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A search for radio emission from the young 16-ms X-ray pulsar PSR J0537−6910

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Abstract

PSR J0537−6910 is a young, energetic, rotation-powered X-ray pulsar with a spin period of 16 ms located in the Large Magellanic Cloud. We have searched for previously undetected radio pulsations (both giant and standard) from this pulsar in a 12-h observation taken at 1400 MHz with the Parkes 64-m radio telescope. The very large value of the magnetic field at the light cylinder radius suggests that this pulsar might be emitting giant radio pulses like those seen in other pulsars with similar field strengths. No radio emission of either kind was detected from the pulsar, and we have established an upper limit of ~25 mJy kpc^2 for the average 1400-MHz radio luminosity of PSR J0537−6910. The 5σ single-pulse detection threshold was ~750 mJy for a single 80-μs sample. These limits are likely to be the best obtainable until searches with greatly improved sensitivity can be made with next-generation radio instruments.

Keywords: Pulsars; Radio emission; Supernova remnants

1. Introduction and motivation

PSR J0537−6910 is a fast-spinning, young, and energetic rotation-powered pulsar that was discovered as a pulsed X-ray source (Marshall et al., 1998) in the supernova remnant N157B, located in the Large Magellanic Cloud (LMC) at a distance of 50 kpc (see Fig. 1). The pulsar is very young, with a characteristic age $\tau_c \equiv P/2\dot{P} \sim 5$ kyr, and its spin-period of 16 ms makes it the fastest non-recycled pulsar known. PSR J0537−6910 is one of only a handful of young ($\tau_c < 10$ kyr), energetic pulsars (of which the Crab pulsar is the prototype) that are known. No radio pulsations were detected in a search (Crawford et al., 1998) conducted soon after its discovery in X-rays.

PSR J0537−6910 also has the largest inferred dipole magnetic field strength at the light cylinder radius ($B_{\rm lc}$) of any known pulsar. The light-cylinder radius is the equatorial distance from the pulsar at which the co-rotation speed equals the speed of light. In Table 1, we list the top 8 pulsars sorted by decreasing $B_{\rm lc}$. PSR J0537−6910 is at the top of the list, and the next 7 all show evidence for giant pulse emission. There is no confirmed evidence of giant pulses from any pulsars with smaller $B_{\rm lc}$ values. Although this may not be an exclusive measure of giant pulse activity, it certainly appears

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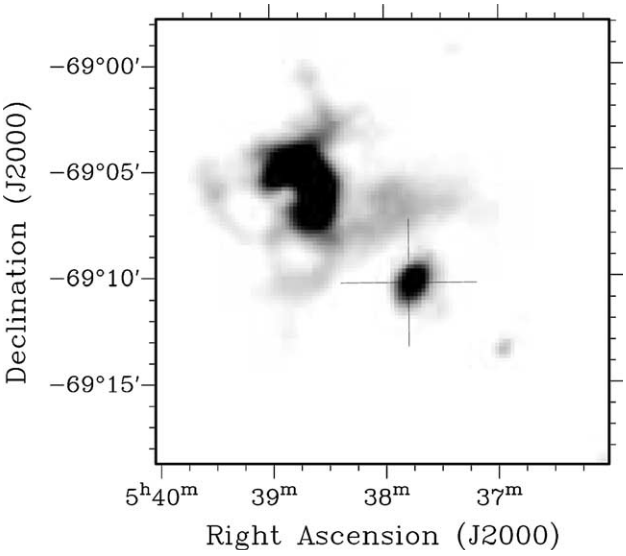

Fig. 1. An 843-MHz radio image of the supernova remnant N157B in the 30 Doradus region of the LMC. This image was taken from the Sydney University Molonglo Sky Survey, conducted with the Molonglo Observatory Synthesis Telescope. The location of PSR J0537−6910, in the supernova remnant N157B, is indicated by the cross.

to be an excellent indicator. We would therefore expect giant pulses to be emitted by PSR J0537−6910.

Discovery of a radio counterpart to PSR J0537−6910 would be important for several reasons. It could provide a secondary timing method for the pulsar using ground-based observations. PSR J0537−6910 is known to glitch frequently (Marshall et al., 2004), and radio timing could be used to study this phenomenon, which is common in young pulsars (Alpar, 1995). A possible determination of the braking index n from long-term timing might be used to test pulsar spin-down models (Melatos, 1997), though this might be impossible given the noisy timing behavior and frequent glitches observed for the pulsar. A measured dispersion measure (DM) for the pulsar would help constrain the plasma distribution in the LMC (Crawford et al., 2001). A radio detection might also allow a measurement of a phase offset between the X-ray and radio pulse profiles. This would aid our understanding of the magnetospheric physics of pulsars (Romani and Yadigaroglu, 1995). Detection of giant radio pulses from PSR J0537−6910 would confirm the connection between giant pulses and the light-cylinder magnetic field strength.

Table 1
Pulsars with the largest values of B_{lc}

PSR	B_{lc} ($\times 10^5$ G)	Giant pulse reference
J0537−6910	20.6	–
B1937+21	10.2	Cognard et al. (1996)
B0531+21 (Crab)	9.8	Staelin and Reifenstein (1968); Lundgren et al. (1995); Cordes et al. (2004)
B1821−24	7.4	Romani and Johnston (2001)
B1957+20	3.8	Joshi et al. (2004)
B0540−69	3.7	Johnston and Romani (2003); Johnston et al. (2004)
J0218+4232	3.2	Joshi et al. (2004)
B1820−30A	2.5	Knight et al. (in press)

2. Observations and analysis

The Parkes 64-m telescope in Parkes, Australia was used to observe PSR J0537−6910 for a continuous 12-h observation on 6 September 2003. The center beam of the multibeam receiver (Staveley-Smith et al., 1996) was used at a center observing frequency of 1390 MHz. A 256-MHz bandwidth was split into 512 contiguous frequency channels, and each channel was one-bit sampled at 80 μs. Data were recorded on magnetic tape at the observatory and transferred to several sites for processing. The observing setup was the same as the one used in a recent search for giant radio pulses from PSR B0540–69 (Johnston et al., 2004).

2.1. Standard pulse search

For the standard pulse search, the data were checked for radio frequency interference (RFI), and a few percent of the data were subsequently excised. The data were then dedispersed at 75 trial DMs ranging from 50 to 200 pc cm^{-3}, corresponding to the expected DM range for LMC pulsars (Crawford et al., 2001). A DM trial spacing of 2 pc cm^{-3} was chosen to ensure that the pulse smear from dedispersion error did not exceed 5% of the pulse period.[1]

For each DM trial, the data were analyzed using both a standard Fast Fourier Transform (FFT) search of the dedispersed time series (Ransom et al., 2002) and a routine which folded each dedispersed time series at a range of periods around the nominal period derived from the X-ray ephemeris (Marshall et al., 1998). Since PSR J0537−6910 was observed to glitch six times in a 2.6-year span with an average glitch magnitude of $\Delta P/P \sim 0.4 \times 10^{-6}$ (Marshall et al., 2004), the true period is probably somewhat offset from the ephemeris period. Periods ±1000 ns from the ephemeris period were tried, with a trial fold step size of 0.5 ns. This again ensured that the pulse smear from folding at the wrong period would not exceed 5% of the pulse period.

2.2. Giant pulse search

For the giant pulse search, the data were dedispersed at 1000 trial DMs ranging from 0 to 300 pc cm^{-3}. This

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[1] This is comparable to the (uncorrectable) intra-channel smearing in the system for a DM of about 100 pc cm^{-3}.

narrow DM spacing ensured that the smearing due to an incorrect DM was less than ~0.1 ms. Two different software codes were used on the data. The algorithms for both are similar and are described in detail in McLaughlin and Cordes (2003) and Romani and Johnston (2001). In brief, each dedispersed time series was searched for single pulses above a 5σ significance threshold. The time series were smoothed multiple times by aggregating adjacent samples in groups of 2, 4, 8, etc., and the search was repeated on each smoothed time series. This technique increased sensitivity to broadened pulses. A procedure was incorporated to remove pulses strongest at low DMs and therefore most likely due to RFI.

3. Results and conclusions

No significant radio signal was detected in either the FFT search or the folding search. No FFT candidates above a signal-to-noise threshold of 5 and no folded profiles with significantly large χ^2-values were found. No individual pulses with high DMs and signal-to-noise ratios greater than 7 were detected and no excess of weaker pulses was detected at a specific DM. The 5σ single-pulse detection threshold was ~750 mJy for a single 80-μs sample. For comparison, previous observations of giant pulses from the Crab pulsar (Cordes et al., 2004) indicate that if the Crab were located in the LMC, we would expect to detect one giant pulse every ~20 min from this source at 1400 MHz; the strongest pulse during a 12-h observation of this source would have a signal-to-noise ratio of ~40. For PSR B0540–69, one giant pulse is detected every ~30 min with a similar observing setup. Giant pulses from PSR J0537−6910 must therefore be a least a factor of two weaker than those from PSR B0540–69.

An upper limit for the 1400-MHz flux density of PSR J0537−6910 was determined using the radiometer equation with an additional factor to account for pulsed duty cycle (Dewey et al., 1985). For an assumed duty cycle of 5%, the sensitivity limit from the observation was determined to be $S_{1400}^{\min} \sim 10$ μJy. This translates into an average 1400-MHz radio luminosity upper limit of $L_{1400}^{\min} = S_{1400}^{\min} d^2 \sim 25$ mJy kpc^2 (where $d \sim 50$ kpc is the pulsar's distance). This limit is comparable to or less than the luminosities of several pulsars with $\tau_c < 10$ kyr.[2] Table 2 shows the list of known rotation-powered pulsars with $\tau_c < 10$ kyr, rank-ordered by increasing τ_c. As can be seen from the table, the luminosity range for the young pulsar population spans more than two orders of magnitude, so no strict conclusions can be made about whether PSR J0537−6910 is actually a radio emitter. It may be the case that more sensitive observations in the future will be able to detect radio emission from PSR J0537−6910, but the limits presented here are likely to be the best obtainable for the foreseeable future. It may also be that PSR J0537−6910 is indeed a strong radio emitter, but that its radio beam is misaligned with our line of sight. With the availability of next-generation radio instruments, such as the Square Kilometer Array, observations of PSR J0537−6910 with greatly improved sensitivity will be possible.

Table 2
Estimated radio luminosities of rotation-powered pulsars with $\tau_c < 10$ kyr

PSR	τ_c (kyr)	P (s)	L_{1400} (mJy kpc^2)
J1846−0258	0.72	0.324	<50
B0531+21 (Crab)	1.24	0.033	56
B1509−58	1.55	0.150	27
J1119−6127	1.61	0.407	20
B0540−69	1.67	0.050	60
J1124−5916	2.87	0.135	2.3
J1930+1852	2.89	0.137	1.5
J0537−6910	4.98	0.016	<25
J0205+6449	5.37	0.065	0.46
J1357−6429	7.30	0.166	2.7
J1614−5048	7.42	0.232	130
J1617−5055	8.13	0.069	20
J1734−3333	8.13	1.169	27

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References

Alpar, M.A. Models for pulsar glitches, in: Alpar, M.A., Kiziloglu, U., van Paradijs, J. (Eds.), The Lives of the Neutron Stars. Dordrecht, Kluwer, pp. 185–195, 1995.

Cognard, I., Shrauner, J.A., Taylor, J.H., Thorsett, S.E. Giant radio pulses from a millisecond pulsar. Astrophysical Journal Letters 457, L81–L84, 1996.

Cordes, J.M., Bhat, N.D.R., Hankins, T.H., McLaughlin, M.A., Kern, J. The brightest pulses in the universe: multifrequency observations of the Crab pulsar's giant pulses. Astrophysical Journal 612, 375–388, 2004.

Crawford, F., Kaspi, V.M., Manchester, R.N., Camilo, F., Lyne, A.G., D'Amico, N. Upper limits on radio emission from the young X-ray pulsars in the supernova remnants G11.2–0.3 and N157B. Memorie della Societa Astronomica Italiana 69, 951–954, 1998.

Crawford, F., Kaspi, V.M., Manchester, R.N., Lyne, A.G., Camilo, F., D'Amico, N. Radio pulsars in the magellanic clouds. Astrophysical Journal 553, 367–374, 2001.

Dewey, R.J., Taylor, J.H., Weisberg, J.M., Stokes, G.H. A search for low-luminosity pulsars. Astrophysical Journal Letters 294, L25–L29, 1985.

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[2] In some cases, the true age of the pulsar is believed to be significantly different than its characteristic age, τ_c.

Johnston, S., Romani, R.W. Giant pulses from PSR B0540–69 in the large magellanic cloud. Astrophysical Journal Letters 590, L95–L98, 2003.

Johnston, S., Romani, R.W., Marshall, F.E., Zhang, W. Radio and X-ray observations of PSR B0540–69. Monthly Notices of the Royal Astronomical Society 355, 31–36, 2004.

Joshi, B.C., Kramer, M., Lyne, A.G., McLaughlin, M.A., Stairs, I.H. Giant pulses in millisecond pulsars, in: IAU Symposium, vol. 218, pp. 319–320, 2004.

Knight, H.S., Bailes, M., Manchester, R.N., Ord, S.M. A Search for giant pulses from millisecond pulsars. Astrophysical Journal, in press.

Lundgren, S.C., Cordes, J.M., Ulmer, M., Matz, S.M., Lomatch, S., Foster, R.S., Hankins, T. Giant pulses from the crab pulsar: a joint radio and gamma-ray study. Astrophysical Journal 453, 433–445, 1995.

Marshall, F.E., Gotthelf, E.V., Middleditch, J., Wang, Q.D., Zhang, W. The big glitcher: the rotation history of PSR J0537−6910. Astrophysical Journal 603, 682–689, 2004.

Marshall, F.E., Gotthelf, E.V., Zhang, W., Middleditch, J., Wang, Q.D. Discovery of an ultrafast X-ray pulsar in the supernova remnant N157B. Astrophysical Journal Letters 499, L179–L182, 1998.

McLaughlin, M.A., Cordes, J.M. Searches for giant pulses from extragalactic pulsars. Astrophysical Journal 596, 982–996, 2003.

Melatos, A. Spin-down of an oblique rotator with a current-starved outer magnetosphere. Monthly Notices of the Royal Astronomical Society 288, 1049–1059, 1997.

Ransom, S.M., Eikenberry, S.S., Middleditch, J. Fourier techniques for very long astrophysical time-series analysis. Astronomical Journal 124, 1788–1809, 2002.

Romani, R.W., Johnston, S. Giant pulses from the millisecond pulsar B1821–24. Astrophysical Journal Letters 557, L93–L96, 2001.

Romani, R.W., Yadigaroglu, I.-A. Gamma-ray pulsars: emission zones and viewing geometries. Astrophysical Journal 438, 314–321, 1995.

Staelin, D.H., Reifenstein, E.C. Pulsating radio sources near the crab nebula. Science 162, 1481–1483, 1968.

Staveley-Smith, L., Wilson, W.E., Bird, T.S., Disney, M.J., Ekers, R.D., Freeman, K.C., Haynes, R.F., Sinclair, M.W., Vaile, R.A., Webster, R.L., Wright, A.E. The parkes 21 cm multibeam receiver. Publications of the Astronomical Society of Australia 13, 243–248, 1996.