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A PERIOD STUDY OF THE ECLIPSING BINARY SYSTEM W URSAE MINORIS

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Since the discovery by Astbury (1913) and by Davidson (Dyson 1913), W Ursae Minoris (BD +86°244), a bright eclipsing binary quite close to the celestial north pole, had attracted much interest in earlier days, particularly among the photometrists. Spectroscopic observations were performed by Joy and Dustheimer (1935) and Sahade (1945), who both gave single-lined radial velocity curves for the system. The most comprehensive study of the system was performed by Devinney et al. (1970), where two sets of photometric light curves were solved by the rectification method to yield the photometric elements. They derived the absolute dimensions and confirmed that W UMi is a semi-detached system of Algol-type. Mardirossian et al. (1980) reanalyzed five light curves of Devinney et al. with the Wood's model.

Occasional monitoring for the times of minima have been done for the system. As to the period study, the following ephemerides for Min I, e.g., have been published.

Dyson (1913):	HJD 241 9487.850 + $1\overset{d}{.}7012E$
Martin and Plummer (1918):	HJD 242 1219.685 + $1\overset{d}{.}70116E$
McLaughlin (1926):	HJD 242 2813.605 + $1\overset{d}{.}70116E$
Dugan (1930):	HJD 242 4999.604 + $1\overset{d}{.}70116E$
Himpel (1937):	HJD 242 7624.485 + $1\overset{d}{.}70116E$
Nason and Moore (1951):	HJD 243 3457.761 + $1\overset{d}{.}7011576E$
Devinney et al. (1970):	HJD 243 9758.846 + $1\overset{d}{.}7011576E$
SAC 66 (1995):	HJD 244 6614.481 + $1\overset{d}{.}7011576E$

(SAC = *Rocznik Astronomiczny Observatorium Krakowskiego*)

As these show, almost everybody considered that the period had been constant, and they devoted in revising the epoch and getting more precise period. The only two exceptions were Gadomski (1926) and Payne-Gaposchkin (1952), who suggested that the period was variable. However, these were not confirmed by others.

As we noticed that the primary minimum did not occur at the predicted time, we observed W UMi in order to know the possible variation of its orbital period. Photoelectric observations of the system were done with the Multichannel Polarimetric Photometer attached to the 91cm reflector at Dodaira Station of the National Astronomical Observatory of Japan and also with a photometer (PMT: 1P21) attached to the 45cm telescope

Table 1: New Photoelectric Observations

Obs. HJD (Min I)	Site	Observer	E^1	$O-C^1$	E^2	$O-C^2$
2449770.0722	Dodaira	Y. Nakamura	5885	–0.0863	4429	0.0018
2450464.131:[3]	Fk. Univ.	K. Asada	6293	–0.0998	4837	–0.0039
2450487.9460	Fk. Univ.	K. Asada	6307	–0.1010	4851	–0.0048
2450857.0866	Fk. Univ.	R. Sato	6524	–0.1116	5068	–0.0112

[1] These values are based upon the ephemeris of Devinney et al. (1970).
[2] These are based upon the new linear ephemeris (4).
[3] This observation provided rather different moments for the minimum in B and V bands. However, the mean value seems reasonable.

at Fukushima University. Their features are described in other publications (Nakamura et al. 1991a, b). The comparison and check stars were BD +86°245 and BD +86°246 for Dodaira observations and 23 and 24 UMi for Fukushima observations, respectively. The estimated times of the primary minimum are listed in Table 1. The observed data at Fukushima are the mean of B and V light curves and those at Dodaira are averaged over four channels. The new observations showed large negative $O-C$ values.

In order to study the long-term behaviour of the period variation, we have collected observed minima timings, including ours, from the literature and from B.R.N.O. (Brno Regional Network of Observers) and BAV Databases, which are all for the primary eclipse. Devinney et al. (1970) observed primary minima, whose central times are, however, not described explicitly in their paper. The mean of the two minima times observed by them is instead given, hence we employed it as useful information. A total of 160 observed times of primary minima (147 visual, 4 photographic and 9 photoelectric) were collected and are plotted in Figure 1 according to the ephemeris by Devinney et al. There is a large scatter in the observed times of minima. Despite such a large scatter, it may be concluded that the orbital period of the system had been constant before $E\sim+1000$. However, recent primary minima have occurred definitely earlier than predicted.

Because the ephemeris by Devinney et al. (1970) was derived with only the limited data up to 1970, we derived another linear ephemeris using all data. In deriving this, we omitted six data which show the large $O-C$ residuals in Figure 1, and we put weight 10 on the photoelectric estimates, 3 on photographic ones, and 1 to visual ones. If the datum is denoted to be uncertain, we set the weight to its half value. Thus, we have

$$\text{Min I} = \text{HJD } 2443392.4794(\pm 13) + 1\overset{\text{d}}{.}70115182(\pm 22)\ E. \qquad (1)$$

The $O-C$ residuals based upon this ephemeris are shown in Figure 2.

We have examined two possibilities for the period change of the system: one is a constant period change (decrease) and the other a sudden period decrease. For the first possibility, the ephemeris should be quadratic. We calculated such a formula as

$$\text{Min I} = \text{HJD } 2443392.4924(\pm\ 7) + 1\overset{\text{d}}{.}70114548(\pm 18)\ E - 8\overset{\text{d}}{.}80(\pm 21)\times 10^{-10}\ E^2. \qquad (2)$$

This quadratic ephemeris is shown with the dash-dot curve in Figure 2.

We next sought for the two linear ephemerides which fit for the sudden period decrease shown in the figures. The following ephemerides were found to be good for the purpose:

$$\text{Min I} = \text{HJD } 2442235.7289(\pm\ 8) + 1\overset{\text{d}}{.}70115716(\pm 22)\ E \qquad (3)$$

before the sudden period decrease, and

$$\text{Min I} = \text{HJD } 2442235.7289(\pm 16) + 1\overset{\text{d}}{.}70113830(\pm 45)\ E \qquad (4)$$

after the period change. The $O-C$ residuals based upon these ephemerides are shown in Figure 3. The $\Sigma(O-C)^2$ values for all the data used are 0.032616 for the eq. (2) and 0.021577 for the eqs. (3)+(4), respectively.

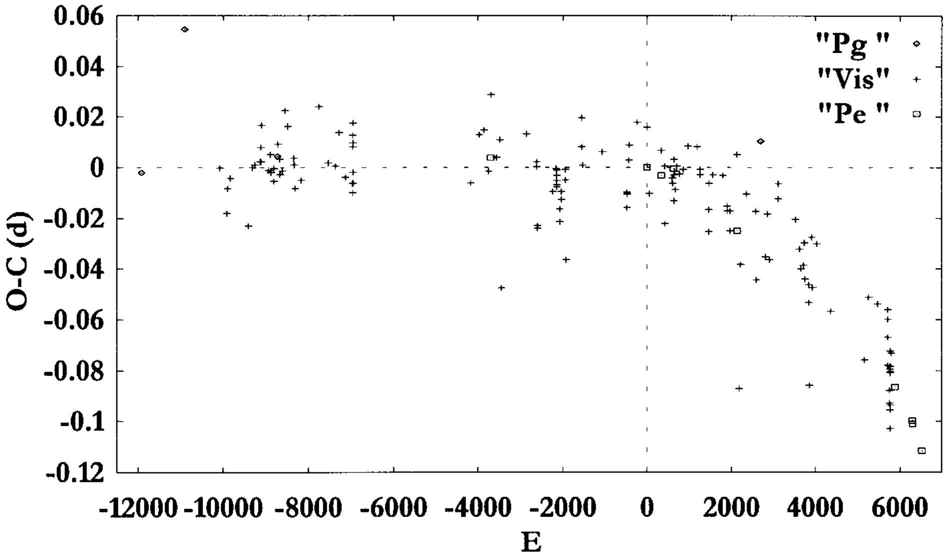

Figure 1. $O-C$ diagram for the primary minimum of W UMi. The calculation is based on the ephemeris of Devinney et al. (1970).

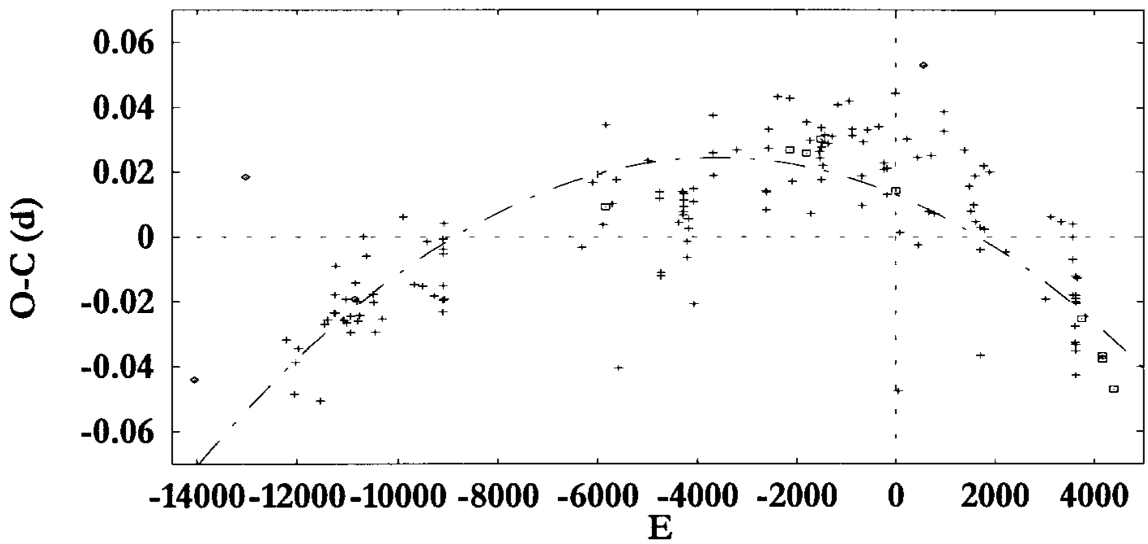

Figure 2. $O-C$ residuals based upon the new single linear ephemeris. The quadratic ephemeris is also represented with the dashed curve.

Though we derived a quadratic ephemeris for W UMi, the fitting by the parabola is worse than the two linear ephemerides, and moreover it is rather difficult to imagine a mechanism which derives constant period decrease in such a semi-detached system as

W UMi. Therefore, we prefer the interpretation of a sudden period decrease which is represented as two straight lines in Figure 3. According to this, the amount of period decrease is $\Delta P/P = -1.11 \times 10^{-5}$, and this change occurred nearly at JD2442236. We think that mass loss from the system is the most natural explanation for this phenomenon.

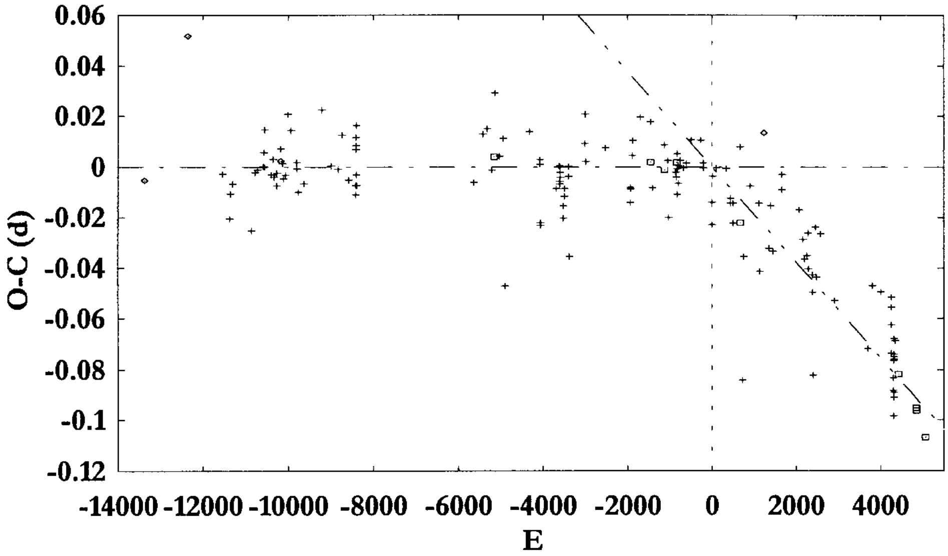

Figure 3. $O-C$ diagram for the primary minimum of W UMi. The observed data are fitted with the two linear ephemerides (3) and (4). The intersection is at JD 2442236.

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