Eclipsing contact binary stars - period analysis using SuperWASP data

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Abstract. Some eclipsing contact binary stars of the W UMa-type are known to undergo changes in orbital period. These changes can be as a result of the light travel time effect if the contact binary is a member of a multiple stellar system or due to some intrinsic phenomena that are poorly understood at this stage. Analysing systems that appear to be undergoing changes in orbital period may shed some light on the important physical processes that occur in close binary systems. Pilecki *et al.* searched through the All Sky Automated Survey (ASAS) database for semi-detached and contact binary systems with high period change rates. They present 31 interacting binaries whose periods either increased (10) or decreased (21) in a five year interval of observations. Using data from the Wide Angle Search for Planets (SuperWASP) project, it has been possible to do period analyses using O−C diagrams which provide a more reliable measure of period change. Results of the analysis of two of the contact binaries studied by Pilecki *et al.* are presented. For both stars, the analysis results indicate that the classification of the stars as high period change rate systems is correct.

1. Introduction

W Ursae Majoris (W UMa)-type variable stars are contact eclipsing binary stars with orbital periods of less than 1d [1]. The component stars of a W UMa-type variable star range in spectral type from mid-A to late-K and each is assumed to be a main sequence star. The structure and evolution of these systems is poorly understood [2–4]. The traditional view is that a W UMa-type star forms from a close, detached binary that loses angular momentum through magnetic stellar winds. Evolution through angular momentum losses due to mass lost in magnetized winds [5–7], thermal relaxation oscillations due to mass exchange between the two components [8–10] or a combination of both processes, are possible ways these systems evolve over time. An alternative formation mechanism is based on observations which suggest that many W UMa-type stars are members of triple or multiple star systems. Hendry and Mochnacki [11] suggest that a tertiary component (or multiple components) may play a vital part in the formation of a W UMa-type star by removing angular momentum from the system.

Some W UMa-type stars are known to display changes in their orbital period. These changes are sometimes complex, with intervals of constant period interrupted with intervals where the period increases or decreases. Typical period change rates for contact binaries are between 10^{-7} and 10^{-8} d yr^{-1}. Changes in orbital period can be due either to a redistribution of the matter between the stars, or when angular momentum is gained or lost by the system [12]. The period of a W UMa-type star can also be reduced by magnetic braking through a magnetized stellar wind. Applegate [13] proposed a mechanism that relates changes in orbital period to changes in the distribution of angular momentum in the active star, which in turn varies the oblateness of the star producing variations in luminosity. The Applegate mechanism is yet to be reliably confirmed. Luminosity changes on parts of the binary star's photosphere can also lead to shifts in the minima times, thus mimicking period changes. Unlike a real change in orbital period, these changes do not accumulate over time. Period changes observed in binary stars do not have to be intrinsic phenomena. Light travel time effects are produced when a binary system is a member of a triple or multiple stellar system. The presence of a third body (or more) can be inferred from periodic variations in an O−C diagram. Clearly, analysing systems that appear to be undergoing changes in orbital period may shed some light on the formation of these stars and the important physical processes that occur in close binary systems.

Situated at the Las Campanas Observatory in Chile, the All Sky Automated Survey (ASAS) is a project that was set up in 1996 to detect and monitor the variability of stars between 8^{th} and 12^{th} mag south of declination $+28°$. The ASAS consists of two wide-field telescopes and all stars are observed once per one to three nights, with observations made in the standard V-band and I-band filters. Although complete light curves of variable stars are never observed by the ASAS, information such as the period and reference time of minimum or maximum brightness are provided so that phase-magnitude diagrams can be created. The project has already detected over 50,000 variable stars, a large portion of which have not been classified previously as variable stars. Of the 50,000 stars, over 5000 have been classified as contact binary systems.

Pilecki *et al.* [14] searched the ASAS data for semi-detached and contact binary systems with high period change rates. For a star to be selected for their analysis, the authors imposed the following selection criteria: a minimum of 300 observations of high quality, random distribution of the observations and orbital periods shorter than 10 d. Of the stars that fulfilled these criteria, the authors imposed a final constraint of a high signal-to-noise ratio, ending up with a total of 1711 stars of which 576 are semi-detached and 1135 contact stars. Using a local scatter reduction method, the authors find 31 binaries (22 contact and 9 semi-detached) whose periods either increased (10) or decreased (21) in a five year interval of observations. Of the 22 contact binaries, the orbital period was found to have increased for 5 and decreased for 17. The period change rates of the 31 binaries are around 10^{-5} d yr^{-1}. The authors suggest mass transfer as one mechanism that can produce the observed period change rates. If the orbital periods of the systems are changing, and if the period change rates are high, it should be detectable in an O−C diagram.

SuperWASP is an exoplanet survey programme, designed to detect exoplanets via transit events. SuperWASP consists of two observatories, SuperWASP-North situated on the island of La Palma and SuperWASP-South, situated at the South African Astronomical Observatory. These robotic observatories each consist of eight wide-angle cameras with a total field of view of 482 deg^2. Because of the observing procedure of SuperWASP, the project has seasons of photometric data for many variable stars. For variable stars with short periods, like W UMa-type stars, complete light curves are often obtained during a night's observing. The complete light curves can be used for photometric modelling of the systems as well as for period analyses.

Using SuperWASP data, a period analysis was performed for the contact binary stars ASAS 002449−2744.3 and ASAS 002821−2904.1. The results of the analyses are presented.

2. Period Analysis

2.1. Method

For the SuperWASP data, times of minimum brightness were determined using a method similar to the Kwee & van Woerden method [15]. Due to the geometry of a W UMa-type variable star, the minima should be symmetrical in shape. By fitting a second-order polynomial of the form $V(t) = at^2 + bt + c$ to a minimum, the time of minimum brightness can be calculated using the parameters of the best fit polynomial, that is, $T_{min} = -b/2a$. The error of the minimum is calculated using the covariance matrix entries.

The minima times were used in conjuction with the second-order ephemeris parameters determined by Pilecki *et al.* and a SuperWASP minimum to construct an O−C diagram. Both a first and second-order least squares analysis was performed. The period change rate is given by $dP/dt = (2k/P)$, where k and P are obtained from the second-order ephemeris

$$T_{calc} = T_0 + PE + kE^2$$

and E is the cycle number.

2.2. Results

2.2.1. ASAS 002449−2744.3 This system is listed in the ASAS database with a period $P = 0.31367$ d. Pilecki *et al.* find $P = 0.313661$ d and $dP/dt = -2.3 \times 10^{-6}$ d yr^{-1}. A total of 44 minima were obtained from the SuperWASP data. The O−C diagram shown in Fig. 1 was obtained using

$$T_{calc} = \text{HJD } 2454296.6348 + 0.313661E - 9.9 \times 10^{-10}E^2$$

The O−C residuals suggest that the period and k value of the system are not correct.

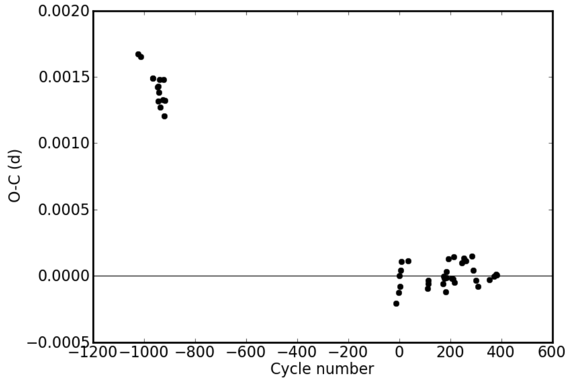


Figure 1. O−C diagram for ASAS 002449−2744.3 obtained using the Pilecki *et al.* period and k value.

The linear ephemeris obtained from the regression analysis is

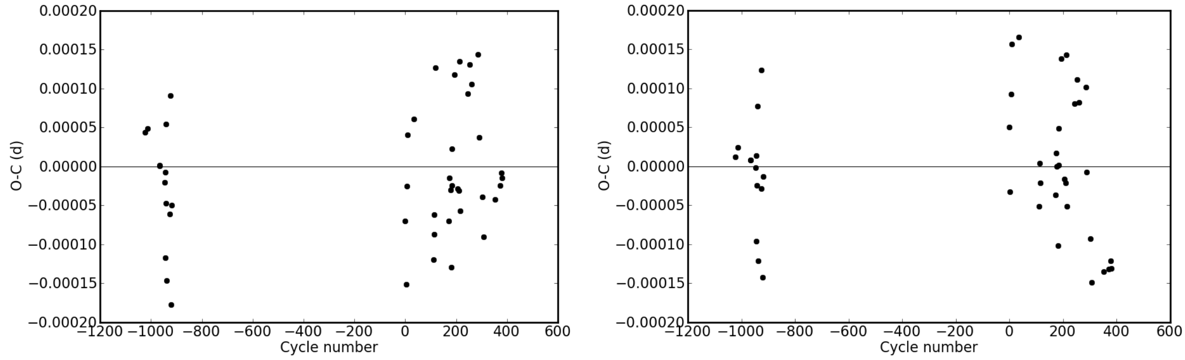
$$T_{calc} = \text{HJD } 2454296.63490(2) + 0.31366049(4)E$$

with the uncertainties listed in brackets. The O−C diagram for this ephemeris is shown in Fig. 2(a). The second-order ephemeris

$$T_{calc} = \text{HJD } 2454296.63478(4) + 0.3136609(2)E + 5.5(2.0) \times 10^{-10}E^2$$

produces a lower O−C residuals value compared to the linear ephemeris. The O−C diagram obtained using this ephemeris is shown in Fig. 2(b).

The value of 5.5×10^{-10} corresponds to a period change rate $dP/dt = 1.3 \times 10^{-6}$ d yr^{-1}. The direction of the period change is different to that determined by Pilecki *et al.* indicating that the orbital period is increasing and not decreasing. The values for the orbital period obtained from the linear and second-order regressions are smaller than the ASAS period, while the period obtained from the second-order regression is very close to the Pilecki *et al.* value.



(a) (b)

Figure 2. O−C diagrams for ASAS 002449 − 2744.3 obtained using the linear ephemeris, (a), and the second-order ephemeris (b). The second-order ephemeris produces a lower residuals value compared to the linear ephemeris.

2.2.2. ASAS 002821−2904.1 Pilecki *et al.* determined a period $P = 0.269892$ d, shorter than the ASAS period $P = 0.269896$ d, and a period change rate $dP/dt = -2.3 \times 10^{-6}$ d yr^{-1}. Fig. 3 shows the O−C diagram for the star obtained using the ephemeris

$$T_{calc} = \text{HJD } 2454003.3140 + 0.269892E - 9.9 \times 10^{-10}E^2$$

The O−C residuals suggest that the k value and the period P are not correct.

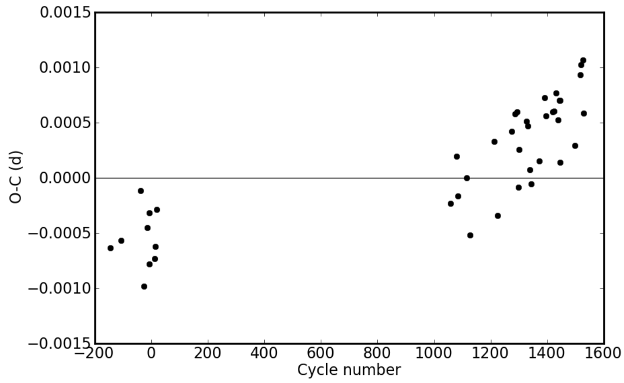


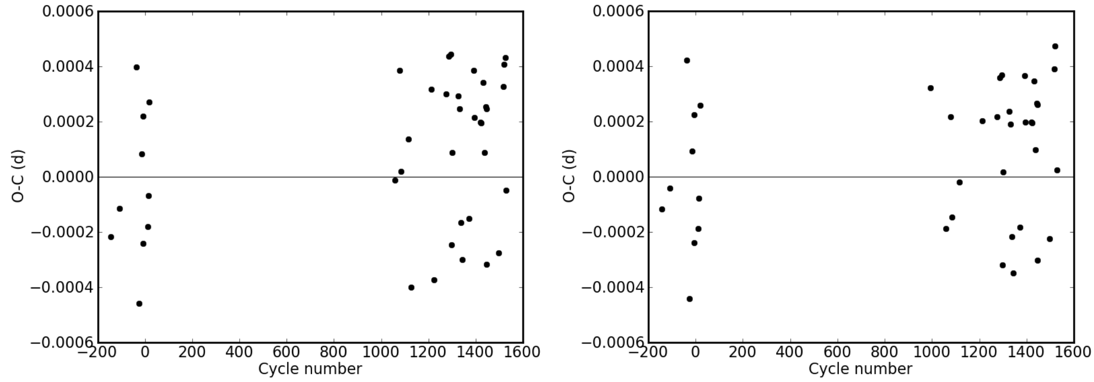
Figure 3. O−C residuals for ASAS 002821−2904.1 obtained using the Pilecki *et al.* period and k value.

A total of 39 minima were obtained from the SuperWASP data. The linear ephemeris obtained from the regression analysis is

$$T_{calc} = \text{HJD } 2454003.3135(1) + 0.26989126(9)E$$

The O−C diagram obtained using the linear ephemeris is shown in Fig. 4(a) and Fig. 4(b) shows the O−C residuals obtained using the second-order ephemeris

$$T_{calc} = \text{HJD } 2454003.3135(1) + 0.2698919(6)E - 4.5(4.0) \times 10^{-10}E^2$$



(a) (b)

Figure 4. O−C diagrams for ASAS 002821−2904.1 obtained using the linear ephemeris, (*a*), and the second-order ephemeris, (*b*). The residuals value for the second-order ephemeris is lower than the linear ephemeris value.

From a visual inspection, the O−C diagrams obtained using the linear and second-order ephemerides appear similar. The O−C residuals value for the second-order ephemeris is lower than the linear ephemeris residuals. The period change rate $dP/dt = -1.2 \times 10^{-6}$ d yr^{-1} and has the same direction of change as the value determined by Pilecki *et al.*, but the corresponding uncertainty value, 1.0×10^{-6} d yr^{-1}, is large. As shown in table 1, the periods returned by the linear and second-order regressions are smaller than the ASAS period. Although the period obtained from the second-order regression is similar to the Pilecki *et al.* period, more data are needed to confirm the validity of a second-order ephemeris.

Table 1. Comparison between the Pilecki *et al.* and SuperWASP values for P and dP/dt for both ASAS stars.

ASAS ID	Pilecki P (d)	SuperWASP P (d)	Pilecki dP/dt ($\times 10^{-6}$ d yr^{-1})	SuperWASP dP/dt ($\times 10^{-6}$ d yr^{-1})
002449 − 2744.3	0.313661	0.3136609	-2.3(0.5)	1.3(0.5)
002821 − 2904.1	0.269892	0.2698919	-2.3(0.5)	-1.2(1.0)

3. Discussion

Pilecki *et al.* searched the ASAS database and identified 22 contact binaries with high period change rates. Two of these stars, namely ASAS 002449−2744.3 and ASAS 002821−2904.1, were selected for period analysis. The periods obtained from the regression analyses are shorter than the listed ASAS periods while the periods obtained from the second-order regressions are the same as the values determined by Pilecki *et al.*. For both stars, a second-order ephemeris is found to produce a lower O−C residuals value compared to the linear ephemeris value, suggesting that the orbital periods of the systems are changing. The calculated period change rates are larger than the typical values found for contact binaries, confirming the classification of these two stars as high period change rate systems.

For ASAS 002449−2744.3, the period change rate dP/dt obtained using the SuperWASP data is 1.2×10^{-6} d yr^{-1}, compared to -2.3×10^{-6} d yr^{-1} determined by Pilecki *et al.*. The direction of the period change is different. Tests are being performed to determine if the orbital period was decreasing while the ASAS data were obtained. This would explain the difference in the direction of the change between the Pilecki *et al.* value and the value determined from the SuperWASP data. The star will be monitored to see if the direction of the orbital period change reverses. For ASAS 002821−2904.1, the value of the period change rate is -1.2×10^{-6} d yr^{-1} compared to the Pilecki *et al.* value of -2.3×10^{-6} d yr^{-1}. The calculated dP/dt uncertainty, 1.0×10^{-6} d yr^{-1}, is large compared to the period change rate. More data are needed to confirm the validity of using a second-order ephemeris for ASAS 002821−2904.1.

The results of the analyses are based on two seasons of SuperWASP data and extra data will confirm the changing period, the direction of the period change and possibly identify the cause of the period change. The SuperWASP data have proven to be extremely useful for the period analysis. The advent of exoplanet survey programmes such as SuperWASP and Kepler provide extra data for binary star research. These survey programmes are likely to have long lifespans and they can provide a long baseline of data. This will be particularly useful for detecting and monitoring orbital period changes in contact binary systems.

Acknowledgments

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