Outburst of PSR J1723-2837 Binary system

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Abstract:
CCD photometric measurements were obtained from the compact binary pulsar system, PSR J1723-2837 in the visual optical band from August to October 2014. Anomalies were observed in the LightCurve (LC) and are probably a result of modulation changes during an outburst. An argument is presented that irradiation in the form of a pulsar wind may be linked to the observed event.

1. Introduction

A previous letter [van Staden, 2014], presented a phased light curve of the compact binary system, PSR J1723-2837. The light curve of the companion was well described by ellipsoidal variations due to tidal distortion. In this case, there was no evidence of irradiation, similar to PSRJ1740-5340, which was described as a surprising result by the researchers [Orosz JA, et al, 2003]. The irregularities reported in the observed LC were not conclusive at that stage.

This letter reports additional observations in support of an outburst of the binary pulsar system. A further look is taken at the modulation of the observed flux and how this may relate to irradiation in the form of a pulsar wind.

Notes

a) In the context of this letter, **"Variations"** refer to the fact that the observed signal varies (in *phase* and/or in *amplitude*) relative to the expected sinusoidal light curve produced by ellipsoidal variations.

b) The frequency of the ellipsoidal variations is $2f_0$, where f_0 is the orbital frequency.

2. Data analysis

Data were obtained from 3 August 2014 to the 20 October 2014 with a total of 797 photometric measurements. The longest continued observation (referred to as datasets in the remainder of this letter) was approximately 66 samples with a 5 minute sampling period that relates to about 40% covering of the 14.8 hour orbital period. All photometric data were corrected for atmospheric refraction and sampling times were converted to Heliocentric times. The light curve magnitude was scaled to approximately ±1.

The photometric data covering the period of observation are shown here as a folded phase light curve diagram in figure 1. The datasets that contain the least variations are shown here with blue markers (+). The blue line is a sinusoidal function $2f_0$ that best fits these data samples. The datasets regarded as variations are shown with fitted red lines. The Companion-Pulsar relation is shown at the top of the diagram with associated phases. (The bottom of the page can be regarded as the viewpoint from earth, assuming the pulsar-companion orbit is in the plane of the surface of the page.) The maxima coincide with Ø ~ 0.0 and Ø ~ 0.5 when the distorted star presents the longest axis of its ellipsoid to the observer.

In order to investigate the observed variations in the frequency domain, the data samples were interpolated with a cubic spline to create evenly spaced samples. The best fitted sinusoidal function (blue curve in figure 1) was subtracted prior to a FFT in order to reveal the remainder of the frequency components. The results from the FourierAnalysis were not particular successful, probably due to the large spaces between datasets and much effort was spent looking at various datasets for prominent signals. However, the observations towards the end, revealed frequency components at f≈1.624 and a weaker signal at f≈1.0. Of particular interest is the frequency at 1.624 that is equal to the orbital frequency (see figure 2).

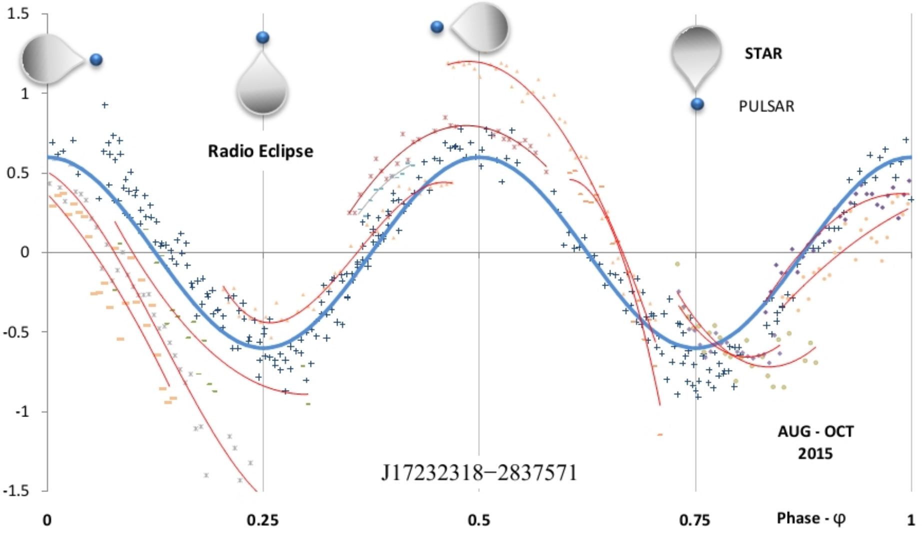

Fig. 1. Light curve of the companion to PSR J1723-2837 from August to October 2015. The star at phases 0 and 0.5 exposes slightly larger surfaces to the observer therefore producing and increase in light intensity. If irradiation played a role, we would expect asymmetry of the minima at phases 0.75 and 0.25 when the star alternatively exposes its "hot" and "cold" surfaces towards earth.

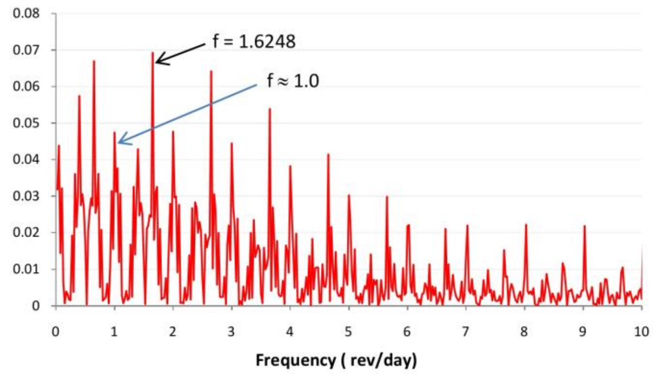

Fig. 2. Fourier Transform with the main frequency, f_0 removed.

If the 1.624 frequency component can be confirmed there are theories to support this particular modulation. [Stapper B.W., et al, 1998, Reynolds M.T., et al, 2007, Bogdanov, et al, 2013, Wang Z., 2013, Li M. et al, 2014]. Binary pulsar system that revealed this particular modulation is believed to be the consequence of irradiation cause by a pulsar wind. This will have the effect brightening and dimming once per orbit as the companion faces the “hot” and “cold” side towards Earth. It is further postulated that material blown off the companion star may also block and reduces light transmission while facing the “cold” side of the star. However, if this is the case, the phase of the modulating signal at peak brightness would have to be synchronized to coincide with Ø= 0.75 when the pulsar is between the Earth and the companion star. Consequently, the minimum is expected around Ø= 0.25

To further investigate the phase and amplitude, an approach was followed where the signal S, measured was the sum of two terms,

$$S = S_{2f0} + X_{f0}$$

where S_{2f0} is the contribution due to ellipsoidal variations and agrees well with a sinusoidal function and X_{f0} is the modulating signal in question. From studies in other binary pulsar system we can assume with reasonable confidence that X_{f0} may be approximated by a sinusoidal function [Stapper B.W., et al, 1998, Reynolds M.T., et al, 2007]. Therefore we can estimate S mathematically as

$$S \approx a_0 \cdot \sin(\varphi_0 + \omega_0 \cdot t) + a_1 \cdot \sin(\varphi_1 + \omega_1 \cdot t) \qquad [1]$$

The first term represents ellipsoidal variations where a_0 is the amplitude, φ_0 is the phase, $\omega_0 = 4\pi f_0$ and f_0 is the orbital frequency. The second term represents the modulating signal where a_1 is the amplitude, φ_1 the phase and $\omega_1 = 2\pi f_0$. By applying the rule of linear combinations we can expand the 2nd term and rewrite (1) to be

$$S \approx a_0 \cdot \sin(\varphi_0 + \omega_0 \cdot t) + [\, \alpha \cdot \sin(\omega_1 \cdot t) + \beta \cdot \cos(\omega_1 \cdot t)] \qquad [2]$$

To be consistent with the published time of the ascending node, we can change the first term to a cosine function and set the phase to zero, $\varphi_0 = 0$. Therefore equation (2) reduces to,

$$S \approx a_0 \cdot \cos(\omega_0 \cdot t) + \alpha \cdot \sin(\omega_1 \cdot t) + \beta \cdot \cos(\omega_1 \cdot t)$$

By using multiple linear regression analysis, the method of least squares was used to estimate the regression coefficients that best fits the data and can be written in a more general form as,

$$S_i = a_0 \cdot \cos(\omega_0 \cdot t_i) + \alpha \cdot \sin(\omega_1 \cdot t_i) + \beta \cdot \cos(\omega_1 \cdot t_i) + e_i, \qquad i = 1,2 \ldots, n \qquad [3]$$

and finally in a matrix form as:

$$\begin{bmatrix} S_1 \\ S_2 \\ \vdots \end{bmatrix} = \begin{bmatrix} \cos(\omega_0 \cdot t_1) & \sin(\omega_1 \cdot t_1) & \cos(\omega_1 \cdot t_1) \\ \cos(\omega_0 \cdot t_2) & \sin(\omega_1 \cdot t_2) & \cos(\omega_1 \cdot t_2) \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} a_0 \\ \alpha \\ \beta \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \end{bmatrix} \qquad [4]$$

The amplitude and phase of the modulating signal were then determined by the coefficients, α, β, obtained from equation (4)

$$a_1 = \sqrt{\alpha^2 + \beta^2} \quad \text{and} \quad \varphi_1 = atan2(\beta, \alpha) \qquad [5]$$

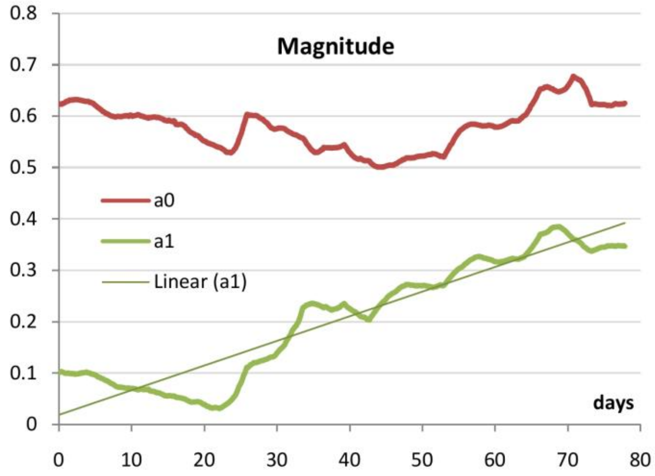

Fig. 3. Magnitudes. Ellipsoidal variations (red) and the derived modulating signal (green). The results are simular to a moving average.

To explore the propagation of a_0, a_1 and φ_1 during the full period, a set of 300 samples (S_i) were calculated according to above procedure while stepping through the full dataset of 797 samples, $S_{1+k \ldots 300+k} \rightarrow a_{0k}\,, a_{1k}\,, \varphi_{1k}$ k = 1,2…,n

From the results obtained, graphs were plotted for magnitudes and phase. In figure 3 we see that the amplitude a_0 from the effects of ellipsoidal variation remains reasonable constant during the full period of 80 days. However, the amplitude, a_1 , of the modulating signal shows a distinct increase in amplitude with a steady slope.

Figure 4 represents the modulating signal phase results. With sufficient signal strength and enough data samples we see that the phase orientated itself to approximately -160°. A phase of +180° or -180° is needed to synchronize the peak brightness of the modulating signal exactly with the $\phi = 0.75$ point. This result is within good limits consistent with the proposed theory.

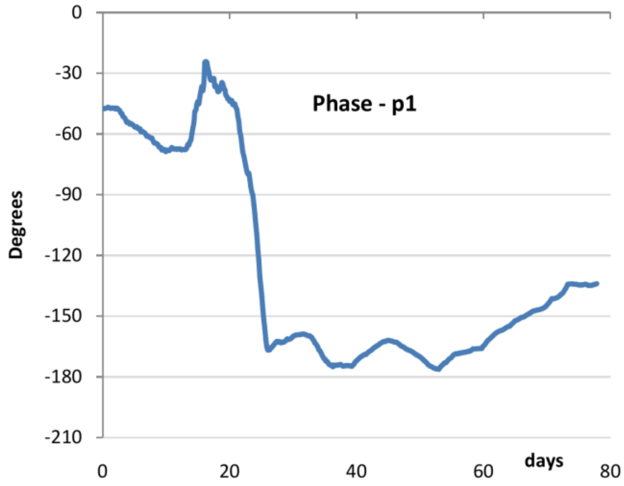

Fig. 4. Phase of the modulating signal

To see how the calculated composite signal S_i compared to the real data, two sections of data were used. Magnitudes and phases were calculated according to the least squares method described above but with an extra term to incorporate the less prominent 1 rev/day frequency component which is simply the sum of three sinusoidal functions,

$$S_i \approx a_0 \cdot \cos(\omega_0 \cdot t_i) + a_1 \cdot \sin(\varphi_1 + \omega_1 \cdot t_i) + a_2 \cdot \sin(\varphi_2 + \omega_2 \cdot t_i) \qquad [6]$$

The calculated phases and magnitudes were substitute in equation 6 to determine the best estimated solutions for S. Figures 5 and 6, illustrate the results from four neighbouring datasets presented as a folded light curve. The markers show the actual samples while the solid lines are the calculated signal S, obtained from equation (6).

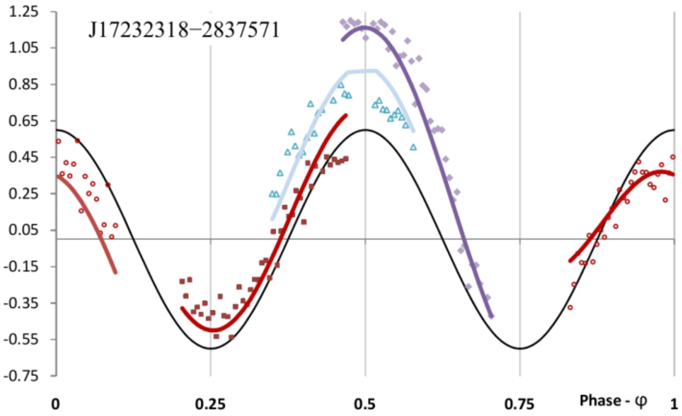

Fig. 5. The raw samples are shown here with markers. The curve-fitting lines produced from two modulating signals illustrate the correlation on the data sets.

From both figures it is clear that the fitted model agrees well with the observed data. It is interesting to note that a resent research found PSR J1628-3205 lags in phase about 0.05 at the φ=0.75 minimum point [Li. M., 2014]. This is in close agreement with the measured lag at minimum of about 0.07 in phase, from measurements on 9 & 17 Oct (see figure 6).

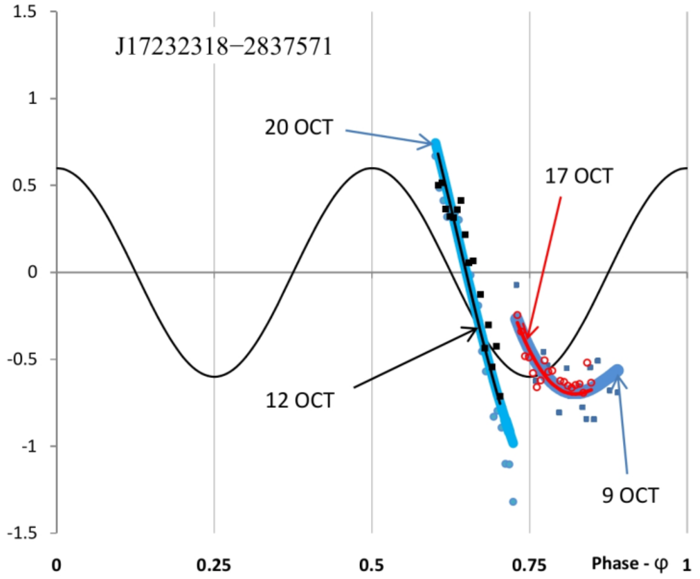

Fig. 6. Four dataset with curve fitting. Notice that the data obtained on 9 & 17 Oct almost coincident and so the data on 12 & 20 Oct which were both separated by 8 days agree with the periodic nature of the signal. Coincidentally, 8 days are equal to 13.998 orbits, thus observing nearly the same phase of the companion star.

3. Discussion

Building on the results obtained from the previous letter and the additional data captured, it becomes evident that the binary pulsar system must have started with an outburst late in August 2014. The possibility to identify a modulating signal in the outburst was examined. Discontinuity in the data and variability of the modulating signals made analysing a challenging task.

Phase and magnitude coefficients were derived for the assumed modulating frequency f_0 by multiple linear regression. The results, in particular the trending data over a large span, were in favour of the argument that irradiation may have played a role in the outburst. The modulating frequency component at 1 rev/day seems to be suspicious by general standards with a connection to terrestrial origin. However, the comparison star (covered the previous letter) did not show this modulation, thus leaving this as an open question.

PSR J1723–2837 is regarded as a candidate for a transitional object that could experience switching between Radio and Gamma radiation (and vice versa) for example the famous state change of PSR J1023+0038 that was observed in 2013. [Bogdanov S, 2014]. PSR J1723–2837 is the nearest such system and 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].

References

Bogdanov S., et al., 2014, *ApJ*, **781**, 6
Li M., Jules P., Halpern P., 2104, *http://arxiv.org/abs/1409.3877*
Orosz JA., van Kerkwijk MH., 2003, *A&A*, **397**,1
Papitto A., Ferrigno C., Bozzo E., et al. 2013, *Nature*, **501**, 517
Reynolds M.T., et al, 2007, *http://arxiv.org/abs/0705.2514*
Stapper B.W., et al, 1998, *http://arxiv.org/abs/0705.2514v1*
van Staden A., 2014, MNASSA, **73**, 9&10, 223
Wang Z., et al., 2013, *http://arxiv.org/abs/1108.4745*

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Irregularity observed in the Light Curve of the companion of PSR J1723-2837.
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