Radio Pulsars in Terzan 5

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19 March 2022

ABSTRACT

We report on searches of the globular cluster Terzan 5 for low luminosity and accelerated radio pulsars using the 64-m Parkes radio telescope. One new millisecond pulsar, designated PSR J1748$-2446C$, was discovered, having a period of 8.44 ms. Timing measurements using the 76-m Lovell radio telescope at Jodrell Bank show that it is a solitary pulsar and lies close to the core of the cluster. We also present the results of timing measurements which show that the longer-period pulsar PSR J1748$-2444$ (formerly known as PSR B1744$-24B$) lies 10 arcmin from the core of the cluster and is unlikely to be associated with the cluster. We conclude that there are further pulsars to be detected in the cluster.

Key words: Pulsars: Millisecond pulsars: Globular Clusters – Individual: Terzan 5

1 INTRODUCTION

Globular clusters were proposed as good hunting grounds for rapidly rotating pulsars because they were known to contain a relatively high proportion of potential progenitor systems such as low mass X-ray binaries (Hamilton, Helfand & Becker 1985). Since the first globular cluster pulsar was found in M28 (Lyne et al. 1987), several dozen have been found in a number of clusters (Lyne 1995). This paved the way for new understanding of the formation and evolution of millisecond pulsars (Kulkarni & Anderson 1996), as well as providing opportunities for other applications such as measuring cluster gravitational potentials (Phinney 1992; Camilo et al. 1999).

In an early search of the cluster Terzan 5 (Lyne et al. 1990), two radio pulsars were found, PSR B1744–24A and PSR B1744–24B. PSR B1744–24A (also known as PSR J1748–2446A) is clearly associated with the cluster and lies $\sim 30''$ from its core. The pulsar is in a 1.7-hour orbit and is often eclipsed by its companion star (Lyne et al. 1990; Nice & Thorsett 1992). PSR B1744–24B is rather weak and, until now, it has not had a phase connected timing solution, so that its precise position was not known and any association with the cluster was unclear.

Radio continuum observations at the VLA have revealed the presence of a number of steep spectrum radio sources, within, or close to, the core of the cluster, hinting at the possibility of as yet undiscovered pulsars (Fruchter & Goss 1990). Since PSR J1748–2446A is not in the core of the cluster and we show here that PSR B1744–24B is not associated with the cluster at all, these two pulsars account for none of the flux density detected by Fruchter & Goss (1990). This suggests that there may be further undiscovered pulsars within the core of the cluster. Any other pulsars may remain undetected as a result of broadening of the pulses due to dispersion in the receiver filterbank channels, broadening of the pulses due to acceleration in tight orbits, very short pulsation period or insufficient sensitivity. In this paper, we report on a search which was undertaken to try to resolve these issues and present the one new pulsar that was found, which we have designated PSR J1748–2446C.

We also report on timing observations of both this pulsar and PSR B1744–24B in order to establish their positions and associations with the cluster.

2 SEARCH OBSERVATIONS AND ANALYSIS

The globular cluster Terzan 5 was observed on 1994 April 15 for 1.6 hours and on 1994 Sept. 14 for 2.8 hours with the Parkes telescope using a 64-MHz band centred on 1392 MHz. Dual channel cryogenic receivers were used in conjunction with a 2x256x0.25 MHz channel filter bank. After detection, the signals from the two linearly polarised channels were added, one-bit digitised at a sampling interval of 0.3 ms and written to magnetic tape. The beam width was 14' arc and the dispersion smearing per channel at the cluster dispersion measure of $\sim 240$ cm$^{-3}$pc was 0.2 ms, a factor of four better than the earlier search (Lyne et al. 1990). For long-period pulsars, the sensitivity of this search is approximately 40 per cent better than the previous search.

The data were first processed using standard techniques for unaccelerated pulsars (Manchester et al. 1996). PSR J1748–2446C was found as an isolated pulsar with a
period of approximately 8 ms. To provide some sensitivity to accelerated pulsars, the two observations were each split into 20 segments. A Fourier transform was then applied to each segment and the resulting power spectra were stacked to give a time versus frequency plot in which accelerated pulsars would show up as sloping tracks. Since we were only searching one location and a small range of dispersion measures (185–260 cm$^{-3}$pc) it was possible to inspect the stacked spectra by eye. Despite having sensitivity to millisecond pulsars in orbits as short as 20 minutes, no further new pulsars were found this way.

3 TIMING OBSERVATIONS AND ANALYSIS

Pulse arrival times for the three pulsars in or near Terzan 5 were obtained on a regular basis since their discovery using the 76-in Lovell telescope at Jodrell Bank with cryogenic receivers at 606 and 1404 MHz. Both hands of circular polarisation were observed using a 2 $\times$ 64 $\times$ 0.125-MHz filter bank at 606 MHz and a 2 $\times$ 32 $\times$ 1.0-MHz filter bank at 1404 MHz. After detection, the signals from the two polarisations were added, filtered, digitised at appropriate sampling intervals and despersed in hardware before being folded on-line, and written to disk. Observations were typically of 18 minutes duration.

For each pulsar, a standard pulse template was fitted to the observed profiles at each frequency to determine the pulse times-of-arrival (TOAs). The TOAs, weighted by their individual uncertainties determined in the fitting process, were analysed with the TEMPO software package (http://pulsar.princeton.edu/tempo), using the DE200 ephemeris of the Jet Propulsion Laboratory (Standish 1982) and the Blandford & Teukolsky (1976) timing model for binary pulsars. The resulting model parameters are summarised in Table 1.

4 DISCUSSION

The new single millisecond pulsar, PSR J1748–2446C (Ter5C), lies only about $\sim$ 10$''$ from the cluster centre (Fruchter & Goss 2000); 17$^h$48$^m$04$^s$.9, 6(J2000): $-$24$^\circ$46$'$45$''$. (Fruchter & Goss 2000) and has a dispersion measure close to that of PSR J1748–2446A (Ter5A), suggesting with high probability that it also is associated with the cluster.

The position for PSR J1748–2444 given in Table 1 is 10$'$ from the cluster centre, indicating that it is unlikely that this pulsar is associated with the cluster. As Table 1 shows, this pulsar has a dispersion measure which differs from the values for the other two pulsars, Ter5A and Ter5C, by about 30 cm$^{-3}$pc, adding weight to the conclusion that PSR J1748–2444 is not associated with the cluster. The period of 0.443 s and the measured period derivative indicates that it is an unremarkable pulsar, having a surface magnetic field of $2.3 \times 10^{12}$ G which is near to the lower end of the distribution of normal pulsars (Taylor, Manchester & Lyne 1993), and a characteristic age of 63 My.

Figure 1 shows the positions of the two cluster pulsars and other sources around Terzan 5 relative to the cluster centre. The two radio sources (N and S) were found by Fruchter & Goss (2000) in a continuum image of the region at around 1400 MHz. Although the position of source N agrees within the errors with that of the 8.4-ms pulsar PSR J1748–2446C, the flux density of the pulsar emission from this pulsar has a mean value of only 0.5 $\pm$ 0.2 mJy. This is significantly less than the flux density of source N, 1.5 mJy. Neither the flux density of the pulsar or of source N vary significantly between observations, so that such variations cannot explain the discrepancy. We conclude therefore that other, rapidly-rotating pulsars or pulsars in short-period binary orbits may exist in Terzan 5. Searches with a more sensitive receiving system having better time and frequency resolution may find them. Johnston, Verbunt & Hasinger (1995) identified a transient X-ray source close to the cluster core; its positional accuracy is not sufficient to confirm an identification with the radio source S.

The negative period derivatives of Ter5A and Ter5C indicate that they lie behind the cluster and are experiencing a gravitational acceleration towards the cluster core in the manner described by Phinney (1992). If we assume that the intrinsic period derivatives are greater than zero and follow the procedures of Phinney (1992) and Camilo et al. (1999), we can place a lower limit on the central mass density $\rho(0)$ of the cluster. Using the cluster core radius $r_c = 7.9$ (Trager, Djorgovski & King 1995), a cluster distance of 7.6 kpc (Johnston, Verbunt & Hasinger 1993), and the cluster position of Fruchter & Goss (2000), we find lower limits on $\rho(0)$ of $0.85 \times 10^{5}$ and $5.0 \times 10^{5}$ M$_\odot$pc$^{-3}$ for Ter5A and Ter5C, respectively. We note that the latter is considerably lower than the value of the density quoted by Webbink (1985) of $24 \times 10^{5}$ M$_\odot$pc$^{-3}$.

Figure 1. Positions of sources associated with the globular cluster Terzan 5. A: PSR J1748–2446A, C: PSR J1748–2446C, circle: cluster core, radius = 7.9 (Trager et al. 1993), N,S: northern and southern radio sources identified by Fruchter & Goss (2000), and X: XB 1745–25 (Johnston et al. 1995).
### Observed Parameters for Pulsars in or near Terzan 5

| J2000 Name | J1748−2446A | J1748−2446C | J1748−2444 |
|-----------|-------------|-------------|-------------|
| B1950 Name | B1744−24A   | –           | B1744−24B   |
| GC Name   | Ter5A       | Ter5C       | –           |
| Right Ascension (J2000) | $17^h48^m02^s255(2)$ | $17^h48^m04^s54(1)$ | $17^h48^m48^s511(5)$ |
| Declination (J2000) | $−24^d46^m36^s9(6)$ | $−24^d56^m36^s4(4)$ | $−24^d44^m43^s11(5)$ |
| Epoch of Period (MJD) | 48270.0 | 50958.0 | 51016.0 |
| Period (ms) | 11.56314838986(3) | 8.4360953044(1) | 442.838503373(3) |
| Period Derivative ($10^{-15}$) | $−0.0000340(4)$ | $−0.000606(4)$ | 0.1107(4) |
| Dispersion Measure (cm$^{-3}$ pc) | 242.1(2) | 237(1) | 207.3(2) |
| Orbital Period (sec) | 6535.8240(2) | – | – |
| Projected Semi-major Axis (lt-s) | 0.11971(3) | – | – |
| Eccentricity | 0.0 | – | – |
| Epoch of Ascending node (MJD) | 48270.02979(7) | – | – |
| Data span (days) | 1739 | 1011 | 856 |
| R.M.S. timing residual (ms) | 0.26 | 0.52 | 2.8 |
| Flux Density (mJy) | $2.5^\dagger$ | 0.5(2) | 0.6(2) |
| $W_{50}$ (ms) | $0.7^\dagger$ | 2.0(5) | 6(1) |

$^\dagger$ From Lyne et al. (1990)

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