D.J. Nice, J.H. Taylor and R.W. Sayer

Timing Observations of the J1518+4904 Double Neutron Star System

Abstract

We summarize timing observations of PSR J1518+4904, a recently discovered pulsar in a double neutron star binary. New measurements include (1) periastron advance of $0.^{\circ}0113 \pm 0.^{\circ}0001\ \mathrm{yr}^{-1}$, for a total system mass of $2.69 \pm 0.04\ \mathrm{M}_{\odot}$; (2) period derivative of 2×10^{-20}, yielding an age comparable to that of the Galaxy and a magnetic field substantially lower than other pulsars in double neutron star binaries; and (3) proper motion of $8 \pm 2\,\mathrm{mas\,yr}^{-1}$, or a transverse velocity of $27 \pm 8\,\mathrm{km\,s}^{-1}$, among the lowest pulsar velocities measured.

I Observations

PSR J1518+4904 is a 40.9 ms pulsar in a moderately eccentric, 8.6 day orbit with a second neutron star. It was discovered in the course of a recent survey of the northern sky for fast pulsars (Sayer, Nice & Taylor 1997). We have made timing observations of this pulsar with the Green Bank 140 Foot Telescope at regular intervals since its discovery. The dataset extends from December 1994 to November 1996, and includes observations made at 370, 575, and 800 MHz. Further details of the data acquisition system, as well as results from an early portion of the data, are given in Nice, Sayer & Taylor (1996).

The pulse arrival times were measured using standard techniques and were fit to a model of pulsar rotation, astrometry, and binary motion using the TEMPO software package. As expected for a moderately sized, eccentric binary, the orbit exhibits relativistic precession (Figure 1). Thus the binary model incorporates periastron advance along with the usual five Keplerian orbital parameters. The best-fit timing model is described in Table 1.

Observed pulse period derivatives are biased by the relative acceleration of pulsars and the earth (Damour & Taylor 1991). This bias can be broken into three components, as quantified in Table 2. For PSR J1518+4904, the intrinsic period derivative turns out to be close to the observed value.

Table 1: Timing Model of J1518+4904

Observed Parameters	
Period (ms)	40.93498826871(2)
Period Derivative	$2.75(6) \times 10^{-20}$
Right Ascension (J2000)	$15^{\rm h}18^{\rm m}16\overset{\rm s}{.}7979(2)$
Declination (J2000)	$+49^\circ04'34\overset{''}{.}292(2)$
Proper Motion in α (mas $\rm yr^{-1}$)	$-1(3)$
Proper Motion in δ (mas $\rm yr^{-1}$)	$-8(2)$
Epoch (MJD)	49894.00
Dispersion Measure (pc $\rm cm^{-3}$)	11.61
Orbital Period (days)	8.63400494(5)
Projected Semi-Major Axis (light sec)	20.044005(3)
Eccentricity	0.2494849(2)
Angle of Periastron	$342\overset{\circ}{.}46221(5)$
Time of Periastron (MJD)	49896.246990(1)
Rate of Advance of Periastron (deg $\rm yr^{-1}$)	0.0113(1)
Derived Parameters	
Distance (kpc)	$0.70^{+0.13}_{-0.07}$
Magnetic Field (G)	1×10^9
Age (yr)	2×10^{10}
Total System Mass ($M_\odot$)	2.69(4)
Orbit Decay Time (yr)	2400×10^9
Composite Proper Motion (mas $\rm yr^{-1}$)	8(2)
Transverse Velocity (km $\rm s^{-1}$)	27(8)

II Discussion

The characteristics of J1518+4904 and other double neutron star systems are compared in Table 3 and Figure 2. Tight binary systems B1913+16, B1534+12, and B2127+11C have remarkably similar ages and magnetic fields. (The ages in this population are, of course, influenced by short coalescence times due to relativistic orbital decay.) The wider J1518+4904 system has a very similar pulse period, but a much smaller period derivative, indicative of a very large age (comparable to the age of the Galaxy, like many low-mass millisecond pulsar systems), and a relatively small magnetic field. The origin of this small magnetic field, and its relation to the evolution of the system, is not clear.

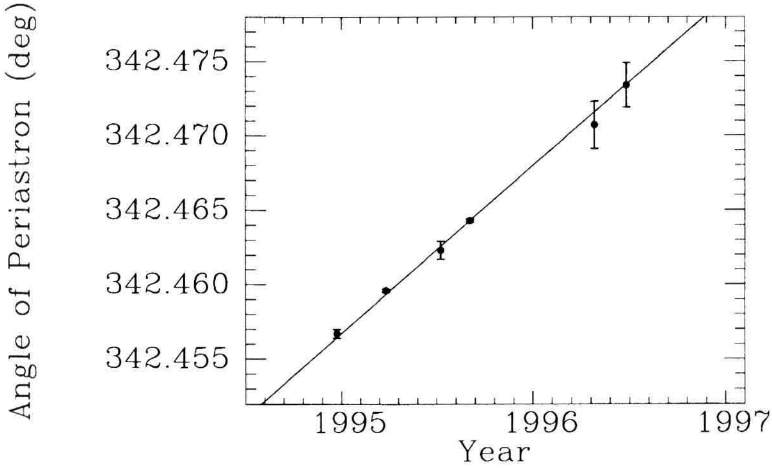

Figure 1. Angle of periastron measured at different epochs by analyzing independent subsets of the data.

The rate of orbital precession, $0\overset{\circ}{.}0113 \pm 0\overset{\circ}{.}0001$ yr^{-1}, yields a total system mass of 2.69 ± 0.04 M$_\odot$. This is slightly less than the total mass of the B1913+16 system (2.83 M$_\odot$), but it is indistinguishable from masses of the other systems. The differences in mass must reflect differences in the evolution of the systems. We expect that future observations will refine the mass measurement of J1518+4904. However, given the range of masses in the tight systems (2.69 to 2.83 M$_\odot$), the interpretation of the J1518+4904 mass will not be simple.

From the proper motion of $8 \pm 2\,\mathrm{mas\,yr^{-1}}$, we estimate the transverse space velocity to be $27 \pm 8\,\mathrm{km\,s^{-1}}$. This is remarkably low compared with pulsars in general and even compared with binary pulsars. (For example, B1913+16 has transverse velocity $100 \pm 40\,\mathrm{km\,s^{-1}}$ and 1534+12 has velocity $80 \pm 20\,\mathrm{km\,s^{-1}}$.) Given the relatively wide orbit, any event, such as an asymmetric supernova, which would have substantially boosted the system velocity would also likely have disrupted the binary. Thus a low space velocity seems like a necessary condition for the survival of such a system.

Table 2: Period Derivative

Observed Period Derivative		$2.75 \pm 0.06 \times 10^{-20}$
Acceleration	Towards Galactic disk	$0.55 \pm 0.02 \times 10^{-20}$
	Galactic rotation	$0.08 \pm 0.01 \times 10^{-20}$
	Transverse motion	$-0.5 \pm 0.3 \times 10^{-20}$
Intrinsic Period Derivative		$2.9 \pm 0.3 \times 10^{-20}$

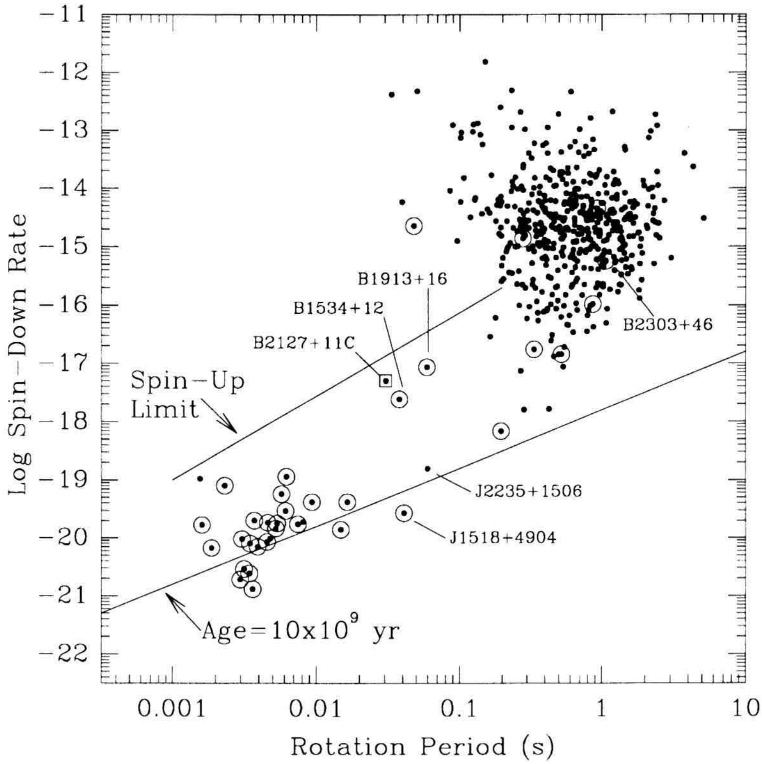

Figure 2. Spin parameters of disk pulsars. Binaries are indicated by circles; one cluster pulsar (B2127+11C) is included. Pulsars likely formed in double neutron star systems are labeled; see text for discussion.

Finally, we comment that parameters of J1518+4904 make it the pulsar closest to PSR J2235+1506 on the P-$\dot{P}$ diagram. This circumstantial evidence suggests that J2235+1506 was formed in a high mass neutron star binary which was disrupted upon the second supernova explosion.

Acknowledgements

We thank Z. Arzoumanian for assistance with collection of some of the pulsar timing data. The 140 Foot telescope is a facility of the National Radio Astronomy Observatory, operated by Associated Universities, Inc., for the National Science Foundation.

Table 3: Double Neutron Star Systems[a]

PSR	Orbital Period (d)	Characteristic Age (yr)	Magnetic Field (G)	System Mass ($M_\odot$)
J1518+4904	8.6	2×10^{10}	1×10^{9}	2.69 ± 0.04
B1534+12	0.4	2×10^{8}	1×10^{10}	2.6784
B1913+16	0.3	1×10^{8}	2×10^{10}	2.8284
B2127+11C	0.3	1×10^{8}	1×10^{10}	2.712
B2303+46	12.3	3×10^{7}	8×10^{11}	2.60 ± 0.06

[a] See Nice et al. (1996) for references.

References

Damour, T. & Taylor, J.H. 1991, ApJ 366, 501

Nice, D.J., Sayer, R.W. & Taylor, J.H 1996, ApJ 466, L87

Sayer, R.W., Nice, D.J. & Taylor, J.H. 1997, ApJ 474, 426

Authors' Address

Physics Department, Princeton University, Box 708, Princeton, NJ 08544, USA