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Research Note

Celestial position of the companion of PSR J1740−5340

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Abstract. We present optical astrometry of archival ground and space based imaging of the companion to PSR J1740−5340. The optical position of the companion is significantly offset from the timing position of the pulsar. We briefly investigate the effects of this inconsistency on other timing parameters and compare our position with an improved position of PSR J1740−5340 from recent, preliminary, timing results.

Key words. stars: pulsars: individual: PSR J1740−5340 – astrometry – Galaxy: globular clusters: individual: NGC 6397

1. Introduction

In many ways, the binary millisecond pulsar PSR J1740−5340 (D'Amico et al. 2001), located in the nearby (2.3 kpc) galactic globular cluster NGC 6397, is an exceptional system; it shows irregular eclipses over a wide range of orbital phases and it has the largest orbital period and the heaviest binary companion among all currently known eclipsing pulsars, including those in globular clusters[1]. An optical variable,discovered by Taylor et al. (2001), was identified as the pulsar companion by Ferraro et al. (2001) on the basis of positional coincidence with the timing position of the pulsar. These and later photometric and spectroscopic observations (Orosz & van Kerkwijk 2003; Kaluzny et al. 2003; Ferraro et al. 2003) have revealed that both the brightness and the radial velocity of the companion vary with the orbital period and phase of the pulsar, unambigously linking this star as the companion to PSR J1740−5340.

The observed pulsar period P and period derivative $\dot{P}$ give rise to a large spin-down luminosity, $L_{\rm SD} \propto \dot{P}/P^3 \approx 1.4 \times 10^{35}$ erg s^{-1} (D'Amico et al. 2001), which is among the highest found for millisecond pulsars. Though part of the period derivative may not be intrinsic, due to accelerations in the potential of the globular cluster, the effects of irradiation of the companion by the pulsar would give rise to heating. No evidence of heating of the pulsar companion, at the level expected from the spin-down luminosity, are found (Orosz & van Kerkwijk 2003).

From accurate absolute optical astrometry of *HST*/WFPC2 observations of NGC 6397 we have found that the optical position of the companion of PSR J1740−5340 is inconsistent with the position of the pulsar D'Amico et al. (2001). A preliminary timing solution (A. Possenti, priv. comm.) provides a celestial position that is in much better agreement with our optical position, but moreover, predicts a significantly different spin-down luminosity, now in agreement with the observed lack of heating of the pulsar companion.

2. Observations and data reduction

The method that was employed to determine the optical position of the companion of PSR J1740−5340 is similar to that described in Bassa et al. (2003); we will focus on the differences. We used an archival 4 min V-band exposure, obtained with the Wide Field Imager (WFI) at the ESO 2.2 m telescope at La Silla, during the night of May 14, 1999. A total of 248 stars from the UCAC2, the 2nd version of the USNO CCD Astrograph Catalog[2] (Zacharias et al. 2004), coincident with an $8' \times 8'$ subsection of the chip containing the cluster center, were selected for the astrometry and their positions were measured. Of these, 88 stars were not saturated and appeared stellar and unblended. An astrometric solution, fitting for zero-point position, scale and position angle, was computed and 6 outliers, having residuals in excess of $0\farcs25$, were iteratively removed. The final solution of 82 stars had rms residuals of $0\farcs068$ in both coordinates.

This solution was transferred to F555W (hereafter V_{555}) images of *HST*/WFPC2 datasets GO5929 and GO7335.

[1] For an up-to-date list, see http://www.naic.edu/~pfreire/GCpsr.html

[2] UCAC, http://ad.usno.navy.mil/ucac/

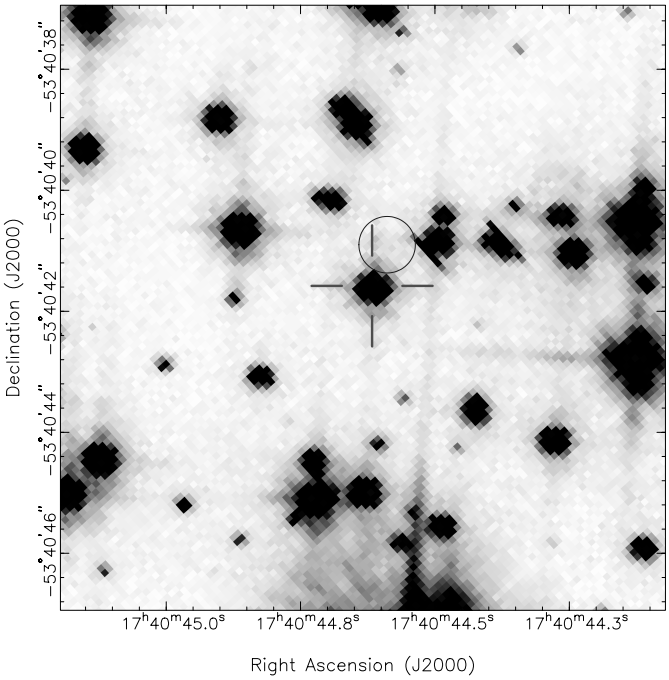

Fig. 1. A 10″ × 10″ subsection of a 249 s V_{555} image from the *HST*/WFPC2 GO5929 dataset. The 99% confidence level on the position of PSR J1740−5340 by (D'Amico et al. 2001) is indicated with a circle. The radius of the circle is 0.″47 and incorporates the uncertainties in the pulsar position, in the astrometric tie between the WFI and the UCAC2 and in the tie between the WFI and the *HST*/WFPC2 image. The position of the pulsar companion, as identified by Ferraro et al. (2001) is indicated with tickmarks (0.″5 in length).

As the pulsar companion is bright (V_{555} = 16.9), we only used 4 V_{555} images, with a total exposure time of 89 s, from both datasets. Positions of stars on these images were obtained with the HSTphot 1.1.5b package (Dolphin 2000). We matched stars that were common to the *HST*/WFPC2 datasets and the WFI image and fitted for zero-point position, scale and position angle between the WFI pixel positions and the distortion corrected *HST*/WFPC2 master frame positions (Anderson & King 2003). Outliers were iteratively removed until the astrometric solution converged. The final astrometric solution contained 154 (190) stars, resulting in rms residuals of 0.″045 (0.″056) in right ascension and 0.″050 (0.″061) in declination for the GO5929 (GO7335) dataset.

The position of the optical companion to PSR J1740−5340 in the WFI image and the two *HST*/WFPC2 datasets is given in Table 1 while Fig. 1 shows a finding chart. The uncertainty in the position of the companion in the WFI image is the quadratic sum of the uncertainty in the tie between the UCAC2 and the WFI and the positional uncertainty of the companion, about 0.″06. In the *HST*/WFPC2 datasets the positional uncertainty of the companion is much smaller, and hence the uncertainty is dominated by that of the tie between the UCAC2 and the WFI and that of the tie between the WFI and the *HST*/WFPC2 images.

The astrometry provided in the UCAC2 is on the Hipparcos system, i.e. the International Celestial Reference System (ICRS), on which the pulsar timing observations are based.

Table 1. Celestial position of the companion to PSR J1740−5340.

Dataset	Date (UT)	α_{J2000}	δ_{J2000}
WFI	May 14, 1999	$17^h40^m44^s.611(10)$	−53°40′41.″57(9)
GO5929	March 6–7, 1996	$17^h40^m44^s.617(9)$	−53°40′41.″58(8)
GO7335	April 3, 1999	$17^h40^m44^s.617(10)$	−53°40′41.″62(9)
Mean:		$17^h40^m44^s.615(8)$	−53°40′41.″59(7)

Random positional uncertainties of the UCAC2 stars range from 0.″020 for 10 to 14th magnitude stars upto 0.″070 for 16th magnitude stars (Zacharias et al. 2004). These uncertainties are incorporated in the uncertainty in the tie between the UCAC2 and the WFI. A comparison of UCAC positions with the International Celestial Reference Frame (ICRF), the primary representation of the ICRS (Feissel & Mignard 1998), is presented in Assafin et al. (2003).

3. Discussion and conclusions

The timing position of PSR J1740−5340 as published by D'Amico et al. (2001) is inconsistent with the optical position of the pulsar companion. The timing position, α_{J2000} = $17^h40^m44^s.589(4)$, δ_{J2000} = −53°40′40.″9(1) (D'Amico et al. 2001) is offset from the optical position by −0.″23(8) and 0.″69(12) in right ascension and in declination, respectively. We attempted to use this position to fit simulated TOAs generated using the ephemeris of D'Amico et al. but found that even with quite large changes in the period derivative it was not possible to get a good fit of the TOAs. This indicated that there was perhaps something wrong with the exisiting timing solution.

Recent timing results, using a longer data span, also revealed the inconsistent position (A. Possenti, priv. comm.). It was found that, as the radio signal of PSR J1740−5340 is eclipsed at phases far from inferior conjunction, the reliability of TOAs is hard to assess, and, as a result, the errors appeared more uncertain than those quoted in the D'Amico et al. (2001) ephemeris. Improved astrometry (Possenti et al., in preparation) is in much better agreement with our optical position; a preliminary position by Possenti et al. (2004) is offset from the position of the companion by 0.″13(7) in right ascension and −0.″16(9) in declination. Though still outside the 1σ errors the accurate optical position of the companion might aid future timing of PSR J1740−5340.

As a result of the change in position, the preliminary ephemeris (Possenti et al. 2004) has an updated pulse period derivative that is significantly different from that of D'Amico et al. (2001). Hence, the spin-down luminosity of PSR J1740−5340 is decreased by over a factor 4; $L_{SD} \approx 3.3 \times 10^{34}$ erg s^{-1}. This value is in much better agreement with the lack of heating of the companion by the pulsar as expected by Orosz & van Kerkwijk (2003).

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