The Massive Binary Pulsar J1740−3052

I. H. Stairs
*Department of Physics and Astronomy, University of British Columbia,*
*6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada*

R. N. Manchester
*ATNF, CSIRO, P.O. Box 76, Epping NSW 1710, Australia*

A. G. Lyne, M. Kramer
*University of Manchester, Jodrell Bank Observatory, Macclesfield,*
*Cheshire SK11 9DL, UK*

V. M. Kaspi
*Physics Dept., McGill University, 3600 University St., Montreal,*
*Quebec H3A 2T8, Canada*

F. Camilo
*Columbia Astrophysics Laboratory, 550 W. 120th St., New York, NY*
*10027, USA*

N. D’Amico
*Osservatorio Astronomico di Bologna, via Ranzani 1, 40127 Bologna,*
*Italy*

Abstract. The young pulsar J1740−3052 is in an 8-month orbit with a companion of at least 11 solar masses. We present multifrequency GBT and Parkes timing observations, and discuss implications for the nature of the companion.

1. Introduction

PSR J1740−3052 was discovered in 1997 in the Parkes Multibeam Pulsar Survey (e.g., [Manchester et al. 2001]), and still leaves a number of fundamental questions unanswered. It is a young, unrecycled pulsar ($P = 570$ ms, $\tau_c = 3.5 \times 10^5$ kyr) in a 231-day, highly eccentric orbit about a companion of at least 11 solar masses whose nature is undetermined. While there is a late-type star coincident with the interferometric position of the pulsar, we have argued that this is probably not the pulsar companion, and that an early B-star or even a black hole is more likely ([Stairs et al. 2001]). Here we present an up-to-date analysis of ongoing multifrequency observations of this pulsar, and explore what these data may tell us about the true pulsar companion.
2. Observations and Timing

Parkes observations were taken at 2380, 1400 and 660 MHz, using multichannel filterbanks and 1-bit digitization. The 1400 MHz data have been taken regularly since mid-1998, while data at the other two frequencies have been acquired primarily in the weeks leading up to various periastron epochs. Some 1400 MHz data were also acquired regularly at Jodrell Bank Observatory from mid-1998 through the end of 2000. Since Sept. 2001, we have been monitoring PSR J1740−3052 with the new 100-m Green Bank Telescope (GBT), using regular 3–4 week spacing with more frequent sampling in the lead-ups to periastrons. At each epoch, multifrequency data were acquired with the “Berkeley-Caltech Pulsar Machine” (BCPM) flexible filterbank: typically centre frequencies of 2200, 1400, 1190 and 590 MHz were used, with occasional points at 1780 or 820 MHz. All profiles were dedispersed and folded according to the predicted topocentric period. TOAs were obtained by cross-correlation and fit to a pulse timing model using \texttt{tempo}.

The templates at different frequencies were aligned by cross-correlation and (for those with scattering tails) by timing.

The timing model used was that for pulsar–main-sequence binaries \cite{Wex1998}. Along with the five standard Keplerian orbital parameters, two correc-

\url{http://pulsar.princeton.edu/tempo}
Figure 2. The points indicate observed values of the pulsar’s dispersion measure (DM) as a function of orbital phase, from data obtained with the GBT and Parkes telescope. The curves show the expected changes in the DM if the pulsar signal passes through a spherically symmetric B-star wind, for inclination angles of 40° (top), 70° and 85° (bottom), with the overall magnitude of the DM predictions scaled to match the observed values. The curves are not fits to the data.

3. DM Variations and Wind Model

The multifrequency GBT and pre-periastron Parkes data allow us to estimate the dispersion measure (DM) at multiple epochs throughout the orbit (Figure 2). The most abrupt changes occur in the month before periastron, as the pulsar swings “behind” its companion. The measured DM variations are 2–3 orders of magnitude too small to be accounted for by a K-star wind (Stairs et al. 2001).
Instead, we use a simple model of the mass-loss and velocity for a line-driven B-star wind (see Kaspi, Tauris, & Manchester 1996 and references therein) and integrate the total expected DM contribution from the wind along the line of sight to the pulsar. We then scale these predictions to match the range of observed DM variations, and compare the shape of the predicted curve to the observed values. A simple $\chi^2$ analysis indicates that the best inclination angle is around 70°–75° and the required scaling implies a mass-loss rate $2 \times 10^{-9} M_\odot/\text{yr}$ and terminal velocity 2200 km/s, which are typical values for a B-star. The model is therefore self-consistent.

4. Implications for Orbital Geometry

An estimated inclination angle of 70° implies a companion mass of 12.8 $M_\odot$ assuming a neutron-star mass of 1.35 $M_\odot$ (Thorsett & Chakrabarty 1999). The spin quadrupole contribution to $\dot{\omega}$ is therefore small and likely negative. Its exact value depends not only on the rotation rate and internal structure of the star, but also on the precession phase $\Phi_0$ and the misalignment $\theta$ of the stellar spin with the orbital angular momentum. The spin-induced $\dot{x}$ depends in the same way on the stellar spin and structure, and so the ratio of the two measured parameters can be used to constrain the two unknown angles (Wex 1998, Kaspi et al. 1996):

$$\frac{\dot{\omega} x}{\dot{x}} \sin \Phi_0 - \cos \Phi_0 = \frac{1 + 3 \cos 2\theta}{2 \cot i \sin 2\theta},$$

where $i$ is the inclination angle of the orbit. Allowing for $2\sigma$ variation in both $\dot{\omega}$ and $\dot{x}$, we find that $\theta$ is most likely to be in the range 30°–75°. This misalignment is likely due to an asymmetric kick in the supernova that created the pulsar. With ongoing long-term timing, we will refine the measurements of $\dot{\omega}$ and $\dot{x}$ and begin to search for the predicted second derivative of each parameter, which will lead to further constraints on the orbital geometry.

References

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