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NEW LIGHT CURVES AND PERIOD STUDY OF THE CONTACT BINARY W URSAE MAJORIS

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W Ursae Majoris (HD 83950, BD+56°1400, F8V+F8V) is a well known eclipsing variable and serves as the prototype for W UMa-type contact binaries. Recent observations of this famous star were conducted at the Villanova Observatory by T. Anselowitz, R. Mittal, M. Sauer, and R. Slevinsky on the nights of April 2, 3, 5, 15, and 16 UT, 1997. A 38 cm Cassegrain reflector equipped with a photoelectric photometer and a refrigerated EMI 9658 photocell were used. Over 300 observations were secured in intermediate-band H_αw (λ_{max} = 6600Å, FWHM = 272Å) and Strömgren y (λ_{max} = 5500Å, FWHM = 250Å) filters. The observation sequence used was the usual *sky-comp.-variable-comp.-sky* routine with an integration time of 20 seconds for each observation. HD 83728 (K2, $m_v = +9.2$) served as the comparison star. Corrections for differential extinction were applied but were always very small because of the close proximity of the comparison and variable stars.

The compiled light curves for both filters are shown in Figure 1. The primary eclipse is about 0.03 mag fainter than the secondary in both bandpasses. Also, the maximum at 0.25 phase is about 0.02 mag brighter in each bandpass than the corresponding maximum at 0.75 phase. The presence of starspots as described by Guinan & Bradstreet (1988) is the likely cause for these asymmetries in the light curve. A representative model using system elements from Maceroni & van't Veer (1996) and Bradstreet's *Binary Maker 2.0* program (1993) is shown above the observed light curves. Times of secondary minimum were obtained on the nights of April 5 and 16 UT, 1997. The moments of minimum were calculated using the method of Kwee & van Woerden (1956) for both the H_αw and y filters, yielding averaged secondary minimum timings of Min II = HJD 2450543.5667 and Min II = HJD 2450554.5776 for the two nights.

The above photometry of W UMa represents only the most recent data taken of this star at Villanova. W UMa has been observed from the Villanova Observatory since 1982. Times of minimum for these observations are presented for the first time in Table 1. The large number of eclipse timings provide an important opportunity to study the system's dynamical evolution over the last decade and a half. Figure 2 shows the observed minus computed (O−C) values of the Villanova data (solid circles) along with other primary minimum timings found in the IBVS (open circles) since 1982. An ephemeris of

$$JD\ Hel.\ Min.\ I = 2444986.3624 + 0.33363808\ \times\ E \tag{1}$$

taken from Hamzaoglu *et al.* (1982) was used in calculating the (O−C)'s.

Table 1: Times of Minimum, March 1982 to March 1995

Filter	Type	JD Hel. (+2440000)	Observer	Filter	Type	JD Hel. (+2440000)	Observer
y	I	5042.7469	R. Donahue	H_αw	II	8311.5459	K. Miller
y	I	5407.7463	D. Speranzini	y	II	8311.5448	"
y	II	5407.9145	"	H_αw	I	9013.6793	B. Abbott
H_αw	I	5753.7242	C. Robinson	y	I	9013.6785	"
y	I	6131.7368	J. Buckley	H_αw	II	9017.8517	"
H_αw	I	6521.7569	S. Carroll	y	II	9017.8511	"
y	I	6521.7590	"	H_αw	I	9021.6850	D. Griffith
H_αw	I	6851.7228	E. Bergin	y	I	9021.6860	"
H_αw	II	6851.8886	"	H_αw	I	9398.6945	T. Mahler
y	I	6851.7218	"	H_αw	I	9399.6955	"
y	II	6851.8887	"	H_αw	II	9402.8660	"
H_αw	I	7558.6958	C. Baluta	y	II	9402.8658	"
y	I	7558.6967	"	H_αw	I	9423.7183	J. Marshall
y	I	7602.7357	L. Ilaria	y	I	9423.7178	"
H_αw	I	7602.7353	"	H_αw	I	9465.7523	J. Maley
H_αw	II	7608.5743	"	y	I	9465.7536	"
y	II	7608.5741	"	y	II	9475.5999	Q. Nguyen
H_αw	II	7990.5871	T. Thrash	H_αw	II	9478.6011	M. Alexander
y	II	7990.5876	"	y	II	9478.6016	"
H_αw	I	8296.6971	K. Miller	Bn	II	9789.5462	N. Morgan
y	I	8296.6967	"	Bn	I	9789.7144	"

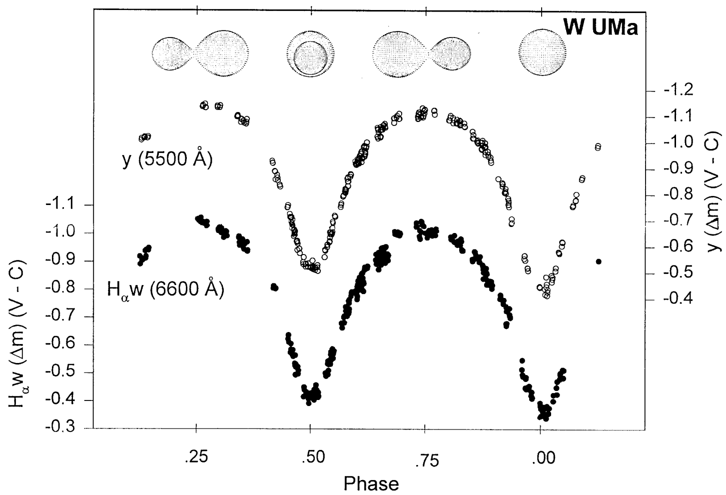

Figure 1. Strömgren y and intermediate band H_αw light curves of W UMa, obtained on the nights of April 2, 3, 4, 5, 15, and 16 UT, 1997. The representative model at top was made using *Binary Maker 2.0* (Bradstreet 1993). Phases were computed using Eq. 1.

Figure 2 shows both a quadratic (dotted line) and linear (solid line) least squares fit to the (O−C) data obtained between 1982 and 1997. The quadratic (parabolic) fit exhibits a slight negative concavity, indicating that the period of W UMa may have continuously decreased during this time interval. This deviation from a linear fit, however, is very small and may not be physically meaningful. The linear fit to the (O−C) data assumes a constant period over the time interval. The slope of the linear regression (-0.0254×10^{-4} days) represents the change in the system's period as given in Eq. 1 required to eliminate (O−C) residuals along the linear fit. Correcting the $P_1 = 0^{d}\!.33363808$ period from Hamzaoglu *et al.*, the system's new observed period becomes $P_2 = 0^{d}\!.33363554$. This apparent change in period corresponds to a shortening of the period by 0.22 seconds.

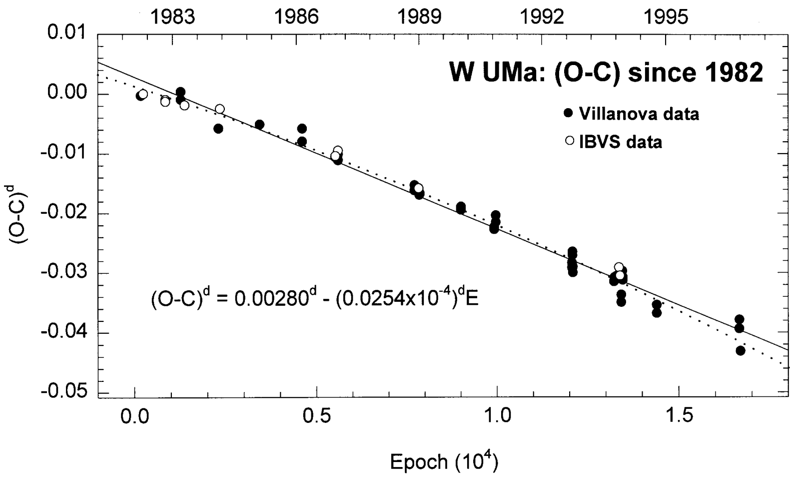

Figure 2. (O−C) analysis for W UMa from 1982 through 1997. The parabolic fit (dotted line) shows a slight negative concavity. The displayed equation describes the linear (solid line) least-squares fit to the (O−C) residuals.

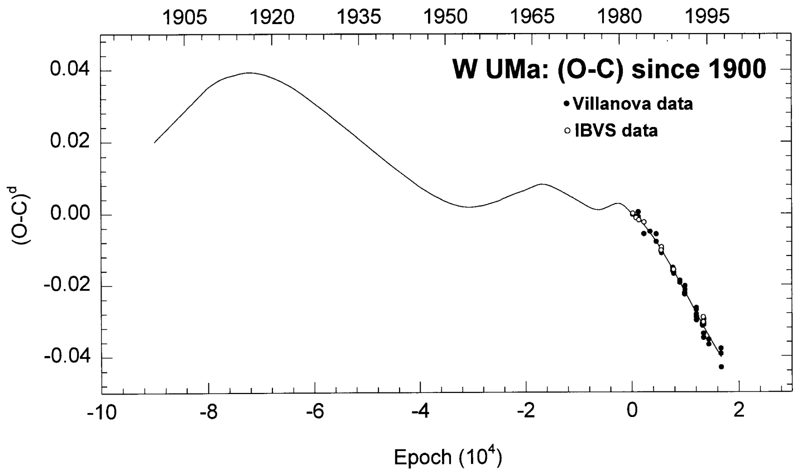

Figure 3. (O−C) analysis for W UMa from 1903 through 1997. The curve prior to 1982 is reproduced from Hamzaoglu *et al.* (1982). It is evident from the overall behavior of the (O−C) values that W UMa has undergone a series of period changes throughout this century.

When combined with the eclipse timings presented above, a new working ephemeris of

$$JD\ Hel.\ Min.\ I = 2450554.7444 + 0.33363554 \times E \qquad (2)$$

can be presented for the system. This linear ephemeris should be accurate enough to predict eclipse timings for the next few years.

A complete set of visual and photometric data on W UMa has been available since its discovery by Müller & Kempf (1903). Hamzaoglu *et al.* (1982) have published a period study of W UMa that covered over three quarters of a century, stretching from 1903 through 1982. In Figure 3, we extend their (O−C) plot from 1982 up to the present continuing to use the ephemeris of Eq. 1. The section of the curve without data points is reproduced from Hamzaoglu *et al.* (1982). Villanova timings (solid circles) and other minimum timings presented in the IBVS (open circles) are shown.

Based on Figure 3, W UMa has apparently undergone a series of significant period changes since 1903. Exactly when these period changes took place, however, is uncertain because of the sometimes ambiguous nature of (O−C) analysis. The (O−C) curve can be viewed as a series of parabolas of alternating concavity (*i.e.*, epochs of continuous increases or decreases in period) or it can be viewed as a series of straight lines with alternating slopes (*i.e.*, abrupt changes in the apparent period). Each interpretation yields different times and rates of mass transfer/loss and magnetic breaking effects. The uncertainties in eclipse timings make it difficult to decide which interpretation is physically correct.

Regardless of when these period changes occurred, there still remains the question of how. One of the more attractive explanations to describe this phenomenon is of mass transfer between the components of the system, causing period changes on the basis of angular momentum redistribution. A favored mechanism to drive the mass flows comes from activity-related phenomena, whose characteristic time-scales match the relatively rapid period changes evidenced in W UMa-type systems (Rucinski 1993). Guinan & Bradstreet (1988) argue that the presence of large starspots, as betrayed from light curve asymmetries, as well as the strong chromospheric and coronal X-ray emissions typical of W UMa-type binaries, indicate the presence of a strong, dynamo-related magnetic activity for the system. These intense magnetic fields may very well control the mass flows and magnetic breaking effects responsible for the observed period changes.

Further photoelectric photometry of W UMa will continue at the Villanova Observatory. For this research, we utilized the SIMBAD database, operated by CDS, Strasbourg, France. This research was supported in part by NSF grant AST-9315365, which we gratefully acknowledge.

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