3. For these reasons Frail et al. (1994) considered the association between PSR 1706–44 and G 343.1–2.3 as unlikely but they could not could rule it out. Proper motion measurements should settle this issue.

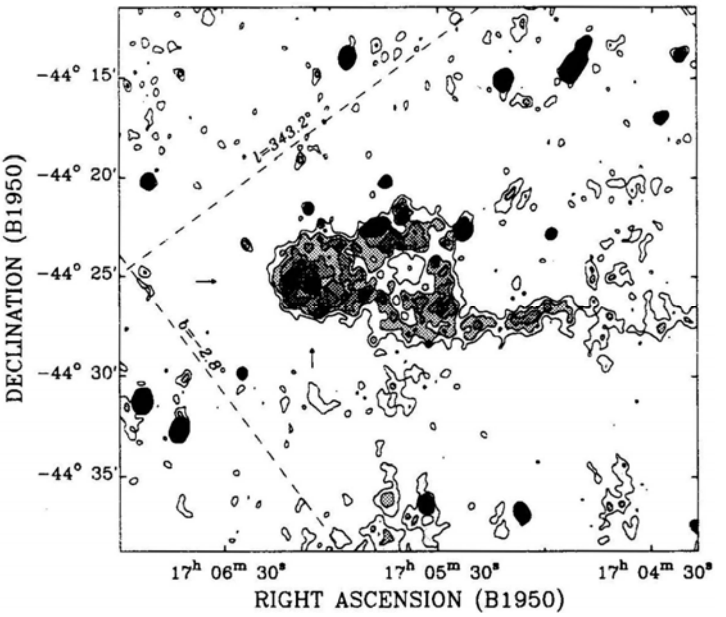

Figure 2: The PSR 1706–44 and G 343.1–2.3 association. The position of the pulsar is indicated by the arrows.

2.3 *PSR 1727–33 and G 354.1+0.I*

PSR 1727–33 has a period of 139 msec, a characteristic age of 26.0 kyrs and a dispersion measure based distance of 4.2 kpc (Johnston et al. 1994). The 20-cm image toward PSR 1727–33 shows a most unusual radio source. In addition to two bright HII regions G 354.486+0.085 and G 354.2–0.054 at a distance of 4.7-5.6 kpc there is a "contrail" of non-thermal emission that appears to originate from the pulsar. G 354.1+0.1 is not a typical shell-type or pulsar-powered SNR, but rather has the axisymmetric morphology of a rare class of non-thermal radio sources which includes G 357.7–0.1 (Shaver et al. 1985, Becker & Helfand 1985). Although it was once believed that the radio emission from these sources was powered by an accreting binary (Helfand & Becker 1985), it is now more likely that it arises from the spindown energy of a young, high velocity pulsar (Predehl & Kulkarni 1994).

Frail et al. (1994) argue that PSR 1727–33 is at the same distance as the complex of HII regions and is physically associated with G 354.1+0.1.

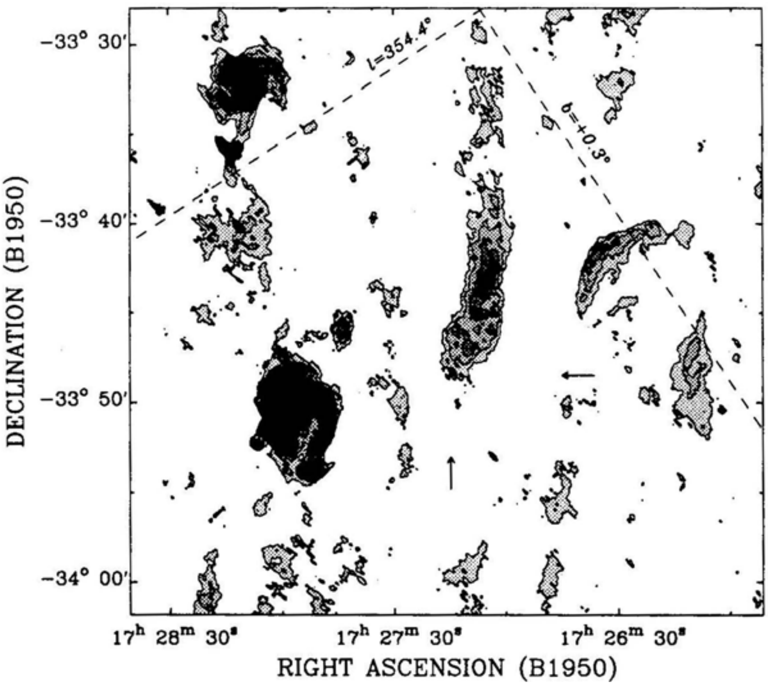

Figure 3: The PSR 1727–33 and G354.1+0.1 association. The position of the pulsar is indicated by the arrows.

3. Discussion

With the new association discussed above and a host of other associations that have been proposed in recent years (e.g Frail, Kulkarni & Vasisht 1993, Kaspi et al. 1992, Kassim & Weiler 1990, Kulkarni et al. 1993) it is worth taking a preliminary look at the data to draw some general conclusions on the current sample of pulsar/supernova remnant associations.

3.1 *The Mean Lifetimes of Supernova Remnants*

Earlier unsuccessful efforts (e.g Braun, Goss & Lyne 1989) to look for supernova remnants around young pulsars lead to the suggestion that the progenitors of pulsars exploded in low density environments ($n_o \simeq 0.01$ cm^{-3}), resulting in the rapid expansion and dissipation of the remnant, which faded beyond detectability after $\simeq 10^4$ yrs (Bhattacharya 1990). Frail et al. (1994) re-examined this result and found that most remnants with associated pulsars were expanding into an ISM with a density of approximately 0.2 cm^{-3}. Furthermore, the radio lifetime of these supernova remnants is > 60, 000 years. Pulsars may play a role in extending these lifetimes (see below).

3.2 *The Distribution of Pulsar Velocities at Birth*

Proper motion studies (e.g. Harrison, Lyne & Anderson 1993) have established that pulsars are high velocity objects giving $\langle V_{PSR} \rangle \simeq 200$ km s^{-1}. However, there are well known selection effects in these samples (Cordes 1986, Helfand & Tademaru 1977) that limit our ability to measure the true distribution of pulsar velocities at birth.

Fortunately, an *inferred* velocity can be derived for the young pulsars associated with supernova remnants which is unaffected by this bias. The displacement of the pulsar from the geometric center of the remnant and the age of the pulsar gives a transverse pulsar velocity (Shull et al. 1989). Details of the method and the various difficulties and uncertainties are discussed more fully in Frail et al. (1994). The median value for V_{PSR} derived by this method is 480 km s^{-1}. Eliminating questionable associations does not significantly change the result. By correcting for the selection effect directly and using the newer Taylor & Cordes (1993) distance model Lyne & Lorimer (1994) have derived a mean pulsar birth velocity of 450 ± 90 km s^{-1}.

3.2.1 The Distribution of Pulsars in the Galaxy

The implications of the existence of large numbers of high velocity pulsars is far-reaching; it has an impact on the mechanisms that give rise to pulsar velocities at birth, and it affects how they interact with their surroundings and what the final distribution of pulsars in the Galaxy will be. If this result holds up we will need to re-examine the birthrate of pulsars, their survival in binary systems and their escape from globular clusters and the Galaxy (Lyne & Lorimer 1994).

For example, if a significant population of high velocity pulsars exist then they could escape the disk, forming a halo population of old neutron stars. This extended halo population has been postulated to exist for many years in order to explain γ-ray bursts as a galactic phenomena (e.g. Li & Dermer 1992). While high velocity neutron stars no longer seem to be an “ad hoc” population, other problems remain if they are the progenitors of γ-ray bursts (Paczynski 1993). In order to not violate the high degree of angular isotropy seen by current γ-ray instruments, the high velocity pulsars must possess some special property (high B field?) that distinguish them from the low velocity objects and this is presumably related to the origin of the γ-ray bursts.

3.2.2 Interacting Composites

With $V_{PSR} \simeq 500$ km s^{-1} a pulsar catches up to its supernova remnant in only 40,000-70,000 years (Shull et al. 1989). Such pulsars will act as a “fountain of youth" injecting fresh relativistic particles and field into the compressed shell of the aging remnant. Thus ambient density may not be the dominant factor influencing the radio lifetimes of supernova remnants. The distinction between shell-type remnants and pulsar-powered nebulae has been blurred, creating a new class of supernova remnants called "interacting composites". Examples may include a number of objects mentioned by Shull et al. (1989) like G 5.4-1.2, W28 and G 57.1+1.7 as well as G 114.3+0.3 (Kulkarni et al. 1993), G 308.8–0.1 (Kaspi et al. 1992), and MSH 15–52 (Caswell, Milne &·Wellington 1981).

4. Caveat Emptor

Some of the 17 pulsar/supernova associations that are currently known are less secure than others. Identifying those associations which are firmly established is an ongoing effort and a matter of active debate. Furthermore, some young pulsars seem to have no associated supernova remnant. Future efforts should concentrate on measuring proper motions to test the veracity of the associations. Both the magnitude and the direction of the velocity vector is useful in this regard. The former will test whether the high velocities are real and the latter will test the association (i.e. the pulsar must originate from the remnant). Instead of concentrating on the centers of supernova remnants, future searches for young pulsars would be well-advised to look both outside the remnant and in regions of the remnant where there is a local brightening, suggesting a possible pulsar/supernova remnant interaction.

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