A SEARCH FOR PULSAR WIND NEBULAE USING PULSAR GATING

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ABSTRACT. Previous searches for radio pulsar wind nebulae (PWN) suggest that only the youngest and most energetic pulsars power PWN. However the selection effects associated with such searches are severe, in that emission from a faint compact PWN will be masked by that from its associated pulsar. This has motivated us to search for radio PWN using the technique of pulsar gating, which allows us to “switch off” the pulsed emission and see what is hidden underneath. This search has resulted in the detection of the faintest radio PWN yet discovered, while non-detections around other pulsars have implications for previous claims of nebular emission and for associations with nearby supernova remnants.

1. Introduction

A pulsar loses most of its rotational energy in a relativistic wind which, when confined, may be observable as a pulsar wind nebula (PWN). PWN are our main diagnostics of the pulsar wind and its environment, but at radio wavelengths, just seven pulsars are known to have definite PWN. All these pulsars are young (six are younger than 20 000 kyr), have high spin-down luminosities ($\dot{E} > 10^{35}$ erg s$^{-1}$) and are associated with supernova remnants (SNRs). The obvious question to ask is whether there are radio PWN around other pulsars. However, finding such PWN presents an observational challenge, because the expected faint and/or compact sources might be masked by emission from their associated pulsars.

The results of a systematic survey for radio PWN have been reported recently by Frail & Scharringhausen (1997, hereafter FS97). They used the Very Large Array (VLA) at 8.3 GHz and at 0′′8 resolution, reasoning that this choice of observing parameters would allow them to best separate out any PWN from its associated pulsar. FS97 observed 35 pulsars, quite sensibly choosing pulsars with a high $\dot{E}$ or space velocity. However, they failed to detect any PWN down to a 5$\sigma$ sensitivity of 0.2 mJy beam$^{-1}$. FS97 concluded that only young energetic pulsars produce observable radio PWN, but could not rule out that they had simply resolved out any nebular emission.

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Fig. 1. Ungated (left) and gated (right) 1.3 GHz observations of PSR B1055–52, both shown with the same grey-scale range. Without pulsar-gating, the pulsar itself, as well as artifacts associated with scintillation effects, make it impossible to say anything useful about the presence or absence of any PWN. With the pulsed emission removed, we can put a limit of 0.4 mJy beam\(^{-1}\) (5\(\sigma\)) on any unpulsed emission.

2. New Observations

The results of FS97 have prompted us to search for PWN at southern declinations using the Australia Telescope Compact Array (ATCA). Rather than just image the pulsar and surrounds, we have used the technique of pulsar gating, in which data are recorded at high time resolution so that images can be made in which the pulsar has been “switched off” (see Figure 1). We observed five pulsars, at significantly lower frequency (1.3 GHz) and resolution (20\('\)) than did FS97. Because we can gate out the pulsar, our choice of observing parameters results in a surface brightness sensitivity 200 times fainter than that achieved by FS97.

Of the five pulsars we observed with the ATCA, we were successful in finding a PWN associated with PSR B0906–49, but saw no nebular emission towards PSRs B1046–58, B1055–52, J1105–6107 or B1610–50. Results on PSR B0906–49 have been reported by Gaensler et al (1998), while the other pulsars will be discussed fully by Stappers et al (1998). Here we review some of the highlights of this study.

2.1. PSR B1610–50

With a characteristic age of just 7.4 kyr, and a high \(\dot{E}\) of \(2 \times 10^{36}\) erg s\(^{-1}\), PSR B1610–50 is a prime candidate for powering a radio PWN. However a gated image shows no PWN down to a 5\(\sigma\) limit of 1 mJy beam\(^{-1}\).

PSR B1610–50 is similar in its age, magnetic field strength and \(\dot{E}\) to PSRs B1757–24 and B1853+01, both of which generate prominent PWN with bow-shock morphologies. A bow-shock PWN is confined by the ram pressure, \(\rho v^2\), resulting from the relative
motion of the pulsar with respect to the ISM. The lack of a PWN associated with B1610–50 suggests that $\rho v^2$ in this case is much less than for PSRs B1757–24 and B1853+01, and we thus infer for B1610–50 a space-velocity $v_{\text{PSR}} < 130 n^{-1/2} \text{ km s}^{-1}$, where $n \text{ cm}^{-3}$ is the ambient density.

An association between PSR B1610–50 and the nearby SNR Kes 32 has been claimed by Caraveo (1993), but implies a projected velocity for the pulsar $>3600 \text{ km s}^{-1}$. This can only be reconciled with our result if $n < 0.001 \text{ cm}^{-3}$, in which case Kes 32 itself should not be visible. Furthermore, as demonstrated in Figure 2 the region is a complex one, containing three spiral arms, at least three SNRs and eight known pulsars. Thus spatial proximity alone is hardly compelling evidence for a pulsar/SNR association. Finally, if PSR B1610–50 indeed has this high inferred space velocity, then one might expect significant distortion of Kes 32 where it was penetrated by the pulsar (as is seen in the case of G5.4–1.2 and PSR B1757–24). However the appropriate part of the shell shows no such effect. From all these results, we can conclude that PSR B1610–50 is not associated with SNR Kes 32, nor with any other known remnant. The lack of an associated SNR for such a young pulsar implies an ambient density $n \lesssim 0.05 \text{ cm}^{-3}$ (e.g. Kafatos et al 1980), which is consistent with the lack of a radio PWN for typical pulsar space velocities.

2.2. PSR B1055–52

PSR B1055–52 is a comparatively old pulsar ($\tau = 345 \text{ kyr}$) with a moderate spin-down luminosity ($\dot{E} = 3 \times 10^{34} \text{ erg s}^{-1}$). An extended radio PWN was reported by Combi et al (1997) using observations with a 30 m single dish, while in hard X-rays an extended
clumpy PWN is seen by ASCA (Shibata et al 1997).

Our gated ATCA data show no radio PWN associated with PSR B1055–52 on any spatial scale (see Figures 2 and 3). Our observations certainly have the sensitivity and $u-v$ coverage to detect the radio nebula of Combi et al (1997), and we conclude that the source they claim as a PWN is clearly spurious and is a result of confusion, typical when small single dishes are pointed at complex regions.

In Figure 3 we show an overlay between radio and X-ray images of the region. The clumps of X-ray emission, claimed by Shibata et al (1997) to be part of an extended PWN, coincide with radio point sources, and also correspond to X-ray point sources in ROSAT data (W. Becker, these proceedings). Thus we think it more likely that the apparent X-ray PWN corresponds to emission from unrelated background sources.

2.3. PSR B0906–49

PSR B0906–49 is a relatively young ($\tau = 112$ kyr) and energetic ($\dot{E} = 5 \times 10^{35}$ erg s$^{-1}$) pulsar. Gated ATCA observations result in the image shown in Figure 4, in which an off-pulse source can be seen at the position of the pulsar. This source is extended and has no detectable polarisation, and we conclude that it is best interpreted as a bow-shock PWN associated with PSR B0906–49. A possible trail extends behind the PWN, with an axis of symmetry which aligns with the direction along which the PWN is extended.

Using a projected space velocity for B0906–49 of $\sim 60$ km s$^{-1}$ (Johnston et al 1998),
Fig. 4. Gated 20 cm image of PSR B0906–49. The pulsar has been gated out, but is coincident with the PWN. The FWHM of the synthesised beam is shown at lower-right.

pressure balance arguments can be used to infer an ambient density \( n > 2 \, \text{cm}^{-3} \). Thus the ram pressure which confines this PWN results mainly from the high ambient density, rather than from the pulsar velocity. PSR B0906–49 is the oldest pulsar yet to be associated with a radio PWN; it is also worth noting that this PWN is 100 times fainter than could have been detected by FS97.

3. Conclusions

Pulsar-gating with the ATCA has allowed us to carry out a deep search for radio PWN around five pulsars. No PWN was found for PSRs B1046–58, B1055–52, B1105–6107 or B1610–50. From these results, we argue that PSR B1610–50 is not associated with SNR Kes 32, and also conclude that there is no evidence to support previous claims of radio and X-ray nebulae associated with PSR B1055–52. We successfully detected a faint PWN around PSR B0906–49. This PWN seems quite different from other bow-shock PWN, in that it is associated with a low velocity pulsar in a dense medium.

Our results bear out the expectation that only pulsars with a high \( \dot{E} \) will produce radio PWN. Data on known PWN suggest that a minimum ram pressure \( n \times v_{\text{PSR}}^2 \gtrsim 10^4 \, (\text{km s}^{-1})^2 \, \text{cm}^{-3} \) is required to confine the wind sufficiently to produce observable radio emission.

Our small survey clearly demonstrates that there are severe selection effects associated with previous searches for radio PWN. There may well be an undiscovered population of faint PWN similar to that found around PSR B0906–49, and we intend
to follow up on this possibility by using pulsar-gating on the VLA to observe a large number of sources. Apart from finding new and interesting PWN, we hope to use the results of such a survey to properly constrain the minimum $\dot{E}$, $n$ and $v_{PSR}$ required to produce a radio PWN.

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