Recent Discoveries of Energetic Young Radio Pulsars

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ABSTRACT. The observed population of young radio pulsars has grown substantially in recent years due to a combination of large-scale surveys and deep targeted searches. Many of the pulsars are associated with supernova remnants and/or unidentified gamma-ray sources. This review summarises the state of play and looks ahead to likely advances in the near future.

1. Introduction
The insightful prediction of Baade & Zwicky (1934) that neutron stars are produced during core-collapse supernovae gained significant observational credence in 1968 with the discovery of young, rapidly-rotating radio pulsars in the Crab and Vela supernova remnants (Staelin & Reifenstein 1968; Large, Vaughan & Mills 1968). The characteristic ages\(^1\) of these pulsars are respectively \(\sim 10^3\) and \(10^4\) yr. Fifteen years later, in 1983, despite the sample rising to over 300 objects, only a further 9 young pulsars\(^2\) were known.

Fig. 1a shows the 1983 sample in the period–period derivative \((P - \dot{P})\) plane. Since we see only a snapshot of the population, most observed pulsars tend to be middle-aged \((10^6 - 10^7\) yr\) objects with \(\sim 0.5\)-s spin periods (the “island” feature in Fig. 1a).

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\(^1\) The characteristic age \(\tau = P/(2\dot{P})\), where \(P\) is the pulse period and \(\dot{P}\) the rate of slowdown.

\(^2\) Throughout this review, “young pulsars” are those with characteristic ages less than \(10^5\) yr. This cutoff is roughly consistent with the maximum observable age of a supernova remnant.
are necessarily bright objects. Recent discoveries show that this conclusion is incorrect. Luminous young pulsars are the exception rather than the rule.

The sample of associations between young neutron stars and supernova remnants has grown substantially in recent years as a result of observational progress in many areas. In the latest census, Kaspi & Helfand (2002) tabulate 52 examples of associations between young neutron stars and supernova remnants. The fact that radio pulsations have been detected in only 18 (35%) of the neutron stars so far highlights the importance of observations throughout the electromagnetic spectrum to obtain a true picture of the population. Issues such as the pulsar birth rate, the supernova rate, the fraction of supernovae that produce a neutron star, the radio pulsar beaming fraction, the birth properties of pulsars (luminosities, periods, velocities etc.) and the subsequent spindown evolution (magnetic field decay, braking index evolution etc.) can all be constrained by studying a statistically significant sample of young objects. This review looks at the astonishing progress in this field in the last few years which has provided many insights into this traditionally elusive part of the compact-object population.

2. Finding young radio pulsars

The two main ways to find young pulsars are blind surveys and targeted searches. In a blind survey, the aim is to cover a large area of sky with good sensitivity with a reasonable investment of telescope time and manpower. The optimum region to find young pulsars is close to the Galactic plane where their progenitors (the massive O and B stars) are known to lie. In addition, supernova remnants and gamma-ray sources likely to be associated with the pulsar population are also found along the Galactic plane.

![Fig. 2. (a): The pulsar population projected onto the Galactic plane. In this projection, the Galactic centre lies at the origin and the Sun at (0.0,8.5). Open circles are pulsars previously known before the PM survey. Filled points represent new PM pulsar discoveries which lie predominantly in the inner Galaxy. (b): The same pulsar samples plotted in $P - \dot{P}$ space. As in Fig. 1a, the dashed line is the locus of points for which the characteristic age is $10^5$ yr.](image)

By far the most successful project of this kind has been the Parkes Multibeam (PM) survey of the Galactic plane which has so far discovered over 600 pulsars (Manchester et al. 2001; Morris et al. 2002; Kramer et al. 2003). The PM survey is about seven times more sensitive than any previous Galactic plane search and, as shown in Fig. 2, has been particularly efficient at finding young objects in the inner Galaxy.

In a targeted survey, the aim is to carry out the deepest searches possible for radio pulsations by choosing well-motivated specific directions in the Galaxy. For young

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3 Many are candidate associations, requiring further observational evidence to confirm/refute them.
pulsars, the obvious regions of interest are supernova remnants and unidentified gamma-ray sources. In the past, despite considerable effort, this approach was not very fruitful (e.g. Kaspi et al. 1996; Nice & Sayer 1997; Lorimer et al. 1998). The main obstacle is the fact that most targets cannot be covered by a single telescope beam (typically several arcminutes in extent). Since there is often extreme competition for telescope time, searches requiring a number of separate pointings are necessarily compromised in sensitivity by the need to reduce the integration time to cover the target area.

Targeted searches are now enjoying something of a renaissance with the advent of new high-energy telescopes, such as Chandra. The spatial resolution of the new instruments has resulted in arcsecond localisation of neutron star candidates in a number of supernova remnants. Armed with this information, and state-of-the-art receivers and data acquisition systems, observers at radio telescopes have been able to carry out very deep single-pointing integrations (often complete rise-to-set transits) of the high-energy point sources, which has resulted in a dramatic leap in sensitivity.

3. Pulsar properties inferred from their spindown

Before moving onto the recent discoveries, let us summarise what can be inferred about pulsar ages by studying their spindown. Timing measurements readily yield precise measurements of the pulsar rotation frequency \( \nu = 1/P \) and its time derivative, \( \dot{\nu} \). Both these quantities provide insights into the age and spin history of the neutron star. Expressing the spindown torque in general terms, we have \( \dot{\nu} \propto -\nu^n \), where \( n \) is the so-called braking index. Integrating this expression, for constant \( n \), gives the pulsar age

\[
t = \frac{P}{(n-1)\dot{P}} \left[ 1 - \left( \frac{P_0}{P} \right)^{n-1} \right],
\]

where \( P_0 \) is the spin period at birth. Under the assumptions \( n = 3 \) (spindown due to pure magnetic dipole radiation) and \( P_0 \ll P \), this expression reduces to \( P/(2\dot{P}) \), i.e. the characteristic age, \( \tau \), defined earlier.

The young pulsar sample provides a means to investigate the validity of the above assumptions a stage further. To date, for five pulsars, the high spindown rates allow measurement of \( \dot{\nu} \) which leads to a direct determination of the braking index: \( n = \nu\dot{\nu}/\dot{\nu}^2 \). For these pulsars, braking indices are in the range \( 1.4 < n < 2.9 \), all below the expected value for pure magnetic dipole radiation (\( n = 3 \)). For pulsars where an independent constraint on \( t \) can be obtained (e.g. from a convincing association with a supernova remnant of known age), we may invert the above expression to constrain the initial spin period. For example, for the Crab pulsar, where \( n \) and \( t \) are known, we find \( P_0 = 19 \) ms.

We shall discuss current constraints on \( n \) and \( P_0 \) available from the newly discovered pulsars in the following sections. Obtaining reliable measurements of \( n \) is non-trivial, since it requires a careful treatment of the contaminating effects of so-called “timing noise” prominent in young pulsars. Nevertheless, timing observations currently underway have the potential to yield new measurements of braking indices in the future.

4. New pulsar/supernova remnant associations from the PM survey

PSR J1119–6127 is a 407-ms pulsar discovered in the PM survey (Camilo et al. 2000). With \( \dot{P} = 4 \times 10^{-12} \), currently the largest known among radio pulsars, the characteristic age for this pulsar \( \tau = 1.6 \) kyr. The extremely high rate of spindown permitted a significant measurement of \( \dot{P} \) and hence a braking index of \( 2.91 \pm 0.05 \). Inserting these parameters into equation (1) for any assumed value of \( P_0 \) implies an upper limit on the age of this pulsar of only \( 1.7 \) kyr — very similar to that of the Crab, B1509–58 and B0540–69, all of which are associated with supernova remnants. Although no catalogued
remnant was known at this position, a faint shell was seen in the Molonglo 843-MHz survey (Green et al. 1999). A dedicated Australia Telescope Compact Array observation revealed the non-thermal shell remnant G292.2–0.5 (Crawford et al. 2001; Fig. 3a).

![Image](image_url)

Fig. 3. (a): G292.2–0.5 and PSR J1119–6127 (Crawford et al. 2001). (b): G284.3–1.8 and PSR J1016–5857 (Camilo et al. 2001). The pulsar positions are marked by crosses.

The distance to the pulsar and remnant are currently not well constrained (Camilo et al. 2000; Crawford et al. 2001). The line of sight suggests that they may lie between two spiral arms in the distance range 2.4–8 kpc. For a best-guess distance of 5 kpc, Crawford et al. argue the age of the supernova remnant to be less than 3 kyr. Another pointer to the youth and validity of the association is the very small offset (< 1′) of the pulsar from the geometric centre of the remnant. This is extremely unlikely to occur in a chance alignment, especially with such a young pulsar, and implies that the transverse velocity of J1119–6127 is less than 500 km s\(^{-1}\). A final constraint on the pulsar parameters comes from the lack of a detection of a radio pulsar wind nebula, as is also the case in the energetic pulsar B1509–58 (Bhattacharya 1990). Extending Bhattacharya’s model to predict the brightness of a nebula around J1119–6127, Crawford et al. show that the lack of detection is consistent with an initial spin period < 200 ms. A distance estimate to both the pulsar and remnant would further constrain the above arguments.

A second, albeit less certain, pulsar/supernova remnant association from the PM survey, between PSR J1016–5857 and G284.3–1.8 was proposed recently by Camilo et al. (2001). As shown in Fig. 3b, the pulsar lies to the western edge of the remnant, right at the tip of a bright “finger” of emission about 15′ from the geometrical centre of the remnant. At the distance of G284.3–1.8 (3 kpc; Ruiz & May 1986) and assuming the 21 kyr characteristic age of J1016–5857 to be correct, the implied pulsar velocity, 500 km s\(^{-1}\), is highly supersonic. Although no pulsar wind nebula is obvious from the radio image, archival X-ray data from the Einstein Observatory show a compact source in the 0.1–4.5 keV band at the pulsar position. Camilo et al. demonstrate that the energetics of this source are consistent with a compact pulsar wind nebula. Further multi-wavelength studies are required to investigate the validity of the proposed association.

The above discoveries highlight the power of the blind pulsar survey approach to find pulsar/supernova remnant associations. Although G292.2–0.5 is nominally above the detection threshold of supernova remnant surveys, its previous non classification reflects the difficulties in identifying remnants in crowded and complex regions of the inner Galaxy. In addition to the above two cases, Manchester et al. (2002) discuss a further seven possible associations between pulsars and supernova remnants in the PM survey. In two of these cases, PSRs J1726–3530 and J1632–4818, evidence for a supernova remnant comes from a posteriori inspection of archival continuum surveys. Further investigation of all these candidate associations is now in progress.
5. Recent progress in pulsar/EGRET source associations

The nature of the ∼ 170 unidentified sources from the EGRET all-sky survey (see the most recent catalogue by Hartman et al. 1999) has perplexed astronomers for some time. For the sources which have been convincingly identified so far, the only counterparts are neutron stars (for example the Crab, Vela and Geminga pulsars), the large Magellanic cloud, a solar flare and AGN. These identifications have motivated many efforts to search the unidentified sources for radio pulsar counterparts. In the past, despite intensive radio searches (see e.g. Nice & Sayer 1997), only a few convincing associations between young energetic radio pulsars and the γ-ray emission were found. Part of the problem was that the large error boxes of the EGRET sources demanded a number of separate radio-telescope pointings to fully cover the area. More recently, however, progress has been made in finding new candidate associations with radio pulsars through the numerous discoveries in the PM survey, and also by careful targeted searches of several sources.

5.1. Pulsar/EGRET source pair statistics

To date, the PM survey has found just under 30 pulsars that lie within the boundaries of EGRET source error boxes (Camilo et al. 2001; D’Amico et al. 2001; Kramer et al. 2003). Positional coincidence alone, of course, is not sufficient to associate these pulsars since the density of pulsars along the Galactic plane is large and the probability of chance alignment is significant. By cross-correlating all pulsars currently known with the EGRET catalogue, Kramer et al. (2003) have been able to quantify the number of chance associations that might be expected and conclude that 19 ± 6 associations are likely to be real. In order to prove an association is real, a detection of the pulsar period in the relevant EGRET photons is required. Although this is possible for some of the pulsars with well-known ephemerides (e.g. the Crab), back extrapolation of ephemerides of recently discovered young pulsars is more problematic due in part to the high level of timing activity. More importantly, many of the EGRET sources are weak and there are not many photons available for folding! Ultimately, γ-ray detections for many of the pulsar candidates will have to await future more sensitive telescopes such as GLAST.

In the absence of a detection in the EGRET photons, it is possible to evaluate the likelihood of a detection using other factors such as the spindown energy loss rate $E \propto P/P^3$, EGRET source variability, and gamma-ray production efficiency $\eta = 4\pi f d^2 F_\gamma / E$. Here, $f$ is the gamma-ray pulsar beaming fraction, $d$ is the distance to the pulsar and $F_\gamma$ is the gamma-ray flux of the EGRET source. For an assumed beaming fraction of 1 sr, $\eta < 20\%$ for the 8 or so associations that can be regarded as being secure. As a result, large $\eta$ values for proposed associations may be used as evidence for them being merely chance alignments. Kramer et al. (2003) investigated the current list with this in mind and conclude that there are now a further 8 proposed associations which look likely. The current total of 16 either definite or likely associations is in good agreement with expectation of 19 ± 6 pairs based on statistical grounds presented above.

5.2. Recent discoveries from targeted searches

The young pulsar J2021+3651 was discovered by Roberts et al. (2002) during a campaign to find young pulsars in EGRET error boxes. In order to minimise the time spent searching the full extent of the error boxes, ASCA point sources with significant flux above 1 GeV (Roberts, Romani & Kawai 2001) were selected as targets for deep observations. From a total of 5 sources selected and observed from Parkes and Arecibo, radio pulsations were detected from just one source, AX J2021.1+3651, which lies within the EGRET source 3EG J2021+3716. PSR J2021+3651, with a period of 103 ms and spindown rate of $9.56 \times 10^{-14}$, has very similar spin parameters to the Vela pulsar, and is therefore most likely to be a young object which will exhibit period glitches in the future.
That the pulsar is associated with 3EG J2021+3716 seems likely, since the only other X-ray source in the field is a Wolf-Rayet star. Currently, the distance to this pulsar is not very well constrained (\(\gtrsim 10\) kpc) from the pulsar dispersion measure (371 cm\(^{-3}\) pc; rather large for this line of sight), so that \(\eta \gtrsim 15\%\). Currently, the proposed association is very intriguing. Further observations are required to constrain the distance to the pulsar, and establish whether an associated supernova remnant exists.

Another EGRET error box in the northern sky, 3EG J2227+6122, has been the subject of a multi-wavelength study by Halpern et al. (2001a). After ruling out many possible sources, Halpern et al. concluded that the only possible counterpart to the EGRET source is the Chandra point source embedded within a faint radio shell. The most likely conclusion is that the EGRET/X-ray source is an energetic young neutron star and the radio shell is the associated pulsar wind nebula. Follow-up observations of the X-ray source using the 76-m Lovell telescope revealed PSR J2229+6114, a faint 51.6-ms pulsar with a characteristic age of only 10 kyr (Halpern et al. 2001b). Kothes, Uyaniker & Pineault (2002) have pointed out that the pulsar lies at the edge of the supernova remnant G106.3+2.7, a larger feature which contains the nebula found by Halpern et al. The energetics of this nebula (which Kothes et al. call the “Boomerang” nebula) are consistent with the energy output of J2229+6114.

Based on the initial radio ephemeris for J2229+6114, Halpern et al. (2001b) were able to detect X-ray pulsations in archival ASCA data from 1999. Although there is still considerable uncertainty, X-ray data suggest the distance to the pulsar is \(\sim 3\) kpc. Assuming 1 sr beaming, the required efficiency of \(\gamma\)-ray production, \(\eta \sim 0.2\%\). While the evidence for the association is compelling, confirmation of the identification of PSR J2229+6114 with 3EG J2227+6122 would be a detection as a \(\gamma\)-ray pulsar. Although a possible EGRET detection of PSR J2229+6114 has recently been reported by Thompson et al. (2002), the significance level is low (\(< 3\sigma\)).

6. New pulsar/supernova remnant associations from Chandra

The discovery of PSR J2229+6114 was one of the first real indications that young energetic pulsars may not be particularly radio-bright. The 1400-MHz flux density of this pulsar (\(\sim 0.25\) mJy) is well below the thresholds of most large-scale surveys. As a result, many faint young pulsars remain to be discovered. Motivated by this, and the discovery of Chandra point sources in several supernova remnants, a number of deep radio searches for pulsations have been carried out since mid 2001.

6.1. PSR J1124–5916 and G292.0+1.8

The first new pulsar followed the discovery by Hughes et al. (2001) of a Chandra point source in the supernova remnant G292.0+1.8. Targeting this position for 9.3 hr with the Parkes telescope, Camilo et al. (2002a) discovered the 135-ms pulsar J1124–5916. Like PSR J2229+6114, J1124–5916 is a weak radio source with 1400-MHz flux density of \(\sim 80\mu\text{Jy}\). At the distance of G292.0+1.8 (5 kpc; see discussion in Camilo et al. 2002a for details), the luminosity in this band is only \(\sim 2\) mJy kpc\(^2\). The association of J1124–5916 with the X-ray source has been confirmed with the detection of 135-ms X-ray pulsations in a recent Chandra observation (Hughes, private communication).

The characteristic age of J1124–5916, 2900 yr, is in good agreement with a recent analysis by Gonzalez & Safi-Harb (2003) of the original Hughes et al. (2001) Chandra observation of G292.0+1.8. Gonzalez and Safi-Harb find an age of 2400–2900 yr under the assumption of that the remnant is in a Sedov expansion phase. If this is correct, then it implies that J1124–5916 was born spinning rapidly with a braking index close to three. This latest age constraint is somewhat at variance with an earlier estimate of 1700 yr from optical observations (Murdin & Clark 1979). It is not clear to me (a humble radio observer) which of these to believe. Reconciling the pulsar age with the Murdin
and Clark estimate requires the initial pulsar spin period to be $> 90$ ms, or the braking index $n < 3$. A future measurement of a braking index for J1119–6127 would clarify this situation. In practice this may be difficult due to the large amount of timing noise observed in this pulsar (Camilo, private communication).

6.2. PSR J0205+6449 and 3C58

In the case of the Crab-like supernova remnant 3C58, Chandra observations by Murray et al. (2002b) identified a point X-ray source and found 65-ms pulsations from it. A reanalysis of archival RXTE data by Murray et al. confirmed the existence of the new X-ray pulsar J0205+6449 in archival RXTE data and showed that the spindown rate $\dot{P} = 1.9 \times 10^{-13}$ so that the characteristic age $\tau \sim 5400$ yr. This spindown rate was confirmed with the recent discovery of extremely faint (0.5 mJy kpc$^2$) radio pulsations using the Green Bank Telescope (Camilo et al. 2002b).

As historical evidence suggests that 3C58 is the remnant of the supernova seen in the year 1181 (see e.g. Stephenson & Green 2002), the age of 3C58 is only 822 yr. Murray et al. reconcile the discrepancy between this and the pulsar characteristic age by appealing to an initial spin period of 60 ms for PSR J0205+6449. Other authors (see for example Bietenholz, Kassim & Weiler 2001) have argued, on the basis of expansion measurements, that the age of 3C58 is in fact closer to 5000 yr and that this is not the remnant of the SN 1181. As Murray et al. comment, the larger age estimate assumes 3C58 to be in free expansion, an assumption which may not necessarily be correct. Further understanding of the expansion measurement is required before we can say with certainty that 3C58 is the remnant of SN 1181.

6.3. PSR J1930+1852 and G54.1+0.3

Chandra observations by Lu et al. (2001) revealed an X-ray point source in the Crab-like supernova remnant G54.1+0.3. Based on the morphology and energetics of the system, Lu et al. proposed that G54.1+0.3 is powered by a young rapidly spinning pulsar, as is the case for the Crab nebula. In an attempt to discover the putative pulsar, Camilo et al. (2002c) carried out a 3-hr observation with the recently upgraded Arecibo telescope and found the 136-ms pulsar J1930+1852. Once again, this is a weak radio source with 1175-MHz flux density of only 60 $\mu$Jy, faint enough to fall below the detection threshold of a pre-upgrade Arecibo search of G54.1+0.3 (Gorham et al. 1996).

![Fig. 4. (a): Radio pulse profile of PSR J1930+1852. (b): ASCA X-ray profile. In both cases, two pulse periods are shown and phase zero is arbitrary (Camilo et al. 2002c).](image-url)
Unfortunately, the time resolution of the original Chandra observation was only 3 s (Lu et al. 2001). However, using the measured spindown rate from the Arecibo observations, Camilo et al. were able to detect the 136-ms pulsations from archival ASCA data taken in 1999. This detection puts the association of the pulsations with the X-ray source beyond doubt and cements PSR J1930+1852 as the pulsar powering G54.1+0.3. Coincidentally, the spin parameters for J1930+1852, and resulting characteristic age (2900 yr), are almost identical to those for J1124–5916 discussed earlier. Unlike G292.0+1.8, there is currently no independent age estimate for G54.1+0.3. Arecibo timing observations of J1930+1852 currently underway are aimed at absolute alignment of radio and X-ray profiles and, timing noise permitting, a measurement of the braking index.

7. PSR J1747–2958: a young pulsar powering the “Mouse” nebula

The Mouse nebula, G359.23–0.82, is an extended non-thermal radio source discovered by Yusaf-Zadeh & Bally (1988) during a radio continuum survey with the VLA. As seen in the radio images in Fig. 5, the Mouse is a point-like feature with a wake of emission, highly suggestive of a compact source moving supersonically through the local interstellar medium. ROSAT observations by Predehl & Kulkarni (1995) detected a point source coincident with the head of the radio source and suggested that the X-ray source is a young high-velocity pulsar powering the surrounding radio nebula through its relativistic wind emission.

![Fig. 5. (a): MOST image of the Mouse Nebula at 0.8 GHz. (b): 8.4-GHz VLA image. The error ellipse shows the pulsar timing position uncertainty (Camilo et al. 2002d).](image)

The putative pulsar, J1747–2958, was recently found in a 9.3-hr observation of the Mouse using the Parkes telescope (Camilo et al. 2002d). With $P = 98$ ms and $\dot{P} = 6 \times 10^{-14}$, the characteristic age of 25 kyr strongly suggests that this is a young pulsar. Although the pulsar position is not yet pinned down in declination (the error ellipse shown in Fig. 5b has been reduced as a result of further timing observations since this figure was produced; Camilo, private communication), the probability of finding a young pulsar this close to the tip of the Mouse by chance is less than $5 \times 10^{-5}$. It therefore seems likely that J1747–2958 is the associated radio pulsar. From the pulsar dispersion measure, and an independent distance constraint to the Mouse ($<5$ kpc; Uchida et al. 1992), we follow Camilo et al. (2002d) and take as a best estimate of ~2 kpc for the distance to the Mouse.

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4 Just where the term “mouse” comes from is a mystery; based on the observed morphology of G359.23–0.82, the “Tadpole nebula” seems a far more appropriate name!
Proceeding under the assumption that J1747–2958 is causing a bow-shock nebula as it ploughs through the local interstellar medium, we can make an estimate of the pulsar velocity, \( V \), required to produce the observed nebula. As discussed by a number of authors (see e.g. Chatterjee & Cordes 2002), the stand-off radius \( R_0 \) between the pulsar and the head of the bow shock scales with velocity as \( R_0 \propto (\dot{E}/V^2)^{1/2} \), where the constant of proportionality depends on the density of the local medium. Camilo et al. make a quick estimate of \( R_0 \) based on the angular separation from the high resolution image shown in Fig. 5, for an assumed distance of 2 kpc (see above). The pulsar velocity can then be parameterised as \( V \sim 570 \ \text{km s}^{-1}/\sqrt{n} \), where \( n \) is the (unknown) local medium number density in units of \( \text{cm}^{-3} \).

The key measurement in this system in the near future will be the pulsar proper motion, currently predicted at 60 mas yr\(^{-1} \) for 570 km s\(^{-1} \) at a distance of 2 kpc. A measurement of this quantity (e.g. using Chandra to perform the astrometry), will not only confirm the association of the pulsar and nebula (from the direction of proper motion), but will also constrain the age of the system. Currently, a crude estimate of the age comes from the length \( L \) of the tail of emission in Fig. 5. Given the pulsar velocity \( V \), the age can be written as simply \( t = L/V \sim 12d_2/V_{570} \ \text{kyr} \), where \( d = 2d_2 \ \text{kpc} \) and \( V = 570V_{570} \ \text{km s}^{-1} \). A proper motion measurement would place a distance-independent constraint on the age and birth spin period of PSR J1747–2958.

8. Future prospects

Further discoveries of energetic young radio pulsars will undoubtably be made in the near future as the PM survey continues, and high-energy instruments continue to reveal neutron star candidates. Although these searches have been particularly successful, there are a number of sources which have been searched for which there is, so far, no known radio pulsar counterpart. One example is the famous Cas-A point source discovered during a first-light Chandra observation (Tananbaum 1999). To date, no statistically significant pulsations have been found in X-ray searches (Murray et al. 2002a). McLaughlin et al. (2001) placed a luminosity limit of 20 mJy kpc\(^2\) on radio pulsations from a 2-hr observation with the VLA. Since this observation does not preclude the existence of a faint pulsar akin to those discovered in other Chandra sources, a group of us (McLaughlin, Hankins, Kern and myself) have recently taken a much more sensitive (18-hr) observation of the source with the VLA. Data analysis is proving challenging due to the radio-frequency interference environment at the VLA. At the very least, we are confident of improving upon the upper limit once the analysis is complete.

Ultimately, a careful study of all the detections and upper limits from the latest round of surveys should be able to place strong constraints on the beaming fraction and luminosity distribution of young pulsars, and test previous model predictions. For example, on the basis of pulsar statistics about a decade ago, we postulated (Lorimer et al. 1993) that few pulsars were born with 1400-MHz luminosities\(^5\) below 4 mJy kpc\(^2\). The recent discoveries of young pulsars with luminosities well below this limit show that this statement is probably incorrect, and that the fraction of faint young pulsars is significant. It should be possible to quantify this remark in the near future.

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\(^5\) In quoting this number, I have scaled the 400-MHz luminosity quoted in the original paper (30 mJy kpc\(^2\)) to 1400 MHz assuming a radio spectral index of \(-1.6\).
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