Light curve irregularity observed in the companion of PSR J1723-2837

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Abstract: The author presents a phase Light Curve (LC) to the companion of PSR J1723-2837, a millisecond pulsar from photometric measurements with a 30 cm telescope. Variation in the LC agrees well with the orbital period and provides supporting evidence for tidal distortion of the companion in the compact binary system. Short period irregularities in the LC was discovered around $\phi \sim 0.25$.

1. Introduction

It is generally accepted that pulsars lose energy through magnetic dipole radiation and rotation rate will decrease over time. When a pulsar's spin period slows down sufficiently, the radio pulsar mechanism is believed to turn off (the so-called "death line"). However in the case of binary systems, the theory is that infalling matter transfer from the companion on to the neutron star can increase angular momentum to the neutron star to "recycle" it as a rotation-powered millisecond pulsar (MSP) [Alpar et al, 1982: Bildsen et al. 1997]

PSR J1723-2837 is an eclipsing, 1.86 millisecond binary pulsar that was discovered in the Parkes Multibeam (PM) survey. The MSP follows an almost circular 14.8 hour orbit, about a companion star (J17232318-2837571) of spectral type G5 that was identified using Infrared, optical, ultraviolet and spectrophotometry [Crawford, 2013]. X-Ray emission was also detected from PSR J1723–2837 and is presumably a candidate for a radio pulsar/X-ray binary transition object (Bogdanov, 2014).

However, sparse orbital photometric data of the companion did not allow constraining the degree of tidal distortion to date, although suggestions were made that there are signatures of a strong tidal effects, for example; a large orbital period derivative; the pulsar is eclipsed for a significant portion of its orbit (~ 15%) and significant flux variability in the radio data (2000 MHz) which may be contributed by obscuration material from a mass-losing companion that could be a star nearly filling its Roche lobe.

In this report I would like to present a LC on the companion star that supports evidence for the expected tidal forces and will report on short period irregularities observed in the continuity of the LC.

2. Observations and data analysis

Data were obtained with a 30 cm amateur class SCT and ST9e CCD (512x512) cooled to -15 ^{o}C, located at code 641, South Africa. FWHM were between 2 to 3 arcsec, occasionally reached < 2 and >3 arcsec. The pulsar position is only 4.3^{o} from the Galactic plane and results in a crowded star field (see Fig. 1).

Light exposures were all 300 seconds, without filters. Measurements were made between 3 Aug 2014 and 13 Sep 2014 on 14 nights. A public photometric program, Muniwin was used to reduce the time series photometry.

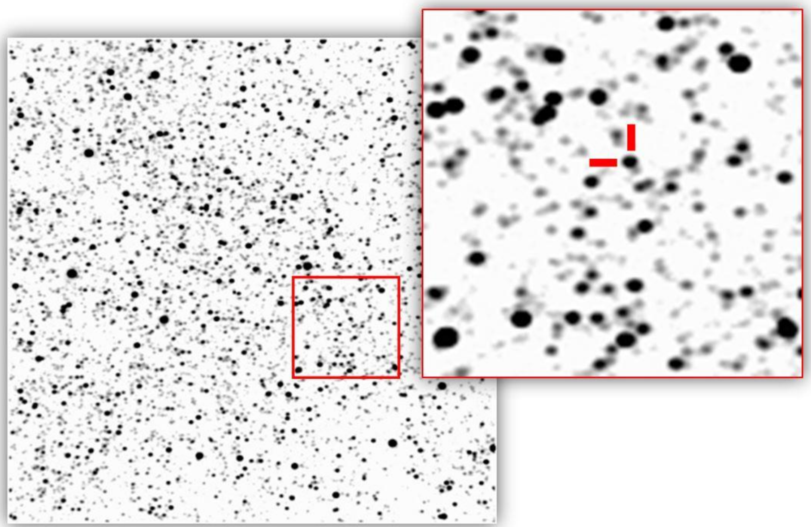

Fig. 1. RA 17h 23m, Dec -28 37’: The 300 second image (left) was made with a 30 cm SCT and ST9eCCD. The ~130 arc seconds “cut-out” box (right) shows the position of J17232318-2837571marked with red bars and the corresponding position on the left image.

3. Results

A phase light curve was constructed (fig 2), with ϕ ~ 0 located at the ascending node [Time of ascending node, T_{asc} (MJD) = 55425.320466] and folded with the pulsar's orbital frequency [f_b (s^{-1}) = 1.88062856(2) × 10^{-5}] corrected with the 1st derivative [$\dot{f}_b$ (s^{-2}) = 1.24(4) × 10^{-18}]. Therefore we see ϕ ~ 0.75 the side of the companion facing the pulsar. The radio eclipses in the PM survey were observed at ϕ ~ 0.25 when the pulsar was behind the companion (at inferior conjunction). All photometric measurements were transforming to Heliocentric times. The Magnitude scale was derived from a virtual comparison star and is only an approximation for V mag.

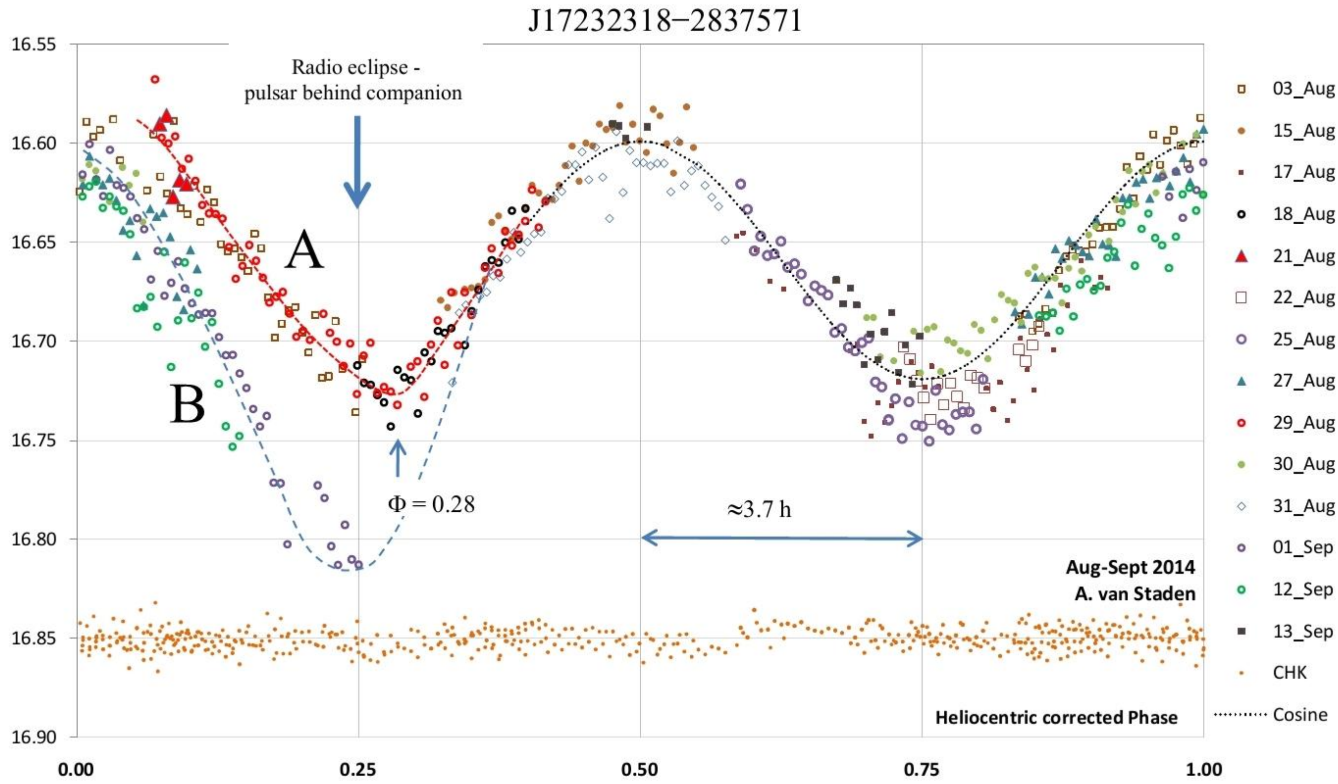

Fig. 2. Light curve of the companion to PSR J1723-2837. Measurements of a check star were plotted below the curve (Orange dots).

The LC shows optical variability (~ 0.12 mag) with two maxima and two minima during each orbit of the companion that nicely correlates with the pulsar's orbital period, confirming variability is associated with the pulsar's binary motion. The observed light curve clearly shows two distinct minima, at phases ϕ ~ 0.25 and ϕ ~ 0.75 at the conjunctions and two maxima at quadratures, ϕ ~ 0.0 and ϕ ~ 0.5 when the distorted star presents the longest axis of its ellipsoid to the observer. Such a shape is a clear signature of tidal distortions induced by the Neutron Star's tidal field on a highly perturbed, bloated star (Pallanca, 2010).

Irregular patterns in the LC shape were observed around ϕ ~ 0.0 to ϕ ~ 0.3 as a function of time. Furthermore, it appears that the flux variation follow two distinct "tracks" (see fig.2, **A** and **B**), however more observations are necessary to confirm this.

If we consider "**B"** as integral part of the LC, then we have two asymmetric minima and the slight increase in signal at the pulsar inferior conjunction (ϕ ~ 0.75) suggesting that irradiation contributes by the pulsar flux onto the companion surface according to the current theoretical models. (See for example: "The red straggler companion to PSR J1740−5340"; (Orosz 2003))
The heating effect in this case will be marginal while the optical modulation of the companion is dominated by ellipsoidal variations.

Surprisingly, on 3 nights the LC flux follows a slower decline from ϕ ~ 0.0 to ϕ ~ 0.25 (see "**A**") with a minima now ϕ ~ 0.28 and then rapidly increases and merge with previous sampled data points.

In order to rule out some systematic errors, a check star was plotted below the LC (see fig. 2 – orange dots) and a standard deviation of 0.00535 magnitude was calculated. A cosine function, -cos(ϕ4π) was over plotted (see fig. 2 – black dots) that best resembles the LC data.

Discussion

In the last few years, optical observations of binary millisecond pulsar systems have been used to great effect. PSR J1723–2837 is a very interesting object that could experience a switch to an accretion disk state. As the nearest such system it provides the best-suited target for studying the transition process of MSPs from accretion to rotation power (and vice versa) and the circumstances surrounding (Papitto, 2013). Additionally the companion star at ~16 magnitude put this in reach of many amateur telescopes to contribute valuable data.

In this report I presented a LC and evidence for tidal distortion in the compact binary systems clearly by comparing observed results and that of simular studies. Additionally, modelling of the LC can be utilized as a means to constrain system parameters including the mass of the neutron star [Schroeder, 2014].

The observed irregularities in the LC are spectacular but non-conclusive. More detailed observations may better characterize the observed phenomena for example, are the irregularities periodic and how does the period relate to other parameters; are there a progression between "track"- **A** and "track"- **B**; Are there smaller anomalies in other parts of the LC? This in turn may help to resolve some of the outstanding issues in the the current research of binary millisecond pulsar systems.

References

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Table 1. Parameters for PSR J1723–2837

Parameter	Value
Right ascension (J2000)	17:23:23.1856(8)
Declination (J2000)	−28:37:57.17(11)
Spin frequency, f (s^{-1})	538.870683485(3)
Timing epoch (MJD)	55667
Time of ascending node, T_{asc} (MJD)	55425.320466(2)
Projected semi-major axis, x (s) [a]	1.225807(9)
Orbital frequency, f_b (s^{-1})	$1.88062856(2) \times 10^{-5}$
Orbital frequency derivative, $\dot{f}_b$ (s^{-2})	$1.24(4) \times 10^{-18}$
Orbital frequency second derivative, , $\ddot{f}_b$ (s^{-3})	$-2.6(3) \times 10^{-26}$
Spin period, P (ms)	1.855732795728(8)
Orbital period, Pb (d)	0.615436473(8)
Companion mass range ($M_\odot$)[d] 0.4–0.7	0.4–0.7
Orbital inclination angle range (degrees)[d]	30–41
Distance, d (kpc) [f]	0.75(10)

$a_x = a \sin i/c$ where a is the semi-major axis and i is the orbital inclination angle.