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Recent Timing Results for PSR B1259−63

Abstract

The binary pulsar PSR B1259−63 is in a highly eccentric 3.4 yr orbit around the Be star SS 2883. Timing observations of this pulsar, made over a 7 yr period using the Parkes 64 m radio-telescope, cover two periastron passages, in 1990 August and 1994 January. The timing observations of PSR B1259−63 clearly show evidence for timing noise which is dominated by a cubic term. Unfortunately, the large amplitude timing noise and data over only two complete orbits make it difficult to produce a unique timing solution for this pulsar. However, if the long term behavior of timing noise is completely modeled by a cubic term, both $\dot{\omega}$ and $\dot{x}$ terms are required in the timing model which could be a result of a precessing orbit caused by the quadrupole moment of the tilted companion star. In this paper we summarise the timing observations for the PSR B1259−63 system; full details are given in Wex et al. (1997).

I Introduction

The binary pulsar PSR B1259−63 is part of a unique system. Discovered at Parkes in a survey of the Galactic plane at 1.5 GHz (Johnston et al. 1992a), it was shown by Johnston et al. (1992b) to be in a highly eccentric 3.4 yr orbit around a $10^{\rm th}$ magnitude Be star, SS 2883. The pulsar period P is relatively short, 47.8 ms, and the measured period derivative gives a pulsar characteristic age, $\tau_c = P/(2\dot{P})$, of 3.3×10^5 yr and a surface magnetic field, $B = 3.2 \times 10^{19}(P\dot{P})^{1/2}$, of 3.3×10^{11} G. This therefore is a young system, which may evolve through an accretion phase to form a single or binary millisecond pulsar. The companion star is of spectral type B2e, with a mass of $M_* \sim 10$ M$_\odot$ and radius $R_* \sim 6$ R$_\odot$ (Johnston et al. 1994). A companion mass of 10 M$_\odot$ and a pulsar mass of 1.4 M$_\odot$ imply an orbital inclination $i \sim 35°$. The orbital eccentricity is very high, 0.87, and for $\sin i \sim 0.5$, the pulsar approaches within 25 R_* of the companion star at periastron, passing through the circumstellar disk.

In this paper we report timing observations made using the Parkes radio telescope over a 7 year interval covering both the 1990 and 1994 periastron passages and discuss their interpretation.

II Timing observations and data analysis

A total of more than 300 pulse times of arrival (TOAs) were measured at the Parkes radio telescope between 1990 January and 1996 October. Most of the observations were at frequencies around 1.5 GHz, giving TOA uncertainties of $\lesssim 100\mu$s. Observations at 0.43, 0.66, 4.8 and 8.4 GHz were also made. Details of the observing systems are given in Johnston et al. (1996).

Pulsar and binary parameters were obtained using the least-squares fitting program TEMPO (Taylor & Weisberg 1989) with the Jet Propulsion Laboratory solar-system ephemeris DE200 (Standish 1982). TEMPO was extended by a timing model for binary pulsars that orbit a companion star with a significant quadrupole moment (Wex 1997).

As discussed by Johnston et al. (1996), significant dispersion and scattering changes were observed around periastron. Because of this, data from 1990 July and 1993 December were omitted from the analysis. The pulsar was eclipsed during 1994 January. Thus there is a gap in the TOAs around the first periastron (August 1990) from day -107 to day $+22$ and a gap around the second periastron (January 1994) from day -51 to day $+25$. Unfortunately this is a crucial problem when searching for the correct timing model for PSR B1259$-$63. One consequence of this is that the timing models are quite insensitive to extra phase-jumps added to the TOAs at each periastron.

The data were first fitted for pulsar position, period, period derivative, dispersion measure and the five Keplerian orbital parameters. The best results give a RMS of 2030 μs. Systematic variations in the residuals are observed at all orbital phases, showing that this set of parameters does not satisfactorily model the timing behavior of the system.

Observations made between 1990 January and 1994 October appeared to be well explained by step changes in the pulsar period at the two periastrons (Manchester et al. 1995), which could originate from a propeller-torque spindown caused by the interaction of the pulsar with the circumstellar matter at the Alfvén radius (Illarionov & Sunyaev 1975). This timing solution now fails to model the TOAs obtained during timing observations from 1995 and 1996.

One could still try to fit for a pure Keplerian motion and the effects of spin-down (modeled as a $\Delta P/P$ term) at each periastron. The best fit for this has an RMS residual of 360 μs. The resulting two period steps for this fit emerge to have opposite signs, certainly a problem if one looks for a physical interpretation.

PSR B1259$-$63 is a comparatively young pulsar with a period derivative $\dot{P}$ of 2.3×10^{-15}. According to Lyne (1996) such a pulsar should suffer a timing noise which is usually dominated by a cubic term. This can be modeled by a period second derivative $\ddot{P}$ of the order of $\pm 10^{-26}$ ss^{-2}. Fitting for a $\ddot{P}$, the pulsar spin parameters and the Keplerian parameters for the orbital motion leads to a RMS of 950 μs, but there are still strong systematics in the residuals.

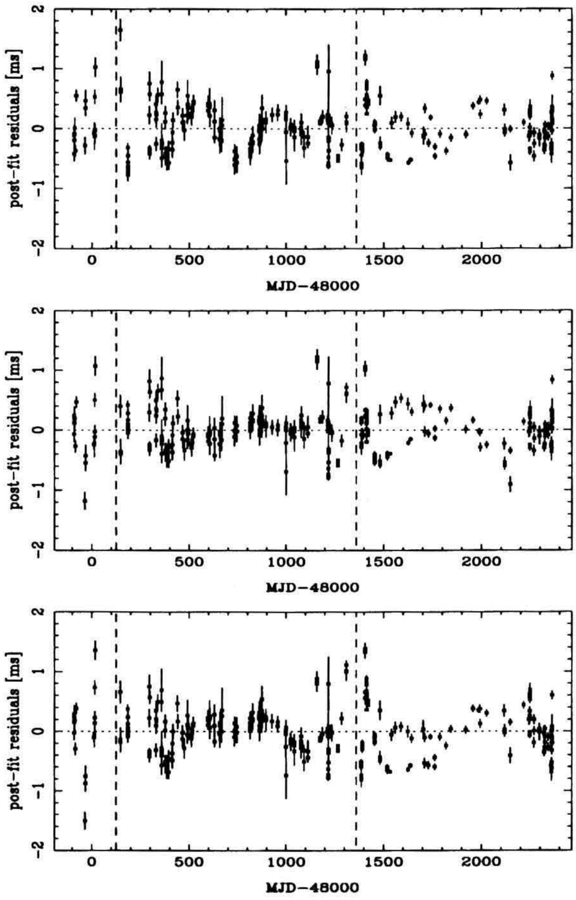

Figure 1. Post-fit residuals for MODEL 1, MODEL 2A, MODEL 2B (unweighted fits). The vertical dashed lines indicate the two times of periastron passage.

A straight forward assumption is that the timing noise is not fully modeled by a $\ddot{P}$ and additional frequency derivatives are needed to account for it. Adding just a third derivative leads to some improvement but does not give a satisfactory fit. So we add a fourth frequency derivative and obtain a fit with a RMS residual of 390 μs (MODEL 1). Figure 1 shows the corresponding post-fit residuals. The resulting fit still shows systematics which of course could result from un-modeled contributions from timing noise. Fitting for even higher frequency derivatives does not improve the fit and does not give significant values for these higher frequency derivatives.

For a pulsar in orbit about a Be star, one expects changes in the longitude of the periastron ω and the inclination of the orbit i (Lai et al. 1995). The latter manifests itself as a change of the projected semi-major axis $x = a_p \sin i$. The physical cause of these changes is the so called "classical spin-orbit coupling," i.e., the fact that the spin-induced quadrupole of the fast rotating companion leads to a $1/r^3$ term in the gravitational potential which leads to apsidal motion and precession of the binary orbit (see Kopal 1978, Smarr & Blandford 1976, and Lai et al. 1995 for details). Fits for the pulsar position, spin parameters (including $\ddot{P}$ to model the timing noise), Keplerian parameters for orbital motion, and the two post-Keplerian parameters, $\dot{\omega}$ and $\dot{x}$, lead to two timing solutions, MODEL 2A (RMS $= 340\,\mu$s, $\dot{\omega} = -0.000019(1)$ deg/yr, $\dot{x} = -0.21(1) \times 10^{-12}$) and MODEL 2B (RMS $= 410\,\mu$s, $\dot{\omega} = -0.000041(1)$ deg/yr, $\dot{x} = -2.42(1) \times 10^{-12}$). The corresponding post-fit residuals are shown in Fig. 1. Realistic errors for the parameters were obtained by adding (or subtracting) an integer number of phase turns at each periastron until the fit deviated from the best fit by about 20 per cent (in RMS residual). These fits are still not perfect, e.g., there are clearly systematic trends in the residuals between MJD 49500 and MJD 50200. But so far these are the best fits for PSR B1259−63. The systematic behavior could be a result of un-modeled timing noise or a physical process so far overlooked in this system.

In conclusion, we have four fits that give reasonably good residuals. We feel the solutions which involve a step change in the period can be ruled out on the grounds of their opposite sign. If we have completely modeled the timing noise with a cubic term then the fact that $\dot{\omega} < 0$ implies that the companion is tilted at least $54\overset{\circ}{.}7$ with respect to the orbital plane. This is an important result with consequences both for the theory of binary evolution and pulsar kick velocities but also for the interpretation of the radio and high-energy emission from the system at periastron. For a detailed discussion of the various timing fits, the full set of parameters derived for the binary system and the implications and restrictions of the orientation of the companion see Wex et al. (1997).

Observations of this pulsar continue to be made in the lead up to the next periastron predicted for 1997 May 29. This periastron passage should enable us to determine which of the above models is the correct description of the PSR B1259−63 system.

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