Revista Mexicana Astron. Astrof., 17, 97-101 (1989)

PERIOD VARIATION DETERMINATION OF THE W UMa TYPE STAR V502 OPH [1]

M.A. Hobart[2,4], J.H. Peña[2,5], T. Gómez[3], and J.M. Alcalá[2]

Received 1988 December 13

RESUMEN

Se reportan observaciones fotométricas recientes de la estrella tipo W UMa, V502 Oph. De los tiempos de mínimos encontrados en la literatura junto con el obtenido de las presentes observaciones, se determina la efemérides cuadrática siguiente:

$$HJD_{min} = 2441174.2304(\pm 0.0035) +$$
$$+ 0.4533921\ E(\pm 1.57 \times 10^{-7})\ E - (2.36 \times 10^{-10})\ (\pm 0.05 \times 10^{-10})\ E^2/2$$

denotando un cambio continuo en su periodo de −1.64 s/siglo.

ABSTRACT

Recent photoelectric-photometry data of the W UMa system V502 Oph are reported. From the times of minima found in the literature and that obtained in the present paper, the following quadratic ephemeris is calculated:

$$HJD_{min} = 2441174.2304(\pm 0.0035) +$$
$$+ 0.4533921\ E(\pm 1.57 \times 10^{-7})\ E - (2.36 \times 10^{-10})\ (\pm 0.05 \times 10^{-10})\ E^2/2$$

implying a continuous change in the period of −1.64 s/century.

Key words: **STARS-ECLIPSING BINARIES – STARS-VARIABLE – STARS-W URSAE MAJORIS**

I. INTRODUCTION

The W Ursa Majoris contact binary system V502 Ophiuchi (BD +0°3562 = HD 150484) was discovered by Hoffmeister (1935) and since then it has been observed fairly extensively. From a study of the period of this system, Kwee (1958) found it to be variable and calculated the ephemeris HJD_{min} = 2435257.4459 + $0^d.45339630$ E. It was later found (Binnendijk 1969) that a period decrease had occurred after 1958 and the following linear ephemeris was calculated:

$$HJD_{min} = 2439639.9431 + 0^d.45339304\ E.$$

Although some studies conclude that the W Ursae Majoris stars show abrupt period changes, most studies have shown that the periods have monotonic variations. Therefore, a comprehensive study of the period behaviour of V502 Oph was carried out in the present paper utilizing newly determined times of minima that significantly increase the time span of the observations and, consequently, the accuracy of the reported results.

1. Based on observations collected at the Observatorio Astronómico Nacional of San Pedro Mártir, B.C., México.
2. Instituto Nacional de Astrofísica, Optica y Electrónica.
3. Instituto de Astronomía, UNAM.
4. Universidad Veracruzana.
5. On leave from Instituto de Astronomía, UNAM.

II. OBSERVATIONS

The observations were carried out during the nights of June 13–14 and 14–15, 1987 in the Observatorio Astronómico Nacional at San Pedro Mártir, with the 84-cm reflecting telescope. A dry ice cooled RCA 31034A photocell with a pulse counting system and a Johnson *V* filter were used. Two comparison stars were chosen according to the standard criteria: namely, that they be of about the same magnitude as the variable star and in its immediate vicinity, i.e., within two degrees from the program star (see Table 1). The stars BD +0°3569 and BD +0°3566 fulfilled these requirements, but during the reduction, the latter was found to be variable (see Gómez, Hobart, and Peña 1988). Figure 1 shows the light curve of V502 Oph for the night of June 13–14, 1987, while Figure 2 shows its light curve for the night June 14–15, 1987. In both cases, each observation consisted of one 40 s integration on each star following the sequence C_1, C_2, V, V, V, C_1, C_2, ... The photometric values shown in Table 2 and plotted in Figure 1 and Figure 2 are the magnitude differences between the variable star and the magnitude of the star BD +0°3569 interpolated at the time of the observation of the variable. Then, an average of the differences was subtracted from each run to establish the zero baseline. The data points were found to be accurate to $0^m.005$; the average span between successive sets of three points is $0^d.01$, while the time accuracy for each point is $0^d.0014$. When an attempt

TABLE 1

COORDINATES AND MAGNITUDES OF THE OBSERVED STARS

Star	BD	α (1900)	δ	V (mag)	Type
V502 Oph	+0°3562	$16^h36^m15^s$	+0°42'00"	8.9	W Uma
Comparison a	+0 3569	16 42 14	+0 06 50	8.5	Ref.
Comparison b	+0 3566	16 42 02	+0 32 36	8.9	New Var.

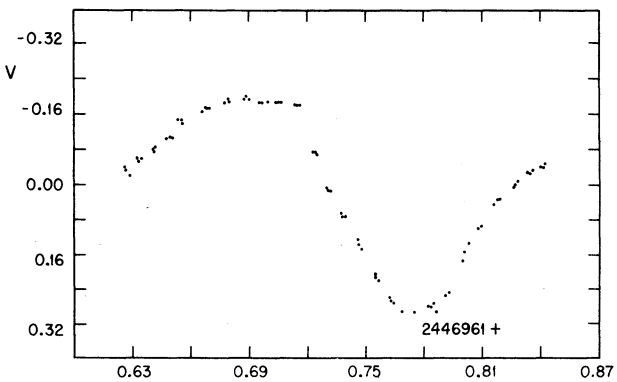

Fig. 1. Light curve of the W Uma star V502 Ophiuchi for the night HJD 2446961.

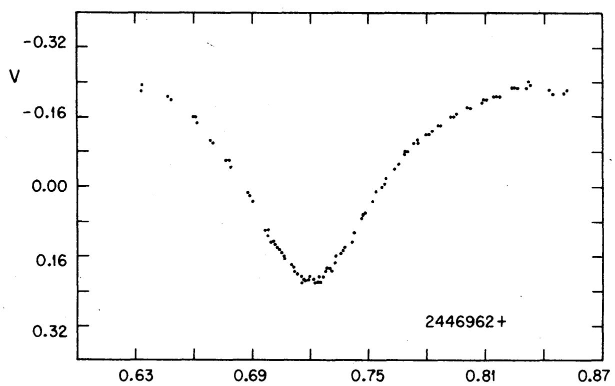

Fig. 2. Light curve of the W Uma star V502 Ophiuchi for the night HJD 2446962. The horizontal axis zero is arbitrary due to a problem in the clock setting at the beginning of the night. This light curve is shown merely to study the amplitude variation behaviour.

was made to fit the two nights in phase, it was realized that there were time shifts for all the data set on the second night, due most likely to a problem with the clock setting. Therefore the data of this night were shifted by 0.085 d and forced to be in phase using the period

TABLE 2

PHOTOELECTRIC OBSERVATIONS OF V502 OPHIUCHI

HJD 2440000+	Δm_V	HJD	Δm_V
6961.6270	-0.040	6961.7250	-0.070
6961.6270	-0.035	6961.7300	0.007
6961.6290	-0.020	6961.7310	0.010
6961.6330	-0.060	6961.7320	0.010
6961.6340	-0.055	6961.7380	0.065
6961.6350	-0.060	6961.7390	0.075
6961.6410	-0.075	6961.7400	0.075
6961.6410	-0.080	6961.7460	0.130
6961.6420	-0.090	6961.7470	0.140
6961.6490	-0.105	6961.7480	0.145
6961.6500	-0.110	6961.7550	0.205
6961.6510	-0.110	6961.7560	0.210
6961.6540	-0.145	6961.7570	0.220
6961.6560	-0.140	6961.7620	0.260
6961.6560	-0.145	6961.7630	0.265
6961.6660	-0.170	6961.7640	0.270
6961.6680	-0.171	6961.7690	0.295
6961.6690	-0.171	6961.7760	0.290
6961.6780	-0.190	6961.7870	0.290
6961.6790	-0.191	6961.7830	0.280
6961.6800	-0.190	6961.7840	0.280
6961.6880	-0.195	6961.7850	0.270
6961.6890	-0.200	6961.7910	0.255
6961.6900	-0.195	6961.7930	0.245
6961.6960	-0.190	6961.8000	0.170
6961.6970	-0.190	6961.8010	0.150
6961.6990	-0.185	6961.8030	0.135
6961.7040	-0.185	6961.8080	0.100
6961.7050	-0.185	6961.8090	0.090
6961.7060	-0.190	6961.8160	0.045
6961.7140	-0.180	6961.8180	0.035
6961.7150	-0.180	6961.8190	0.030
6961.7160	-0.180	6961.8260	0.005
6961.7230	-0.075	6961.8270	0.000
6961.7240	-0.075	6961.8280	-0.005

TABLE 2 (CONTINUED)

HJD 2440000+	Δm_V	HJD	Δm_V
6961.8340	-0.025	6962.7170	0.213
6961.8350	-0.030	6962.7180	0.213
6961.8360	-0.035	6962.7190	0.213
6961.8410	-0.040	6962.7200	0.208
6961.8420	-0.040	6962.7210	0.213
6961.8430	-0.050	6962.7220	0.213
6962.6330	-0.222	6962.7230	0.218
6962.6340	-0.232	6962.7240	0.218
6962.6470	-0.207	6962.7250	0.218
6962.6490	-0.202	6962.7250	0.208
6962.6600	-0.162	6962.7270	0.208
6962.6610	-0.157	6962.7280	0.193
6962.6620	-0.147	6962.7290	0.188
6962.6690	-0.107	6962.7300	0.188
6962.6700	-0.102	6962.7310	0.193
6962.6700	-0.097	6962.7330	0.173
6962.6770	-0.062	6962.7330	0.158
6962.6780	-0.057	6962.7360	0.153
6962.6790	-0.047	6962.7370	0.148
6962.6880	0.013	6962.7380	0.138
6962.6890	0.018	6962.7410	0.128
6962.6900	0.033	6962.7420	0.108
6962.6970	0.103	6962.7460	0.073
6962.6980	0.103	6962.7470	0.068
6962.6980	0.113	6962.7480	0.063
6962.7000	0.128	6962.7520	0.033
6962.7010	0.128	6962.7540	0.013
6962.7020	0.133	6962.7570	-0.002
6962.7030	0.143	6962.7580	-0.007
6962.7040	0.148	6962.7590	-0.017
6962.7050	0.153	6962.7630	-0.037
6962.7060	0.163	6962.7630	-0.042
6962.7060	0.168	6962.7650	-0.052
6962.7070	0.168	6962.7680	-0.072
6962.7100	0.183	6962.7690	-0.077
6962.7110	0.188	6962.7700	-0.077
6962.7120	0.193	6962.7740	-0.102
6962.7130	0.198	6962.7750	-0.107
6962.7140	0.203	6962.7760	-0.102
6962.7160	0.208	6962.7800	-0.122
6962.7160	0.218	6962.7810	-0.122

0.45339304 d given by Binnendijk (1969). Due to the uncertainty in its determination in time, this time of minimum was not considered in the period determination analysis and the photometric values obtained are presented merely to show the light curve behaviour. The time of minima was determined by the method of bisecting cords connecting points of equal magnitude on the opposing branches of the light curves.

III. ANALYSIS

For an accurate determination of the period, a long time span is required. If a smooth period variation is supposed, then the following equations hold

$$T(E) = T_0 + P_0 E + \alpha E^2/2 \quad , \qquad (1)$$

and

$$P(E) = P_0 + \alpha E \quad , \qquad (2)$$

and from them, assuming a fixed uncertainty in the determination of the times of minimum light $dT = 0^d_{\cdot}0035$, the accuracy of P and α can be calculated from the time span of the observations (Table 3) or equivalently, from the number of cycles E covered in that time interval. For an assumed period of $0^d_{\cdot}45339304$ the number of cycles would be E = 31454, which allows an accuracy in the period of 1.57×10^{-7} and of 5×10^{-12} in the quadratic coefficient.

TABLE 3

TIMES OF MINIMA AND O–C RESIDUALS FOR LINEAR AND QUADRATIC FITS

HJD	Min	$(O-C)_L$	$(O-C)_Q$	Ref.
2432701.6510	I	-0.0326	-0.0009	1
2434514.7822	I	-0.0179	-0.0002	2
2434515.4616	II	-0.0186	-0.0009	3
2434840.5465	II	-0.0161	-0.0006	3
2434897.4501	I	-0.0132	0.0019	4
2434899.4890	II	-0.0146	0.0005	4
2434899.4888	II	-0.0148	0.0003	5
2435257.4459	I	-0.0111	0.0019	6
2435261.5260	I	-0.0115	0.0015	6
2435262.4322	I	-0.0121	0.0009	6
2435544.6726	II	-0.0085	0.0029	6
2435579.5852	II	-0.0071	0.0040	6
2435582.5274	I	-0.0120	-0.0008	6
2435587.5148	I	-0.0119	-0.0008	6
2435617.4408	I	-0.0098	0.0012	6
2435621.5205	I	-0.0106	0.0003	6
2437394.9740	II	-0.0018	0.0013	7
2437404.9460	II	-0.0045	-0.0014	7
2437405.8546	II	-0.0026	0.0004	7
2438557.4660	II	-0.0081	-0.0082	8
2439631.7829	I	-0.0047	-0.0064	9
2439637.9078	II	-0.0006	-0.0023	9
2439639.9436	I	-0.0051	-0.0067	9
2439642.8951	II	-0.0006	-0.0023	9
2440719.4714	I	-0.0047	-0.0067	10
2440778.4110	I	-0.0062	-0.0080	10
2441174.2288	I	0.0000	-0.0016	11
2441184.2031	I	-0.0003	-0.0019	11
2441194.1799	I	0.0018	0.0002	11
2441214.1326	I	0.0053	0.0037	11

TABLE 3 (CONTINUED)

HJD	Min	$(O-C)_L$	$(O-C)_Q$	Ref.
2441833.4620	I	0.0005	-0.0002	12
2441844.3440	I	0.0011	0.0004	12
2441858.4000	I	0.0020	0.0013	12
2441860.4400	II	0.0017	0.0010	12
2443238.5250	I	0.0003	0.0030	13
2443292.4761	I	-0.0023	0.0006	13
2443665.8463	II	-0.0009	0.0034	14
2443666.7545	II	0.0006	0.0049	14
2443668.7951	I	0.0009	0.0052	14
2443671.7469	II	0.0056	0.0100	14
2444076.3910	I	-0.0030	0.0029	15
2444446.3740	I	0.0117	0.0193	16
2446582.4954	II	-0.0255	-0.0053	17
2446584.5391	I	-0.0221	-0.0019	17
2446585.4478	I	-0.0202	-0.0001	17
2446586.3496	I	-0.0252	-0.0049	17
2446586.5744	II	-0.0270	-0.0068	17
2446587.4811	II	-0.0272	-0.0069	17
2446590.4235	I	-0.0318	-0.0115	17
2446595.4205	I	-0.0221	-0.0018	17
2446961.7750	I	-0.0088	0.0143	18

Struve and Gratton (1948); 2) Fitch (1964); 3) Kwee (1958); 4) Szafraniec (1962); 5) Hinderer (1960); 6) Kwee (1968); 7) Wilson (1967); 8) Oburka (1965); 9) Binnendijk (1969); 10) Popovici (1971); 11) Polushina (1975); 12) Vader (1973); 13) Ebersberger (1978); 14) Maddox and Bookmyer (1979); 15) Troispoux (1980); 16) German (1980); 17) Rovithis *et al.* (1988); 18) Present paper.

All the times of minima which are reported in Table 3 and which cover a time span of 39 years were used to analyze the period behaviour of V502 Oph. As a first step the residuals O–C were calculated according to the linear ephemeris ($\alpha = 0$)

$$HJD_{min} = 2441174.2288(\pm 0.0035) + $$
$$+ 0.4533925\ (\pm 1.57 \times 10^{-7})\ E$$

which was determined by means of a computer program that estimates the O–C residuals for a set of frequencies around an initial first estimate of the frequency. For each frequency considered, the standard deviation of the O–C residuals is calculated for the whole set of times of minima. The best frequency is determined to be the one that gives the smallest of these deviations. In its turn, if a refinement of the frequency is desired, this best frequency is used as a new estimate of the frequency and a new and narrower frequency interval around it is considered. This procedure is followed until the accuracy imposed by the time span of the observations is reached.

The residuals from this linear ephemeris are shown in the third column of Table 3 under the header $(O-C)_L$. The standard deviation of these residuals is equal to 0.01. The plot of these residuals versus HJD is shown in Figure 3 where it can be clearly seen that the period is changing.

For a better description of the residuals a quadratic term is necessary as can be seen from equation (1), implying a continuous variation of the period (equation (2)).

With the times of minima obtained from this linear ephemeris a least square fit was made obtaining the relation

$$HJD_{min} = 2441174.2304 + $$
$$+ 0.4533921\ E - (2.36 \times 10^{-10})\ E^2/2 \quad .$$

The residuals obtained from this quadratic ephemeris are shown in the fourth column of Table 3 under the header $(O-C)_Q$. The plot of $(O-C)_Q$ versus HJD is shown in Figure 4, where it can be seen that the quadratic fit gives a much better description than the linear ephemeris (Figure 3), since all the times of minima are around a zero base line. A categorical demonstration would have to be carried out quantitatively. The standard deviation of the residual was evaluated in order to be compared with the analogous deviation of the linear ephemeris already reported. Since in the quadratic ephemeris the corresponding value is of 0.005, numerically less than the linear, it can safely assumed that the variation on the period has been smooth and not abrupt. These results qualitatively agree with the recent study of this system by Rovithis, Niarchos and Rovithis-Livaniou (1988); the period rate of change reported by them is –5 sec/century.

IV. DISCUSSION

From the analysis of the period behaviour carried out in the present work one could conclude that V502 Oph

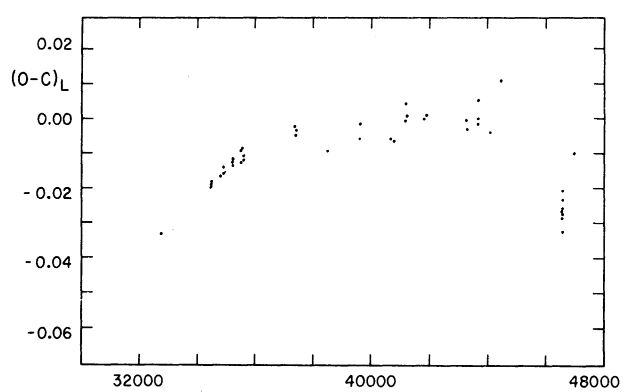

Fig. 3. O–C residuals versus time obtained from the linear ephemeris HJD 2441174.2288 + 0.4533925 E. It clearly shows the variation of the period in time. To convert time shown into HJD add 2400000.

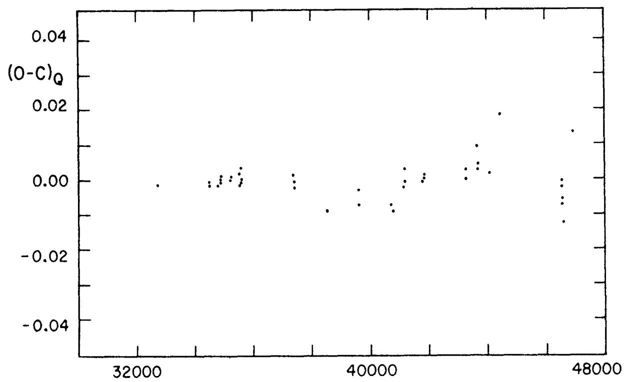

Fig. 4. O–C residuals versus time obtained after applying the quadratic ephemeris determined in the present analysis. To convert time shown into HJD add 2400000.

has a smoothly decreasing period with a rate of change of −1.64 s/century. More observations are encouraged in order to increase the time span and hence to obtain more accurate values for the rate of change of the period.

We would like to thank the staff of the Observatorio Astronómico Nacional for the assistance provided, to A. García for the drawings. Proofreading was done by Ms. J.A. Miller. Fruitful discussions with R. Peniche are acknowledged.

REFERENCES

Binnendijk, L. 1969, *A.J.*, **74**, 218.
Ebersberger, J. 1978, *Inf. Bull. Var. Stars*, No. 1449.
Fitch, W.S. 1964, *A.J.*, **69**, 316.
German, R.G. 1980, *BBSAG Bull.*, 49.
Gómez, T., Hobart, M.A., and Peña, J.H. 1988, *Inf. Bull. Var. Stars*, No. 3221.
Hinderer, F. 1960, *J. Observateur*, **43**, 161.
Kwee, K.K. 1958, *Bull. Astr. Inst. Netherlands*, **14**, 131.
Kwee, K.K. 1968, *Bull. Astr. Inst. Netherlands Suppl.*, **2**, 277.
Maddox, W. and Bookmyer, B. 1979, *Inf. Bull. Var. Stars*, No. 1569.
Oburka, O. 1965, *Bull. Astr. Inst. Czechoslovakia*, **16**, 212.
Polushina, T. 1974, *Bull. Var. Stars Suppl.*, **2**, 161.
Popovici, C. 1971, *Inf. Bull. Var. Stars*, No. 508.
Rovithis, P., Niarchos, P.G., and Rovithis-Livaniou, H. 1988, *Astr. and Ap. Suppl.*, **74**, 265.
Struve, O. and Gratton, L. 1948, *Ap. J.*, **108**, 497.
Szafraniec, R. 1962, *Acta Astr.*, **12**, 184.
Troispoux, G. 1980, *BBSAG Bull.*, 46.
Vader, P. 1973, *Inf. Bull. Var. Stars*, No. 842.
Wilson, R.E. 1967, *A.J.*, **72**, 1028.

Juan M. Alcalá: Instituto Nacional de Astrofísica, Optica y Electrónica, Apartados Postales 51 and 216, 72000 Puebla, Pue., México.
Teresa Gómez and José H. Peña: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F., México.
Marco A. Hobart: Facultad de Física, Universidad Veracruzana, Apartado Postal 270, Xalapa, Ver., México.